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The geology of Kong Karls Land, Svalbard

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Summary. The only substantial descriptions of the small, generally ice-bound archipelago in eastern Svalbard were from an expedition led by Nathorst in 1898 which landed in Kong Karls Land for fourteen days. Our paper amplifies those findings, from work with a helicopter-borne expedition in 1969. The easternmost of the three main islands, and all the small islands, are formed of basic igneous rocks of Cretaceous age. Two of the main islands, Svenskøya and Kongsøya, are formed of latest Triassic to early Cretaceous strata, protected by caps of Cretaceous lava that determine their shape and the general topography. The third, Abeløya, is basaltic throughout.

The rock successions in Kong Karls Land differ between and within each of the three hill areas; newly defined formations and members within them are therefore established to assist in their description. These are included in the newly extended Kapp Toscana and Adventdalen Groups and are related to the 13 divisions outlined by Nathorst. Movements about an axis between Svenskøya and Kongsøya led, during sedimentation, to thinning and disappearance of some strata of late Jurassic age, and thus to some difficulty in comparison between the successions in the two islands.

1. Introduction

Kong Karls Land is a group of three main islands and many smaller ones, in the east of the Svalbard Archipelago. The surrounding seas are largely covered by sea-ice through most summers as well as winters, so it is one of the least accessible parts of Svalbard, and the geological field work done by the Norsk Cambridge Svalbard Expedition 1969 appears to have been the first systematic study since the major investigation in 1898 (Nathorst, 1899, 1901, 1910). The recent visit, organised in connexion with work commissioned by Norske Fina, depended on helicopter transport based on an ice-strengthened vessel (Harland, 1970) and other geologists have since visited the area using the same methods of transport. Work continues but we now take the opportunity, by agreement with Norske Fina, to present in one account what we know of the geology of the islands.

The westernmost island, Svenskøya (Swedish Foreland), is 20 km long and

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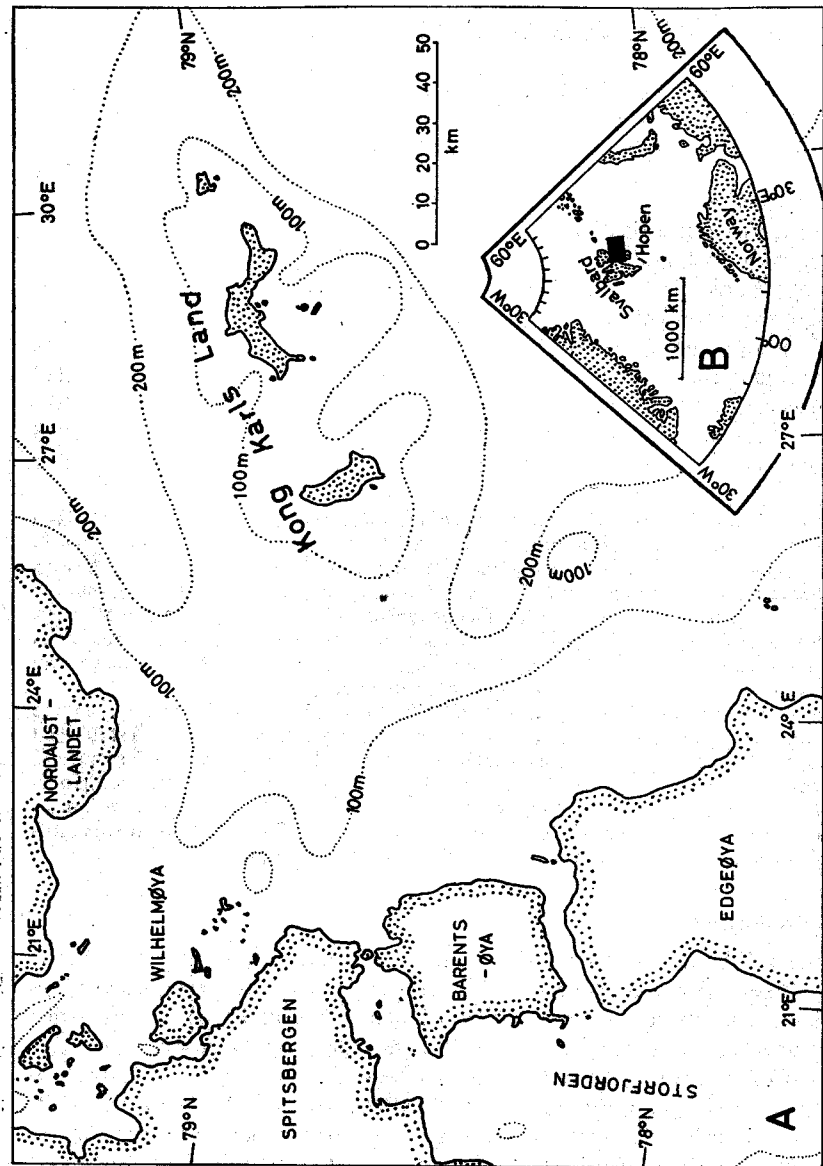


Figure 1. (A) Kong Karls Land - geographical location showing 100 m submarine contours. (B) (Inset) Setting within Arctic region.

generally 6 km wide. The greater part of the island is low-lying and formed of beach deposits dissected by a distinctive drainage pattern. An axial ridge runs the length of the island, its altitude ranging from 250 m in the north to 180 m at the south.

The main island, Kongsøya (King Charles Island), is central, about 40 km long and up to 8 km wide (Fig. 1). It divides naturally into five regions from west to east: (1) a western complex of several flat-topped hills (up to 320 m high), (2) a neck of low ground with raised beach and blown sand, (3) a low-lying rocky plain of basalt, (4) a low hilly area of basalt with a small ice cap, Rundisen, and (5) one main hill 240 m high sloping down to low cliffs at the east coast.

The eastern island, Abeløya, is of irregular outline not exceeding 4 km across and mostly less than 5 m above sea level.

The geological structures are generally flat-lying and the topographically dominant rock is basalt, which forms the caps of all the tabular hills in the two main islands, also most of the low ground, and all of Abeløya. Indeed, the preservation above sea level of the relatively soft late Triassic to early Cretaceous sediments is due to the protection of comparatively thin lava flows. These, together with their associated intrusions, are also responsible for most of the conspicuous coastal promontories and all the smaller islands.

On 1 June 1973, by Royal (Norwegian) Decree, Kong Karls Land became part of the North East Svalbard Nature Reservation. With the restrictions thus imposed, further expeditions may therefore find difficulty in obtaining permission to visit the islands to conduct a similar investigation.

Three of us (WBH, NFH and DGS) participated in the field work, NFH directed the biostratigraphic work, DGS was responsible for the palynology of the Svenskøya Formation and for plotting most of the sections, CAGP completed the sections, compiled the figures and examined the igneous samples, WBH led the investigation and drafted much of the paper.

2. Sequence of investigations

2.a. Early work

Although probably sighted in 1617 by the English whaling captain Thomas Edge who named it Wiches Land, Kong Karls Land was not rediscovered until the 1850s (Hoel, 1935). The first recorded geological specimen was collected in 1872 by a Norwegian captain, Nils Johnsen. This was a piece of petrified wood which found its way to the chief forester in Tromsø, who gave it to the Swedish palaeobotanist Heer. The specimen was described by Schröter (1880) as *Larix johnseni* sp. nov. and was presumed to be Tertiary in age. The Englishman Arnold Pike landed on Kongsøya in 1897 and recorded some useful information on the raised beaches, though his observation that the solid geology of the island consists entirely of dolomite was rather less accurate, even allowing 'dolomite' as a misprint for dolerite (Pike, 1898).

2.b. 1898 expedition and results

In 1898 A. G. Nathorst led a Swedish expedition to Svalbard with the primary object of visiting Kong Karls Land. The expedition was successful, was ashore

for 14 days, and almost all published information on the islands derives from it. A topographic survey was made on which the presently available maps (1:100000) are based (Hamberg, 1905), and detailed biological and geological observations and collections were made. As well as several general and preliminary accounts of the expedition, Nathorst himself published the geological work in 1901 [in Swedish] and in 1910 as part of a larger work on the geology of the whole Svalbard area [in German]. A diagrammatic summary of his interpretation of

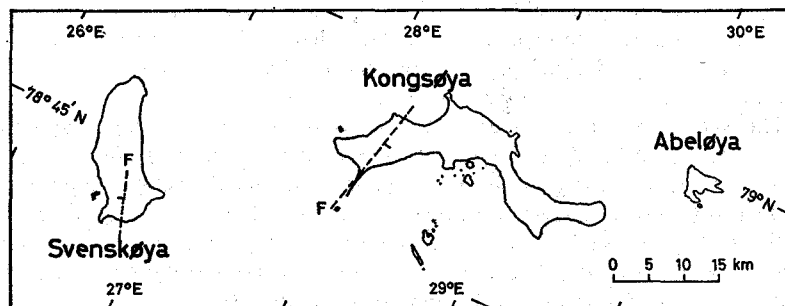


Figure 2. Sketch map and block diagram to illustrate structure and stratigraphy of Kong Karls Land as interpreted by Nathorst (1901).

the stratigraphy and structure of the two main islands is shown in Figure 2. Several shorter papers were published by geologists to whom Nathorst sent material; Hamberg, the expedition topographer, also studied the igneous rocks (1899); Pompeckj (1899) gave a preliminary account of the palaeontology and hence of the age of the rocks and his results were incorporated in Nathorst's papers. Lindström (1900) described a new species of coral of early Cretaceous age, and Woodward (1900) described a new Jurassic fish species from Svenskøya. Petrified wood was described by Gothan (1907, 1911) who also figured a specimen in his paper on the climatic significance of tree rings (Gothan, 1908). The igneous rocks were further investigated by Backlund (1907). Blüthgen (1936) studied the ammonites, bivalves and belemnites, producing an extensive list of species, and dated the marine strata more precisely than before.

2.c. 1930 to 1969 expeditions

The 1930 Norwegian expedition to Franz Josef Land (Horn, 1932) landed on Abeløya on its outward journey and confirmed that it consists entirely of igneous rocks. The work in this and the earlier accounts was summarised in its wider setting by Frebald (1935, 1951) and Harland (1973).

The first aerial photographs of Kong Karls Land (an incomplete set of obliques) were published by the Norsk Polarinstitutt (NPI) in 1938, but the place names were stabilised in 1964 on the NPI's 1:100000 map of Kong Karls Land, still based on the 1898 survey. Vertical aerial photographs completely covering the group of islands were taken and published in 1969, and have been used in this work.

An expedition in 1965 organized by Norsk Polar Navigasjon A/S placed two geologists, T. Löken and I. Isaksson, on the islands, primarily for staking claims but some geological observations were made (though not published).

2.d. 1969 and later expeditions

Arising from the search for oil and the employment of powerful steel sealers with helicopter platforms, it had become possible to land field parties even when ice prevents close access to the shore.

This was the basis of the Norske Fina operation (leader N. Golenko) in 1969 when a Cambridge expedition of 13 geologists with assistant geologists (leader W. B. Harland) explored most areas of unmetamorphosed rocks in eastern Svalbard (Harland, 1970). Good weather from 14 to 21 August during the visit to Kong Karls Land allowed about 80 man days to be worked on shore, in about 30 task groups, using two helicopters almost continuously. The locations of the principal stratigraphic sections measured, which included most of the slopes where strata could be seen through the talus, are marked with station numbers on Figures 4 and 9.

The Norsk Polarinstitutt placed geologists B. Flood, J. Nagy and T. Winsnes on the two main islands in 1969 (Gjelsvik, 1970, pp. 150, 162) and T. Winsnes visited the area again in 1971 (Gjelsvik, 1973, pp. 105, 113). D. Worsley spent some days on Kongsøya in 1973 (Gjelsvik, 1975, p. 230).

3. The local rock units

Table 1 shows the 13 rock units, mostly based on fossiliferous horizons, established by Pompeckj (1899) and Nathorst (1901), and those recognized in addition by Blüthgen (1936) with estimates of their ages. The sequence of 13 units as listed by Nathorst is a composite one and is not seen at any one locality. He recorded only two lava flows (units 11 and 13); we have identified at least six.

This chapter introduces the scheme adopted and depicts the lithostratigraphic information for each of the three new formations in measured sections (Figs 5-8 and 10-15). Figure 3 shows the conventions used.

Table 1. Lithological units and their ages in Kong Karls Land as described by previous authors.

