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B. E. LOCK, C. A. G. PICKTON,  
D. G. SMITH, D. J. BATTEN and W. B. HARLAND

# The Geology of Edgeøya and Barentsøya, Svalbard



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NORSK POLARINSTITUTT  
OSLO 1978

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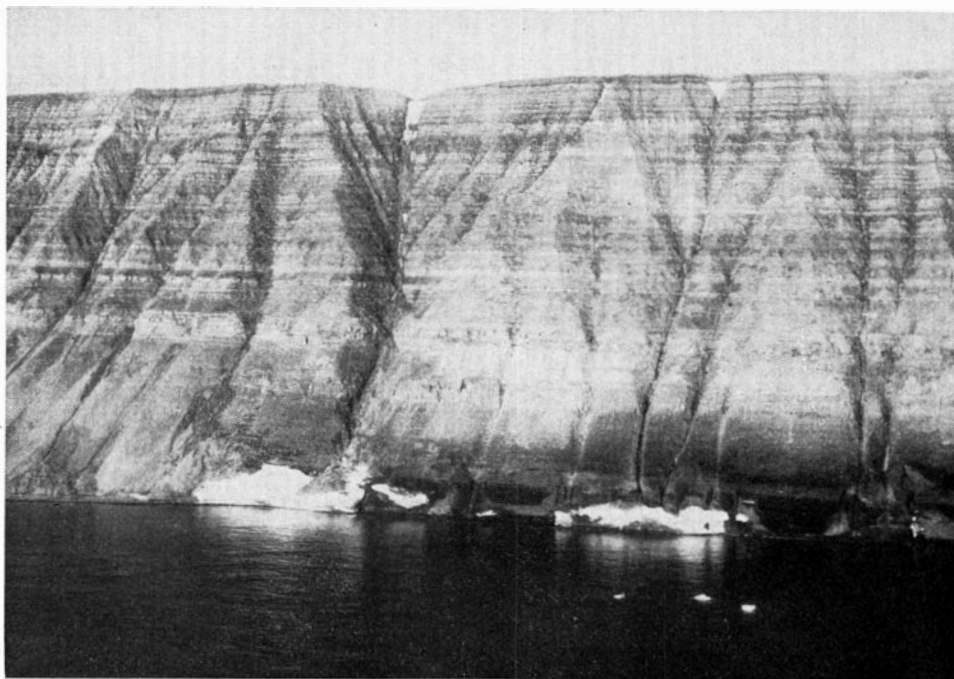
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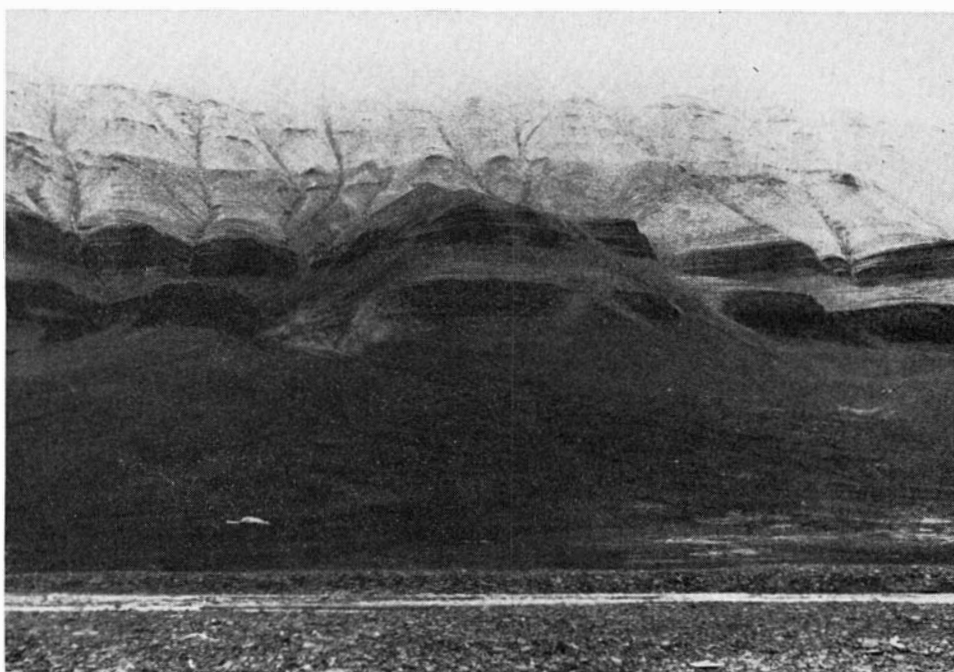
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*Cliffs of the Negerfjellet Formation on southwest Negerfjellet, southeast Edgeøya, viewed from the west. The cliffs are about 300 m high. Photo [Ø2642.18]*



*Dark, cliff-forming shales of the oil shales member (Barentsøya Formation) north of Barthreen, east Barentsøya, viewed from the east. The top of the range, just under cloud cover, is at c. 500 m. Photo [S1508.32]*



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# The Geology of Edgeøya and Barentsøya, Svalbard

By B. E. Lock, C. A. G. Pickton, D. G. Smith,  
D. J. Batten and W. B. Harland

## Abstract

This paper reviews the geology of Edgeøya and Barentsøya in the light of an investigation undertaken in 1969. A review of the history of research, with comprehensive reference list, is given. Measured sections, structural and geological maps are presented, and a detailed discussion of the biostratigraphy is included. Previous work is collated with the results of the 1969 expedition and, taking into account what is known of the Triassic rocks over the whole of Svalbard, new stratigraphical units are defined for this area and discussed in relation to variations in their thickness, facies and age.

## I. Introduction

Edgeøya and Barentsøya are two of the largest islands of the Svalbard Archipelago, with land areas of 5120 km<sup>2</sup> and 1300 km<sup>2</sup> respectively. They lie to the east of Spitsbergen, the principal landmass of the group, so that the warm currents from the southwest do not have the moderating effect on these islands that they have in the case of Spitsbergen itself (Fig. 1). One consequence of this has been that most visitors to Svalbard have not penetrated to Edgeøya and Barentsøya, and these islands are still relatively unknown.

### 1. PHYSIOGRAPHY AND CLIMATE

Edgeøya and Barentsøya differ markedly from the mainland of Spitsbergen in several respects, as is most readily illustrated by direct quotation from the descriptions of Watkins (1928):

«To the west lay Spitsbergen, a mass of jagged peaks and large glaciers running down into the sea; in fact, the Alps brought down to sea-level. To the

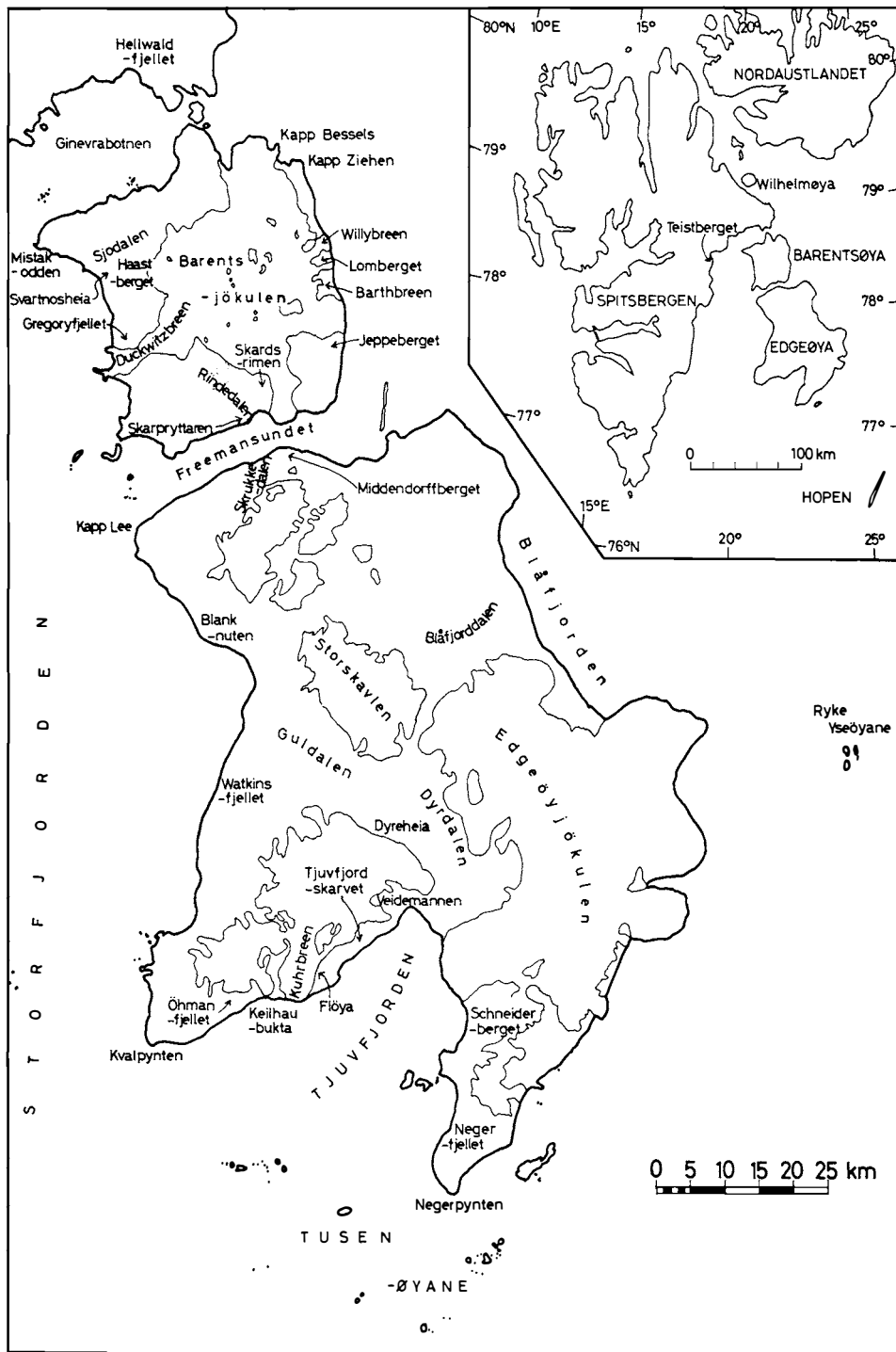


Fig. 1 Geographic setting of Edgeøya and Barentsøya with place-names mentioned in text.

east lay Edge Island with its long dark cliffs and tabular hills» (p. 119), or again;

«The Gulf Stream, which keeps the west coast of Spitsbergen open for a great part of the year, has hardly any effect on the lands to the east (of Storfjorden); consequently these lands differ in many ways from the Spitsbergen mainland. They are more bleak, they have less animal and vegetable life, and they are scenically duller than Spitsbergen . . . Bad gales and bad fogs are common on and around Edge Island . . . It is sometimes impossible to enter Stor Fjord owing to the ice».

The Watkins party were unfortunate in the weather conditions which they encountered on Edgeøya — «hampered by almost continuous cloud and mist, so that plane-tableing only proved feasible on five days out of one month on the island».

The islands are characterised by gentle, open topography which makes access to most points relatively easy. The valleys are broad and hillslopes are seldom steep, while outwash plains are a feature of a large proportion of the coasts. More than a third of the land area is covered in permanent ice, notably Barentsjøkulen and Edgeøyjøkulen, together with lesser ice-caps on Edgeøya. Watkins (1928) reported that the ice was retreating and that ablation exceeded the accumulation of fresh snow. There are many indications of recent uplift on the island, probably a result of the continued reduction in ice-cover. Falcon (1928) arrived at a figure of 200 ft (60 m) for the isostatic readjustment on Edgeøya, based on the elevation of raised beaches. Deeply incised stream beds at many localities provide strong evidence that the process is still continuing.

Fox, reindeer and polar bear are found in the islands, and at one time walrus were very numerous on the Tusenøyane and Ryke Yseøyane. Recently it would appear that the walrus are beginning to return, following sightings by the Norsk Polarinstitut (NPI) and by a Cambridge expedition in 1972. Hunters have been the only regular visitors to the region, and their huts and other relics of their activities are widely scattered along the coasts and on the islands. Walrus and whale bones are scattered over many of the beaches, amongst the washed-up driftwood which occurs in great quantities.

## 2. HISTORY OF EXPLORATION AND OF GEOLOGICAL INVESTIGATION

Thomas Edge (d. 1624), the English merchant and whaler, is usually credited with the discovery of Edgeøya in 1616 (Nathorst 1899), and the island is named in his honour. However, the possibility remains that the island may have been sighted a few years earlier. Plancius produced a map in 1612 which showed an «indented south coast fringed with islands» (Hoel 1942); this suggested to Wieder (1919) that an otherwise unrecorded Dutch expedition may have visited the area between 1596, when Barents discovered Svalbard, and 1612. Carolus, who was pilot to an expedition in 1614, indicated a similar coastline on his map of 1614, a detail which may have been derived from Plancius or may have resulted from an independent discovery of the island.

In the years immediately following its discovery, Edgeøya was variously known as «Gerrits Eyland», «Marfyn», «Whales Wiches Landt» and «Witches Island», as well as by other names.

Barentsøya was not known to be a separate island until about the middle of the nineteenth century — until that time it was thought to be part of Ny Friesland (the north-eastern part of Spitsbergen), and was generally referred to as «South East Land» or «Barents Land», after Willem Barents (d. 1597), the discoverer of the archipelago.

The first geologist to visit Svalbard was B.M. Keilhau, who landed in Edgeøya in 1827, followed by J. Lamont who made collections from Tjuvfjorden and Negerpynten (see Fig. 1 for place names) in 1859 (Lamont 1860). Lamont's fossils were identified, in an appendix to his paper, by J.W. Salter. Further collections were made by A.E. Nordenskiöld from Kvalpynten and Kapp Lee during the 1864 Swedish Academy of Science Expedition (Nordenskiöld 1866); the new material included invertebrate fossils which enabled G. Lindström (1865) to show that Triassic sediments are present in Edgeøya.

The first accurate maps of any part of the area were those prepared by the Russo-Swedish «Arc of Meridian» Expeditions of 1899—1901, of the west coast of Edgeøya. The collections made by this series of expeditions enabled Wittenburg (1910) to publish an account of the Triassic fauna of the areas bordering Storfjorden, including Edgeøya and Barentsøya, while Backlund (1907) described the dolerite intrusions and (in 1921) commented on the regional tectonics and isostasy.

De Geer, in his general account of the physiographic evolution of Spitsbergen (1919), gave some details of the geology of Edgeøya, while in 1933 G.W. Tyrrell published geological results obtained by the Scottish Spitsbergen Syndicate expeditions of 1919 and 1920 — preliminary reports having appeared some years previously (Tyrrell 1920). Tyrrell described two stratigraphic sections from Barentsøya (from south of Mistakodden and from north of Duckwitzbreen) and more from Edgeøya (all near to Kapp Lee).

Perhaps the most important work to be carried out in the region between the wars was that of N.L. Falcon, who was a member of the 1927 Cambridge Expedition to Edgeøya (Watkins 1928). Falcon proposed a threefold division of the Triassic in the area which is the basis for the stratigraphic classification used in this paper.

Geological investigations of the Edgeøya and Barentsøya region received new impetus after the Second World War, with the international search for new petroleum deposits. Nagy (1965) has summarised the history of these investigations up to 1964, but in general few results have been published — a notable exception being the work of Klubov (1964, 1965a, b, c) in which Soviet observations on the geology of the two islands are reported. Burov (1964) and Burov et al. (1964) discussed the dolerites and the Permian rocks of the archipelago respectively. Two English-language publications on the Triassic rocks of the whole region have been those of Buchan et al (1965) and Tozer & Parker (1968). With few other exceptions most of the new geological information relevant to the two islands was in the fields of glaciology and glacial geo-

morphology; the principal of these were the publications of Büdel and his colleagues (Büdel 1960, 1961, 1962; Büdel & Wirthmann 1964, 1965; Wilhelm & Wirthmann 1960).

1969 was an important year for fieldwork in Edgeøya and Barentsøya, since it was during that season that the Norsk Polarinstitutt carried out a major geological and topographical investigation supported by a sealing ship and helicopter (Flood et al. 1971b). The Norwegian geologists visited about a hundred localities in eastern Svalbard and measured about 50 stratigraphic sections by means of Paulin altimeters. A new geological map was produced as a result of these investigations.

In 1969 the islands of eastern Svalbard were also the subject of intensive exploration by the Norsk-Cambridge Svalbard Expedition (NCSE), also with a ship and helicopters. The present paper is a product of the work done by this expedition (see below).

Since 1969 the geodetic and topographical units of the NPI have worked in the area (1973) and the geologists Winsnes and Worsley have both visited the islands. In 1973—74 exploratory wells were sunk by various companies (see Chapter IV), and in 1975 NPI flights off Kvalpynten (Edgeøya) enabled Edwards (1976 a and b) to report on the appearance of growth faults in cliff sections of the Upper Triassic beds.

Parties of Soviet geologists have certainly visited this area since the mid-sixties, but at present no publication concerning the area and published within the last ten years is known to us.

### 3. THIS STUDY 1969 TO 1976

The investigation of Edgeøya and Barentsøya was part of a study of much of the land area of eastern Svalbard undertaken by a Cambridge group, directed by W.B. Harland in an arrangement with Norske Fina, the Norsk-Cambridge Svalbard Expedition of 1969. The fieldwork was carried out by a Cambridge geological party of eight geologists and eight assistants (Harland 1970). Edgeøya was visited in all three phases of the expedition as one of the main objectives, while Barentsøya was visited on the second and third phases, initially by groups working from camps supplied by helicopter and later by day parties based on the sealer M/S NORVARG, Captain S. Jakobsen. M/S NORVARG, equipped with an afterdeck structure for two helicopters which were extensively employed, was chartered by Norske Fina, represented during the expedition by N. Golenko. Phases 1 and 2 of the expedition were led by Harland while phase 3 was led by Batten. In the course of this work about 120 stratigraphic sections were measured and 7000 specimens collected.

Consequent office and laboratory work was carried out in Cambridge by Lock, Smith, Batten, Harland, D.J.W. Piper and A.B. Reynolds, and the first results were largely compiled by Lock. As the work continued E.T. Tozer checked the ammonite determinations by Smith. Other studies continued, for example sedimentological by Piper (in preparation), on vertebrates by C.B.

Cox (Cox & Smith 1973), and the palynological work of Batten was continued by Smith.

