An outline pre-Carboniferous stratigraphy of central western Spitsbergen

By W. B. Harland, W. T. Horsfield, G. M. Manby, and A. P. Morris

Contents

Abstract

The stratigraphy of Prins Karls Forland and Oscar II Land is outlined by defining a sequence in each area with 19 formations in 5 groups and 15 formations in 4 groups respectively. Many of the units proposed and their names come from a long history of research but this paper for the first time relates these rocks into two nearly continuous successions that can be correlated by the common tillite formations (up to 4 km thick). Prins Karls Forland has 6.7 km above it and Oscar II Land has 6.9 km below it and an estimate of the total thickness is 18 to 20 km.

The only reliable fauna for dating is of Wenlock or Ludlow age in one of the upper formations. This sequence of flyschoid conglomerates and volcanic facies is distinct and is named the Holtedahl Geosyncline.

I. Introduction

This paper deals with the pre-Carboniferous stratigraphy of western Spitsbergen between Kongsfjorden and Isfjorden – that is Oscar II Land and Prins Karls Forland. These areas are two of the most accessible of all the pre-Carboniferous terrains of Svalbard and yet have recently been among the least understood.

The earliest substantial stratigraphic conclusions for Oscar II Land were drawn by Holtedahl (1913) and Orvin (1934), and later by Weiss (1953 and 1958) and Winsnes (1965), in the form of disconnected sequences for the north and south of the area. Our work began in 1958 with a reconnaissance survey by C. B. Wilson (who died in 1959). WBH visited St. Jonsfjorden and Engelskbukta briefly in 1959 in continuation of this work, and later A. Challinor worked on the Tertiary Fold Belt to the east, dealing only incidentally with the older rocks. Geophysical investigations were carried out by K. Howells and P. I. Maton between 1962 and 1968, but it was not until 1967 that geological work was resumed seriously – by WTH from 1967 to 1969, with visits by WBH in 1968, 1971 and later.

After many early visits Prins Karls Forland was first surveyed by the Scottish Spitsbergen Expedition (Bruce 1910), and for long the only substantial account was that of Tyrrell (1924). Then, at the suggestion of one of us, D. J. Atkinson and R. A. McDonald in a tour de force reconnoitred the whole island in 1949, 1951 and 1952 (*Polar Record 6* (44) 527 and *7* (49) 317). Thus a general idea of structure and stratigraphy was available but no single stratigraphic scheme emerged. This was the reason for our visits between 1968 and 1975, with two of us (GMM and APM) engaged in detailed work on Prins Karls Forland from 1973 to 1975; all these visits were organized by Cambridge Spitsbergen Expeditions whose support is acknowledged here by references to accounts in the *Polar Record* (1958, *9* (62) 464–465; 1959, *10* (64) 40–44; 1967, *14* (88) 43–45; 1968, *14* (91) 492–494; 1969, *15* (96) 331–332; 1971, *16* (100) 63–64; 1972, *16* (103) 579–580; 1973, *17* (106) 43; 1974, *17* (109) 383–384).

Our work is expected later to yield separate, more detailed, accounts of the geology of Prins Karls Forland and Oscar II Land. This present paper gathers together the principal stratigraphic conclusions to date. Modifications are likely as work proceeds but we believe the main outlines will stand, as they have for some time been tested.

Both areas have suffered both mid-Palaeozoic and mid-Cenozoic deformation and metamorphism. The rocks were overthrust in opposite senses (Atkinson 1960, Harland and Horsfield 1974), and metamorphism produced rocks of biotite grade together with some mineralisation (Siggerud 1962, Flood 1969). This leads to a complex mutual dependence of stratigraphic and structural interpretation. Therefore, a fuller understanding of the stratigraphy will depend on a more detailed treatment of the structural units within which the many sequences are found. Until such time thicknesses given are provisional.

Both sides of Forlandsundet being familiar in some degree to all of us we have decided to set up two independent systems of nomenclature, since there is no

obvious correlation of many of the rocks. In the next two sections, therefore, we treat each area independently before attempting a synthesis in the last chapter.

The theme of this Symposium includes Devonian as well as earlier history. We have no knowledge of Devonian rocks occurring in our area (HEINTZ and SIGGERUD 1965). The youngest pre-Carboniferous rocks may be late Silurian. It once seemed that the first "Hecla Hoek" fossils in Oscar II Land had been discovered by the 1948 Birmingham expedition, but these proved to be of Carboniferous age (BAKER, FORBES and HOLLAND 1952). Similarly, LEE (1908) described fossils collected by BRUCE from Prins Karls Forland of Permian age; these are now presumed to have originated from glacial erratics. Tectonic slices of younger rocks are liable to be confused with the older rocks along the whole length of the area.

For the present we avoid referring to the rocks we are dealing with as Hecla Hoek because of the possibility that this sequence was formed at a great distance and in a different environment from the type Hecla Hoek rocks of Ny Friesland. For a general name we refer to the Western Complex or Sequence and the island part of it as the Forland Complex or Sequence (HARLAND et al. 1974). We describe the strata from the top downwards and begin with the Forland Complex where the preservation of the younger rocks appears to be more complete.