Pompeckj (1899) and Nathorst (1901)			Blöthgen (1936)	
Neocomian		13 Basalt		
		12 Plant-bearing layer with <i>Phoenicopsis</i>		
		11 Basalt		
		10 Plant-bearing layer		
		9 Bed with <i>Aucella keyserlingi</i>	Beds with <i>Aucella</i> spp. and <i>Acroteuthis</i> spp.	L.-M. Valanginian
Volgian	Upper	8 Bed with <i>Aucella fischeriana</i> , <i>A. volgensis</i> , etc.	Beds with <i>Aucella</i> spp., <i>Pecten</i> spp., etc.	Middle
	Lower	7 Bed with <i>Aucella pallasi</i>	Beds with <i>Cylindroteuthis</i> , <i>Aucella</i> spp., etc.	Lower
				Lower Volgian
		6 Bed with <i>Cardioceras</i> and <i>Aucella</i> spp.	Beds with <i>Amoeboceras</i> spp.	U. Oxf. - L. Kimm.
		5 Bed with <i>Aucella branni</i> var. <i>lata</i>		
Cretaceous	M.-U.	4 Bed with <i>Cadoceras</i> and belemnites		
	Lower	3 Bed with <i>Macrocephalites</i> (= <i>Arctoccephalites arcticus</i>) and belemnites		
		2 Bed with <i>Pseudomonotis</i> etc.		
		1 Sand and sandstone, no fossils (200m)		

3.a. Proposed lithostratigraphic scheme

Because of the broad similarity between the sedimentary succession in Kong Karls Land and that in Spitsbergen we considered the possibility of extending the definitions of the Helvetiafjellet, Janusfjellet and De Geerdalen Formations to encompass the Kong Karls Land rocks. However, the distance from Spitsbergen, the differences in development in parts of the succession, and the remaining uncertainties in correlation appear to us to demand the establishment of a new formational nomenclature for Kong Karls Land. Our new scheme is shown in Table 2, from which it will be seen that three formations are recognised in Svenskøya and Kongsøya to describe the overall sandstone-shale-sandstone sequence. Their variability is taken account of by the definition of a different set of members for each in each of the three separate outcrop areas of Svenskøya, Western Kongsøya and Eastern Kongsøya. Formal descriptions of all new formations and members are given below (Chapters 4 to 6). The Adventdalen Group (of Spitsbergen; Parker, 1967; Buchan, Challinor, Harland & Parker, 1965; Harland *et al.* 1974) is extended to include the newly defined Kong Karls Land and Kongsøya Formations, and the Kapp Toscana Group (of Spitsbergen) is extended to include the Svenskøya Formation.

3.b. Outcrop maps and stratigraphic sections

The primary observations are depicted in Figures 4-16 and only a few additional explanations are necessary. Stratigraphic sections are identified by station

Table 2. Local rock unit nomenclature proposed for Kong Karls Land and defined in this paper, showing equivalence of beds numbered in Table 1.

	KONG KARLS LAND	SVENSKØYA	WESTERN KONGSØYA	EASTERN KONGSØYA
ADVENTDALEN GROUP	Kong Karls Land Formation	Kükenthalfjellet Sandstone Member 50m Beds 10 & 12	Hårfagrehaugen Sandstone Member 14m Beds 10 & 12	Johnsenberget Sandstone Member 30m Bed 10
	Kongsøya Formation	Dunérfjellet Shale Member 60m (Upper & Lower) Beds 3-7	Tordenskjoldberget Limestone Member 30m Bed 9 Retziusfjellet Shale Member 75+ m Beds 6 & 7 Passet Clay Member 65m Bed 4	Upper part of Kongsøya Formation (not named) 250m Nordaustpynten Shale Member 2150m Bed 8
KAPP TOSCANA GROUP	Svenskøya Formation	Mohnhøgda Sandstone Member Beds 1 & 2 Arnesenodden Shale Bed	Sjögrenfjellet Sandstone Member Beds 1 & 2	

numbers (in brackets) in the Cambridge Spitsbergen Expedition system of documentation and are located on the maps (Fig. 4 - Svenskøya, and Fig. 9 - Kongsøya). Our interpretations are given in Figures 8 and 16, which should be compared with those of Nathorst (1901), shown in Figure 2.

3.b.1. Svenskøya

The N-S ridge forming the backbone of Svenskøya rises to its highest point in the north where, at Mohnhøgda, the lowest strata are exposed (Sections H1748 and H1749; Fig. 5). It is only in this northern part of the island that two basalt flows can be distinguished; they are in contact over Dunérfjellet and separated by sediments at Mohnhøgda. The ridge dips southwards across Dunérfjellet, where only one exposure could be found (S1417; Fig. 5); it rises again in the south and widens to form the plateau of Kükenthalfjellet, where the south-facing cliffs provide a succession of good exposures at which sections were measured (C1371, C1373, C1374, C1375 and N797-801; Figs. 6-7). Additional short sections were measured in the southwest at D826-30 (see Fig. 6) and D838 (Fig. 5). A summary of the correlation of these sections is shown in Figure 8. A number of occurrences of intrusive igneous rocks are to be found in the south of the island.

3.b.2. Western Kongsøya

The mountains in the west of Kongsøya include the highest in the islands and they reveal variable strata, capped as in Svenskøya by one or two lava flows usually in contact with one another. At Hårfagrehaugen, where the oldest strata are seen, the two lava flows are partly separated by sediment (C1380; Fig. 14).

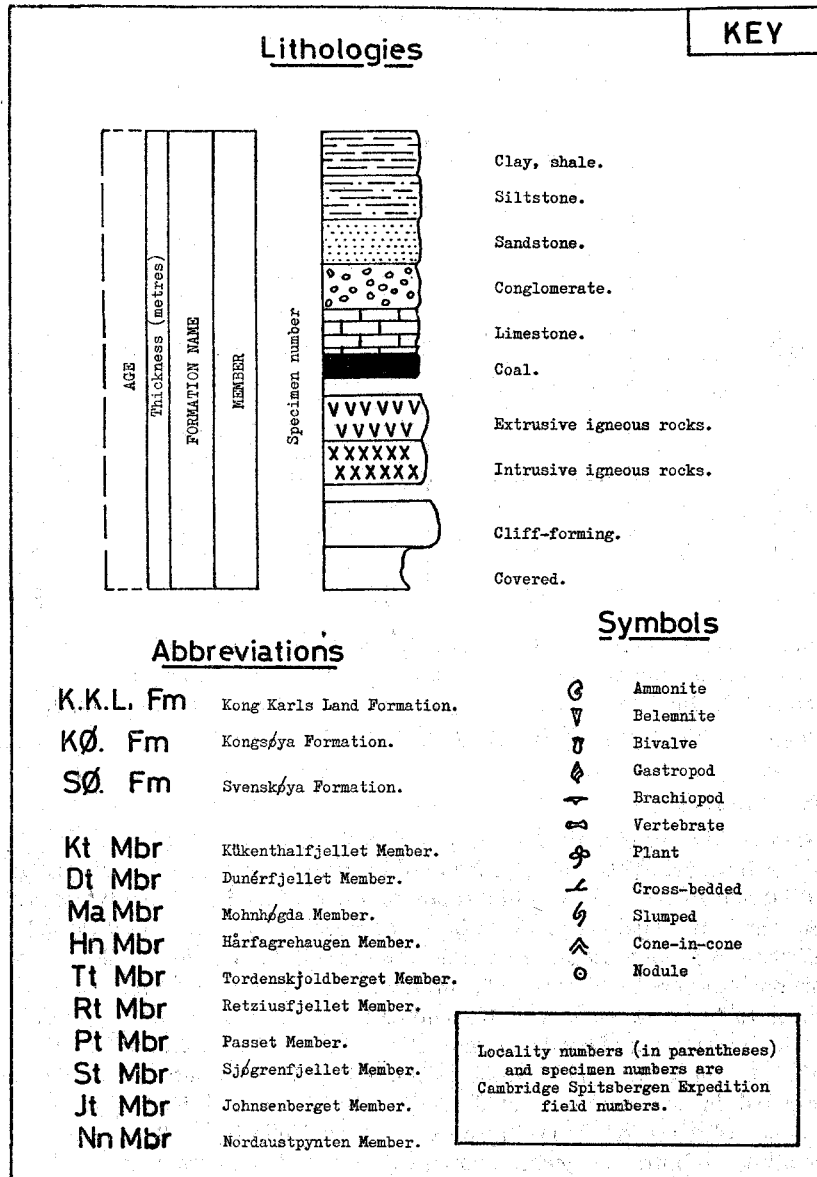


Figure 3. Key to measured stratigraphic sections, Figures 5, 6, 7, 8, 10, 11, 12, 13, 14, 15

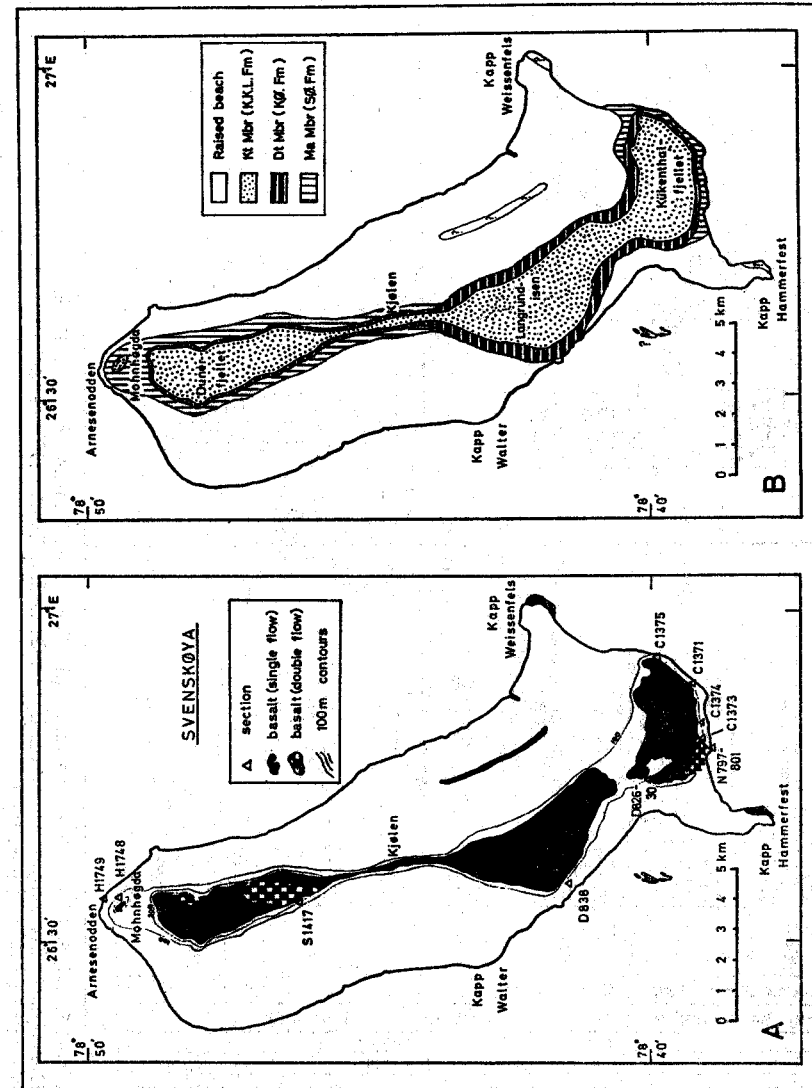


Figure 4. (A) Svenskøya: locality map of measured stratigraphic sections (Figs. 5, 6, 7, 8) showing extent of cap basalts. (B) Svenskøya: geology underlying the cap basalts.

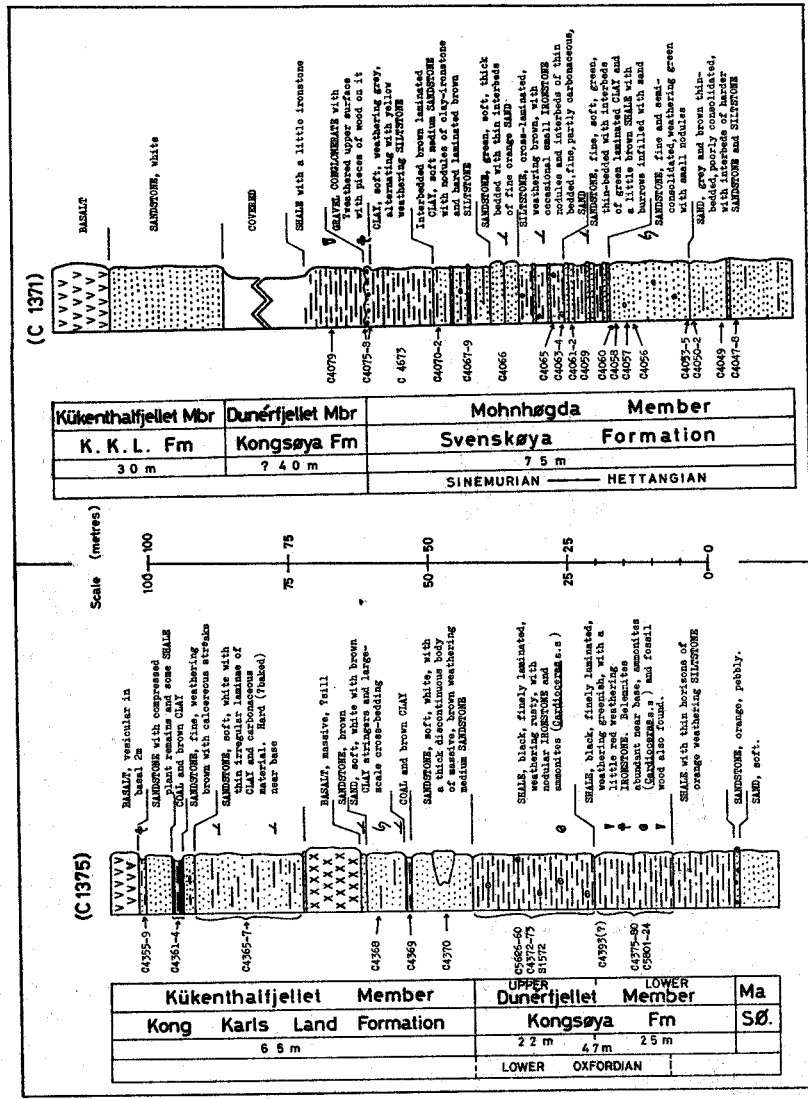


Figure 7. (C1375) - Section on north-eastern Kükenthalfjellet, Svenskøya. Measured by J. L. Cutbill, 1969. (C1371) - Section on eastern Kükenthalfjellet, Svenskøya. Measured by J. L. Cutbill and D. G. Smith, 1969.