Subsequent field work by Norske Fina provided some further information, especially on Permian rocks.

The preparation of this paper from all these sources, in relation to parallel work by us on other areas in eastern Svalbard (e.g. Smith 1975; Smith, Harland & Hughes 1975; Harland, Hughes & Smith 1976; Smith, Harland, Hughes & Pickton 1976) was resumed by Lock when on sabbatical leave and completed by Pickton who also checked and redrew all the figures.

## II. Stratigraphy

A Triassic age for rocks from Edgeøya was established by Lindstrøm as early as 1865, while Falcon (1928) was able to show that the strata on that island can be divided into three units. More recently, it has been found that two small inliers of Permian strata are present on Edgeøya, as well as a rather larger outcrop on Barentsøya. The age of the youngest strata present has long been debated, but no fossils younger than Norian have yet been identified with certainty.

One of the objectives of the present publication is the formalisation of the stratigraphic nomenclature for Edgeøya and Barentsøya, while we attempt to show how the succession on the islands may be correlated and compared with that in other parts of Svalbard.

### 1. RESUMÉ OF PREVIOUSLY PROPOSED STRATIGRAPHIC SCHEMES FOR THE PERMIAN AND TRIASSIC OF SVALBARD

Falcon (1928) recognised the following three-fold division of the Triassic rocks of Edgeøya, numbered from the base upward:

- iii. Sandstone group — «estuarine or deltaic type» alternating fissile sandstones and sandy shales, thick, found up to the highest points of those parts of the island visited (by Falcon).»
- ii. Purple Shales group — «blue and purple shales about 250 ft (75 m) thick», with «numerous bands of ferruginous limestone and ironstone nodules».
- i. Oil Shales group — «tough, well-bedded bituminous shales with intercalated limestone bands and bands of septarian nodules, the latter being most noticeable in the higher horizons», with «a maximum exposed thickness of 400 ft» (120 m).

It was not until much more recently that the presence of Permian strata beneath the lowest Triassic «group» was recorded from Edgeøya (King 1964) and from Barentsøya (Burov et al. 1964).

In more recent years, as a result of more systematic studies, the stratigraphic nomenclature for the Triassic rocks of Svalbard has been amended by Buchan et al. (1965) and by Flood et al. (1971a) — the latter published their proposals in the form of the legend to their geological map of southern Spitsbergen. The most recent modifications (for example, by Harland et al. 1974) have resulted principally in changes of rank of several units.

Table 1 compares the scheme proposed for the Triassic strata of Edgeøya and Barentsøya in this publication with those used by Falcon (1928), Klubov (1965) and Flood et al. (1971b) for the same region, while Table 3 of Section II.5.F summarises the classification for Spitsbergen of Buchan et al. (1965), as modified by Harland et al. (1974).

## 2. STRATIGRAPHIC SCHEME FOR THE PERMIAN AND TRIASSIC OF EDGEØYA AND BARENTSØYA USED IN THIS PAPER

In this paper we define new names for those units of formational and lower rank for use in Edgeøya and Barentsøya, since, although we are able confidently to suggest correlations with the mainland of Spitsbergen, the mainland formations are not always satisfactory as mapping units on the islands and some lithological distinctions between the areas are considered sufficient to warrant separate nomenclature, as has been proposed for Hopen (Smith et al. 1975) and Kong Karls Land (Smith et al. 1976).

The Permian rocks of Edgeøya and Barentsøya consist of a variety of lithological types, all of which can be matched with similar rocks in the Kapp Starostin Formation of Spitsbergen. The isolated character of the Edgeøya and Barentsøya outcrops is such, however, that we are not yet able to decide whether the difference between the outcrops is a result of lateral facies change or a result of a difference in stratigraphic level. Buchan et al. (1965) noted that, over most of Spitsbergen, the Permo-Triassic contact is marked only by an interval of non-deposition and by a sharp lithological break, although the Triassic oversteps progressively older Permian strata towards the south of Spitsbergen and rests on basement rocks (Precambrian to Lower Palaeozoic) at Sørkapp.

In this paper we designate the Permian rocks of Edgeøya and Barentsøya as the Kapp Ziehen formation — an informal term which may be discarded if the correlation with the Kapp Starostin Formation is confirmed.

During mapping in 1969, we found that Falcon's three divisions of the Triassic were very convenient for field use, and we formalise their status later in this paper. Falcon's «Oil Shales group», which we here rename the Barentsøya Formation (formally defined below), is more or less equivalent to the entire Sassendalen Group of Spitsbergen. The bituminous paper shales at the top of the new formation are probably equivalent to the Botneheia Formation, while the underlying strata include equivalents of the Sticky Keep and, probably, the Vardebukta Formations. Although the Sassendalen Group is readily divided into three or more distinct mappable units in Spitsbergen, this is not

so in the islands; it is therefore appropriate that the Sassendalen Group should be represented by a single formation.

The «Purple Shales group» is here formally renamed the Edgeøya Formation (see below). It is laterally equivalent to the Tschermakfjellet Formation of the mainland, while the overlying «Sandstone group», here renamed the Negerfjellet Formation, is equivalent to the De Geerdalen Formation. The boundary between these two units appears to be diachronous, while that between the Edgeøya and Barentsøya Formations is considered to be a good time-marker horizon.

FALCON 1928	KLUBOV 1965	FLOOD <i>et al</i> 1971		THIS PAPER
Sandstone group	"Sandstone formation" (upper unit of T <sub>3</sub> )	KAPP TOSCANA GROUP	De Geerdalen Formation	Negerfjellet Formation
Purple (Blue & Purple) Shales group or series	"Passage Beds formation" } (lower two units of T <sub>3</sub> ) "Argillite formation"		Tschermakfjellet Formation	Edgeøya Formation
Oil Shales group or series	T <sub>1</sub> & T <sub>2</sub>	SASSENDALEN GROUP	Botneheia Member Sticky Keep Member Vardebukta Formation	oil shales member Barentsøya Formation
( Permian rocks not recognised )	"Selander suite"		Kapp Starostin Formation	Kapp Ziehen formation

Table 1.

*Local rock-unit nomenclature proposed for Barentsøya and Edgeøya (as defined in this paper) compared to lithological units of previous authors.*



### 3. THE PERMIAN ROCKS OF EDGEØYA AND BARENTSØYA

In the structural high of northeast Barentsøya lies a coastal exposure of Permian rock (dipping slightly SSE) which extends about 10 km north to south. First recorded by Burov et al. (1964), the only description available is by Klubov (1965c). The outcrop area, which he described as a vast plain between Kapp Bessels in the north and Willybreen to the south, is poorly exposed, and Klubov was not able to describe a complete section. Our own investigations did not show the Permian to be quite so extensive (see Fig. 5B). Figure 2 is a sketch profile, based on Klubov's data, and the poor exposure is readily apparent from the large gaps in the column. At least 250 m of strata, however, appear to be represented.

Klubov provided petrographic descriptions of the exposed rocks and dated them all as being «the youngest of all the Permian rocks known in Spitsbergen

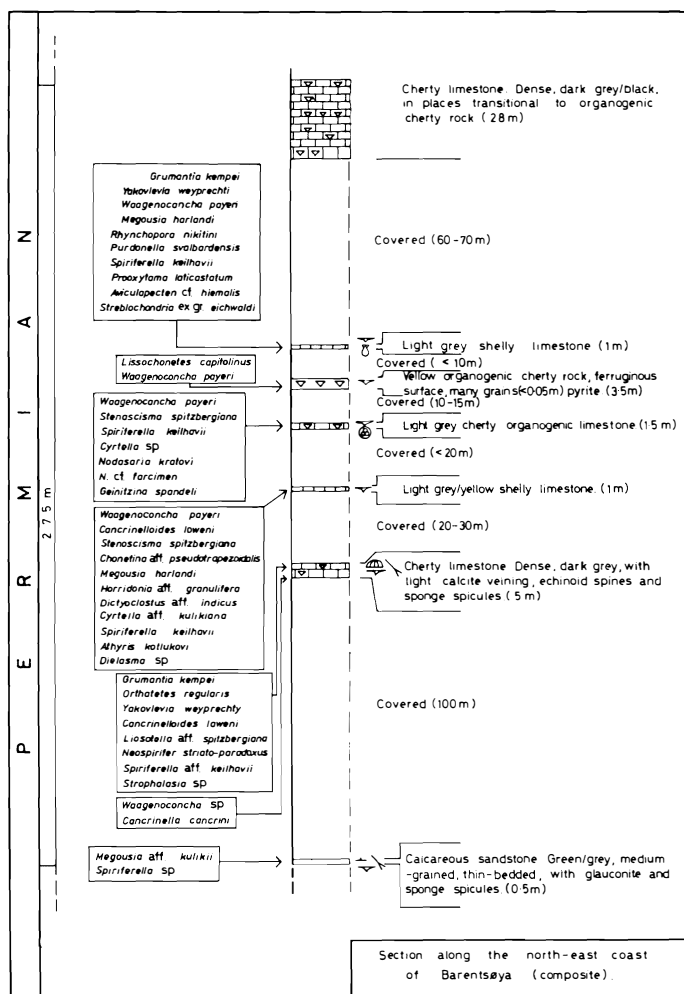


Fig. 2 Section through the Permian strata of N.E. Barentsøya, based on the data of Klubov (1965c).

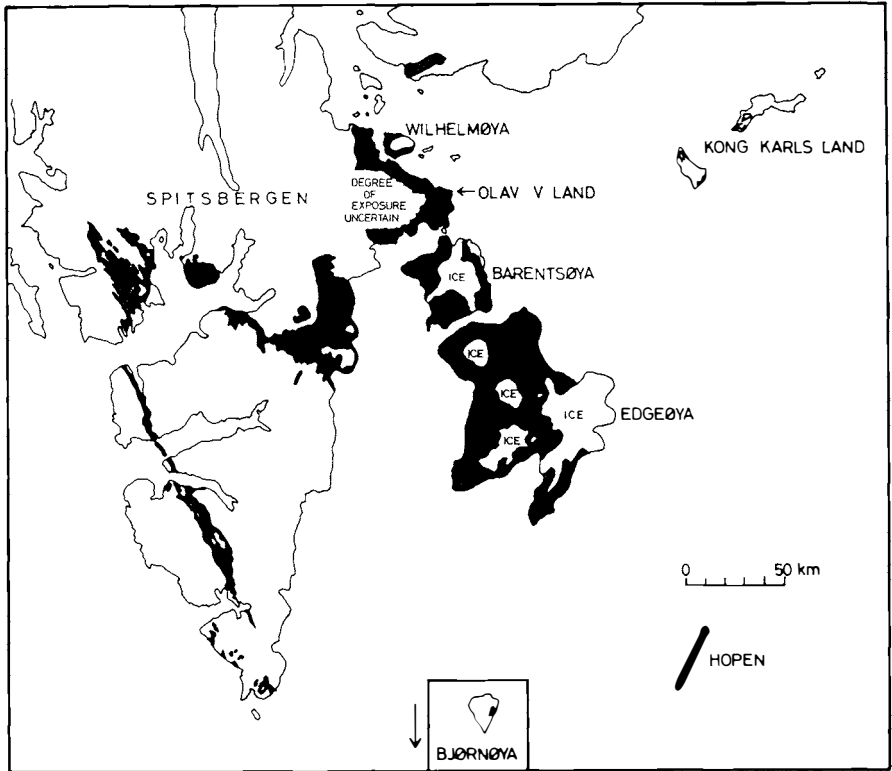


Fig. 3 Occurrences of Triassic rocks (in black) over Svalbard.

— corresponding to the upper part of the 'glaucinitic beds' established in the Selandemeset area by Burov et al. (1964)». On faunal grounds he attributed them to the «lower part of the upper section of the Permian», the Kazanian stage of the Russian platform being favoured in particular.

However, these sandstones and limestones may well be the lateral equivalents of the sandstones and limestones of the Hovtinden Member (Kapp Starostin Formation) on the mainland, which pass laterally (westwards) into shale, siltstone and chert facies in Oscar II Land (Cutbill 1968). Further work by Burov et al. (1965) has indeed now established that these Permian strata of the «Selander suite» in Nordaustlandet and Barentsøya may be assigned to the Ufimian stage, and that Kazanian and Tartarian strata are absent.

In Edgeøya two small inliers of Permian strata, each less than 1 sq. km, were reported following the visit of the American Overseas Petroleum Limited expedition of 1963 (King 1964). The outcrops, 28 km apart, are poorly exposed, the only samples obtained by NCSE being collected as float, and their relationship to the overlying Barentsøya Formation was not established in the field.

The positions of the outcrops have been figured previously by Cutbill &

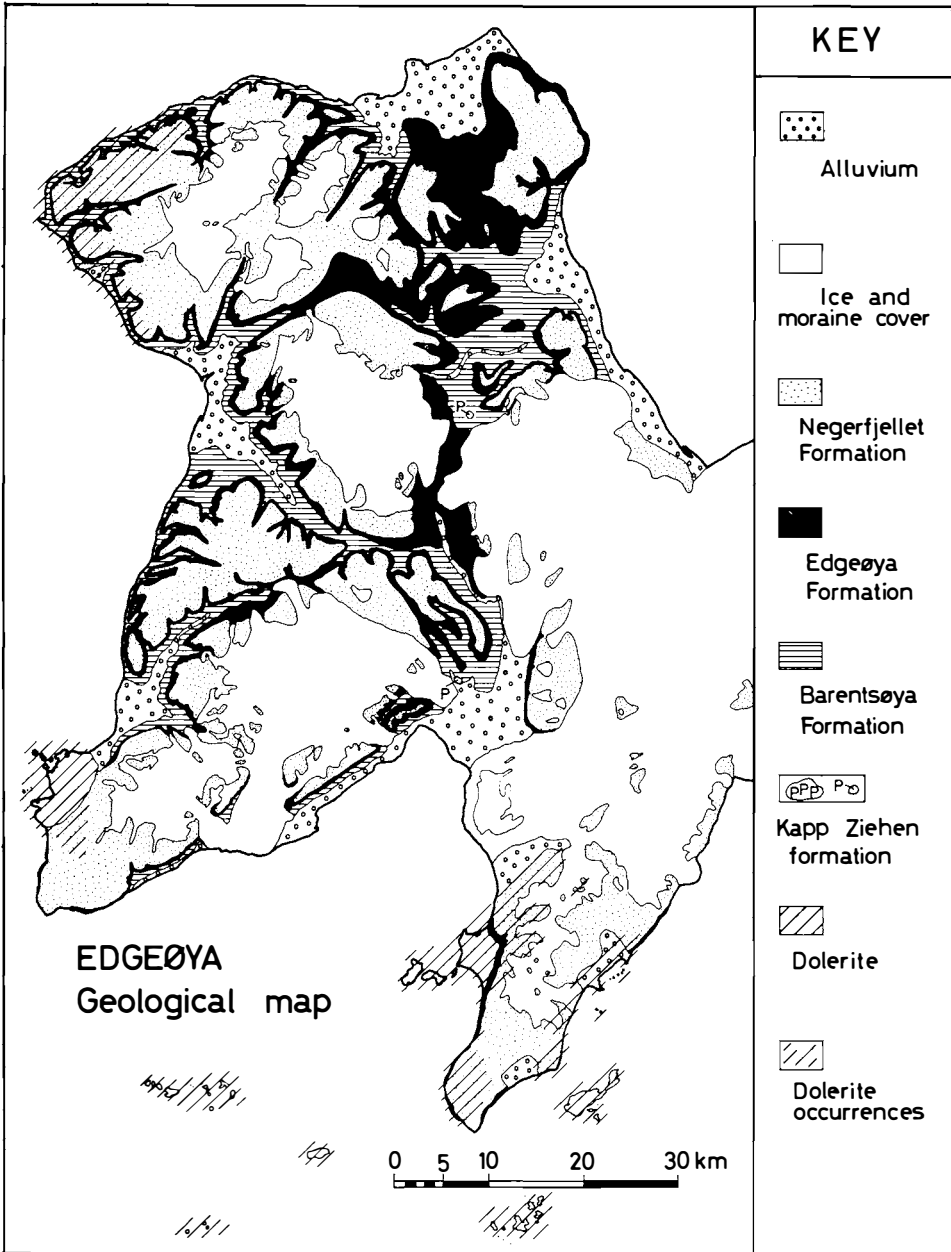


Fig. 4 Geological map of Edgeøya.

Challinor (1965: approximate location) and Lowell (1972: more accurate location). The northern one occurs at the northern end of the pass between Stor-skavlen and Edgeøyjökulen (above Blåfjorddalen), the southern at the foot of the spur immediately north of the Veidebreen terminal moraine, south end of Dyreheia (see Figs. 4 and 5B). The former, consisting of a highly fossili-

ferous, sandy, silicified limestone, rich in brachiopods, pectinid bivalves and bryozoa, has yielded the following brachiopods (identified by D.J. Gobbett):

*Streptorhynchus* sp.  
*Liosotella pseudohorrida* (Wiman)  
? *Probolionia involuta* (Tsch.)  
*Waagenoconcha irginae* (Stuck emend. Tsch.)  
*Kochiproductus* sp.  
*Cancrinella spitsbergiana* Gobbett  
*Cancrinella* sp.  
*Anidanthus aagardi* (Toula)  
*Camerophoria spitsbergiana* Stepanov  
*Spirifer striato-paradoxus* Toula  
*Neospirifer* cf. *fasciger* (Keyser.)  
*Spiriferella* sp.  
? *Spiriferella Keilhavii* (Von Buch)  
*Cleiothyridiana* sp.  
*Dielasma* sp.

The latter, consisting of light grey chert with sponge spicules and bryozoa (but no brachiopods), has not yielded any readily identifiable forms. A palynological investigation by J.F. Laing produced only indeterminate ?spore fragments and one or more species of the long-ranging acritarch genus *Micrhystridium*.

Thus there is no way in which it may be ascertained whether the lithologic difference between these two small inliers is one of facies or due to erosion to different levels prior to the deposition of the overlying Triassic strata.

For the moment, therefore, the informal name of «Kapp Ziehen formation» is proposed for all the Permian strata on both Barentsøya and Edgeøya until such time as their relationship to the Kapp Starostin Formation in the rest of Spitsbergen and Nordaustlandet is more fully known.

#### 4. THE TRIASSIC ROCKS OF EDGEØYA AND BARENTSØYA: STRATIGRAPHIC UNITS DEFINED

The following litho-stratigraphic units, listed in an earlier section of this paper (Section II.2) are here defined or redefined for use in the islands.