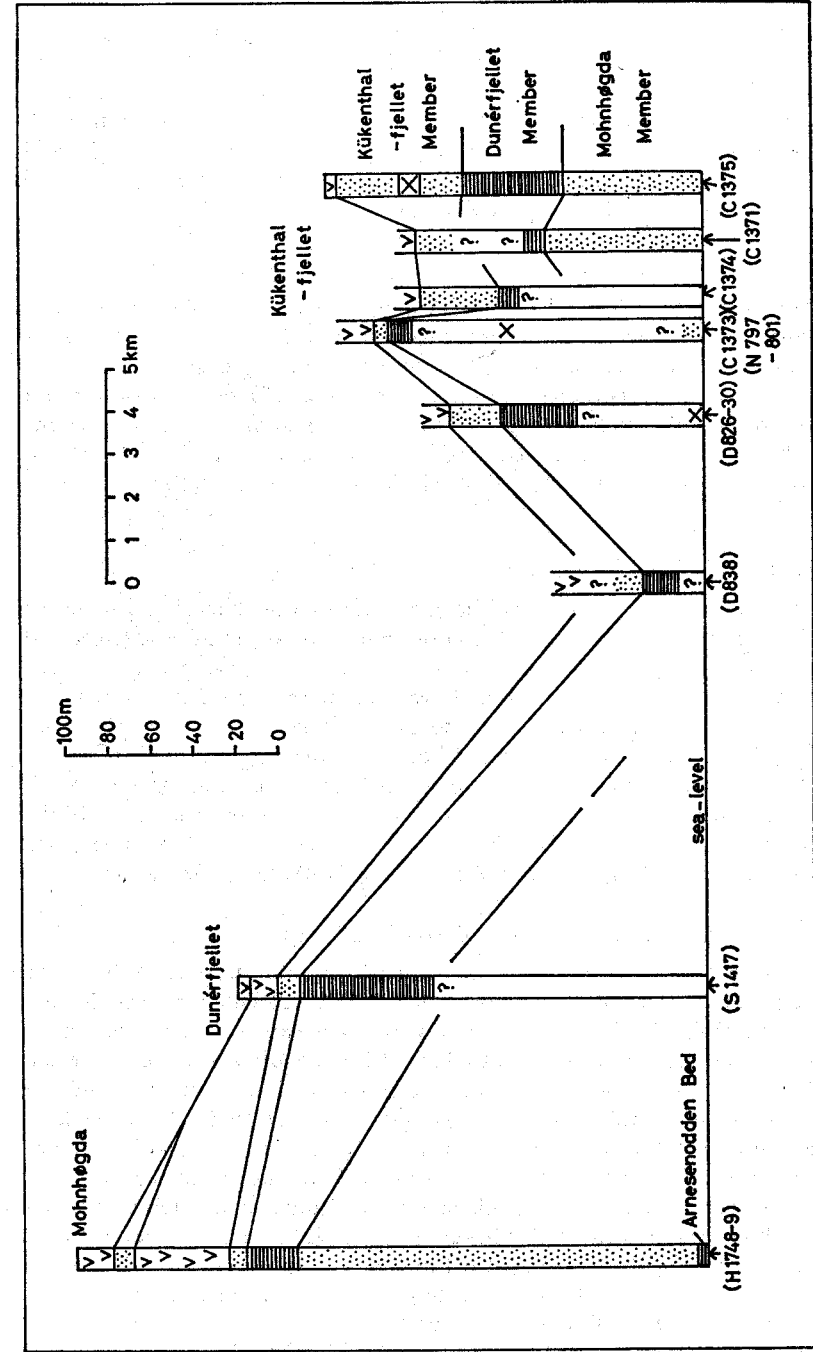


Figure 8. Svenskøya - Correlation of measured sections (Figs. 5, 6, 7).

An important section, not recorded by Nathorst, was measured northeast of Retziusfjellet, the highest mountain (C1381; Fig. 14). An isolated exposure was found at the northwest corner of Tordenskjoldberget (D834; Fig. 13), but the most useful sections for interpreting the structure of Western Kongsøya are those found along the south coast from Sjögrenfjellet (S1416; Fig. 10) through Passet (S1413, S1412; Fig. 11) to southwest Tordenskjoldberget (S1414 and D833; Figs 12 and 13). Intrusive igneous rocks are found in places, the principal body being that which forms Kapp Altmann.

3.b.3. Eastern Kongsøya

Much of the ground between the western and eastern mountain complexes of Kongsøya is underlain by igneous rocks which are exposed at a number of headlands around the coast. Johnsenberget, the mountain in the east, is also characterised by a number of igneous horizons. The exposures of the sedimentary strata in this area are poorer than in the other two main areas and composite sections have been constructed from scattered observations (H1756, H1774, H1775, H1776, H1777, H1778, H1793, H1794, H1795, H1797) in Figure 15.

4. Kong Karls Land Formation

This new formation is named from the interbedded sandstone and lava sequence which caps the sedimentary succession on both Svenskøya and Kongsøya and thus dominates the topography of Kong Karls Land. It approximates in stratigraphic position to the Helvetiafjellet Formation of Spitsbergen, which is generally taken to be Barremian in age and also includes evidence of vulcanicity (Parker, 1967). The Kong Karls Land Formation includes units 10, 11, 12 and 13 of Nathorst (1901) (Table 1). We define here three members, each of which represents the entire formation in a particular area; the reference section of the Kükenthalfjellet Sandstone Member at Mohnhøgda in Svenskøya (described below) is taken as the type section for the Kong Karls Land Formation.

4.a. Kükenthalfjellet Sandstone Member (in Svenskøya)

The type section is at northeast Kükenthalfjellet, the steep face above the shore, about 500 m south of the point where the basalt cliff top turns inland. The Kükenthalfjellet Member (65 m) comprises a very variable sequence of predominantly arenaceous sediments. At its base is a bed (11 m) of soft white sandstone, in which is a discontinuous body of very well consolidated brown-weathering medium sandstone, presumably a channel-fill. Above comes a succession of softer and harder sandstones, mostly light in colour, with interbeds and laminae of clayey and carbonaceous material. There are two beds of coal near the top, one of them nearly 1 m thick, and the sandstone immediately underlying the basalt at the top of the section has compressed plant stems. This development is similar to that of the Helvetiafjellet Formation in Spitsbergen, which shows a massive sandstone bed at the base (Festningen Sandstone) and coals in the higher beds of deltaic facies (Glitrefjellet Member).

The igneous rocks included in the Kükenthalfjellet Member generally consist

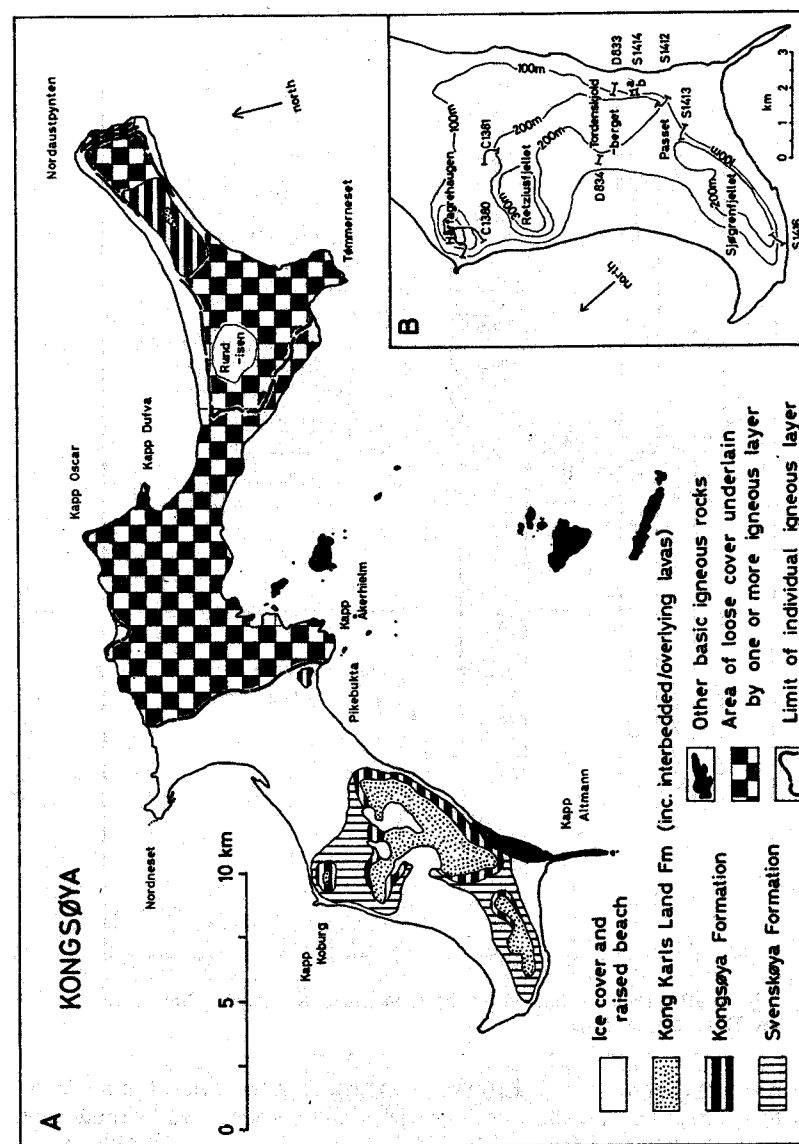


Figure 9. Kongsøya - (A) Geological map. (B) Section locality map. (Topography adapted from NPI 1:100000 maps.)

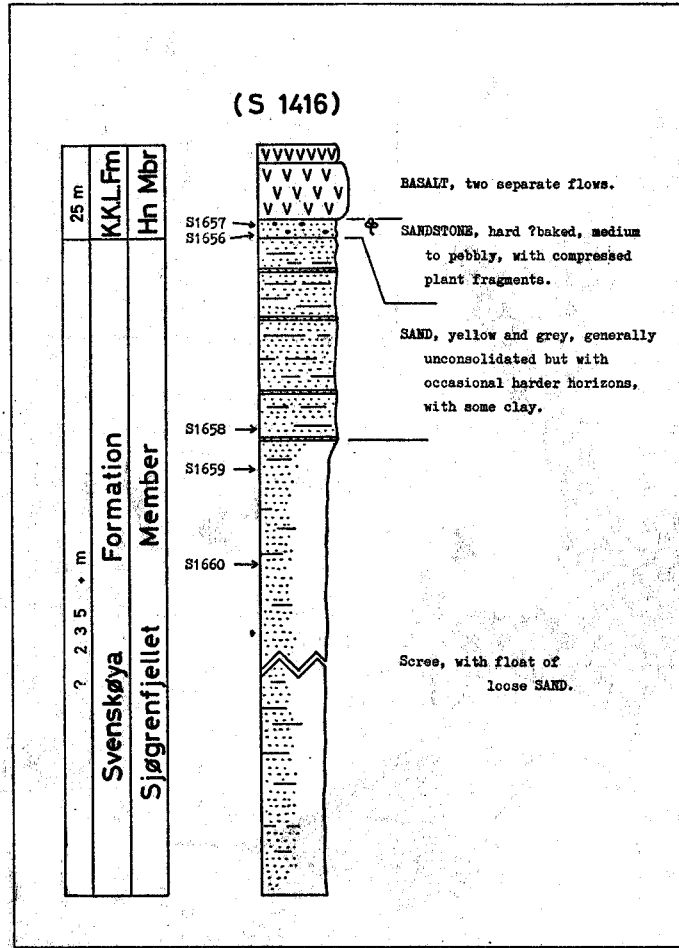


Figure 10. (S1416) - Section on Sjøgrenfjellet, Kongsøya. Measured by D. G. Smith, 1969.

of a single lava flow at the top. However, two lava flows are evident in northern Svenskøya, which are in contact at Dunérfjellet and are separated by sandstone at Mohnhøgda. The lava forms a single flow in the western part of Küken-thalfjellet, but east of the section C1371 the lower part becomes detached and forms a sill, separated from the extrusive part by about 20 m of sediments (this was illustrated by Nathorst, 1901, p. 348, Fig. 2). At the type section of the Küken-thalfjellet Member the upper, capping, basalt is highly vesicular at its base, while the lower is massive throughout and has baked the under and overlying sediments.