##### A. *Sassendalen Group*

This group was defined by Buchan et al. (1965), whose usage is here retained. The Barentsøya Formation (new, this paper) is the only component formation in the islands.

##### A(i) *Barentsøya Formation*

Equivalents — «Oil Shales group» or «Oil Shales series» of Falcon (1928); «T<sub>1</sub>» plus «T<sub>2</sub>» of Klubov (1965a, b); Vardebukta Formation, Sticky Keep

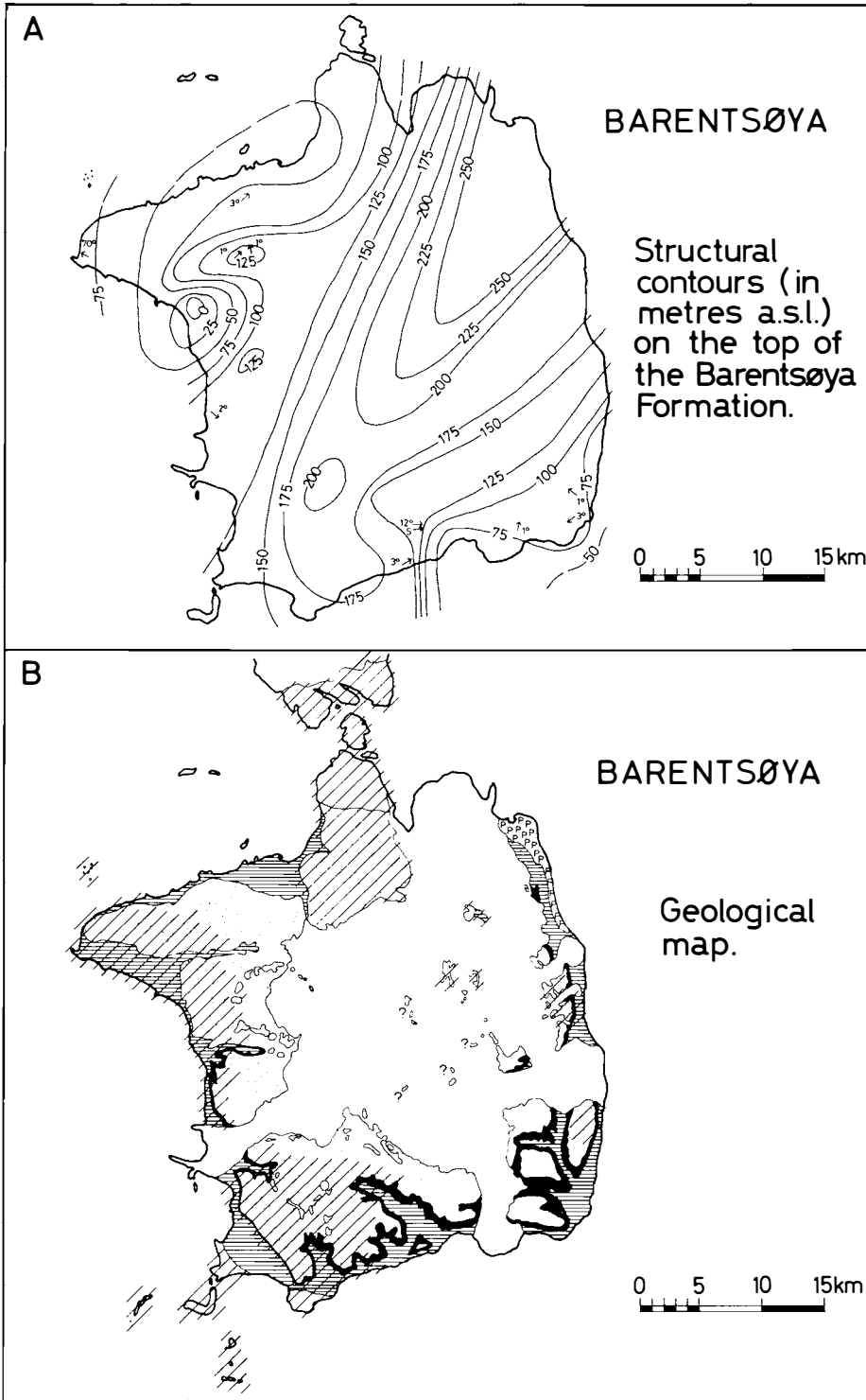


Fig. 5 (A) Structural map of Barentsøya with contours at 25 m intervals. Apparent dips are also shown.

(B) Geological map of Barentsøya. For legend see Fig. 4.

Member (Kongressfjellet Formation), and Botneheia Member (Kongressfjellet Formation) of Flood et al. (1971b). Corresponds in stratigraphic position with the Botneheia, Sticky Keep and Vardebukta (part, at least) Formations of Spitsbergen (Buchan et al. 1965).

Type section — C1387, near Kapp Ziehen, northeast Barentsøya (see Fig. 7) is a section measured and recorded on computer-readable forms («SM3 forms»; see Piper et al. 1970) by J.L. Cutbill on 25 August 1969. Only the lower part of the formation, including its basal contact, is seen in this section, and the nearby H1825 measured by W.B. Harland (on the same day) is designated the type section for the upper part of the formation. Correlation between the two sections, which are about 5 km apart, is based on the faunal content and leaves the possibility of 10 to 20% error in the estimated thickness in the type area of 300 m. No single measured section can be used for the type section.

The Barentsøya Formation is defined as that interval of shales, often bituminous and papery towards the top, with subordinate bands of limestone, septarian nodules, calcareous siltstones and argillaceous sandstones lying between the distinctive Permian sediments below and the Edgeøya Formation above. The lower contact is poorly exposed, and we did not see it clearly. The quality of the exposure is assumed to have deteriorated since the 1963 visit of Klubov (1965b) to the Kapp Ziehen area, since he was able to describe an unconformity with an irregular erosion surface. This contrasts with the statement by Buchan et al. (1965) that «no evidence of erosion is seen on the upper surface» of the Permian in Spitsbergen itself. The top contact is taken at the top surface of the cliff-forming unit of bituminous shales — this surface is usually the top of a distinctive bed of yellow-weathering argillaceous limestone or calcareous siltstone which yielded large numbers of bones of ichthyosaurs from many localities. The overlying strata consist of non-bituminous blue or grey shales. We experienced no difficulty in determining the position of the contact in the field.

The lower part of the formation is seldom well-exposed, but where seen consists largely of grey shales and siltstones with a few prominent beds of yellow-weathering carbonate-cemented siltstones and silty, clayey limestones. The uppermost 30 m form a prominent escarpment with a bench at the top, or, in southernmost Barentsøya, two escarpments with a subordinate bench intervening. The cliff-forming strata consist of shales, often bituminous, very papery at the top, with horizons of septaria, yellow and orange-weathering siltstones and thin limestones. Some of the septarian nodules are found to contain liquid bitumen when broken open. This phenomenon was noted at Kapp Lee, Blåfjorden and south of Mistakodden on the west flanks of Haastberget. Phosphatic nodules occur in the shales in the lower part of the formation. In the type section (number H1825), in northeast Barentsøya, several specimens found in the float consisted of a conglomerate of rolled phosphatic nodules, bone fragments and teeth in a matrix of scale fragments. It is not known ex-

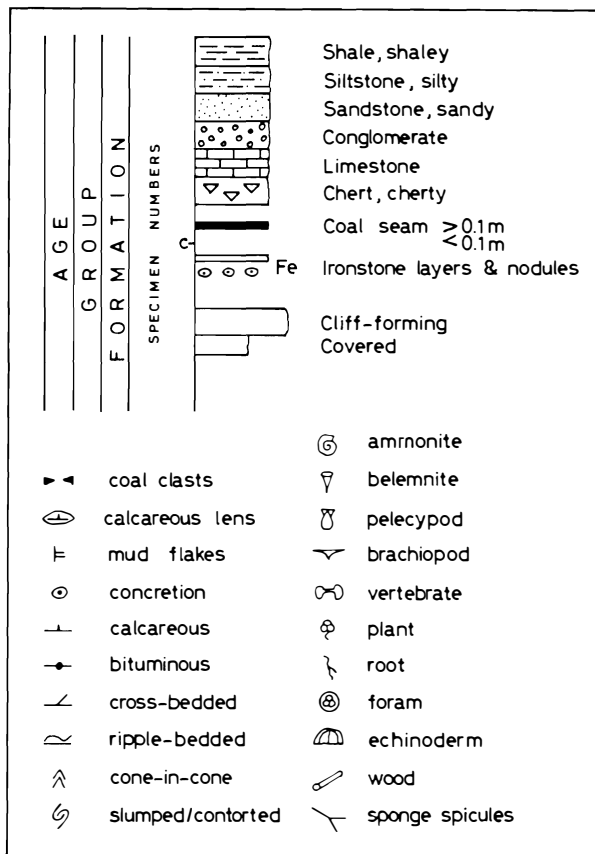


Fig. 6 Key to measured sections.

actly from what horizon this condensed deposit was derived, but it probably originated somewhere in the upper half of the formation.

The base of the cliff-forming bituminous shales probably corresponds with the base of the Botneheia Formation of Spitsbergen, while the top of the formation is an important non-sequence which can be traced, as the top of the Sassendalen Group, over most of the Svalbard Archipelago. Landslips have complicated the structure of this part of the succession on the east flanks of Gregoryfjellet, eastern Barentsøya.

In this publication we consider the cliff-forming bituminous shales as an informal member (the oil shales member) of the Barentsøya Formation.

The Barentsøya Formation is richly fossiliferous, and has yielded large numbers of ammonites (impressions) and thin-shelled, possibly planktonic, bivalves such as *Daonella* as well as bones of reptiles (ichthyosaurs and plesiosaurs) and fish. These are all compatible with the usual interpretation of bituminous shales — that is, that they accumulated under euxinic conditions of stagnant bottom waters. The stratigraphic implications of these fossils are discussed in a later section of this paper.

The oil shales member is atypically developed in certain areas, particularly north western Edgeøya. In Skrukkedalen the upper part of the Barentsøya

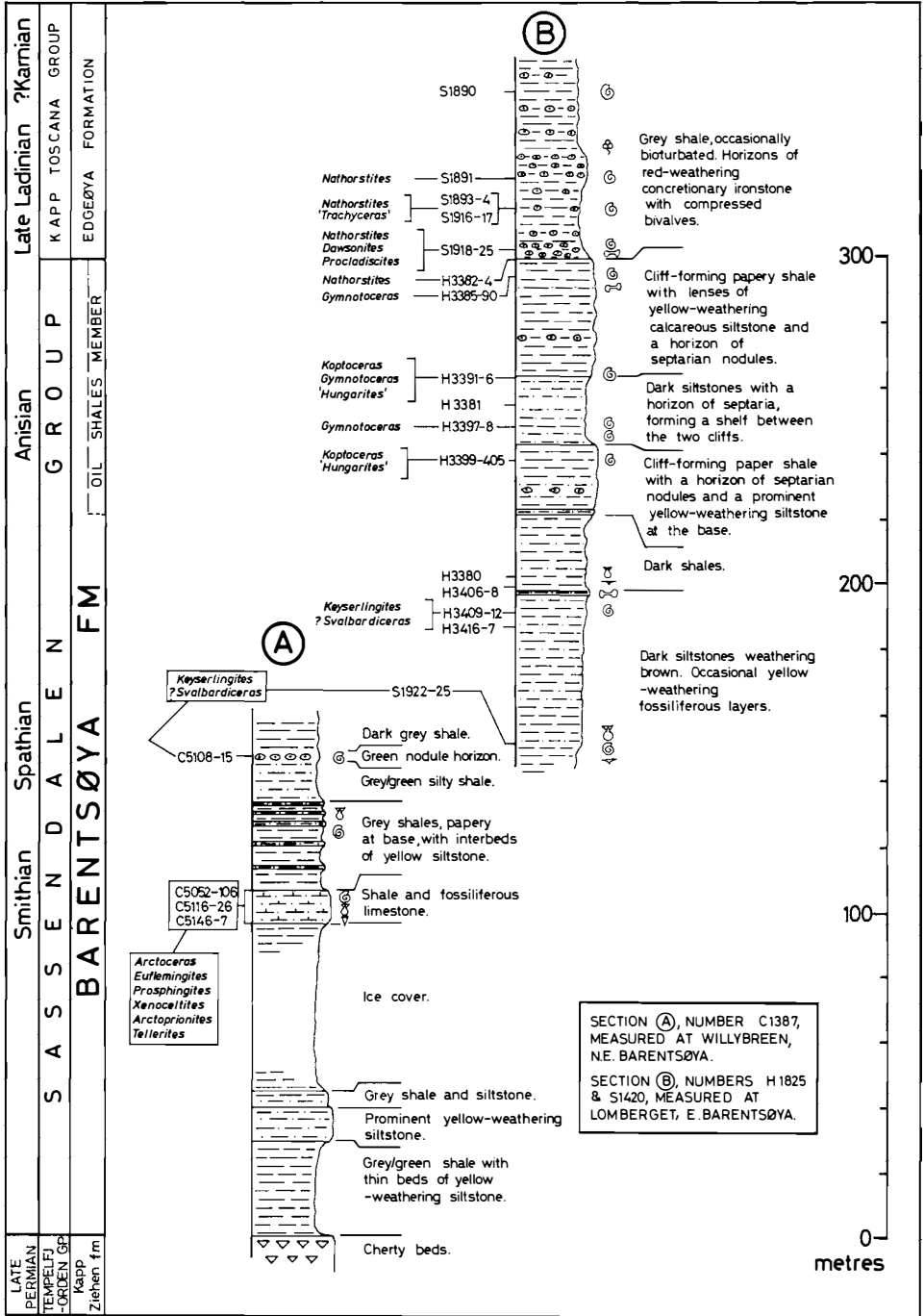


Fig. 7 Type section(s) of the Barentsøya Formation. For detailed location see Fig. 17.



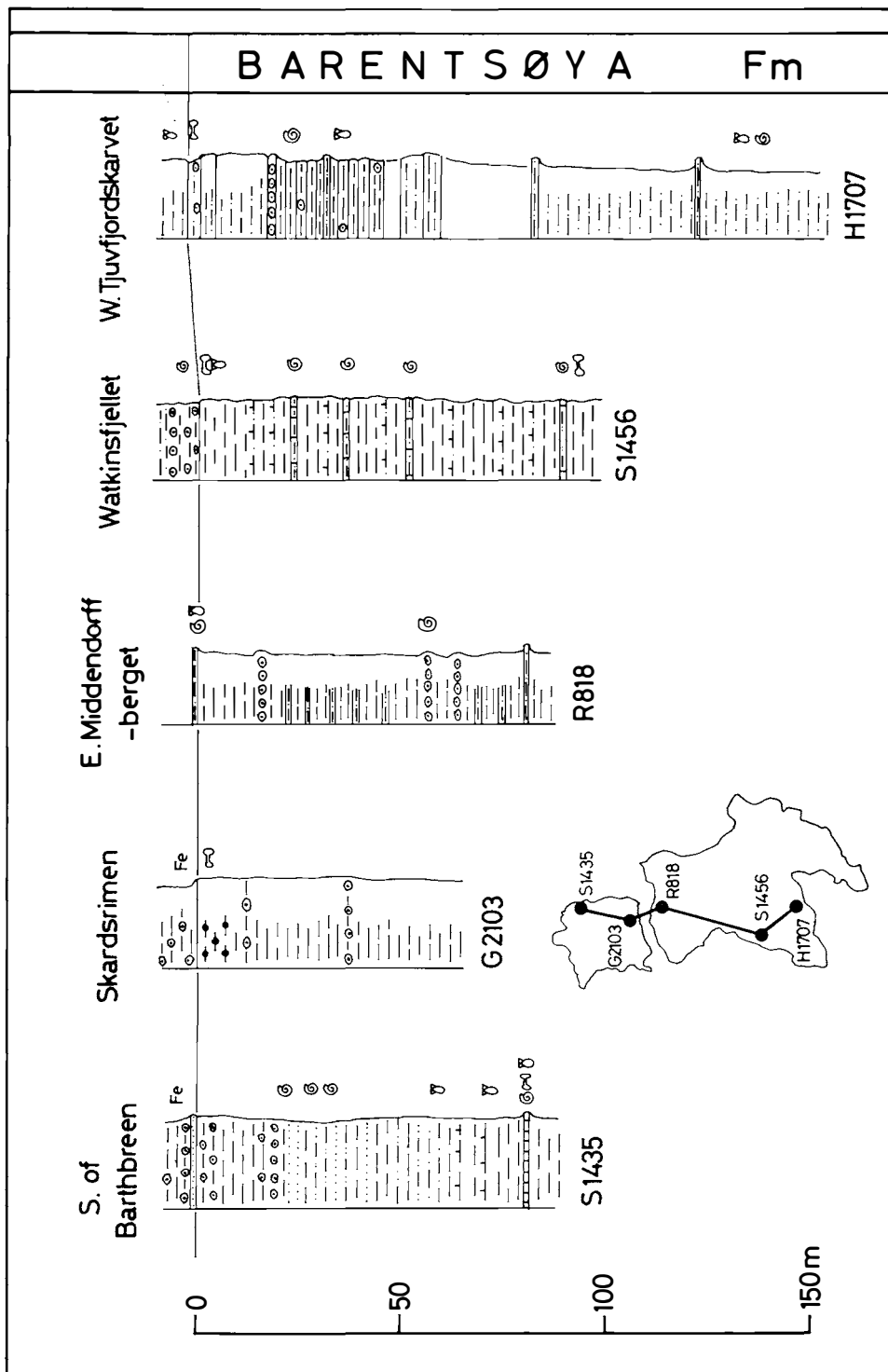


Fig. 8 Sections through the upper part of the Barentsøya Formation.

Formation consists of well-indurated siltstones and fine to medium grained sandstones, with very abundant phosphatic concretions at many horizons, and locally rich with carbonised plant detritus. These concretions consist of the isotropic material collophane, and range down to half a millimetre in diameter, while the larger ones are several centimetres across. The strata are exceedingly well jointed into large rectangular blocks.

Twenty metres below the top of the formation there occurs a zone of large septaria, up to 3 m in diameter.

The oil shales member is also siltier than usual in the upper Rindedalen area of Barentsøya, across Freemansundet from Skrukkedalen, and in the Mistakodden area of northwest Barentsøya — an area characterised also by considerable structural complexity.

The oil shale member thins considerably when traced from west to east. In the west of both Edgeøya and Barentsøya the member exceeds 100 m, while in the east the thickness drops to about 50 m.