The unit is very variable in thickness, but is nowhere thicker than at the type section; only 34 m were recorded in Dunérfjellet (Fig. 5). The 10 m of brownish

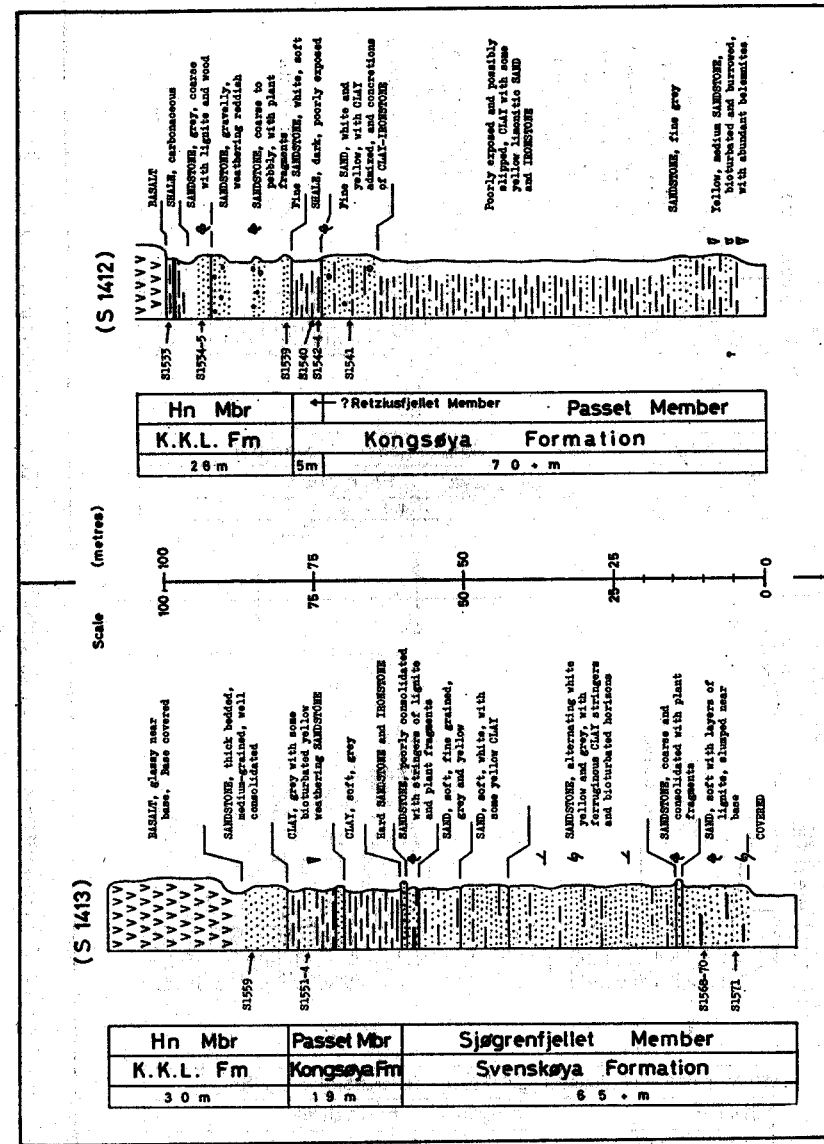


Figure 11. (S1413) - Section on western Passet, Kongsøya. Measured by D. G. Smith, 1969. eastern Passet, Kongsøya. Measured by D. G. Smith, 1969

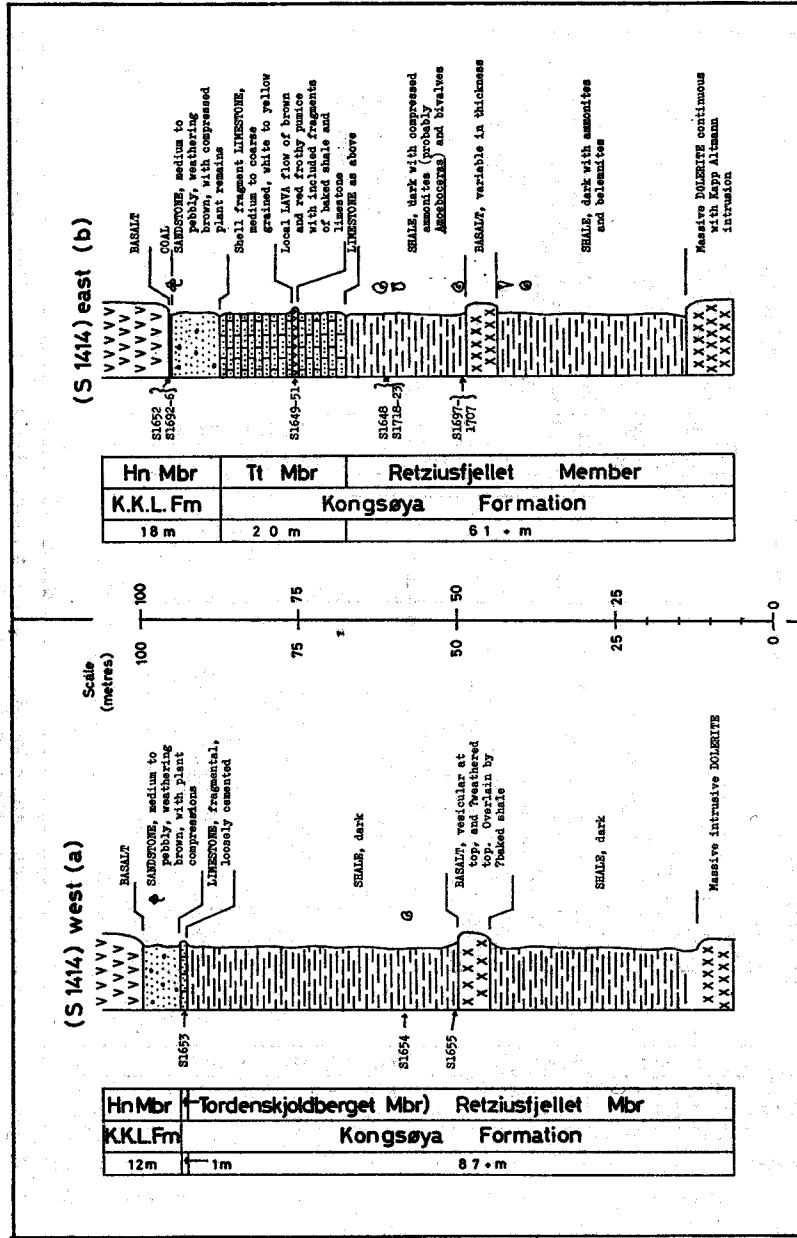


Figure 12. (S1414) west and (S1414) east - sections on Tordenskjoldberget, Kongsøya. Measured by D. G. Smith, 1969.

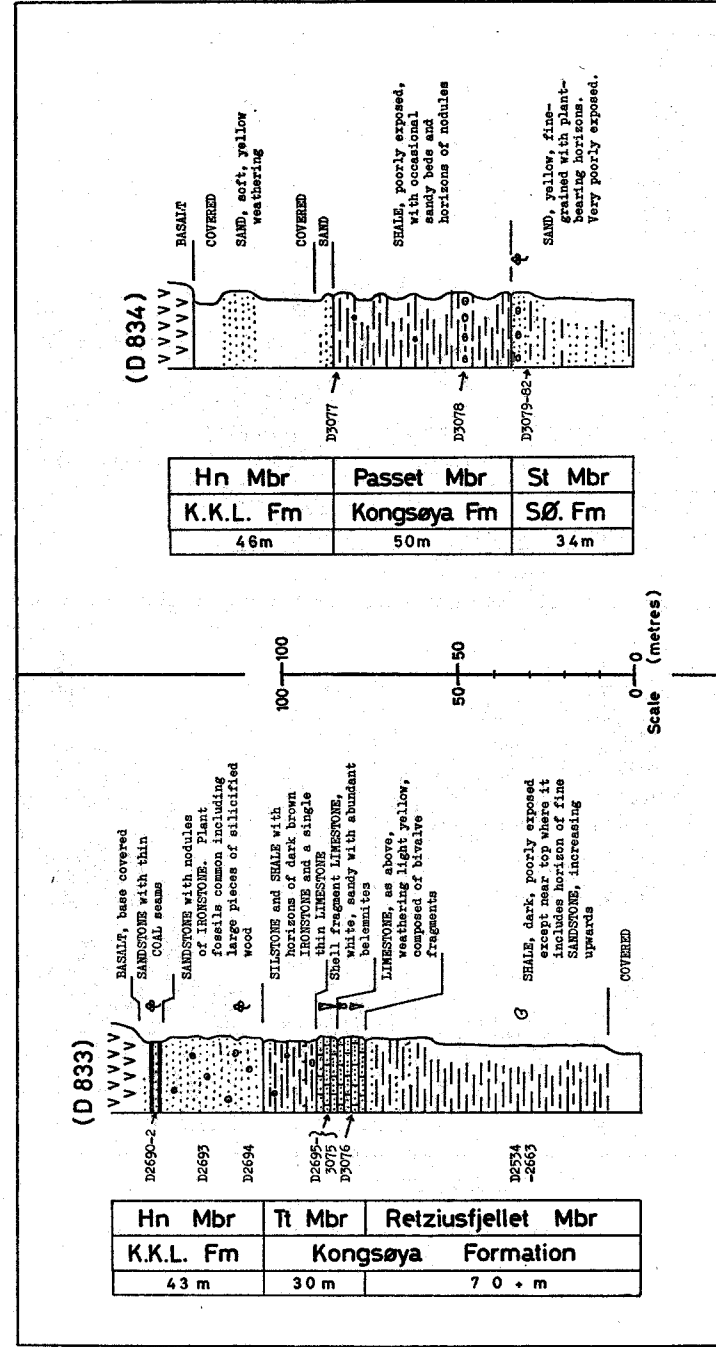


Figure 13. (D833) and (D834) - Sections on Tordenskjoldberget, Kongsøya. Measured by D. G. Smith and D. J. Batten, 1969.

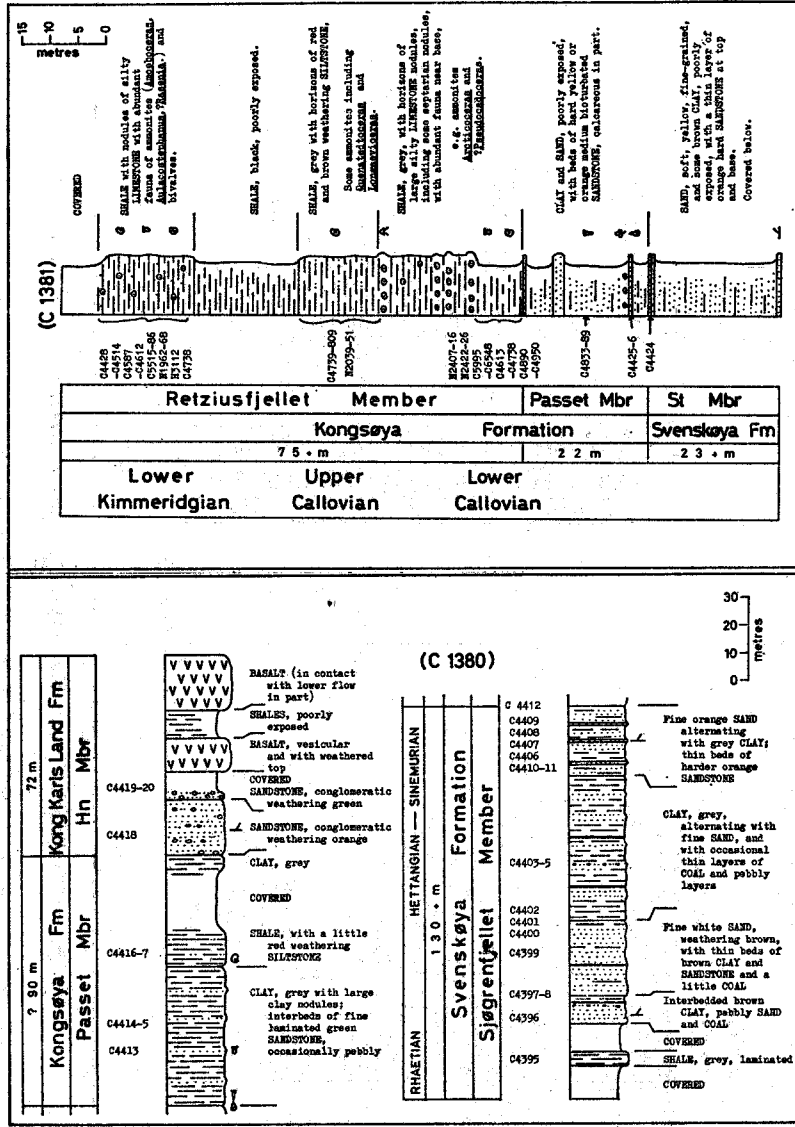


Figure 14. (C1380) - Section on Hårfagrehaugen, Kongsøya. Measured by J. L. Cutbill, 1969. (C1381) - Section on Retziusfjellet, Kongsøya. Measured by J. L. Cutbill, 1969.