Several stratigraphic sections showing the varying lithology of the upper part of the Barentsøya Formation are presented in Figure 8.

### B. *Kapp Toscana Group*

This group was originally defined as a formation by Buchan et al. (1965). It was raised to the rank of group by Harland et al. (1974), the upper boundary was revised, and its members are now regarded as formations. In Barentsøya and Edgeøya the group comprises the Edgeøya and Negerfjellet Formations (both new, this paper).

#### B(i) *Edgeøya Formation*

Equivalents — «Purple Shales», «Blue and Purple Shales» of Falcon (1928).

The «Argillite Formation» plus «Passage Beds Formation» of Klubov (1965a, b), i.e. the lower two of the three divisions of his «Тз». Most or all of the Tschermakfjellet Formation of Flood et al. (1971b). Equivalent in stratigraphic position with the Tschermakfjellet Member of Spitsbergen (Buchan et al. 1965), now the Tschermakfjellet Formation (Harland et al. 1974).

Type section — H1707, from Veidemannen, southwest Edgeøya, (Fig. 9) is a section measured by W.B. Harland with a survey altimeter on 27 July 1969.

The contacts with the cliff-forming shales of the Barentsøya Formation below and with the lowest sandstone of the Negerfjellet Formation above are clearly seen.

The Edgeøya Formation consists of an interval of shales, with subsidiary fine siltstones becoming commoner towards the top of the section and thin red to purple-weathering clay-ironstone beds and thin argillaceous and arenaceous micritic limestones, some of which display cone-in-cone structures. The

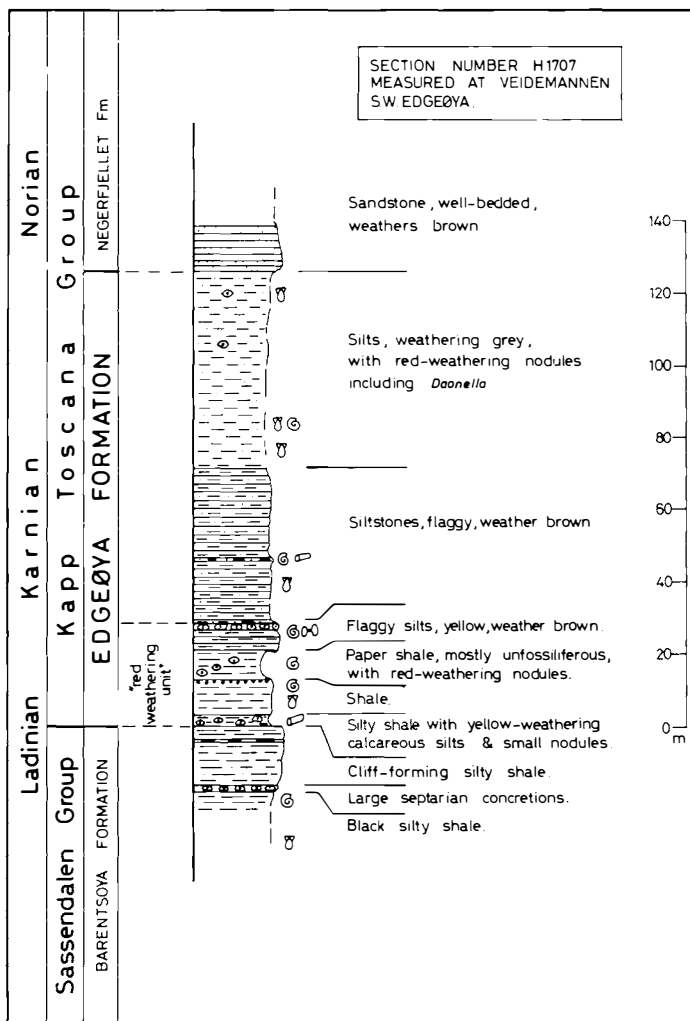


Fig. 9 Type section of the Edgeøya Formation. For detailed location see Fig. 17.

base of the formation is taken immediately above the top of the cliff-forming bituminous shales of the Barentsøya Formation, generally therefore immediately above the top of the bed of yellow to orange-weathering argillaceous limestone. There is a marked difference in the nature of the shales in the Edgeøya Formation when compared with those of the Barentsøya Formation. Those of the Barentsøya Formation are black and papery and bituminous, whereas those of the Edgeøya Formation are dark-grey, thin bedded and non-bituminous. The top of the formation is the base of the first prominent sandstone of the Negerfjellet Formation, where «prominent» is defined (see below) as «thicker than 1 cm». This definition of the formation boundary has the practical advantage that it is easily identified in the field. A disadvantage is that the basal part of the Negerfjellet Formation consists of a series of coarsening-upwards cycles (see below), and the present classification would generally place the formation boundary in the middle of the first such cycle. How-

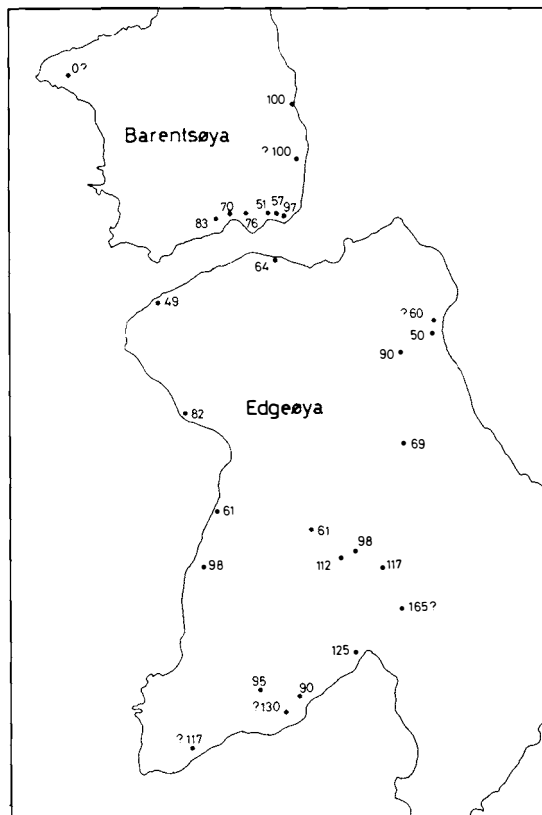


Fig. 10 *Thicknesses of the Edgeøya Formation (in metres).*

ever, the whole upper part of the Edgeøya Formation shows the influence of the incoming of deltaic conditions, justifying Klubov's (1965a, b) use of the term «Passage Beds Formation» for these rocks.

We at first attempted to subdivide the Edgeøya Formation into two members while fieldwork was in progress; the lower member is almost entirely composed of shales with relatively abundant red-weathering clay-ironstones, while the upper member has only rare clay-ironstones and contains a large proportion of siltstones which increase as it is traced upwards. However, the boundary is not always well-defined, and it is extremely doubtful that we were identifying a consistent stratigraphic level when we attempted to measure the thicknesses of strata distributed between the two «members». We now prefer to regard the formation as a simple transitional unit with an overall upward coarsening which continues through to the base of the Negerfjellet Formation.

A striking feature of the Edgeøya Formation is the variation in its thickness; Figure 10 summarises these variations. It is particularly notable that the formation is missing entirely in the Mistakodden area and that no distinctive trends are shown by the variations in thickness. Figure 11 shows a series of measured sections through the formation.

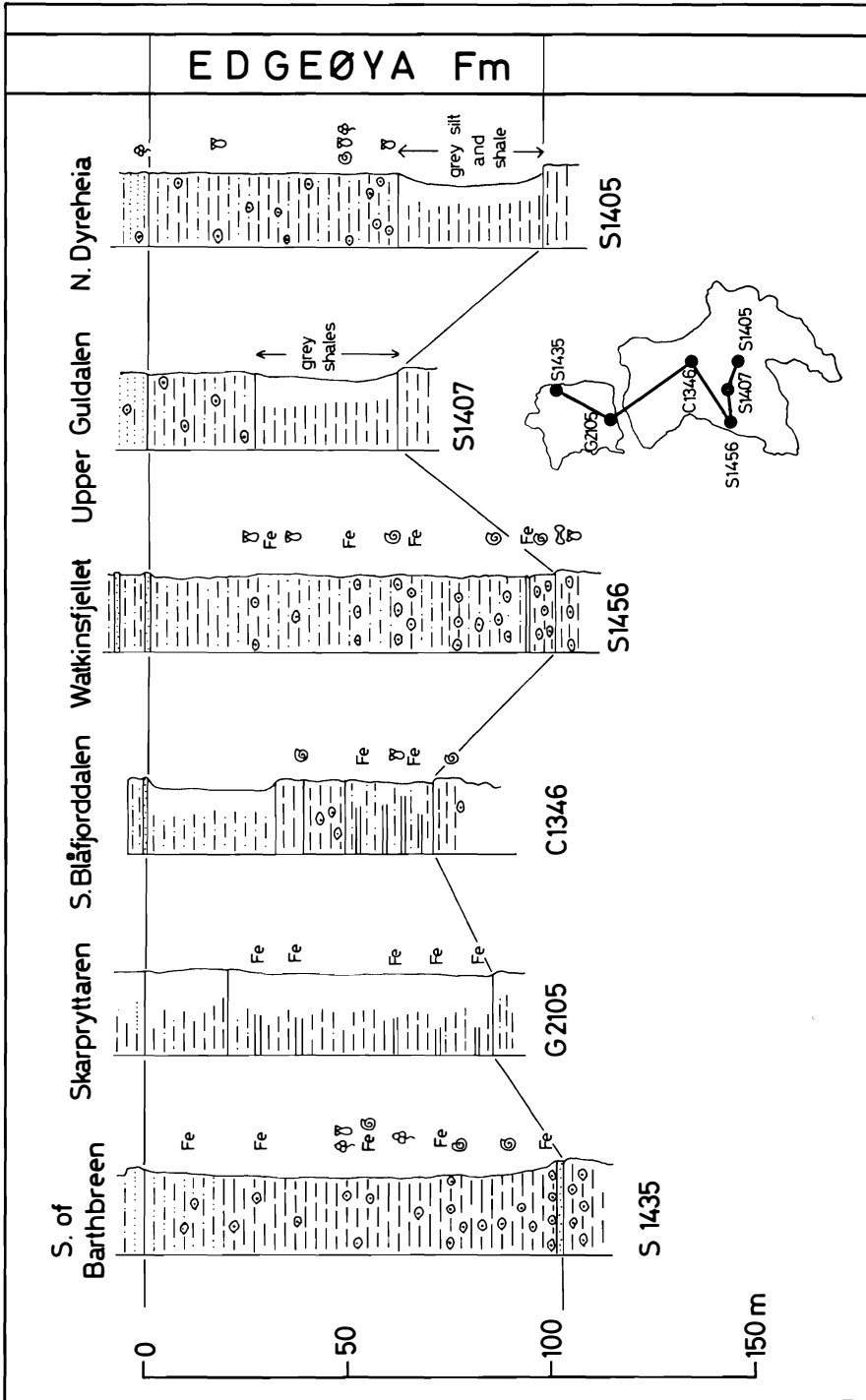


Fig. 11 Sections through the Edgeøya Formation.

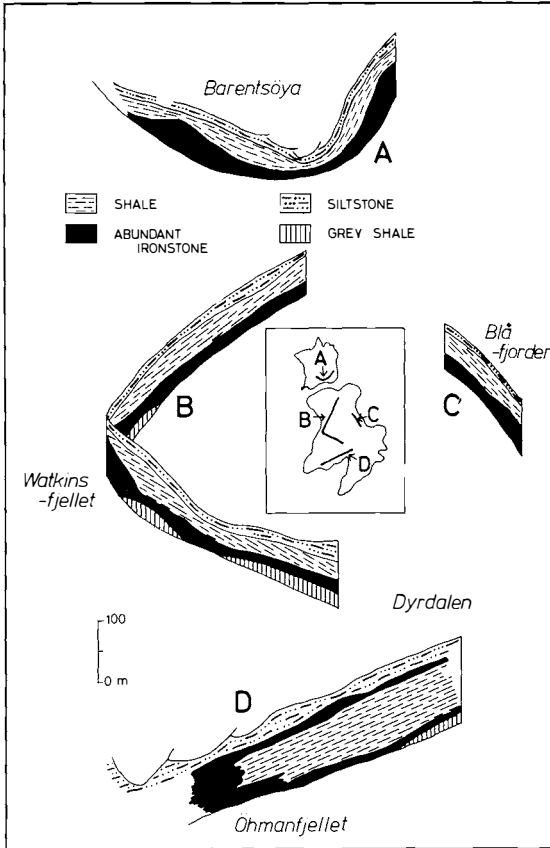


Fig. 12 Lithological variations in the Edgeøya and Barentsøya Formations.

Marine fossils — ammonites and bivalves especially — are common in the formation, particularly the basal part. Very large numbers of the ammonite *Nathorstites* occur in a horizon which is usually 20 to 30 m above the base of the formation; this is informally termed the «*Nathorstites* band». This horizon is a good stratigraphic marker. Several specimens of silicified wood were found in the lower part of the Edgeøya Formation.

#### B(ii) *Negerfjellet* Formation

Equivalents — «Sandstone Group» of Falcon (1928). De Geerdalen Formation and perhaps the uppermost part of the Tschermakfjellet Formation of Flood et al. (1971b). Correlative of the De Geerdalen Member of the Kapp Toscana Formation of Buchan et al. (1965), the De Geerdalen Formation of Harland et al. (1974) in Spitsbergen, and Svenskøya Formation of Kong Karls Land (Smith et al. 1976). Also correlative to part of the sequence in Hopen (Smith et al. 1975), particularly the Iversenfjellet Formation (in part).

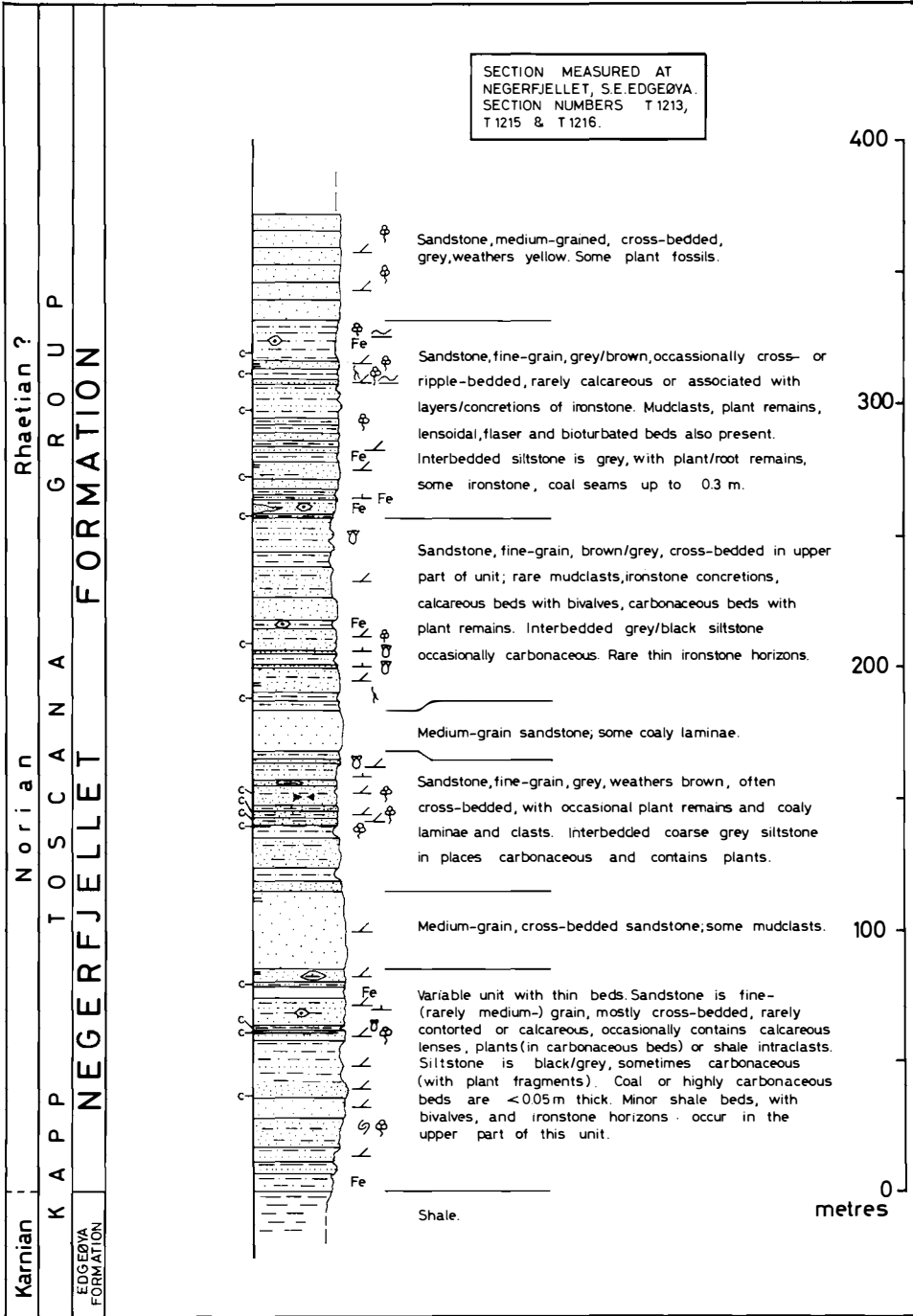


Fig. 13 Type section of the Negerfjellet Formation. For detailed location see Fig. 17.