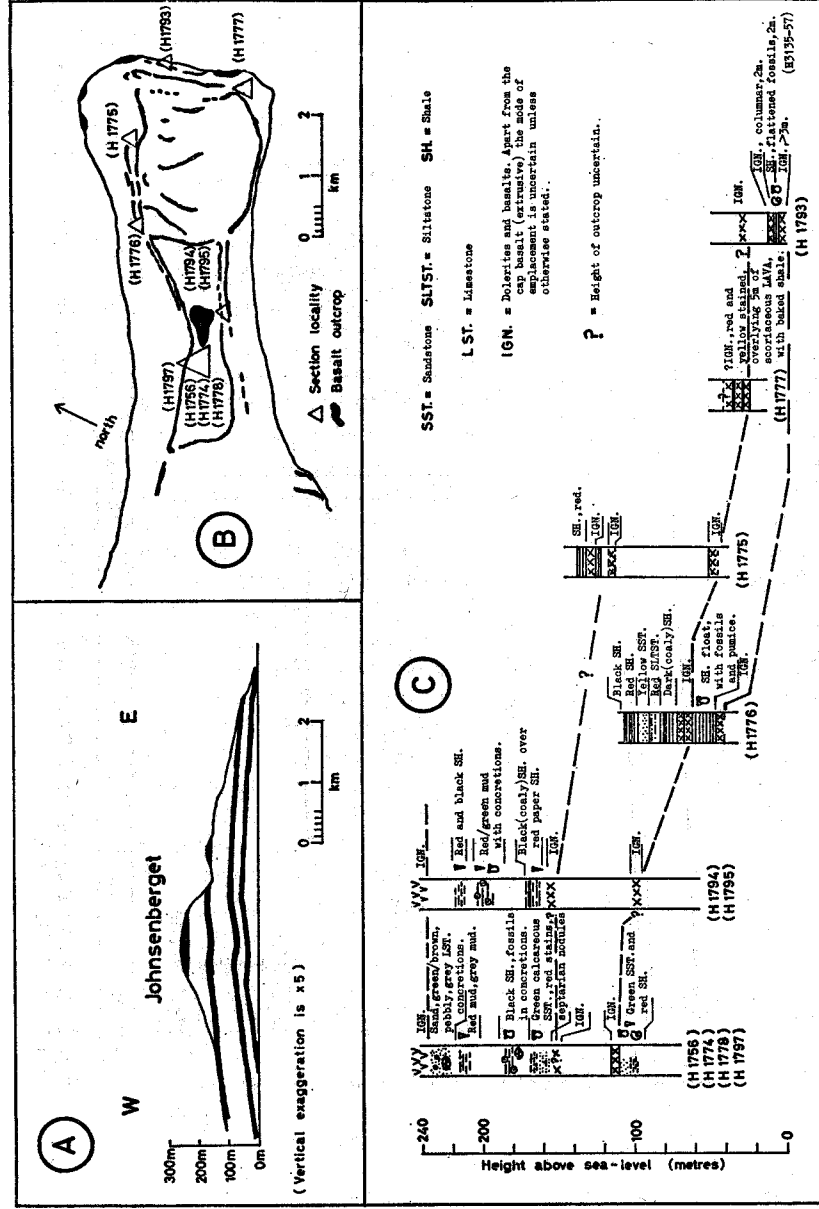


Figure 15. (A) Sketch cross-section of eastern Kongsøya showing igneous layers. (B) Eastern Kongsøya, showing section localities for Figure 15 (C) and outcrop pattern of igneous rocks. (C) Short sections around eastern Kongsøya, showing possible correlation of igneous layers. Measured by W. B. Harland, 1969.

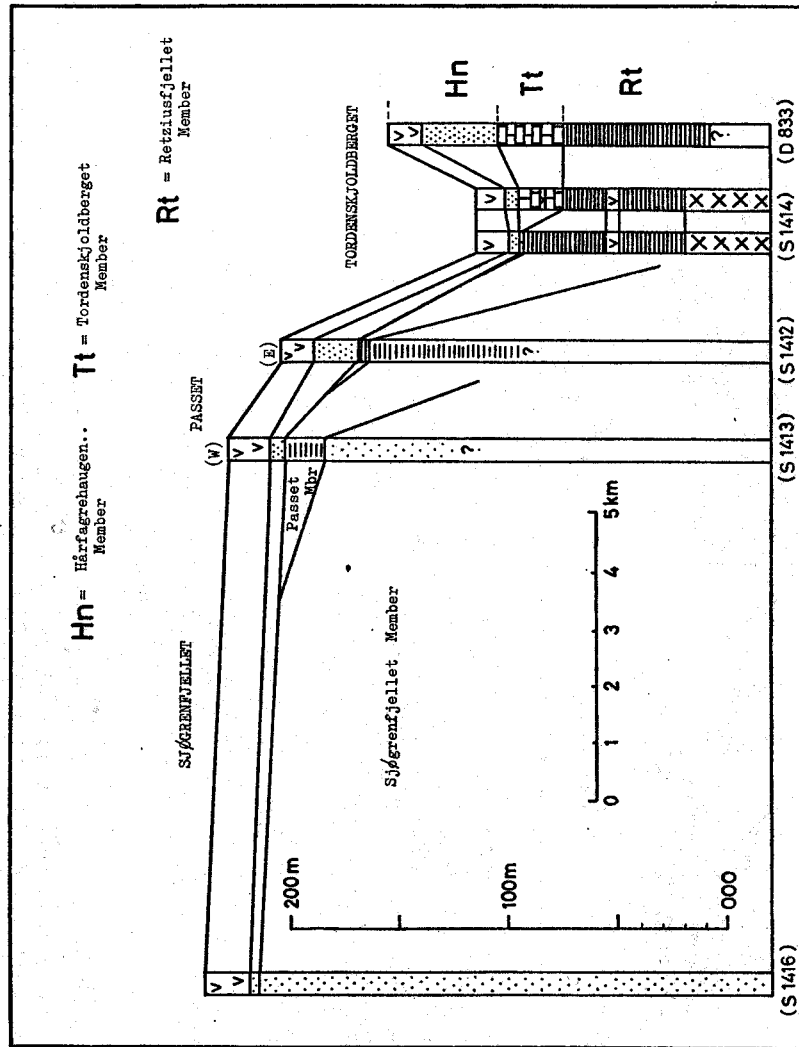


Figure 16. 'Fence diagram' to show the relationship between sections measured in south-western Kongsøya (Figs. 10, 11, 12, 13).

sandstone recorded between the two lava flows at Mohnhøgda are included in this unit.

Equivalents are beds 10 and 12 of Nathorst (1901, p. 362).

Nathorst (1901, p. 350) recorded the following plant fossils from the south side of Langrundisen [approximately the site of section D838; Fig. 5]: *Cladophlebis* sp., *Taeniopteris* or *Anomozamites*, *Podozamites lanceolatus eichwaldi* and *Pinus* sp. He gave no estimate of age other than 'Neocomian'. Blüthgen's dating of the latest underlying beds implies that the plant-bearing beds are post-mid-Valanginian. The equivalent plant beds of the Helvetiafjellet Formation in Spitsbergen are generally taken to be Barremian in age (Parker, 1967).

4.b. Hårfagrehaugen Sandstone Member (in Western Kongsøya)

The type section is at Tordenskjoldberget, south face, approximately 3 km east of Passet (section D832, measured by D. J. Batten and D. G. Smith; not illustrated). This is the location of several large slipped masses of sediment referred to as the Belemnite Mounds (Belemnittullarna) by Nathorst (1901, p. 354); they include material from the Hårfagrehaugen Member as well as from the Tordenskjoldberget Member of the Kongsøya Formation.

This member (14 m) includes the non-marine, dominantly arenaceous, beds below and between the capping basalt flows which are themselves included here. It comprises sandstones, medium to coarse in grain size, loosely to well consolidated and often conglomeratic in part; siltstone and shale make up part of the unit in places. Coal, carbonaceous beds and plant fossils are characteristic. The unit is variable in thickness and lithology. Two lava flows (generally in contact) are found in several localities; at Hårfagrehaugen the two flows are separated by sediments on one side of the peak but in contact on the other.

Compressed plant fragments, with well-preserved cuticle in some specimens from the type section, are common, and petrified wood is found at some localities. At locality D833 (Fig. 13) several large (up to a metre long) trunks of wood were found immediately below the lower basalt; a few pieces of wood were found enclosed in fragments of the basalt and are shot through with siliceous veins. Petrified wood from Kong Karls Land, collected on the 1898 expedition, was described by Gothan (1907) and, although he did not give any information on the horizon or locality from which his material came, it was presumably from the Hårfagrehaugen Member, as he mentioned the fact that the excellent preservation is probably due to the contemporaneous eruptions of basalt. He described six species of wood, three of them new, belonging to five genera, of which one (*Protopiceoxylon*) was new. He implied that the material was late Jurassic in age, but corrected this to early Cretaceous in a later paper (Gothan, 1911). The identifications were as follows:

- Phyllocladoxylon* sp.
- Xenoxylon phyllocladoides* Gothan
- Cupressinoxylon* cf. *McGeei* Knowlton
- Cedroxylon cedroides* n.sp.

Cedroxylon transiens n.sp.

Protopiceoxylon exstinctum n.gen.et sp.

The Hårfagrehaugen Member can so far be dated only as Valanginian or later on the evidence available from Kong Karls Land. Just as for the Kükenthalfjellet Member of Svenskøya, with which it corresponds in stratigraphic position, it may be mid-Cretaceous (possibly Barremian) in age. Equivalents include beds 10 and 12 (as developed in western Kongsøya) of Nathorst (1901, p. 362).

4.c. Johnsenberget Sandstone Member (Eastern Kongsøya)

The type section is at the top of Johnsenberget. The thickness is 30 m of sediment plus perhaps 20 m of basalt. The sediments (including Nathorst's bed 10) comprise sandstones, conglomeratic in part, with plant fossils. The member corresponds in stratigraphic position with the beds elsewhere in Kong Karls Land assigned to the Kong Karls Land Formation.

4.d. Lavas

Two separate flows sometimes separated by a thin sandstone bed are found, the upper at the top of the Kong Karls Land Formation, the lower within a few metres of its base. In Svenskøya the thicknesses of the flows vary from 43 m (lower) and 17 m (upper) on Mohnhøgda (H1748-9) to 15 m and 5 m on southern Dunérfjellet (S1417). In Kongsøya the thicknesses range from 15 m (lower) and 5 m (upper) on Sjøgrenfjellet (S1416) to 12 m (lower) and 20 m (upper) on Hårfagrehaugen. On Sjøgrenfjellet the upper flow rests directly on the lower, but at Hårfagrehaugen they are separated in places by up to 10 m of shales.

4.e. Palynomorphs of the Kong Karls Land Formation

A preliminary examination by J. F. Laing of three palynological preparations made by one of us (DGS) from samples from the Kong Karls Land Formation has yielded some interesting information, although no precise age determination is yet possible on this basis. Preservation of palynomorphs was found to be good, although some other samples proved to be barren, possibly due to contact metamorphism by the lavas. The assemblage was unexpected, as several spore and pollen types characteristic of 'Rhaeto-liassic' times and encountered in the Svenskøya Formation (see Section 6.d below) are present. These include *Ricci-sporites tuberculatus*, *Camarozonosporites laevigatus* and *Tigrisporites halleinsis*. Leaving these types out of consideration, the remainder of the assemblage is less distinctive and many of the pollen and spores seen are long-ranging through much of Mesozoic time. If the 'Rhaeto-liassic' palynomorphs are accepted as being re-worked, the remainder of the assemblages examined are not inconsistent with the early Cretaceous age which could be predicted from the field evidence. In addition, the presence of a few grains of *Cicatricosisporites*, in an assemblage from Kükenthalfjellet, indicates an age not older than latest Jurassic, while the lack of angiospermous pollen grains argues against an age later than, say, Albian or Cenomanian. The presence of 'Rhaeto-liassic' palynomorphs is significant in suggesting that rocks of this age, possibly elsewhere in Svalbard, were undergoing erosion at the time of deposition of the Kong Karls Land Formation.