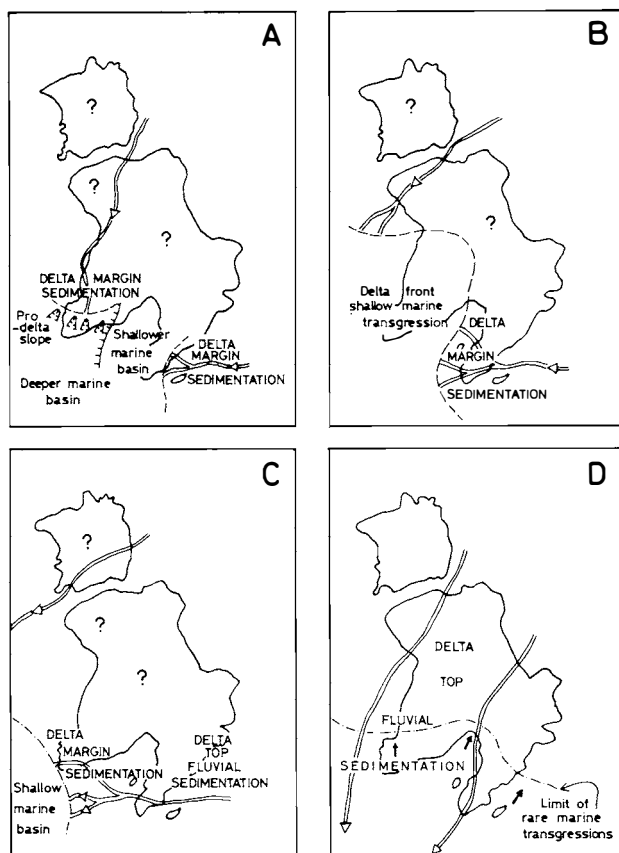


Fig. 14 *Speculative sequence of palaeogeographies for the Negerfjellet Formation (from Piper (in preparation)).*

Type section — T1213, T1215—6 (Fig. 13), Negerfjellet (cliffs to northwest), measured by D.J.W. Piper on 1—4 August 1969. The exposure is almost continuous and the contact is clearly exposed in T1213, here nominated as a reference section for the purpose of defining this contact (see below). No upper contact for the formation is seen, within the type section or elsewhere on Edgeøya and Barentsøya. The De Geerdalen Formation of the mainland of Spitsbergen is overlain by a phosphate-nodule conglomerate (the Brentskardhaugen Bed) followed by the shales of the Janusfjellet Formation.

The formation consists of sandstones — usually rather flaggy — with subordinate siltstones, sandy and silty tan and buff shales and rarer black and grey shales, thin coal seams, ironstone and oolitic, micritic and shelly limestone beds. The micritic limestones commonly display well developed cone-in-cone structures.

The sandstones of the Negerfjellet Formation have been subjected to petrographic study by Flood et al. (1971b), and most of their findings are confirmed by the present authors. The sand grains, with a mean size which varies from sample to sample but which rarely exceeds half a millimetre, consist of a va-



riety of types, usually with quartz making up much less than half the total sand fraction. An average composition might be:

- Quartz 40%
- Rock fragments 30%
- Chert 15%
- Alkali felspar 10%
- Other grains (including muscovite and plagioclase) 5%

Many of the quartz grains display good euhedral faces — Flood et al. (1971b) regarded the majority of these as primary features, suggesting derivation from quartz-porphyrines in Nordaustlandet, but we believe that these faces are virtually entirely authigenic in origin. Some grains show mutual interference during growth, and in most slides the euhedral faces are developed only where the grain is in contact with calcite cement. This cement is usually sparry and often very coarse. Carbonate mud is also present in some samples, and often forms distinct laminae. All gradations exist between calcareous sandstones and arenaceous micritic limestones.

During the course of low-grade burial metamorphism, a good deal of recrystallisation has taken place. This is particularly obvious when shell fragments or oolites are seen in thin section — fine structure is in many cases obscured or totally destroyed. Some development of dolomite has also taken place — the characteristic rhombohedral crystals are commonly observed.

The base of the formation is taken at the base of the first prominent sandstone as one passes up from the shales of the Edgeøya Formation. For this

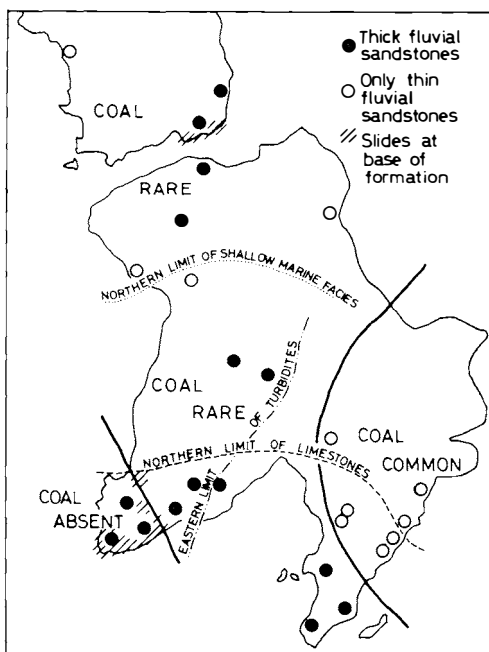


Fig. 15 Limits of distribution of various lithologies in the Negerfjellet Formation (from Piper (in preparation)).

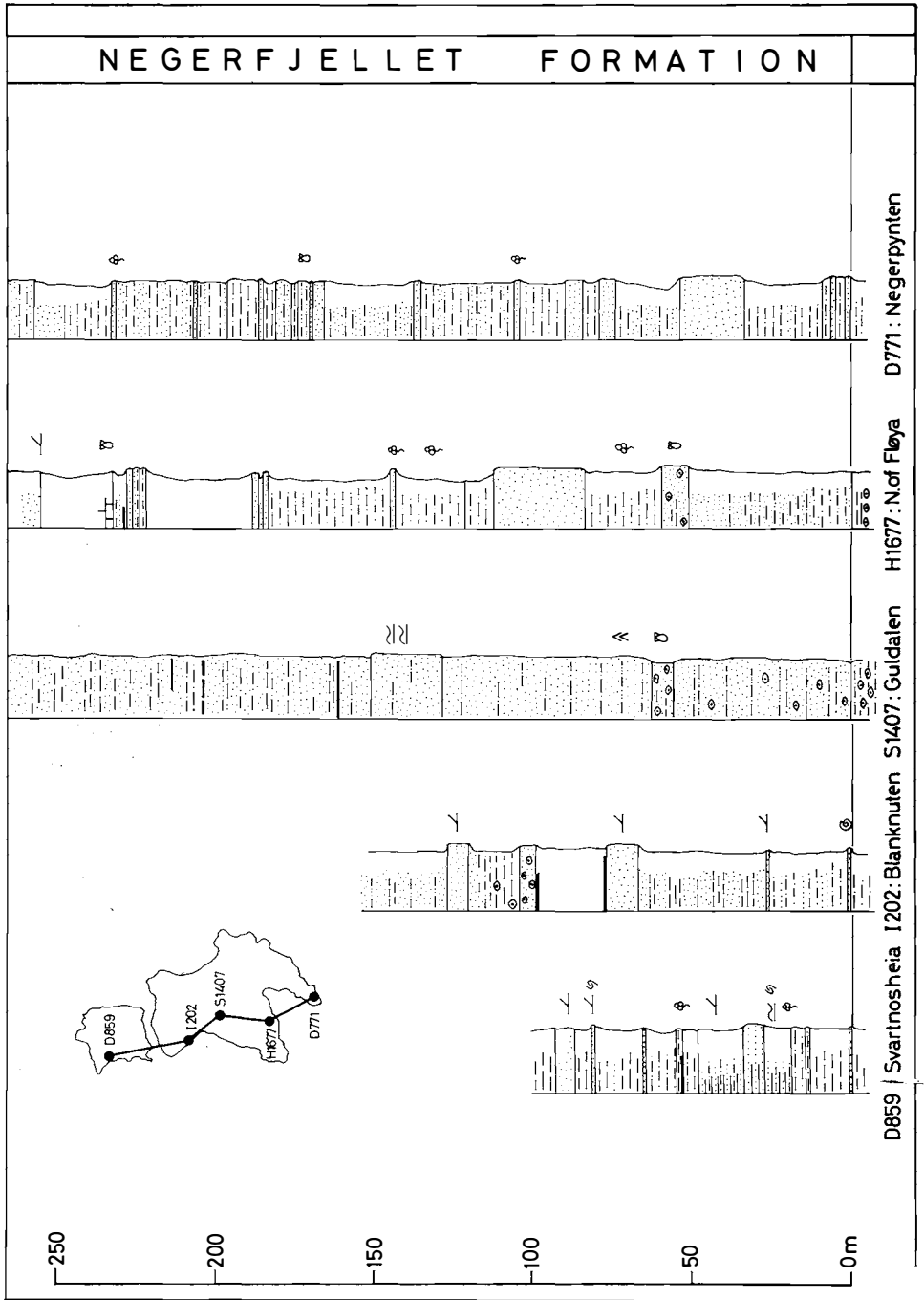


Fig. 16 Sections through the lower part of the Negerfjellet Formation.

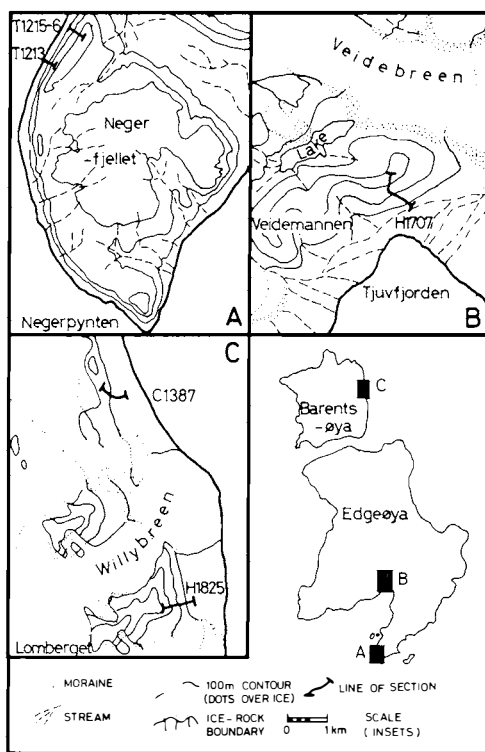


Fig. 17 Locality maps for type sections of the Barentsøya, Edgeøya and Negerfjellet Formations (Figs. 7, 9, 13).

purpose «prominent» is defined as thicker than 1 cm. This practice leads to considerable regional variations in the thickness of the Edgeøya Formation, and the boundary is probably highly transgressive. No top boundary is defined, as no overlying strata are found in Edgeøya or Barentsøya (see above). The maximum thickness measured for this formation in Barentsøya was 240 m (in the east of the island), while about 400 m are present on Negerpynten, in Edgeøya.

Poorly preserved plant fossils are common, and bivalves, including oysters, occur in a few beds. Klubov (1965a) has mentioned finding a specimen of *Nathorstites* sp. at the base of the formation at Negerpynten, Edgeøya. Flood et al. (1971b) reported echinoderms from one locality and a fragment is present in one of the lithological specimens collected by the Cambridge expedition in 1969. Falcon (1928) recorded «a reptilian jawbone with teeth» from near Negerpynten. Plant microfossils (including spores) have been recovered from the Negerfjellet Formation. They provide the best evidence for the age of the formation, and their significance is discussed below (Section II.5.D).

Falcon (1928) recognised that «the sandstones are of 'estuarine' or deltaic type» — a view which has been shared by subsequent workers. Piper (in preparation) gives a detailed account of the sedimentology of the formation, and justifies his interpretation of it as the product of a major delta complex deposited by rivers entering a marine basin from the northeast (Figs. 14 and 15). Piper (op. cit.) recognised seven principal lithofacies within the formation, summarised in the following paragraphs.

(i) *Turbidites*. Turbidites occur near the base of the formation at a number of localities and were studied in detail by Piper at Kvalpynte in particular. Individual turbidites range in thickness from 0.01 to 1.5 m; sole marks, especially groove casts, are common, and Bouma C and BC sequences are found.

(ii) *Thick sandstones filling slide scars*. The basal portion of the formation is characterised by local sliding of sedimentary masses, notably in the Kvalpynten area of Edgeøya and in the Jeppeberget area of southeast Barentsøya. The sediments involved in the sliding are, for the most part, of turbidite facies, although the uppermost parts of the underlying Edgeøya Formation have been affected as well at some localities. Many of the slide scars are up to 30 m deep, and some of those near Kvalpynten are filled by thick, massive sandstones believed by Piper to be the products of single episodes of sedimentation. We are impressed by similarities between the massive sandstones from Edgeøya and the larger scale «sand flows» of the Gres d'Annot of the Maritime Alps (Stanley 1975). The scar-filling sandstones are massive, planar bedded, or cross-bedded on a large scale. Channel structures occur within some of the massive units, and mudstone intraclasts are found in the upper levels. Grading is characteristically absent.

(iii) *Shallow marine sequences*. These occur as coarsening-upwards cycles of silty shales and sandstones, with characteristic bioturbation. The normal sequence consists of shale, followed by stratified sandstone — often cross-bedded in sets up to 10 m thick — followed by massive sandstone (Edwards 1976b). They are sometimes capped by a coquina or an oyster bed. Marine sequences are abundant in the lower part of the Negerfjellet Formation. Piper (op. cit.) suggests that these are deposits which accumulated in a progressively shallowing marine environment on the delta-front platform.

(iv) *Mouth-bar sequences*. Some of the coarsening-upwards cycles described in the previous paragraph are overlain by thick (up to 3 m), medium-grained sandstone units with large-scale, high-angle cross-bedding. Load structures are abundant in the thinner sandstone beds which immediately underlay the thick units. This combination of lithological types displays the characteristics considered typical of the prograding mouth-bar facies.

(v) *Fluvial-channel sequences*. Fining-upwards cycles are characteristic of the upper part of the Negerfjellet Formation. They consist of medium-grained sandstones with high-angle cross-bedding which pass upwards into siltstones, with common mudstone intraclasts and plant fossils, and are interpreted as the deposits of fluvial distributary channels.

(vi) *Fluvial overbank facies*. This facies, which is also found generally in the upper part of the formation, consists of thick, dark siltstones, often with minor silty coals. Bands and nodules of ironstone and thin beds of fine sandstone are associated.

(vii) *Marginal marine sequences*. This facies comprises several distinctive lithologies, such as thin beds of ironstone (some of which are oolitic), sandy stromatolites, thin algal limestones and beds containing high concentrations of bivalves, usually all of a single species. However, the great bulk of the marginal marine sediments is composed of thin coarsening-up cycles overlain by dark siltstones and coal. The depositional environments are believed to have been varied, ranging from shallow open marine and lagoonal to tidal flat and swampy terrestrial. Although Klubov (1965a, b) attempted to use a prominent coal seam as a stratigraphic marker throughout Edgeøya and Barentsøya, it is unlikely that it was the same seam in each locality. We found no satisfactory marker horizon within the Negerfjellet Formation.

In two recently published papers, Edwards (1976a, b) has described features from the uppermost part of the Edgeøya Formation and lowermost part of the Negerfjellet Formation on the western side of Kvalpynten, Edgeøya, which he interprets as growth faults. These are rotational faults developed contemporaneously with sedimentation in the prograding delta facies (Piper's «shallow marine sequence»). The structures were first noted by De Geer (1919) and by Falcon (1928), who observed that the inaccessible cliff sections in this area displayed what appeared to be an unconformity between the two formations — the strata in the lower part of the cliffs are tilted northwards at angles of up to  $20^\circ$ , while the immediately overlying beds are horizontal. Buchan et al. (1965 p. 51) suggested that the structure might be a form of large-scale crossbedding, but Edwards was able to demonstrate a close similarity between the Kvalpynten features and growth faults described from Tertiary deltaic sediments by a number of authors. Abnormally high fluid pore pressures are believed to be, at least partially, responsible for the formation of faults dipping at angles of between  $20^\circ$  and  $50^\circ$  towards the delta margin. These faults delimit blocks of sediment which are tilted towards the north, away from the delta margin, so that the strata affected (those in the lower part of the cliffs) are arranged in a series of rotated blocks. Within each block, individual strata thin updip away from the fault, so that individual beds tend to be wedged-shaped rather than sheet-like.

Local variations in thickness of sandstone units deposited during delta progradation are believed to cause corresponding variations in local rates of compaction and subsidence, as well as some shale flowage. This in turn is believed to lead to the formation of soft-sediment gravity faults, which, once formed, lead to further thinning of individual sandstone units, controlled by lateral variations in subsidence rate and by some erosion of sandstone units in the updip direction. Thus, once formed, growth faults tend to be self-perpetuating.

Down-basin dipping growth faults indicate a bulk horizontal component of mass movement southward (Edwards 1976b). The original prodelta slope is likely to have been less than  $1^\circ$ , and growth faulting is only likely to have been possible if extremely low shear strengths were present in the underlying shales as a result of excess pore-fluid pressures, and if some form of micro-seismic shock took place, perhaps repeatedly, to trigger displacement.

Edwards (1976a) mentioned the presence of extensive folds and faults in

correlative strata at Mistakodden, Barentsøya, and suggested that related phenomena were responsible. However, the geometry of the structures at Mistakodden is quite different — folding is chaotic, and the strata are locally nearly vertical, while faulting is nearly absent. The Mistakodden area is characterised by extensive and complex dolerite intrusion, and the structural disturbance in the area may reflect the effects of the intrusions on what may have been poorly consolidated sediments.

## 5. STRATIGRAPHIC PALAEOLOGY

### A. *Introduction*

In this section we are concerned solely with the Triassic strata; the Permian rocks have been investigated less intensively, and our available data are reviewed in Section II.3.

Fully marine Triassic sequences are relatively rare throughout the world, and many of the other areas where such sequences occur have been involved in subsequent tectonism. This situation lends a particular interest to the Svalbard rocks, which record marine conditions through most of the period and which have been only slightly affected by tectonic disturbances, especially in Edgeøya and Barentsøya. At the same time, the problems facing the stratigraphic palaeontologist are made more difficult by the lack of comparable sequences elsewhere. It is fortunate that the region in which the most comprehensive study has been made of Triassic marine faunal sequences is nearby Arctic Canada (Tozer 1967; Silberling & Tozer 1968). Tozer's biostratigraphic classification of the marine Triassic is used as the basis for the present discussion of the Edgeøya and Barentsøya rocks, and is reproduced as part of Table 2.

Large numbers of fossils were collected during the course of fieldwork by members of the 1969 NCSE expedition — over nine hundred specimens of the ammonite *Nathorstites* alone — and these have been the subject of study by several members of the team including two of the authors of this paper (DGS and DJB).

### B. *Ammonites*

The stratigraphic value of the Triassic ammonite faunas of Svalbard has been greatly enhanced as a result of the detailed studies by Tozer (1967), in the Canadian Arctic. Tozer's work has shown that the previously accepted succession of Triassic ammonite zones, based upon the «classical» Alpine localities, contained many imperfections. Some of the originally defined zones are now known to have been in incorrect order, others are equivalent to one another, and some were based on condensed sequences.

Tozer & Parker (1968) reviewed the Svalbard faunas in terms of the new Canadian standard, in a paper which was essentially a revision and amplification of the section on palaeontological age in Buchan et al. (1965, p. 52—56). Table 2 summarises the scheme of stages and zones used by Tozer & Parker (*op. cit.*), and forms the basis for the following paragraphs, which are designed as an extension of their work to cover Edgeøya and Barentsøya.

(i) *Griesbachian and Dienerian* (roughly equivalent to the Induan or Lower Scythian of various authors).

Griesbachian ammonites are known from the Vardebukta Formation of Spitsbergen (Tozer & Parker 1968), and Dienerian strata are also assumed to be present by those authors. The Vardebukta Formation is believed to correlate with the lowest part of the Barentsøya Formation of Edgeøya and Barentsøya, but the latter is characterised by poor exposure and few fossils, and no definitely Lower Scythian ammonites have yet been found, other than the *Ophiceras*(?) sp. recorded by Flood et al. (1971b, Fig. 2).

(ii) *Smithian* (roughly equivalent to the lower part of the Olenekian — the Olenekian is in turn roughly equivalent to the Upper Scythian).

Six genera have been identified (by DGS) from the NCSE material collected in 1969. These are as follows:

*Arctoceras*  
*Arctoprionites*  
*Euflemingites*  
*Prospiringites*  
*Tellerites*  
*Xenoceltites*

All six were found in the type section for the lower part of the Barentsøya Formation (section C1387, Willybreen; Barentsøya), while *Arctoceras*, *Prospiringites* and ?*Xenoceltites* were also collected from south Dyreheia in Edgeøya, and ?*Arctoprionites* and ?*Xenoceltites* from Watkinsfjellet, also in Edgeøya. Flood et al. (1971b) recorded *Arctoprionites nodosus* but did not record the locality. This faunal list indicates that both Tozer's zones of the Smithian are represented in the islands.

(iii) *Spathian* (roughly equivalent to the upper part of the Olenekian).

*Keyserlingites*, a genus characteristic of the *subrobustus* Zone, together with somewhat doubtfully identified, flattened specimens of *Svalbardiceras* (a common associate of *Keyserlingites* elsewhere in Svalbard) has been found in Edgeøya and Barentsøya at a stratigraphic level just beneath the base of the oil shale member of the Barentsøya Formation. This confirms the suggestion

that the cliff-forming paper shales of the oil shales member are time-correlatives of the Botneheia Formation of Spitsbergen, since Tozer & Parker (1968) have shown that the boundary between the Sticky Keep and Botneheia Formations is approximately at the Spathian-Anisian boundary. Flood et al. (1971b) similarly recorded *Keyserlingites* cf. *subrobustus* and, from a somewhat higher horizon, *Svalbardiceras*(?) cf. *spitzbergense*. It should be noted that the forms identified by the latter authors are listed in a single table for Edgeøya and Barentsøya combined, without details of localities.

Klubov (1965b) listed the following Scythian ammonites from 90 m above the base of the Triassic on Barentsøya:

*Flemingites* cf. *flemingianus* Konink  
*Meekoceras* cf. *corrugatum* Smith

and the following from a little higher in the succession:

*Xenoceltites* sp. indet.  
*Arctoceras* cf. *blomstrandii* Lindström  
*A.* cf. *oebergi* (Mojsisovics)  
*Prospiringites* *spathi* Frebold  
*Epiceltites* cf. *gentii* Arthaber  
*Goniodiscus* cf. *nodosus* Frebold  
*Olenekites* cf. *volutus* (Mojsisovics)  
*O.* cf. *spiniplacatus* (Mojsisovics)  
*Wasatchites*(?) gen. indet.  
*Svalbardiceras* *spitzbergense* Frebold  
*Arctoprionites* sp. indet.

The last two forms were also found on Edgeøya, by the same author (Klubov 1965a).

#### (iv) *Anisian*

The presence of Lower Anisian (*caurus* Zone) strata in Edgeøya and Barentsøya at the base of the cliff-forming oil shale member is suggested by the presence of *Koptoceras*, accompanied in one section (H1825 — the designated type section for the upper part of the Barentsøya Formation) by a few specimens of a poorly preserved hungaritid genus. *Koptoceras* is a genus which is characterised by poor preservation, and it has proved impossible so far to identify the species present; the genus ranges up into the Middle Anisian.

Falcon collected a large crushed beyrichid from Keilhaubukta, Edgeøya (Spath 1951 p. 13) at a horizon about 15 m above the *Koptoceras*-bearing beds and which Tozer & Parker (1968) compared with *Hollandites* or *Anagygnotoceras* probably indicating the *varium* Zone (Middle Anisian). Further beyrichid specimens, tentatively assigned to *Hollandites*, were collected in 1969 from Mistakodden and Barthbreen in Barentsøya. Two specimens of *Japonites* were found at Gregoryfjellet, in Barentsøya, associated with fragmentary ?*Hollandites*, and a number of specimens of *Gymnotoceras* were found



in the upper part of the oil shale member in both islands, some at least of which appear to be *G. laqueatum*, which indicates the *chisca* Zone of the Upper Anisian.

Klubov (1965a) listed the following ammonites of Anisian age from the base of the oil shale member on Edgeøya:

*Leiophyllites* sp. indet.  
*Hollandites* sp. indet. (ex. gr. *organi* Smith)

and from a little higher

*Gymnotoceras* cf. *blackei* (Gabb)

and from the middle part of the member

*Frechites* ex. gr. *bisulcatus* Popow.

At the top of the formation Klubov found the following ammonites, which he considered to be indicators of Ladinian age:

*Aristoptychites* cf. *kolymensis* Kipar.  
*Ussurites* cf. *spitsbergensis* Mojsisovics

It should be noted that these genera are listed as «Middle Triassic (Anisian)» in the Treatise on Invertebrate Palaeontology.

From Barentsøya, Klubov (1965b) recorded the following ammonites:

*Tropigastrites* aff. *londerbacki* Hyatt & Smith  
*Hollandites*(?) cf. *organi* Smith  
*Gymnotoceras* cf. *blackei* Gabb  
*G.* cf. *herschei* Smith  
*Frechites* cf. *humboldtensis* Hyatt & Smith  
*F.* ex. gr. *breweri* Smith  
*Cuccoceras*(?) sp.  
*Arctohungarites*(?) sp. indet.  
*Leiophyllites*(?) sp. indet.  
*Monophyllites* sp. indet.

Flood et al. (1971b) included the following forms in their combined list for the two islands:

*Ptychites trochlaeformis*  
*Ptychites* sp.  
*Gymnotoceras* cf. *laqueatum*  
*Parapopanoceras verneuli*

This assemblage indicates the presence in Edgeøya and Barentsøya of the true *Gymnotoceras laqueatum* fauna (*chisca* Zone of the topmost Anisian) described by Tozer & Parker (1968 p. 535—536) and earlier workers from Spitsbergen.

(v) *Ladinian*

The boundary between the Botneheia and Tschermakfjellet Formations of Spitsbergen appears to lie within the Ladinian (Tozer & Parker 1968), rather than at the top of the Anisian as suggested tentatively by Buchan et al. in 1965 (although the latter authors did note the possibility that the upper part of the Botneheia Formation might be Ladinian). None of the fossils characteristic of the lowest Ladinian zones were found amongst the 1969 collections from the Barentsøya Formation — specimens of *Nathorstites* and *Ptychites* from the very top of the formation might be either Anisian or Ladinian fauna.

The following possibly Ladinian ammonites have been identified from the Edgeøya Formation:

*Ptychites*  
*Ussurites*  
*Nathorstites* (including *N. gibbosus*)  
*Procladiscites*  
*Dawsonites*  
*Protrachyceras*  
«*Trachyceras*»

Most of the specimens come from a narrow horizon (the «*Nathorstites* Bed») near the base of the formation, the species *Nathorstites*, showing a considerable range of form, being extremely abundant. The first four of the following ammonite species have been recognised from low in the formation (presumably from the «*Nathorstites* Bed») by Flood et al. (1971b), while the final identification was by Klubov (1965a):

*Nathorstites mcconnelli* (Whiteaves)  
*N. tenuis* Stolley  
*N. aff. gibbosus* Stolley  
*Procladiscites cf. martini*  
*Paracladiscites cf. duiturnus* Mojsisovics

Although this fauna has been regarded as a Karnian one by some workers, Tozer & Parker (1968) have indicated that conclusive evidence for this view is lacking. The identification of *N. mcconnelli* by Flood et al. (1971b) suggests that the fauna is in fact a very late Ladinian one (*sutherlandi* Zone), on the basis of the distribution of this species in Canada (Tozer 1967).

(vi) *Karnian*

Klubov (1965a) reported *Sirenites* ex. gr. *hayesi* Smith from the Edgeøya Formation at Kapp Lee, Edgeøya, and Korchinskaya (1972) recorded *S. cf. yakutensis* Kiparisova from the same area, as well as from eastern Spitsbergen. The genus is unknown from pre-Karnian rocks, and it is therefore concluded that the Edgeøya Formation is Karnian at least in part. Klubov also listed *Cladiscites tolli* from throughout his «argillite formation» (apparently the

lower part of the Edgeøya Formation) and *Trachyceras*(?) sp. from the middle part of his «passage beds formation» (apparently the upper part of the Edgeøya Formation).

(vii) *Norian and Rhaetian*

No undoubted Norian or Rhaetian ammonites have yet been recorded from the main group of islands of the Svalbard Archipelago, but five specimens were found in Hopen by two separate expeditions in 1969 (Flood et al. 1971b; Smith et al. 1975). The former reported the find of a probable *Arctosirenites* (a genus previously recorded only from the Karnian — Tozer 1971), while Smith et al. reported four specimens of *Sirenites* (sensu lato), also from their Flatsalen Formation. Palynological assemblages from that formation indicate a Rhaetian age, and the latter authors suggested that ammonites of *Sirenites* type survived into the Rhaetian as a relict group in the Svalbard area, having become extinct elsewhere by early in the Norian. The Flatsalen Formation has been correlated on lithological grounds with the Wilhelmøya Formation of Wilhelmøya (Worsley 1973); it may or may not have lateral equivalents in the De Geerdalen Formation of Spitsbergen, the Negerfjellet Formation of Edgeøya and Barentsøya, and the Svenskøya Formation of Kong Karls Land, in all of which ammonites are unknown.

C. *Bivalves*

After the ammonites, the molluscan class Bivalvia probably provides the most useful stratigraphic information available for the Triassic of Edgeøya and Barentsøya. The following genera have been reported by Klubov (1965b) from the lower part of the Barentsøya Formation (at least 40 m above the base) on Barentsøya, from a locality in the vicinity of the type section:

- Pseudomonotis* (*Eumorphotis*) ex. gr. *multiformis* Bittner
- Myalina* cf. *scharmarae* Bittner
- M.* cf. *dalailamae* Vern
- Anodontophora* sp. indet.

Tozer & Parker (1968, p. 529) have pointed out that bivalves identical with the «*Pseudomonotis* cf. *multiformis*» described by Frebold (1939) from Draschedalen in Spitsbergen occur in the *sverdrupi* Zone (upper Dienerian) of Ellesmere Island. Thus a Dienerian age is also suggested for this lowest fauna from the Barentsøya Formation.

Flood et al. (1971b) recorded *Claraia stachei* Bittner from the strata in northeast Barentsøya which they correlate with the top of the Vardebukta Formation of Spitsbergen — that is to say, from a position rather less than 60 m above the base of the Triassic in the area. Since Klubov's fauna, with an apparently late Dienerian indicator, lies at a stratigraphically lower level, there is a conflict between the latter and the upper Griesbachian stage normally implied by *Claraia stachei*. It would seem either that one or other identifi-

cation is incorrect, or that the range of one or other species is greater than was previously believed.

Klubov (1965b) listed *Posidonia mimer* Oeberg from a second horizon, about 90 m above the base of the Triassic sequence in Barentsøya. In Edgeøya *P. aranea* Tozer has also been found (Klubov 1965a); both forms were also recorded by Flood et al. (1971b). In Spitsbergen *P. mimer* is characteristic of the Smithian faunas, particularly at the horizon known as the Fish Niveau (see below, Section II.E). The main level for this species is the *romunderi* Zone. «*Pseudomonotis*» *occidentalis* (Whiteaves), reported by Flood et al. (1971b) from a somewhat higher horizon, is an indicator of the late Smithian *tardus* Zone.

The overlying strata on Barentsøya yielded the following bivalve fauna to Klubov (1965b):

*Pseudomonotis* cf. *aurita* Hauer  
*Claraia* ex gr. *subaurita* Krumb.  
*C. aurita* Hauer  
*Posidonia aranea* Tozer  
*P. mimer* Oeberg  
*P.* cf. *backlundii* Wittenburg  
*Pecten* aff. *sojalis* Wittenburg

Of these, *Posidonia aranea* (which occurs immediately beneath the base of the overlying oil shale member, in association with the two species of *Claraia*) is restricted to the *subrobustus* Zone (topmost Spathian) in Canada (Tozer & Parker 1968). Unfortunately, Klubov has not recorded sufficient detail of the horizons from which his specimens were collected to reveal whether *P. aranea* and *P. mimer* are in association or not. If they are associated, an extension of the range of one or other species beyond that typical of the Canadian Arctic occurrences would be suggested. The report by Flood et al. (1971b) is in the form of a correlation table, in which it is clearly indicated that *P. aranea* was found at a higher level than *P. mimer*.

The lower and middle parts of the oil shale member yielded the following bivalves in Barentsøya (Klubov 1965b):

*Uelopecten* cf. *alberti* (Goldfuss)  
*Mysidioptera* sp.  
*Sphaera* ex gr. *whitneyi* Meek

*Meleagrinnella* ex gr. *tas-aryensis* Voronetz was found in Edgeøya (Klubov 1965a). The associated ammonites suggest an Anisian age.

The upper parts of the oil shale member contain the following bivalves:

*Daonella* cf. *frami* Kittl.  
*D.* cf. *lommeli* Wissman  
*D.* cf. *moussoni* Merian  
*Anodontophora* cf. *lettica* Quenstedt  
*Eumorphotis* aff. *vagans* Böhm

*E. ex gr. variabilis* Böhm

*Hoernesia* cf. *torta* Popow.

*Pseudomonotis (Eumicrotis)* cf. *tas-aryensis* Voronetz

all from Edgeøya (Klubov 1965a), and the same three species of *Daonella*, *A.* cf. *lettica*, together with the following additional forms from Barentsøya (Klubov 1965b):

*D. densisulcata* Gabe & Schim.

*D. subarctica* Popow.

and *Moernesia* cf. *torta* Popow.

*D. frami* may be a variant of the species *D. degeeri*, which is characteristic of the *subpersum* Zone of the basal Ladinian in Arctic Canada (Tozer 1967), although Tozer & Parker (1968) have suggested that the equivalent Spitsbergen fauna, which is associated with *Nathorstites*, may be slightly younger.

The Edgeøya Formation has yielded species of the Karnian genus *Halobia*. Klubov (1965a and b) has reported *H. zitteli* Lindström from his «argillite formation» (i.e. low in the Edgeøya Formation) from both islands and from the lower part of his overlying «passage-bed formation» in Edgeøya (1965a), while Flood et al. (1971b) have recorded the same species from a level nearer the top of the Edgeøya Formation. *Halobia* aff. *superba* Mojsisovics was found by Klubov (1965a) in both of his units, and a further, indeterminable, species was found at the base of the Negerfjellet Formation (Klubov's «sandstone formation»).

Other bivalves reported by Klubov (1965a) from the Edgeøya Formation are as follows:

from the top of the «argillite  
formation» —

*Anodontophora ephippium* Böhm

from the «passage-bed formation» — *Nucula* sp.

*Myophoria*(?) sp. indet.

*Inoceramus*(?) *nicolaiewi* Voronetz

*A. ephippium*

from the middle part of the  
«passage-bed formation»

*Gervilleia* sp.

*Eomorphotis*(?) *artus* Böhm

from the top part of the same unit — *Pecten (Eupecten)* cf. *deformis* Gabb

*Anodontophora*(?) sp.

A long list of bivalves has been recorded from the Negerfjellet Formation by Klubov, particularly from the island of Edgeøya (1965a). It should be noted that he attached significance to a prominent coal seam between 0.1 and 0.2 m thick, which occurs in the middle of this formation (his «sandstone formation»), and which he considered a useful marker horizon. Our own experience was that several coal seams occur and that they are *not* to be correlated

directly from one section to another. This feature is discussed in greater detail above (in Section II.4.E).

The bivalves listed by Klubov are as follows:

- at the base of the formation — *Halobia* sp. indet.
- 50—60 m higher — *Posidonia* cf. *stella* Gabb  
*Gryphaea* sp. indet.  
*Modiola* ex gr. *paronas* Bittner  
*Trigonodus*(?) sp.  
*Cardinia* sp.  
*Pleurophorus*(?) sp.
- sandstones 100 m above base— *Cassianella* cf. *tectiformis* Böhm  
*Gervillia* cf. *bennetti* Böhm  
*Pecten* (*Entolium*) *obergi* Lundgreen  
*Myophoria* cf. *tennei* Dames  
*M.* cf. *urd* Böhm  
*Trigonia* cf. *margaritifera* Böhm  
*Pleuromya* sp.  
*Shafhäütli* sp.
- 120 m above base— *Cardinia* sp. (cf. *ovula* Kittl.)  
*Cuspidaria* sp. indet.
- immediately below «coal marker» — *Modiola* sp. indet.
- immediately above «coal marker» — *Macrodon*(?) sp.  
*Cardinia*(?) sp. indet.
- sandstone 8 m above «coal marker» — *Trigonodus* cf. *keuperinus* Berger  
*Macrodon* sp.  
*Megalodon* sp.  
*Pleuromya*(?) sp.
- and from higher up, mainly in sandstones — *Macrodon*(?) sp.  
*Meleagrinella antiqua* Tozer  
*Gryphaea* sp.  
*Myoconcha*(?) sp.
- and — *Anodontophora* ex gr. *munsteri* Wissman  
*Trigonodus keuperinus* Berger  
*Pachycardia*(?) sp.

*Meleagrinella antiqua*, which is an indicator of Norian age, has also been found in Barentsøya, as have *Anodontophora munsteri* Wissman and *Meleagrinella* aff. *formosa* (Klubov 1965b). *M. antiqua* was located 60 m above the «coal marker».