5. Kongsøya Formation

The Kongsøya Formation is a dominantly argillaceous marine sequence, found in both Svenskøya and Kongsøya but more fully developed in Kongsøya where up to three members can be recognised. Units 3-9 of Nathorst (1901) all fall within the delineation of this formation which extends from the lowest marine argillaceous beds, overlying the continental sandy beds of the Svenskøya Formation, to the highest black shales underlying the interbedded sandstones and lavas of the Kong Karls Land Formation. In stratigraphic position, therefore, the Kongsøya Formation is approximately equivalent to the Janusfjellet Formation of Spitsbergen though the difference in development and the lack of contiguity with Spitsbergen led us to erect a new formation. The Kongsøya Formation is further defined in terms of local members for each of the three main areas.

The *Arcticoceras* fauna, found in the lower parts of the Kongsøya Formation, is the oldest fauna in our Kong Karls Land collections (Table 3). The age of the *Arcticoceras* beds of the Arctic is uncertain: in Greenland the overlying beds are definitely Lower Callovian, the underlying *Arctocephalites* beds are Bathonian. Hence these Svalbard forms can only be considered late Bathonian or initial Callovian. They are apparently pre-dated by the record of *Arctocephalites arcticus* (Newton) (Pompeckj, 1899; Arkell, 1956) in Kong Karls Land.

5.a. Dunérfjellet Shale Member (in Svenskøya)

The type section (S1417) is about 1 km NNW of the southern end of the Dunérfjellet plateau, in a steep west-facing flank. The member is 63 m+ thick (base not seen) and consists entirely of shale with distinct upper and lower divisions (S1417; Fig. 5). Equivalents include units 3-7 of Nathorst (1901, p. 362).

5.a.1. *The upper division* comprises 19 m of tougher shale, not crumbly or weathering like that of the lower unit, grey in colour, and with a fauna of bivalves of 'Aucella' (*Buchia*) type, ammonites and fish fragments, all compressed.

The fish fragments are comparable with those described as *Leptolepis nathorsti* sp.nov. by Woodward (1900), also from Svenskøya, from a 'bituminous limestone'. No calcareous beds are seen at Dunérfjellet but the uppermost part of the unit in the sections (C1373) and (C1374) at Kükenthalfjellet (Fig. 6) contains calcareous siltstone nodules with a similar ammonite, bivalve, and fish fragment fauna. Nathorst did not describe the Dunérfjellet section and there is therefore no published estimate of the ages of the sediments in it. The compressed ammonites in the upper shale bed are *Amoeboceras* (*Amoebites*) of early Kimmeridgian age. They belong to the *Amoeboceras* fauna of Blüthgen (1936).

5.a.2. *The lower division*, of which 42 m are seen at the type section, consists of soft-weathering, dark grey shales, with small belemnites, ammonites preserved in full relief in pyrite and rare crinoid fragments. The cardioceratids collected in 1969, being pyritised, were treated to prevent disintegration by Dr C. L. Forbes (Curator, Sedgwick Museum), who suggested a Late Oxfordian age. The *Cardioceras* s.s. include forms close to *C. cordatum*, and lowermost in the formation are found *Arcticoceras* and *Cadoceras*, setting a lower age limit of around late Bathonian to initial Callovian.

Shales which can be assigned to the Dunérfjellet Member occur in all the

measured sections illustrated, but usually with either the top or the base covered. A through succession was seen at northeast Kükenthalfjellet (C1375; Fig. 7) where the unit is 47 m thick and includes horizons of clay-ironstone concretions very similar to those in the Janusfjellet Formation in Spitsbergen. Belemnites and pyritised ammonites were again found in the lower part, and fish fragments in the upper part. At Mohnhøgda 20 m of dark shale lie between the arenaceous beds below and above. Though no megafossils were found, the shales contain abundant organic microplankton, and are evidently marine and are hence assigned to the Dunérfjellet Member. The reduction in thickness, from more than 60 m at the type section (6 km to the south) to 20 m, is probably due to pre-Kükenthalfjellet Member erosion.

5.b. Tordenskjoldberget Limestone Member (Western Kongsøya)

The type section is on the south face of Tordenskjoldberget, about 1.5 km east of Passet (D833). The member (30 m) is described at the type section in two divisions. Equivalents include Nathorst's bed 9 as developed at Tordenskjoldberget; also the 'sandkalk' and 'sandige eisenschüssige Mergel' of Blüthgen (1936, p. 59), dated by him to the Lower and Middle Valanginian. This member has no equivalent on Svenskøya.

The Tordenskjoldberget Member is seen *in situ* only along a little over a kilometre of the south face of Tordenskjoldberget, and nowhere else in Western Kongsøya. East of the type locality it is obscured by snow and scree, although between 1.5 and 2 km to the east it is found in the Belemnite Mounds. To the west it thins rapidly as it is overstepped by the Hårfagrehaugen Member. About 600 m to the west (Fig. 12 east) the whole of the upper division has been cut out, and 150 m to the west again (Fig. 12 west), 1 m is all that remains of the lower division. This overstepping relationship is summarised in Figure 16.

One of the few occurrences of extrusive igneous rocks below the Kong Karls Land Formation is found within the Tordenskjoldberget Member at locality S1414 (Fig. 12) and consists of a small outcrop of bright red weathering pumice with included fragments of baked sediment. It is presumably of Valanginian age and constitutes the earliest evidence of igneous activity in Western Kongsøya.

5.b.1. *The upper division* comprises 15 m of shales and siltstones with dark brown weathering ironstone nodules; a calcareous horizon occurs at about 4 m above the base in the type section. Nathorst reported bivalves from this unit (1901, p. 355).

5.b.2. *The lower division* consists of 15 m of white and light yellow, loosely cemented, coarse to medium sandstone. The sandstone is calcareous, and consists almost entirely of prismatic bivalve shell fragments (*Inoceramus* fragments according to Nathorst, 1901, p. 355). Complete bivalve shells, particularly of *Buchia* type are also found, but characteristic of the unit is the abundance of large belemnite guards found in it. Many of these have numerous small borings (for examples, see Blüthgen 1936, pl. 6, Figs 12–13, pl. 7, Fig. 2, pl. 8, Figs 1 and 9) rather similar to those described by Seilacher (1968), also in belemnites, and ascribed by him to boring barnacles (order Acrothoracica). A single solitary coral was found in 1969, and may be comparable with that described as *Thecocyathus nathorsti* sp. nov. by Lindström (1900) from the 'Sandkalk'.

5.c. Retziusfjellet Shale Member (Western Kongsøya)

The type section is between south-eastern Retziusfjellet and northern Tordenskjoldberget, on the ridge curving northwards and westwards down the eastern edge of the snow patch (C1381). Nathorst evidently missed this important section, in which the beds dip eastwards at 17°; everywhere else on Kongsøya they are practically horizontal. Equivalents include Nathorst's beds 6 and 7, recorded from Tordenskjoldberget (Nathorst, 1901, p. 362).

This member (75 m+, top not seen) is similarly developed and corresponds in stratigraphic position to the upper part of the Dunérfjellet Member of Svenskøya. At the type section it rests on a thin, orange-weathering hardground at the top of the mainly soft sands and clays of the Passet Member. It consists largely of grey and black shales with occasional nodule horizons. The nodules are usually of ironstone, weathering red or yellow, but at the type section there are several horizons of large calcareous nodules, some of them septarian, and many with very well preserved fossils including ammonites, bivalves, and belemnite phragmocones, all in full relief. This is an unusual development for the formation, in which fossils are generally preserved only in compression. The occurrence of bivalves and ammonites in calcareous nodules near the top of the Dunérfjellet Member on Svenskøya (Fig. 6) is comparable.

The youngest ammonite fauna (see Table 3 and section C1381, Fig. 14) consists of *Amoeboceras* (*Amoebites*) *kitchini* group and *Aulacostephanus* (*Xenostephanus*) (probably representing the early Kimmeridgian *mutabilis* Zone) and *Amoeboceras* (*Amoebites*) cf. *kitchini* with *Rasenia*? (probably representing the *cymodoce* Zone). Another possible early Kimmeridgian form is *Amoeboceras* (*Hoplocardioceras*?) (flattened). Middle or late Callovian ages are implied by the presence of *Longaeviceras*? and *Quenstedtoceras* s.l. (probably s.g. *Eboraciceras*) lower down the sequence. The *Arcticoceras* fauna (see introduction to this chapter) is present in the lowermost strata.

The Retziusfjellet Member is seen at several exposures along the southeast face of Tordenskjoldberget (Figs 12, 13). It is overstepped at Passet by the Hårfagrehaugen Member; about 5 m of dark shale between the Passet Member and the Hårfagrehaugen Member at the east side of Passet (Fig. 11) are probably the westernmost remnant of the Retziusfjellet Member.

5.d. Passet Clay Member (Western Kongsøya)

The type section is at Passet, east side of col, exposed below the south-western corner of Tordenskjoldberget (Fig. 11). The base of this member was not exposed at this locality in 1969, but is seen on the western side of the col below the eastern end of Sjøgrenfjellet (Fig. 11). The thickness is 65+ m. Equivalents include bed 4 of Nathorst (1901, p. 362).

The member corresponds in stratigraphic position with the lower part of the Dunérfjellet Member of Svenskøya. It consists of the predominantly clayey beds overlying the sands of the Sjøgrenfjellet Member and underlying the distinctly harder and darker shales of the Retziusfjellet Member above. The clay is generally unconsolidated, but includes occasional ironstone nodules and beds of sand or sandstone. A fauna of small belemnites is characteristic of the unit.

To the west of Passet the Passet Member is cut out progressively by the Hårfagrehaugen Member, about 20 m only being present at the eastern end of Sjøgrenfjellet (Fig. 11) and none at all at the western end (Fig. 10). To the east it is seen in sections on Hårfagrehaugen (Fig. 14) and Retziusfjellet (Fig. 14), but it is presumably below sea level along the southeast face of Tordenskjoldberget. About 50 m of light grey fissile clay with occasional ironstone nodules in the section at the northwest corner of Tordenskjoldberget probably also belong to this unit.

No new evidence for the age of these beds is offered here; Nathorst dated his belemnite-bearing unit 4 as Middle to Late Callovian.

5.e. Upper division of Kongsøya Formation (in Eastern Kongsøya)

These rocks are seen only in the upper slopes of Johnsenberget where exposure is poor and our work inadequate to propose formally a new member. The rocks are clays, siltstones, yellow and green sandstones with belemnites and bivalves and a horizon of calcareous sandstone near the top. The approximate equivalents are Nathorst's beds 8 and 9. The Kongsøya Formation as a whole is about 200 m thick in this area and this upper division is possibly about 50 m.

Nathorst's correlation would give an age estimate as ranging from Volgian to Valanginian, the 'sandkalk' at the top being dated as Lower and Middle Valanginian on the evidence of the bivalves. Nathorst implied that the Jurassic-Cretaceous boundary is about 150 m above sea level in this section (1901, p. 358).

5.f. Nordaustpynten Shale Member (in Eastern Kongsøya)

This member is of black shale and constitutes the lower part of the Kongsøya Formation. At least 100 m and possibly 150 m are exposed in the lower slopes of Johnsenberget and in the sea cliff at Nordaustpynten where a fossiliferous horizon is contained between igneous layers (probably extrusive). In other localities volcanic eruption appears to have baked the shales to a bright red colour.

Flattened ammonites and bivalves were collected in 1969 and provisionally identified as *Rasenia/Aulacostephanus*, with cardioceratids suggesting an Early Kimmeridgian age (see Table 3 and section H1793, Fig. 15).

5.g. Lavas

The Kongsøya Formation contains both intrusive and extrusive igneous rocks. In Svenskøya there is only one intrusive basalt, over 5 m thick, which cuts across the southern face of Kükenthalfjellet (C1373) to join the cap basalt in the Kong Karls Land Formation. In Kongsøya there is more variety. At Tordenskjoldberget (S1414) a 1 m lava flow appears within the limestone of the Tordenskjoldberget Limestone Member, while two ?intrusive basalts (each about 5 m thick and 30 m apart) are found in the Retziusfjellet Shale Member below.

Table 3. Preliminary faunal identifications by P. Rawson.