D. *Palynomorphs*

Palynology is becoming increasingly recognised as an important tool in elucidating the stratigraphy of the Mesozoic rocks of eastern Svalbard. Early results from Spitsbergen were disappointing (Buchan et al. 1965, p. 58), but much more successful extraction and use of plant microfossils has recently been achieved in the Kapp Toscana Group of Hopen, Wilhelmøya and Kong Karls Land by Smith and others, and by Bjærke (1975) in Hopen. Hughes, Harland & Smith (1976) have discussed the possible causes for the improvement in preservational quality from west to east across Svalbard, concluding that differing burial histories under later sediments was probably the principal controlling factor.

Following the 1969 Cambridge expedition, a pilot palynological study of samples from Edgeøya and Barentsøya was carried out by DJB in order to assess the potential of this method. Most of the preparations made were disappointing, including three from the Negerfjellet Formation, and they lacked any stratigraphically significant palynomorphs. One, however, a sample of medium grained siltstone from 8 m below the top of the Barentsøya Formation (oil shale member) at Sjudalen, northwest Barentsøya, yielded a fairly diverse assemblage. A preliminary examination revealed the presence of the following miospore genera:

*Duplexisporites*  
*Klukisporites*  
*Camarozonosporites*  
*Lundbladispota* (and other monosaccate genera)  
*Ovalipollis*  
*Apiculatisporis*  
*Verrucosisporites*  
*Osmundacidites*  
*Stereisporites*

This assemblage appears to be consistent with the probable Ladinian age of this horizon.

Another palynomorph assemblage from Ladinian rocks of Barentsøya has been reported by Klubov (1965b). He listed the following:

*Coniopteris*(?) sp.  
*Leiotriletes* sp.  
*Trachytriletes* sp.  
*Selaginella* aff. *obtusosetosa* K.-M.  
*Lophotriletes nordvikiensis* K.-M.  
*L.* aff. *anabarensis* K.-M.  
*Periplecotriletes amplectus* (Waltz)  
*P. amplectus* var. *tajmyrensis* K.-M.  
*P. intertektus* (Waltz) var. *triassicus* K.-M.  
*Osmunda jurassica* L.-M.

*Leiotriletes turgidorimosus* K.-M.  
*Stenozonotriletes* sp.  
Bennettitales pollen  
Ginkgoales pollen  
*Podozamites* sp.

Palynology is undoubtedly of greatest potential importance for dating the rocks of the Negerfjellet Formation. As part of a wider project on the palynology of the Kapp Toscana Group in eastern Svalbard, one of us (DGS) has processed a number of samples from the type section of the Negerfjellet Formation (Fig. 13). These have not yet been fully investigated, but preliminary results are encouraging. Of 12 samples processed, from 80 to 320 m above the base of the section, most yielded moderately well preserved palynomorphs. Fortuitously, the best preserved assemblage is the highest one stratigraphically, which must be from some of the youngest strata on either Edgeøya or Barentsøya. This assemblage is dominated by monolete and monocolpate miospores, including *Marattisporites*, *Polyodiisporites* and *Cycadopites*. Bisacate pollen is rare; it includes *Vitreisporites*. Of greater importance stratigraphically, though present in small numbers only, are miospores closely comparable with the following taxa:

*Anapiculatisporites spiniger* (Leschik)  
*Annulispora*  
*Aratrisporites minimus* Schulz  
*Araucariacites*  
*Camarozonosporites rudis* (Leschik)  
*Concavisporites*  
*Deltoidospora*  
*Equisetosporites*  
*Eucommiidites troedssonii* Erdtman  
*Gliscopollis*  
*Granulatisporites*  
*Granuloperculatipollis rudis* Venkatachala & Goczan  
*Kyrtomisoris* sp. nov. in Bjærke 1975  
*Lycopodiacidites*  
*Neoraistrickia*  
*Ovalipollis ovalis* Krutzsch  
*Uvaesporites ressingeri* (Reinhardt)

This assemblage is characteristically later Triassic. It cannot be dated in terms of the traditional stages because of the lack of palynological data from ammonite-bearing sequences elsewhere in the world; it is most likely to be Norian. However, it is readily correlated with sections already examined palynologically by DGS in eastern Svalbard. Similar assemblages were found in Hopen in the Iversenfjellet Formation, from 55 m above its exposed base (the lowest assemblage examined) up to 110 m below its top (Smith, Harland



& Hughes 1975). Near the top of the Iversenfjellet Formation the palynofloras take on a distinctively Rhaetian aspect, not observed in the material from Negerfjellet. In Wilhelmøya (Smith 1975), similar assemblages were recovered from the Uleneset Member of the De Geerdalen Formation.

The samples from lower down in the Negerfjellet Formation yielded less well preserved palynomorphs and further work will be needed to make firm identifications. The assemblages are diverse, however, and appear to be consistent with the Karnian to Norian age of the strata as indicated by invertebrates.

### E. *Vertebrates*

Large numbers of vertebrate fossils were collected by the members of the Norsk-Cambridge Svalbard Expedition of 1969. Although this material provides no new stratigraphic information, it is of sufficient interest to warrant a summary here.

A comprehensive list of Triassic fossils from Svalbard was included in Buchan et al. (1965), so far as that was possible at the time. Virtually no material from Edgeøya and Barentsøya was then available however, and it remained for Cox & Smith (1973) to provide details of the additional collections which had accrued in the intervening years (particularly from Edgeøya and Barentsøya as a direct result of the 1969 expedition).

#### (i) *The Barentsøya Formation*

It will be recalled that the Barentsøya Formation is considered to be equivalent to three units in Spitsbergen, viz. the Vardebukta, Sticky Keep and Botneheia Formations. The Vardebukta Formation, which may not be fully represented in the islands east of Storfjorden, is not known to have yielded any vertebrate fossils (Cox & Smith 1973, p. 406). Wiman (1910), in one of the first of a long series of papers describing Triassic vertebrates from Spitsbergen, proposed a detailed stratigraphic breakdown of the Triassic succession which included three principal vertebrate bearing horizons within what is now known as the Sticky Keep Formation. These three horizons were named the Fish Niveau, the Grippia Niveau and the Lower Saurian Niveau, in ascending order. Cox & Smith (1973) recorded «isolated parasphenoid bones of a coelacanth fish, probably *Sassenia*». This was specimen H2939, from a horizon low in the Barentsøya Formation of Edgeøya, and it was associated with Smithian ammonites. It is therefore possible that this horizon is equivalent to Wiman's Fish Niveau. Fragments of labyrinthodont amphibians, consisting of parts of the pectoral girdle, ribs and vertebrae (specimens H2935-7) were found at the same horizon. Another fossil fish specimen, H3380, was found a few metres above a stratum containing Spathian ammonites at Lomberget, Barentsøya, and has been identified as a fragment of the jaw and dentition of the palaeoniscid fish *Birgeria*.

The Botneheia Formation of Spitsbergen, and its equivalent in Edgeøya and Barentsøya (the oil shale member of the Barentsøya Formation), has yielded several vertebrate fossils, but these are not concentrated into bone beds. Relatively abundant ichthyosaur remains were found at the top of the yellow-weathering, carbonate-cemented siltstone at the very top of the Barentsøya Formation of Edgeøya, and Cox & Smith (op.cit.) have identified one specimen (F6449) as the anterior part of the skull and lower jaw of *Pessosaurus*, of the family Shastasauridae. The identification is provisional, and based upon a consideration of those genera previously described from Spitsbergen (from the Upper Saurian Niveau, see below). Since the identifications made by Cox & Smith are strongly influenced by the known age of the containing strata, it will immediately be clear that the vertebrates themselves should not be relied upon as indicators of the stratigraphic ages in question.

Falcon (1928) collected a specimen identified by him as «apparently a Plesiosaurus» from a gorge near the end of Kuhrbreen, on the north side of Deevie Bay (Tjuvfjorden). The specimen, which is now in the British Museum, has been catalogued as *Mixosaurus*, an ichthyosaur genus (A.J. Charig, quoted in Cox & Smith 1973). Falcon mentioned that other specimens were observed at the same locality, but that they were beyond his parties' «powers of extraction». The horizon was close to the top of the oil shale member of the Barentsøya Formation.

#### (ii) *The Edgeøya Formation*

The Tschermakfjellet Formation of Spitsbergen, which is equivalent to the Edgeøya Formation east of Storfjorden, includes the Upper Saurian Niveau of Wiman (1910). This horizon has yielded many vertebrate fossils, including the ichthyosaur genera *Mixosaurus* and *Pessosaurus*. The Upper Saurian Niveau has not been identified in Edgeøya or Barentsøya — it is described by Buchan et al. (1965) as «of local significance» — and the only vertebrate material found by the 1969 expedition from strata above the top of the Barentsøya Formation consists of plesiosaur remains discovered in strata close to the boundary between the Edgeøya and Negerfjellet Formations at Blåfjordalen, Edgeøya. The specimens (G2290—G2327) consist almost exclusively of vertebrae (mainly centra), with a few fragments of ribs. A plesiosaur vertebra was described by Wiman (1916) from the Upper Saurian Niveau of Spitsbergen as the oldest recorded plesiosaur fossil (Persson 1963), and the Edgeøya specimens mentioned here are also significant for their antiquity, which is nearly as great.

#### F. *Other fossil groups*

Coal seams and other plant fossil material, including silicified wood and leaf impressions, are common in the Negerfjellet Formation, but they provide

little information of stratigraphic value. Flood et al. (1971b) listed the following fossil leaves from the upper part of the formation:

*Pterophyllum* sp.  
*Todites* sp.  
*Macrotaeniopteris* sp.  
*Taeniopteris* sp.  
*Podozamites* sp.

Klubov (1965a) recorded the following plant impressions from the upper part of the formation in Edgeøya:

*Neocalamites* sp.  
*Asterotheca* aff. *cottoni* Zeill.  
*Miassia* sp.  
*Glossophyllum* ?*spitsbergense* sp.n.  
*Equisetites* sp.  
*Pterophyllum* *jaegeri* Brong

The last two items appear on the floral list for the same strata in Barentsøya as well (Klubov 1965b), together with

*Glossophyllum* sp.  
*Asterotheca* sp.  
*Marattiopsis* sp.

Other fossils identified from the Triassic strata of the islands include brachiopods, echinoderms and crustaceans. *Lingula polaris* Lindström has been recorded from high in the Negerfjellet Formation of Barentsøya by Klubov (1965b) and *L. cf. polaris* is listed by Flood et al. (1971b) from lower in the formation. Klubov (1965a) also found «*Rhynchonella*» sp. and *Spiriferina* sp. in the Edgeøya Formation of Edgeøya, and *S. cf. shaleshalensis* Bittner near the top of the Negerfjellet Formation of the same island.

*Pentacrinites*(?) sp. has been listed by Flood et al. (1971b) from the lower part of the Negerfjellet Formation, and the same authors mentioned that they found crinoids, ophiuroids, and asteroids at a locality on Schneiderberget in Edgeøya. Echinoid fragments are common in the lower part of the formation.

Tyrrell (1933) mentioned that he found ostracods in the Mistakodden area of Barentsøya — no stratigraphic level is recorded — but these were too poorly preserved for a positive identification at generic level. The brachiopod *Cyzicus* cf. *minuta* (referred to by the invalid name *Estheria*) is listed by Flood et al. (1971b) from the lower part of the Negerfjellet Formation.

### G. Conclusions

Table 2 summarises the principal conclusions to be drawn from the available palaeontological evidence, with the most significant fossils listed. The oldest fossils found in the Barentsøya Formation are of Late Griesbachian age, while the base of the oil shale member coincides closely with the base of the Anisian, and the formation contains earliest Ladinian forms. In contrast, the oldest fossils yet identified from the base of the overlying Edgeøya Formation are latest Ladinian, so that there is a strong possibility that the formation boundary — normally very sharply defined in the field — is a non-sequence, with most of the Ladinian missing.

The age of the boundary between the Edgeøya and Negerfjellet Formations is less easily defined. The ammonite, *Sirenites*, in the former is a Karnian indicator, while *Meleagrinnella antiqua* in the Negerfjellet Formation is a Norian bivalve. The palynological assemblage found near the top of the highest exposure of the Negerfjellet Formation suggests a time correlation with the Norian strata of Hopen and Wilhelmøya. Table 3 summarises the proposed correlations with the other Triassic rocks of Svalbard.

## 6. SUMMARY OF THE TRIASSIC HISTORY OF THE AREA

The strata of the Barentsøya Formation, as well as those of the correlative strata in Spitsbergen, are fully marine in character, and were deposited on a relatively stable continental shelf. The black, phosphatic and bituminous shales of the oil shale member and of the Botneheia Formation of Spitsbergen, deposited during the Anisian and earliest Ladinian, can be traced throughout Spitsbergen, with the exception of Sørkapp Land in the extreme south, representing a depositional basin of at least 50,000 sq. km within which euxinic conditions were ubiquitous. In Nordaustlandet the Sassendalen Group is recognisably present, although the development is thin; cliff-forming shales occur at the top of the succession but are not as distinctive as elsewhere.

Several areas in Edgeøya and Barentsøya are unusual in that the upper part of the Barentsøya Formation is composed of a much sandier facies; this is particularly notable in the vicinity of Mistakodden (Barentsøya) and both north and south of the central part of Freemansundet. The cause of this variation is not clear, but Mistakodden was a positive area subsequently, and the Edgeøya Formation is absent there, so that both areas may have been shallower than the rest of the basin during the Anisian, with the development of shoal-water conditions contrasting with the surrounding euxinic basin.

The bed which marks the top of the Barentsøya Formation is found in most of Spitsbergen. It varies from «grey or yellow weathering siltstone, through calcareous siltstone, to limestone, but is often siliceous or cherty» (Buchan et al. 1965, p. 24). Its thickness decreases as it is traced from west to east across Spitsbergen.

The top of the Sassendalen Group is the only Triassic boundary which can

SERIES	Stage	Sub-stage	Zone	Key Fossils	Formation		
LATE TRIASSIC	RHAETIAN		Marshi	Palynomorphs  <i>Meleagrinnella antiqua</i>	NEGERFJELLET FORMATION		
		NORIAN	Late			Suessi	
	Middle		Columbianus				
			Rutherfordi				
			Magnus				
	Early		Dawsoni				
			Kerri				
	KARNIAN	Late	Macrolobatus			<i>Sirenites</i> sp	EDGEØYA FORMATION
			Wetleri				
		Dilleri					
Early		Nanseni					
	Obesum						
MIDDLE TRIASSIC	LADINIAN	Late	Sutherlandi	<i>Nathorstites mcconnelli</i>	Possible non-sequence		
			Maclearni				
			Meginae				
		Early	Poseidon				
			Subasperum				
	ANISIAN	Late	Chischa	<i>Daonella trami</i> <i>Gymnoceras ?laqueatum</i>	oil shales member		
			Deleeni				
		Middle	Varium				
			Early			Caurus	
		EARLY TRIASSIC				OLENOKIAN	SPATHIAN
Pilaticus							
SMITHIAN	Tardus						
	Romunderi						
DIENERIAN	Sverdrupi						
	Candidus						
GRIES-BACHIAN	INDUJAN		Late	Strigatus			
				Commune			
	Early		Boreale				
			Concavum				

Table 2.  
Correlation of Edgeøya and Barentsøya Triassic formations.

be traced throughout Svalbard (Buchan et al. 1965) and it is therefore an important stratigraphic datum horizon. The youngest strata underlying the boundary appear to be consistent in age — both Buchan et al. (1965) and the present authors conclude that oldest Ladinian forms are present at the top of the oil shales. Flood et al. (1971b) suggested that the boundary falls within the Upper Ladinian, but this view is based on fossils from the base of the overlying Edgeøya Formation and does not take account of the probable absence of the greater part of the Ladinian, represented only by the stratigraphic break of the non-sequence.

During the greater part of the Ladinian there was a pause in sedimentation, probably extending throughout the Svalbard area. This does not necessarily imply sub-aerial exposure — in fact it is more probable that the area remained

TIME		SVALBARD						
Ma	AGE	GROUP	SPITSBERGEN	WILHELMØYA & E. OLAV V. LAND	HOPEN	KONG KARLS LAND SVENSKØYA KONGSØYA	BJØRNØYA	BARENTSØYA & EDGEØYA
(195)	RHAETIAN	KAPP TOSCANA		Lyngefjellet sandstone >80m Flatsalen shale 55m Iversenfellet >325m	Svenskøya (ARNESODDEN) SHALE BED >5m Svenskøya (SØKREIN) FJELLET SANDSTONE MBR >100m			Negerfjellet >400m
(205)	NORIAN		De Geerdalen 190m	(Wilhelmøya Mbr) 120m (Uleneset Mbr) 400m	De Geerdalen			Upper Triassic 140m
(215)	KARNIAN	SASSENDALLEN	Tschermakfjellet 60m	Tschermak-fjellet >35m				oil shales member 50-100m
	LADINIAN		Botneheia 260m	Botneheia >5m				
225	ANISIAN		Sticky Keep (Kaostjellet and Iskletten Mbrs) 120-310m					
	OLENEKIAN		Vardebukta (Siksaken and Selmaneset Mbrs) 140-290m					
	INDUAN							Lower Triassic 38m

Table 3.

Summary of conclusions on the Triassic sequence in Svalbard. The sources for other areas are: Spitsbergen — Tozer & Parker 1967; Wilhelmøya — Smith 1975; Hopen — Smith et al. 1975; Kong Karls Land — Smith et al. 1976; Bjørnøya — Pchelina 1972.

submerged but that no permanent accumulation of sediment took place, a condition characteristic of large areas of the North Sea at the present time. Had the area been uplifted and exposed, it is likely that erosion would have left its mark on the underlying strata, which would have been removed to a variable extent.

When sedimentation resumed, late in the Ladinian, more normal marine conditions prevailed. Before long the first effects were felt of the advance from the northeast of a major delta complex. An increasing proportion of the incoming sediment was of silt grade, fossils (particularly ammonites) became rarer, and conditions appropriate for the deposition of clay ironstones were more rarely attained. Sedimentary ironstones have been the subject of considerable controversy amongst sedimentologists, so that the significance of their presence in the lower part of the Edgeøya Formation (and also, although far less commonly, in the succeeding strata as well) is uncertain. It is likely, however, that the iron was introduced in the form of colloidal material in river water, and that deposition resulted from differences between the chemical environment in the river water and that in the sea. This would imply that even while the lower beds of the Edgeøya Formation were accumulating, a major supply of fresh water was not far distant.

Piper (in preparation, see above) has described the sediments of the Negerfjellet Formation and interpreted them as the products of the various environments which are present in a major deltaic complex. The sedimentary record reveals the details of the advance of such a complex into the Edgeøya-Barentsøya area from the northeast — the base of the Negerfjellet Formation, which is the base of the main deltaic sedimentary pile, is therefore likely to be strongly diachronous. Piper has prepared a series of palaeogeographical maps for this time, which are reproduced here as Figure 14.

The Negerfjellet Formation delta was probably only one of several which built out into the late Triassic basin of central Svalbard. Land lay to the south, in Sørkapp Land and beyond, as well as to the north in Nordaustlandet (where the Triassic strata above the level of the *Nathorstites* horizon are absent). No sedimentological data from the De Geerdalen Formation of Spitsbergen has yet been published, but the distribution of the Tschermakfjellet Formation of Svalbard and its correlative, the Edgeøya Formation, which are confined to east-central Spitsbergen, Edgeøya and Barentsøya, suggests that a source area also lay to the west.

The Iversenfjellet Formation of Hopen (Smith 1975), which is equivalent to the Negerfjellet Formation, is largely of marine facies, so that open ocean may have lain to the southeast.

The deltaic complexes are overlain elsewhere in Svalbard by the Brentskardhaugen Bed (formerly «Lias conglomerate»), which is found throughout Svalbard underlying the base of the Janusfjellet Formation. Thus the episode of deltaic sedimentation concluded with a major regional uplift.

The youngest solid rocks of the area would be expected to occur on the relatively flat mountain tops in southeastern or southwestern Edgeøya. A Jurassic age for these has been indicated by, for example, Orvin (1940) in

his geological map. This suggestion may have been based on the presence there of quartz arenites bearing a lithological resemblance to the topmost strata of the De Geerdalen Formation in Spitsbergen. We sought confirmation of the possible Jurassic age without success, but our search was not exhaustive and we are not able completely to dismiss the possibility. None the less, at the time of going to press, we know of no evidence for the presence of Jurassic rocks in Edgeøya.

## 7. THE DOLERITES

Intrusive sills and dykes of dolerite are widespread in the islands. The investigation of these was not one of the primary objectives of the 1969 NCSE expedition, and they were not, therefore, mapped in detail (Figs. 4 and 5B). Since, however, they occur over such large areas of Barentsøya, western and southern Edgeøya and form the Tusenøyane to the south, a brief review of the available information is given here.

Burov (1964) summarised what was then known about the dolerites, mostly as a result of the Swedish expeditions of 1919—20 and the Oxford University expeditions of 1921, 1923 and 1924. An early account had also been published in 1907 by Backlund. Burov (1964) reported that the undifferentiated dolerites are exceptionally uniform in their composition, falling into four petrographic types — quartz-bearing dolerites, quartz dolerites, quartz dolerites with horizons of pegmatoid gabbro-dolerite, and microdolerite.

Klubov (1965b) mentioned briefly the dolerites of Barentsøya and set them into two categories — dolerite and gabbro-dolerite intrusions. These intrusions are of appreciable thickness and extent, one example quoted being a sill 20—40 m thick which caps the hills to the east (at about 500 m a.s.l.) and extends over to the west coast of the island.

Further information on poorly-differentiated dolerites was given by Burov & Livshits (1965), who discussed the dolerites of the Storfjord region. They noted that intrusions in northwest Barentsøya, usually 10—30 m thick and of relatively great length (several kilometres in some cases), sometimes show signs of differentiation. One example from northwest Barentsøya was a dolerite dyke of northwest strike at Mistakodden, which may be traced for about 8 km, reaching a maximum thickness of about 180 m and displaying pyrite-chalcopyrite mineralisation. The intrusions in this area range from olivine-bearing dolerites to porphyritic leucocratic gabbro-dolerites, and a section through the thickest part of this dyke at Mistakodden was given as follows:

1.5—2.5 m	Porphyritic microdolerites and amygdaloid dolerite.
60—70 m	Olivine-bearing dolerites from lower part of dyke.
20—26 m	Porphyritic leucocratic gabbro-dolerites at centre.
70—80 m	Olivine-bearing dolerites from upper part of dyke.
0.5—1.5 m	Porphyritic microdolerites and amygdaloid dolerite.



A detailed discussion of petrography and petrochemistry was presented by Burov & Livshits (1965), but the outstanding question is still the age of these intrusions. In Barentsøya and Edgeøya they intrude Triassic strata and in Spitsbergen Jurassic strata. In Kong Karls Land (Smith et al. 1976) extrusive basalts lie above strata of probable Barremian age, while in southern Spitsbergen dolerite pebbles are found in the Basilika Formation (Paleocene-?Eocene). Thus the basic magmatism in Svalbard may be limited generally to the interval between the late Jurassic and earliest Tertiary. Whereas extrusive volcanic activity is evident in Kong Karls Land as late as Barremian, *no* intrusions in Spitsbergen cut rocks even as young as early Cretaceous age, so the presumption must be, as concluded by Tyrrell and Sandford (1933), that magmatism was most intense in Spitsbergen in earliest Cretaceous time, (see discussion and figure in Harland 1973). Parker (1964) showed that the intrusions in the region of eastern Spitsbergen could be even more accurately dated as emplaced at approximately the Jurassic/Cretaceous boundary. Edgeøya, however, lies between Spitsbergen and Kong Karls Land so that the arguments employed for Spitsbergen do not apply so strongly here. On internal evidence the dolerites of Edgeøya and Barentsøya can only be dated as post-Triassic, but are probably of latest Jurassic/early Cretaceous age.

### III. Structural geology

#### 1. GENERAL ACCOUNT

The most striking structural feature of Svalbard is the (Tertiary) West Spitsbergen Orogen, which runs down the western side of Spitsbergen. Some investigations of particular sections of the orogen have recently been published, e.g.: Challinor (1967), Birkenmajer (1972 a & b) and Harland & Horsfield (1974). Along the eastern boundary of the belt overthrust structures produced an often vertical monoclinical western limb to the broad basin which occupies central Svalbard. To the west, the strata are overturned, thrust and folded, in a complex orogenic belt which extends to the west coast and beyond. Harland et al. (1974) summarised the movements which caused the West Spitsbergen Orogeny as «the result of compression coupled with dextral strike slip which transported the Barents Shelf (with Spitsbergen) from a position north of Greenland».

Over most of eastern and central Svalbard the post-Caledonian strata are essentially horizontal, lying above a basement complex (generally referred to as «Hecla Hoek»). The tectonic effects of the West Spitsbergen Orogeny are localised and largely restricted to a series of north-south lineaments, most of which have a long history — the north-south trend is one which has been inherited from at least as far back as late Precambrian time and is dominant in the mid-Palaeozoic orogenic structures of Svalbard.

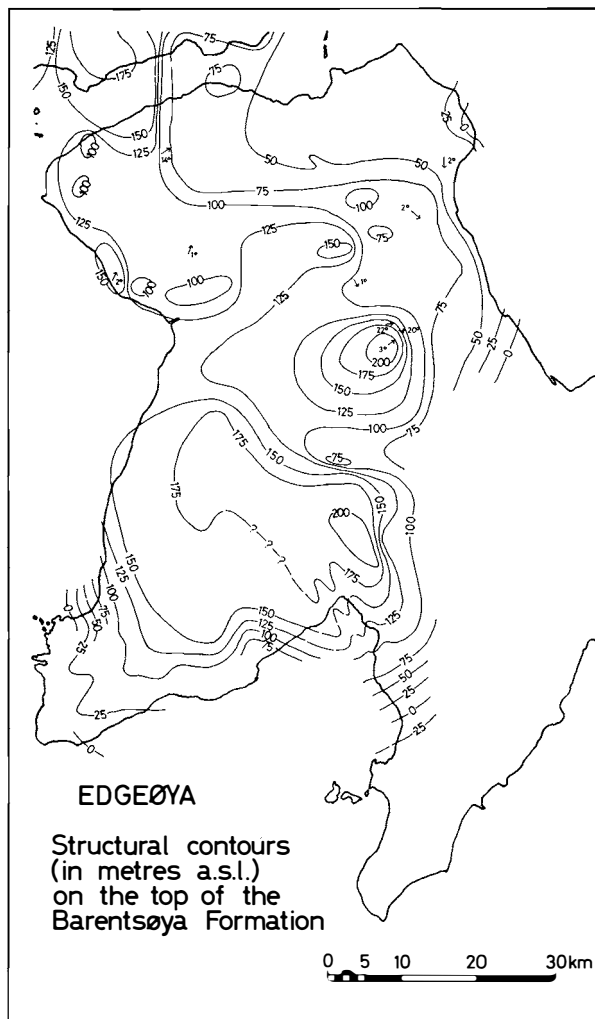


Fig. 18 Structural map of Edgeøya with contours at 25 m intervals. Apparent dips are also shown.

In order to analyse the structure of Barentsøya and Edgeøya we prepared a structural contour map of the region by measuring the altitude of a suitable marker horizon at a large number of localities. The bench-forming top of the Barentsøya Formation was selected for this purpose, being easily identified and because the erosional bench provided many good localities for helicopters to land. An aneroid altimeter was used, with appropriate corrections for variations in the ambient barometric pressure being provided by a recorder at our base. The contoured maps (Figs. 5A and 18) display the first results of this survey.

From these maps it is clear that the regional structure consists of a complex pattern of very gentle basins and domes, with a sharply defined monocline in the Freemansundet area. A gentle anticline trends northeast-southwest across Barentsøya, plunging towards the southwest. This structure exposes an area of Permian strata in its core, in the northeast at Kapp Ziehen. The struc-

ture of Edgeøya is less easily summarised — the two most important features are domes with further exposures of Permian strata in their cores (in upper Blåfjorddalen and lower Dyrtdalen, respectively).

A small area characterised by complex folding and minor faulting is found in the region of Mistakodden, Barentsøya. The strata are thrown into a chaotic series of tight folds, generally trending southwest-northeast. Edwards (1976a) suggested the possibility that these disturbances are related to the phenomenon of growth faulting observed to the south (see II.B.ii) but we feel that the association of these structures with complex dolerite intrusion may indicate that the latter was responsible.

An important fault observed to cut the exposed strata is seen at Negerpynten (Klubov 1965a). It has a strike of  $310^{\circ}$ , and a downthrow to the northeast of approximately 50 m.

This limited description of the structure of the islands reflects the fact that our field investigation was basically of a reconnaissance nature, an evaluation of the structures being further refined in detail by Fina geologists during a subsequent field-investigation.

## 2. THE IMPORTANCE OF NORTH-SOUTH LINEAMENTS IN CONTROLLING MESOZOIC STRUCTURE AND SEDIMENTATION IN SPITSBERGEN

Several of the north-south trending lineaments, to which brief reference has been made in the preceding paragraphs, had an important influence on post-Caledonian sedimentation. The Billefjorden Fault Zone, for example, has been the subject of detailed investigations by a number of Cambridge University geologists, and their findings are summarised by Harland et al. (1974). A major episode of dominantly sinistral transcurrence took place between mid-Devonian (Givetian) and earliest Carboniferous (Tournaisian). Harland et al. (1974) recognised, from internal evidence, that movement on the Billefjorden Fault Zone amounted to at least 200 km, while from external evidence a total of 100 to 1000 km displacement is possible. This latter displacement may have been distributed along more than one lineament. No subsequent strike slip is recorded from strata, ranging in age up to the Paleocene, that cover the Billefjorden Fault Zone in the south part of Spitsbergen, but some vertical movements affecting sedimentation do indicate continuing basement control — this was particularly true during the Carboniferous Period. A long episode of relative stability continued until late in the Jurassic, at which time faulting, folding and dolerite intrusion took place (e.g. Parker 1964). Intrusion was in no way limited to the lineament, although some considerable sills seem to have been controlled in their emplacement by the fault zone.

This north-south trend also appears to dominate the structure of Barentsøya and Edgeøya (see below), 100 to 150 km east of the Billefjorden Fault Zone.

3. THE RINDEDALEN STRUCTURE OF FREEMANSUNDET  
AND THE TEISTBERGET STRUCTURE OF ADJACENT SPITSBERGEN

The north-south trending monocline, seen in the Freemansundet area (mentioned above), is known as the Rindedalen Structure, after a valley on the north side of the straits. The structure has a steep limb, dipping eastwards at up to  $20^\circ$ , with horizontal strata on either side. The western (anticlinal) hinge zone is abrupt, and dips change from near horizontal to between  $10\text{--}20^\circ$  to the east over a short distance (Fig. 19). The dips then gradually decrease towards the east until the strata are once again flat-lying. The total vertical displacement across the structure is about 100 m, while the width of the inclined limb is approximately 3 km. The monocline dies out when traced both to the north and to the south of Freemansundet, though it can be traced over a total distance of slightly less than 20 km.

A similarly acute flexure, again with a north-south trend, occurs at Teistberget on the east coast of mainland Spitsbergen, on the opposite side of Storfjorden from Mistakodden.

Both of these structures are believed to result from basement control, either during the West Spitsbergen Orogeny or during the earlier deformational episode which coincided, approximately, with the boundary between the Jurassic and the Cretaceous. It is believed that these two structures form part of a series with the Billefjorden Fault Zone and the other north-south trending lineaments of Spitsbergen mentioned by Harland et al. (1974).

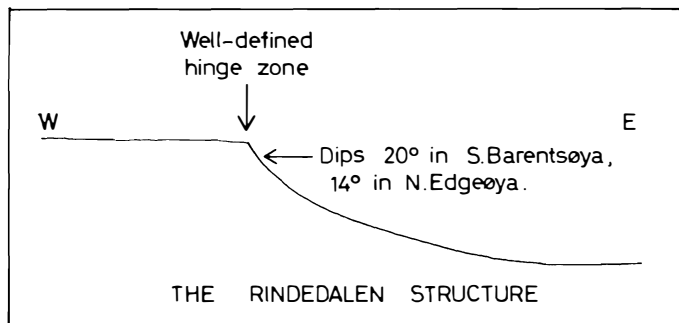


Fig. 19 *West-east profile of the Rindedalen Structure.*

#### IV. Economic geology

##### 1. PETROLEUM

Indicators of the presence of natural gas and other hydrocarbons within the Triassic rocks of Edgeøya and Barentsøya have long been known. In 1919 Tyrrell had reported a «Broxburn smell» (of natural gas) from Changing Point (Mistakodden) in Barentsøya and noted that many of the bituminous

shales produced «a fair oil content on distillation» (Tyrrell & Wordie 1920).

Far more detailed investigations have been more recently conducted by Soviet geologists. Klubov (1965a) reported dispersed bitumen and bituminous stains from the upper part of the Barentsøya Formation around Kapp Lee and from lower in the formation north of Blåfjorddalen, Edgeøya. At Kapp Lee nodules of grey marl within bituminous argillites (oil shales member) contain liquid bitumen in cavities at their centre, while at Blåfjorddalen semi-liquid bitumen and oil droplets occur within limestone lenses. Klubov reported that the argillites in the upper part of the Barentsøya Formation generally have a high content of dispersed chloroform bitumen A (0.314—0.625%), while those lower down have rather less (0.08—0.625%). Those of the Edgeøya Formation have only 0.01—0.1% in comparison. However, the Barentsøya Formation has a very low effective porosity and near zero permeability, though the Negerfjellet Formation sandstones and silts have open pores with an average 5—15% porosity and over 20% in places. The permeability of the Negerfjellet Formation in Edgeøya is not usually >35 millidarcy but samples from Barentsøya produced readings of 350—1820 millidarcy (possibly as a result of the specimens being very weathered). Sandstones with these high permeabilities occur in sets up to 21 m thick.

However, as pointed out by Klubov earlier (1964), the deep erosion of the Triassic of these islands must dismiss any hope of finding petroleum reserves in Mesozoic strata. Apart from this it also seems likely that these rocks have never been buried to any great depth (Hughes, Harland & Smith 1976), so that the search for petroleum must be concerned with Late Palaeozoic and older rocks. Favourable anticlinal structures certainly appear to be present (see Chapter III) and two exploratory wells have now been sunk.

Arising out of the earlier surveys of Amoseas (1961—63) a deep well was drilled near the head of Dyrdaalen in east central Edgeøya (Raddedalen-1, approximately 77° 54' 10" N, 22° 41' 50" E and 80 m a.s.l.) by arrangement with Total Marine Norsk (Cie. Française de Petroles) in 1972 within claim areas established by Amoseas.

Subsequent to the first Cambridge work and within claim areas established by the 'Fina Group' in Svalbard, Norske Fina arranged for a deep well to be drilled in south western Edgeøya west of the snout of Philippibreen in upper Plurdalen (Plurdalen-1, approximately 77° 44.5' N, 21° 50' E and 140 m a.s.l.) in 1972.

The results of these investigations have not been published.

## 2. COAL

Coal occurs within the Negerfjellet Formation, usually in thin (< 0.1 m) silty seams or as discontinuous laminae. Klubov (1965a) reported one coal seam, 0.1—0.2 m thick, that could be used as a marker horizon throughout Edgeøya, but our own investigations indicate that this is not continuous and may not appear at the same stratigraphic level at every locality. This seam is

about 0.3 m thick in the type section at Negerfjellet. According to Alekseeva (in Klubov 1965a) the coal is of the clarain-durain type, with lipoid components, at the «gas-coal» stage, a typical composition being: Ash — 5%, volatiles — 44%. A calorific value of 8000 Kcal/Kg was quoted.

Such a thin seam in such a remote area is unlikely to be of great economic significance.

### 3. OTHER MINERALS

The Edgeøya and Negerfjellet Formations both contain nodules and bands of sedimentary clay-ironstone (siderite). A sample analysed by Klubov (1965a) from the Edgeøya Formation of northeast Edgeøya was found to have an  $\text{Fe}_2\text{O}_3$  content of 38% (26% metal) — «within the usual range for marine siderite ores». These nodules and bands appear to be nowhere concentrated in sufficient density to be of commercial interest.

Phosphorite nodules occur within the Barentsøya Formation which Klubov (1965a) recorded as being 11.5—25%  $\text{P}_2\text{O}_5$ , much the same as nodules analysed by ourselves from the Botneheia Formation in western Spitsbergen. He also recorded  $\text{P}_2\text{O}_5$  contents of up to 26.5% in (rare) nodules within the Edgeøya Formation. Again these nodules do not appear to be present in sufficient concentration on the islands to merit commercial extraction.

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Kay Herod and Marie Wells assisted with the references and Pauline Kearsley typed the manuscript. Mrs. Anne Brekke saw the paper through the press.

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