ISLAND	MEMBER (Kongsøya Formation)	LOCALITY	SPECIMEN NUMBERS	DETERMINATIONS AND NOTES	AGE
Kongsøya	Retzius-fjellet	C1361 (fig. 14)	C4440-5, 4447-9, 4451-8, 4460-8, 4471-4529, 5514-5986.	<i>Amoeboceras</i> (<i>Amoebites</i>) <i>Kitchini</i> & <i>Aulacostephanus</i> (<i>Xenostephanus</i>).	Early Kimmeridgian, probably <i>mutabilis</i> Zone.
Kongsøya	Retzius-fjellet	C1361 (fig. 14)	M1962-5, 1967-8, and C4739.	<i>Amoeboceras</i> (<i>Amoebites</i>) cf. <i>Kitchini</i> (crushed). <i>Rasenia</i> ?	Early Kimmeridgian, probably <i>Synodoce</i> Zone.
Kongsøya	Retzius-fjellet	D873 (fig. 13)	D2574-2663.	<i>Rasenia</i> or <i>Aulacostephanus</i> , with <i>Amoeboceras</i> (<i>Amoebites</i>) and <i>Amoeboceras</i> (<i>Hoplcardioceras</i> ?). All flattened.	Early Kimmeridgian.
Svenskøya	Dunér-fjellet	D827 (fig. 6)	D2105, 2108, 2117, 3394.	<i>Amoeboceras</i> , flattened.	Early Kimmeridgian
Kongsøya	Retzius-fjellet	S1414 (fig. 12)	S1697-1707, 1718-1722.	<i>Amoeboceras</i> .	Early Kimmeridgian
Svenskøya	?Dunér-fjellet	B842 (not shown)	M2034-8, 2095, 2097.	<i>Euchla</i> and flattened cardioceratids. Some are <i>Amoeboceras</i> ?	Early Kimmeridgian?
Kongsøya	Nordaustpynten?	E1793 (fig. 15)	B3135-57.	Possibly <i>Rasenia/Aulacostephanus</i> and cardioceratids.	Early Kimmeridgian?
Svenskøya	Dunér-fjellet	S1417 (fig. 5)	S1775-1815.	<i>Cardioceras</i> s.s.	Early Orfordian.
Svenskøya	Dunér-fjellet	C1375 (fig. 7)	C5801-24, 5626-60.	<i>Cardioceras</i> s.s. including forms close to <i>Cardioceras cordatum</i> . Material is decomposing.	Early Orfordian, probably <i>cordatum</i> Zone.
Kongsøya	?Retzius-fjellet	B82 (not shown)	M2125-32.	<i>Longavriceras</i> ?	Middle or Late Callovian
Kongsøya	Retzius-fjellet	C1361 (fig. 14)	C4742-4801, and M2039-51.	Variable assemblage, fragmentary material, including <i>Quenstedticeras</i> s.l. (probably s.-e. <i>Eberaciceras</i> ?) and <i>Longavriceras</i> .	Middle or Late Callovian.
Svenskøya	Dunér-fjellet	C1379 (see fig. 7, C1375)	C4393.	<i>Arcticoceras</i> ?	Initial Callovian or late Bathonian.
Svenskøya	Dunér-fjellet	D837 (see fig. 6, D826-70)	D3104-3120.	<i>Arcticoceras</i> and <i>Cadoceras</i> .	Initial Callovian or late Bathonian.
Kongsøya	Retzius-fjellet	C1361 (fig. 14)	M1971, 2407-16, 2422-26, and C6002-6562.	The <i>Arcticoceras</i> fauna, large, well preserved, apparently of mainly undescribed forms, but including <i>Arcticoceras</i> .	Initial Callovian or late Bathonian.

5.h. Ammonites

The ammonites collected from the Kongsøya Formation in 1969 have been provisionally identified by P. F. Rawson, of Queen Mary College, London. The determinations are mentioned above under the appropriate stratigraphic unit and are collected together in Table 3.

6. Svenskøya Formation

This new formation is named from the dominantly sandy, continental beds at the base of the succession in north and south Svenskøya and in part of western Kongsøya. It is similar in facies to parts of the De Geerdalen Formation of Spitsbergen but the sandstones are less consolidated, more massive, and porous. The beds in Kong Karls Land are younger than those in Spitsbergen and lack the conglomerate which usually marks the top of the De Geerdalen Formation. The formation is described in terms of a single member for each of the two main areas in which it outcrops; it includes units 1 and 2 of Nathorst (1901, p. 362), the type section being that for the Mohnhøgda Sandstone Member. Nathorst and other earlier workers did not give an estimate of age, but Orvin's (1940) map of Svalbard marked considerable areas of Triassic outcrop on both Svenskøya and Kongsøya, presumably referring to these lowest beds, but with no explanation. From palynological investigation the lower part of each member exposed in Svenskøya and Kongsøya is Rhaetic and the main body in each case is probably Hettangian to Sinemurian. As this is entirely new information it is given more fully below (6.d).

6.a. Mohnhøgda Sandstone Member (in Svenskøya)

The type section is on the northeast side of Mohnhøgda (Fig. 5). The succession (196 m+, base not seen) consists largely of sandstones of varying degrees of consolidation, variously coloured, white, grey, yellow or brown, with occasional interbeds of grey and brown siltstones and shales, and rare coal and ironstone horizons. The sandstones are cross-bedded and ripple-marked in places. The only megafossils found were pieces of petrified wood.

Similar lithologies characterise the occurrence of the Mohnhøgda Member elsewhere in Svenskøya, with the occasional addition of thin pebble horizons. At the top of the unit at section C1371, Kükenthalfjellet (Fig. 7), is a thin bed of gravel conglomerate with an apparently eroded top. The greatest thickness seen is at Mohnhøgda.

6.b. Arnesenodden Shale Bed

The lowest 70 m of the section at Mohnhøgda are largely talus-covered, except for a small exposure on the shore a little to the east of Arnesenodden. Here are about 5 m of black shale and siltstone, overlain by brownish sandstone. These are believed to be the lowest beds exposed on Svenskøya, and are distinguished as the Arnesenodden Shale Bed.

6.c. Sjøgrenfjellet Sandstone Member (in Western Kongsøya)

The type section is on the northwest face of Hårfagrehaugen (Fig. 14) (better exposure than Sjøgrenfjellet). The Sjøgrenfjellet Member (130 m+, base not seen) corresponds to the Mohnhøgda Member of Svenskøya in stratigraphic position and is also of non-marine facies.

It consists mainly of poorly consolidated fine sand, with stringers and interbeds of grey and brown clay, and thin coal seams. A few thin beds of harder sandstone occur, and there are also a few pebbly horizons. Elsewhere the development is similar; plant fragments, wood and lignite were noted at Passet (Fig. 11), where slump structures were also seen in the soft sands; hard grounds weathering bright orange were seen at Sjøgrenfjellet (Fig. 10) and Retziusfjellet (Fig. 14). The unit reaches a maximum thickness of possibly as much as 235 m at the western end of Sjøgrenfjellet, though the section there is much obscured, and it was difficult to determine in the field how much of the loose sand had slipped down from above.

6.d. Palynomorphs of the Svenskøya Formation

Seven palynological preparations from the Svenskøya Formation were chosen for the purpose of correlating the well-documented sections at Mohnhøgda (representing north Svenskøya), Kükenthalfjellet (south Svenskøya) and Hårfagrehaugen (West Kongsøya). The sample and preparation data are listed in the caption to Table 4 together with the percentages of certain categories of palynomorph based on a count of not less than 250 grains in the first slide of each preparation. Preservation of palynomorphs was found to be generally very good, in contrast with other areas of Svalbard (Hughes, Harland & Smith, 1976).

Stratigraphically significant palynomorphs are generally not abundant, and they are accompanied by quantities of smooth trilete spores, monocolpate and bisaccate pollen, as well as by miscellaneous organic debris including well preserved plant cuticles in some cases. A little microplankton (acritarchs) was found in a few of the assemblages, indicating some marine influence at times during the deposition of the Svenskøya Formation in Kong Karls Land; no dinoflagellates were recorded.

Table 4 shows the distribution of certain palynomorphs in the selected preparations; all of the taxa shown have restricted ranges about the interval generally known in Europe as the 'Rhaeto-liassic'; the approximate known ranges are shown. The seven assemblages are shown in the table in what is believed to be their approximate stratigraphic order on the basis of their palynomorph content. The assemblages in the highest preparations from each of the three sections are broadly similar, and their relative order in Table 4 may not be significant. Preparations DS3A and DS147 are not greatly different from these three, although they are clearly earlier from their position in the sections, but DS155 and W004, the lowest assemblages from north Svenskøya and West Kongsøya, show marked differences from the others.

Most of the extensive literature on the palynology of European 'Rhaetic' or 'Rhaeto-liassic' strata relates to studies on sequences of Germanic type in which little or no megafaunal control is available to link the stratigraphy with the

Table 4.

TAXA	Recorded range		DISTRIBUTION	
	MID-JURASSIC AND LATER	TOARCIAN	SAMPLE NUMBER	NUMBER
	SINEMURIAN	PLIENS-BACHIAN	PREPARATION NUMBER	
<i>Roemeriella lazarovi</i> Playford & Bettmann	---	---	H3072 C4395 C4399 C4052 C4412 C4073 H3032	23(4)
<i>Microsporites hallensis</i> Klaus	---	---	W004 DS155 DS147 DS3A DS154 DS20 DS86	9(5) 100(13) 3(2)
<i>Plantosporites aralis</i> (Nilsson) Danes-Corsir & Laveine	---	---		9(9) 20(10) 108(105) 20(10)
<i>Leptocollinites silvatica</i> Cooper	---	---		20(20) 4(4) 9(4)
<i>Sarcocollinites thierzerii</i> Schulz	---	---		24(8) 13(13) 20(10)
<i>Leptocollinites zwickiana</i> (Cooper) Schulz	---	---		2(1) 13(5)
<i>Strombolidia brodesoni</i> Bettmann	---	---		100(50)
<i>Rosalesporites cetriceus</i> (Rogalski) Danes-Corsir & Laveine	---	---		10(5)
<i>Glaucobolites korobus</i> (Heissinger) Cooper	---	---		4(4) 10(4) 15(5) 32(32) 19(11)
<i>Zeltonosporites rodesoni</i> (Harris) Chaloner	---	---		
<i>Androsporites anelastensis</i> Halvorsen	---	---		3(2)
<i>Chamaesporites scorria</i> (Rogalski) Nilsson	---	---		6(3) 6(3)
<i>Duvalosporites spangui</i> (Nilsson) Playford & Bettmann	---	---		20(10) 21(9) 8(3)
<i>Chamaesporites major</i> Nilsson	---	---		11(6) 27(4)
<i>Palaeohalimnospores araneolensis</i> (Halvorsen) Playford & Bettmann	---	---		3(3)
<i>Zehnerosporites laevigatus</i> Schulz	---	---		5(2)
<i>Mabesporites lundbladii</i> Nilsson	---	---		30(30)
<i>Arctosporites saetiae</i> (Klaus) Schulz	---	---		7(3)
<i>Microsporites subarcticus</i> Lundblad	---	---		40(40)
<i>Zehnerosporites interstitialis</i> Thiergart Klaus	---	---		13(7) 13(5)
<i>Amulianora foliicola</i> (Rogalski) De Jersey	---	---		23(12)
<i>Chamaesporites laevigatus</i> Schulz	---	---		3(3)
<i>Krizeleporia speciosa</i> Mäler	---	---		17(9)

ammonoid-bearing sequences of the Alps and North America and hence with the traditional stratigraphic scales of zones and stages. Megafloral evidence has been used in northwest Europe to distinguish the *Lepidopteris* and *Thaumatopteris* Zones of the late Triassic-early Jurassic. Orbell (1973) studied the palynology of this transition in England, Sweden and Greenland, and divided his assemblages between two zones which are recognisable in all three areas. These are the *Rhaetipollis* Zone and the *Heliosporites* Zone; he considered their boundary to approximate both to the megafloral *Lepidopteris* Zone-*Thaumatopteris* Zone boundary, and to the Triassic-Jurassic boundary. Comparison with Orbell's zones would suggest that preparations DS155 and W004 could belong to the *Rhaetipollis* Zone and the remaining preparations to the *Heliosporites* Zone; however, there are many differences of detail (e.g. the total absence in Kong

Table 4. Distribution of selected palynomorph taxa in seven assemblages from the Svenskøya Formation of Kong Karls Land, with the approximate known ranges of those taxa. (First numbers = total grains observed; second numbers = average number of grains per slide.) Sample and preparation details as follows:

Mohnhøgda, Svenskøya (Mohnhøgda Member) (see Fig. 5)

Sample H 3032: locality H 1746, 174 m above s.l. Light grey, laminated, micaceous siltstone. Preparation no. DS 86; 15 min. HNO₃, short centrifuging. Palynological facies: 30% triletes, 17% monocolpates, 36% bisaccates, 3% microplankton, 14% miscellaneous pollen, etc.

Sample H 3072: locality H 1749, 2 m above s.l. Grey siltstone, weathering yellow. Preparation no. W 004: 20 min HNO₃, mineral separation, short centrifuging. Palynological facies: 60% triletes, 2% monocolpates, 6% bisaccates, 5% microplankton, 27% miscellaneous pollen etc.

Kükenthalfjellet, Svenskøya (Mohnhøgda Member) (see Fig. 7)

Sample C 4073: locality C 1371, 70 m above s.l. Brown-grey crumbly silty clay. Preparation no. DS 20: 10 min HNO₃, mineral separation, short centrifuging. Palynological facies: 27% triletes, 14% monocolpates, 22% bisaccates, 7% microplankton, 30% miscellaneous pollen etc.

Sample C 4052: locality C 1371, 15 m above s.l. Unconsolidated fine sand with carbonaceous fragments. Preparation no. DS 3A: 10 min HNO₃, mineral separation, short centrifuging. Palynological facies: 27% triletes, 14% monocolpates, 22% bisaccates, 7% microplankton, 30% miscellaneous pollen, etc.

Hårfagrehaugen, Kongsøya (Sjögrenfjellet Member) (see Fig. 14)

Sample C 4412: locality C 1380, 160 m above s.l. Grey micaceous laminated siltstone. Preparation no. DS 154: 15 min HNO₃, mineral separation, short centrifuging. Palynological facies: 29% triletes, 11% monocolpates, 33% bisaccates, 3% *Botryococcus*, 24% miscellaneous pollen, etc.

Sample C 4399: locality C 1380, 67 m above s.l. Grey laminated silty fine sandstone. Preparation no. DS 147: 10 min HNO₃, mineral separation, short centrifuging. Palynological facies: 19% triletes, 12% monocolpates, 22% bisaccates, 47% miscellaneous pollen etc.

Sample C 4395: locality C 1380, 30 m above s.l. Light-grey laminated siltstone with carbonaceous fragments. Preparation no. DS 155: 15 min HNO₃, mineral separation, short centrifuging. Palynological facies: 53% triletes, 5% monoletes, 10% monocolpates 3% bisaccates, 29% miscellaneous pollen, etc.

Karls Land of the key species *Rhaetipollis germanicus* and *Rhaetogonyaulax rhaetica*) and it would be unwise to suggest a position for the Triassic–Jurassic boundary on this basis alone, particularly as the English sequence on which Orbell's zones are based is a transitional one characterised by rapidly changing conditions from terrestrial 'Keuper' facies to marine 'Liassic' facies. The same drawback applies to other studies of Germanic 'Rhaeto-liassic' sequences, and it is notable that the order of appearance of the various palynomorphs regarded as markers for this interval is different from study to study.

A more suitable sequence for comparison is the Rhaetian Stage of the Kendelbachgraben in Austria (Morbey, 1975), which, besides its relatively stable facies, has the advantage of being the only section where the base of the Rhaetian stage can be said to have been defined. However, the section is not suitable as a boundary stratotype for the base of the Rhaetian Stage as there is a sharp facies change at the base below which palynological assemblages have not been recovered. Morbey subdivides the section from the base of the Rhaetian Stage to the appearance of the first megafauna of Jurassic aspect into four zones and six subzones, based on concurrent ranges of selected taxa in 65 productive samples. The occurrence together of the taxa found in preparation W004 is found as low as Morbey's RG subzone, the base of which is thought to approximate to the base of the Rhaetian Stage in the Kendelbachgraben. Taxa additionally found in DS155 do not occur before the LR Zone, the top of which is located within the Kössen beds in the Kendelbachgraben. (The basal part of the overlying Salzburg beds is the only part of the section containing ammonoids, and is the type horizon for the *Choristoceras marshi* Zone of Tozer, 1967.)

The palynomorphs which characterise Morbey's higher zones are largely lacking in Kong Karls Land and his zonal scheme cannot readily accommodate the higher assemblages. However, the occurrence in them of taxa not known elsewhere from strata older than earliest Jurassic strongly suggests that they are Jurassic and hence outside the scope of Morbey's scheme. The age of the youngest productive samples from the Svenskøya Formation (DS20, DS86 and DS147) is difficult to establish precisely, but is probably not younger than Sinemurian on the available evidence; it is certainly early Jurassic, to judge by the absence of any recognisable mid Jurassic markers. Thus the Triassic–Jurassic boundary is located within the Svenskøya Formation of both Kongsøya and Svenskøya; the Svenskøya Formation comprises beds of Rhaetian and early Jurassic, probably Hettangian and Sinemurian, age. Comparison with Hopen (Smith, Harland & Hughes, 1975) suggests that the base of the Kong Karls Land succession overlaps in time with the top of the Hopen succession. Assemblages including the taxa found in preparations DS155 and W004 occur in the uppermost Iversenfjellet Formation, the Flatsalen Formation and the Lynggefjellet Formation and were concluded to be Rhaetian, possibly to very earliest Jurassic, in age. The lower part of the exposed Hopen succession undoubtedly includes the base of the Rhaetian Stage as understood by Morbey (1975) in Austria.

7. Igneous rocks

7.a. Distribution

A large part of the outcrop area of the islands is igneous; these rocks provide the only resistant material. From the three areas where sedimentary rocks are seen to separate the lava flows it is possible to establish at least six volcanic episodes. Because of uncertainty of correlation between the three areas and the much greater areas where only igneous rocks are seen, the number of eruptions could be greater.

The age range of these lavas is from about Kimmeridgian to probably Barremian or later. The peak intrusive episode in Spitsbergen is between early Volgian and Valanginian and some of the middle flows could be of this age.

7.b. Petrography

The igneous rocks were first described in detail by Hamberg (1899). We ourselves have not yet investigated the extensive collection made in 1969 in any such detail, but we summarise our initial findings below.

All samples of lava, pumice, etc., appear very similar in thin section – fine grained with no phenocrysts. Plagioclase feldspar laths (of labradorite composition, showing Carlsbad and albite twins) are the major constituent in each case. Olivine is rare or absent, although green, red and brown replacement materials, abundant in some samples, may be pseudomorphs after olivine of the iddingsite, bowlingsite, chlorophaeite family. Clinopyroxenes are the dominant ferromagnesian mineral, augite being the most common although small amounts of pigeonite occur. In the finer grained samples chlorite is replacing the pyroxenes.

Calcite is found interstitially in small amounts, but is more commonly found as a filling in vesicles in pumice. Glass is present in the matrix of several samples and is also found as 1–5 mm beads in pumice. Opaque minerals are present in moderate amounts in every sample.

The classification of these rocks as tholeiitic basalts is consistent with the observations listed above.

7.c. Conclusion

The petrographic uniformity and similarity of occurrence throughout the area suggests a single sequence of magmatism ranging through latest Jurassic well into early Cretaceous time. We have no positive limit to the age of the latest flows but by analogy with Franz Josef Land it would seem unlikely that they post-date Aptian time.

8. Structure

A generally flat-lying structure is evident from the tabular hills capped by lava and the near horizontal bands of lava seen in some of the cliff sections. The overall structure is anticlinal or dome-like with Kimmeridgian rocks at sea level in easternmost Kongsøya (and probably higher lavas exposed at sea level in Abeløya farther east), while to the west of Kongsøya and in northern Svenskøya

Rhaetian rocks extend well above sea level. In the only three areas where cliff sections are clear in the hillsides, minor flexures are evident with dips generally less than 5° but occasionally reaching 10° and with approximately N-S axes.

The sandy raised beach that extends N-S across central western Kongsøya lacks igneous exposures; the area is interpreted as largely overlain by the loose sands of the Svenskøya Formation. However, to the east of the area, ridges of clay with belemnites (see Fig. 9) probably *in situ* appear with a N-S strike and a probable easterly dip, showing that the Kongsøya Formation has already reached sea level there. The main central areas of igneous rock, immediately to the east of these clays and all the way to Johnsenberget, are probably lavas of the Kongsøya Formation gently folded with synclinal-anticlinal-synclinal structure. The westerly syncline of these structures, if extended southwards, would account for the great concentration of igneous islands along this N-S axis. There are few islands to east and west, so the syncline is the main structure separating the higher anticlines to the west from the lower ones to the east. Even within the anticlinal Johnsenberget there is a minor syncline.

The structure referred to above is evident from the later rocks and therefore reflects post-Barremian and probably mid-Cenozoic movements corresponding to the West Spitsbergen Orogeny.

Within the succession, however, there is evidence of Mesozoic uplift in western Kongsøya that could also be on a N-S axis, but this is uncertain. It was this structure that was interpreted by Nathorst as a horst (see Fig. 2). The movement that we interpret as cutting out members within the Kongsøya Formation could well correspond to the established Agardhfjellet-Rurikfjellet unconformity in Spitsbergen (Table 5), with disturbances corresponding to the main dolerite intrusive phase there. However, there are more igneous and diastrophic episodes in Kong Karls Land, as seen in the movement between the Passet Clay and Retziusfjellet Shale Members (?pre-Callovian) and between the Tordenskjoldberget Limestone and Hårfagrehaugen Members (post-Valanginian).

From the lack of a late Cretaceous record in Svalbard and generally in the Arctic, and from the absence of Tertiary strata east of Spitsbergen, the later sequence of movements is uncertain. However, a sequence of instability through later Mesozoic and probably earlier Cenozoic time is clear. Nevertheless it never did more than flexure a platform sequence. It is remarkable what a small thickness of strata is exposed through so large an area, if Franz Josef Land be also considered, and thus stratigraphic evidence serves to confirm the Soviet view that these areas are part of an ancient craton. The history recorded on land, at least, is of very slow subsidence with minor disturbances.

9. Conclusions

The three formations - Kong Karls Land, Kongsøya, and Svenskøya (with their members) - defined here represent a sequence from continental, through marine, and back to continental facies. They are analogous lithologically to the three formations of Spitsbergen: Helvetiafjellet, Janusfjellet, and De Geerdalen, respectively (Parker, 1967; Smith, 1975). The two groups that contain these and other formations in Spitsbergen (revised in Harland *et al.* 1974) are extended to

Table 5. Summary of conclusions on the stratigraphic sequence in Svalbard. The sources for other areas are: Spitsbergen (Parker, 1967, modified Harland *et al.* 1974); Wilhelmøya (Smith, 1975); Hopen (Smith, Harland & Hughes, 1975).

TIME	SVALBARD									
	Spitsbergen	Wilhelmøya	Hopen	Kong Karls Land	Kongsøya (west)	Kongsøya (east)	Adventdalen	Kapp Toscana		
Ma	Group	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)	Formation (n° of members)
100	ALBIAN	Caroline (5) -fjellet	Lyngfjellet Sandstone 60m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
110	APTIAN	Helvetia (2) -fjellet	Fråttalen Shale 55m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
120	BARREMIAN	Rurikfjellet Member 35m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
130	HAUTERIVIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
140	VALANGINIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
150	BERRASIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
160	RIAZANIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
170	VOLGIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
180	KIMMERIDGIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
190	OXFORDIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
200	CALLOVIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		
210	BATHONIAN	Agardh -fjellet Member 176m	Uvenet -fjellet 190m	Kong Karls Land	Kongsøya	Svenskøya	Adventdalen	Kapp Toscana		

KEY

- igneous clasts
- ▼ Extrusive igneous
- ▲ Intrusive igneous
- ⊙ Ammonites
- ∩ Bivalves
- ♀ Plants
- ⊕ Foraminifera
- ⊙ Palynomorphs
- Fm Formation

Thicknesses are given for type sections for several of these the top or base is not seen.

Fossils are shown only where they provide evidence for probable or certain age determination.

include those in Kong Karls Land, and so are applicable throughout Svalbard. Of these the Kapp Toscana Group also extends to Hopen (Smith *et al.* 1975).

Much biostratigraphic work on our collections remains to be done but some provisional determinations are listed (Tables 3 and 4). Combining the new data with results from Nathorst's expedition (Table 1) we set out a tentative correlation scheme in Table 5.

The dominantly continental rocks of the Svenskøya Formation are now established as ranging from Rhaetian possibly through Sinemurian ages. The sandy facies are loose and porous, suggesting no great depth of burial, and this is confirmed by the state of preservation of the palynomorphs.

The succeeding Kongsøya Formation is of variable marine shelf facies and was already known to range in age from Callovian to Valanginian. This has been confirmed by rich faunas now being described. Volcanic activity possibly began in mid-Kimmeridgian time or earlier and was well established in early Cretaceous time. At least four volcanic episodes are known from this formation.

The continental Kong Karls Formation, including the extensive lavas, occurs in three main hill areas, capping each. The lavas of Abeløya could belong to this or the underlying formation. At this stage we suppose its age to be approximately Barremian. Derived earlier palynomorphs make a quick assessment difficult.

Diastrophism was associated with the igneous activity and, in particular, uplift took place in western Kongsøya along a N-S axis more than once between Callovian and Valanginian time. Part of this diastrophism and vulcanism was probably correlative with the unconformity and intrusive phase between Kimmeridgian and Valanginian time in Spitsbergen (Parker, 1966).

Kong Karls Land lies between Spitsbergen and Franz Josef Land (distant respectively 50 and 150 km). There is a remarkably similar sequence in Franz Josef Land (Dibner, 1957, 1961, 1962*a*; Dibner & Shulgina, 1960) with three formations, namely:

- Early Cretaceous volcanic and continental strata
- Late and Middle Jurassic marine strata
- Early Jurassic and Late Triassic continental strata

Similar Mesozoic rocks are known off Novaya Zemlya (e.g. Dibner, 1962*b*), and dredged from the floor of the Barents Sea (e.g. Edwards, 1975). Comparisons throughout the Barents Shelf, as well as with the similar sequence in the Queen Elizabeth Islands of Canada (e.g. Harland, 1975, p. 246), are the subject of further studies.

The magmatism extending from Franz Josef Land through to the Canadian Arctic reflects a time of mantle heating which preceded the postulated opening of the Canada Basin (Alpha Phase). This was earlier than that of the Eurasia Basin (Gakkel Phase), which was sited more immediately north of Svalbard (Harland, 1975).

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