II. Prins Karls Forland

Although we have reconnoitred the whole island in outline, the area accessible from Scotiadalen has been surveyed in detail by two of us (GMM and APM) on a scale of 1:10,000. The stratigraphy found to apply throughout the island is named and described from the centre of the island where this detailed work has been done and where the relationship between the rocks north and south of Scotiadalen, long in doubt, has been established.

Our scheme is set out in Table 1 and the individual units are defined below, in sequence from top down. The nomenclature we have chosen follows so far as possible that of TYRRELL and ATKINSON, whose work we thereby acknowledge. This granting of historical priority is not only correct but has the advantage of yielding names that are shorter than we should now be obliged to adopt. The names we in turn have needed to introduce have been selected both for their topographical position and for their brevity (in so far as this is not seriously misleading).

As ATKINSON showed (1956 and 1960), the island consists of a number of thrust sheets each with a distinctive stratigraphy so that neither stratigraphy nor structure will be fully elucidated in isolation. It is often difficult to discover the way up for parts of the sequence and our interpretation of some units differs in this respect from that of Atkinson. In addition to sedimentary structures the clast content of the Sutorfjella Conglomerate Member has been critical for our interpretation.

One difficulty, that we hope has now been overcome, arises from the repetition of distinctive facies that were at first treated as one unit. For example,

Table 1.

Sequence of older strata in Prins Karls Forland

Group	Formation	Dominant lithology	Thickness in metres
Grampian	Geddesflya	slaty turbidites	1800
[3.6 km]	Fugelhuk	massive quartzites & slates	400
	Barents	slaty turbidites	500
	Conqueror	quartzites	850
	Utnes	grey slate & quartzite	80
Scotia	Roysha	grey siltstones & black slates	400
[1 km]	Kaggen	green & grey slates	300
	Baklia	grey siltstones, slates & limestones	200–300
Peachflya	Knivodden	chloritoid phyllites	400
[1.3 km]	Hornnes	phyllites & sandstones	350
	Alasdairhornet	volcanics	190
	Fisherlaguna	phyllites	350
Geikie	Rossbukta	sandstones	300
[0.77 km]	Gordon	limestone	470
Ferrier	Neukpiggen	flyschoid mixtites	300
[0.73 km]	Peterbukta	greywackes	160
	Hardiefjellet	flyschoid mixtites	120
	Isachsen	mixtites, schists & volcanics	150+
[0.2 km]	Pinkie	metavolcanites	200+

banded turbidite slates occur throughout the Grampian Group and characterise both the Geddesflya and Barents Formations. Hard black mudstones with white veins similarly occur throughout the Scotia Group and form an important part of both the Roysha and Baklia Formations. Green, grey and purple slates occur within both the Kaggen and the Knivodden Formations.

The Forland Complex shows a complex post-depositional history. The rocks have been subjected to diagenetic changes, followed by polyphase deformation primarily of Palaeozoic age but reactivated during Cenozoic time. Early folding was accompanied by metamorphism up to biotite grade; tightening of folds produced a slaty cleavage which was followed by thrusting and nappe emplacement in a south-westerly direction and later by more open refolding. The extent of deformation attributable to the Cenozoic West Spitsbergen Orogeny is difficult to disentangle, as trends are at a low angle to those of mid-Palaeozoic age (roughly NNW-SSE). However, later graben deformation can more easily be identified with some E-W fold axes.

1. GRAMPIAN GROUP

Rocks assigned to this group are typically flyschoid in character. This obvious stratigraphic grouping was first suggested by Tyrrell (1924, Major et al. 1956) for his Northern Grampian Series. These rocks extend further north

than the Grampianfjella. The name Grampian was not used stratigraphically by ATKINSON (1956, 1960) and he described corresponding rocks as the Fugelhuk, Barents, Conqueror, Pinkie and Larsen Groups. We now define the Grampian Group as comprising the Geddesflya, Fugelhuk, Barents, Conqueror and Utnes Formations.

A. *Geddesflya Formation*

This unit comprises about 1800 m of dominantly quartzite lithology. It is the uppermost unit of the Grampian Group. It is found exposed in the type area of Geddesflya and from the tops of Tvihyriningen south to Kaldneset. It also occurs in the Grampianfjella northwards from Margaretfjellet. Similar facies have been noted west of Richardlaguna and to the north. In the type area the highest members seen consist of an alternation of quartzites with dolomite-banded siltstones, breccias and thin siltstones and slates. Lower down thinly bedded quartzites occur which give way to slate pebble breccias interbedded with banded siltstones. Beneath these are sequences dominated either by thinly bedded quartzites or by banded siltstones.

B. *Fugelhuk Formation*

The Fugelhuk Formation here refers to a sequence of quartzites, somewhat more restricted than those defined by ATKINSON (1956, 1960) who used this name for one of his groups comprising a thick sequence of massive bedded quartzites in Fugelhukfjellet at the northern end of the island. In central Prins Karls Forland they occur below the Geddesflya Formation, exposed in a series of folds from Tvihyrningen to Skarvnes. They also outcrop in the vicinity of Margaretfjellet, along the eastern slopes of the Grampianfjella to Djevletumen-Klöne-Neglene. This formation as defined here is most readily observed at Skarvnes and around the southern end of Hyrneknatten. It is dominated by thickly bedded quartzites often in units of more than one metre, interbedded with banded siltstones. The facies suggest a mobile environment. In the lower slopes of Tvihyrningen and north across Geddesflya they pass down into black – dark grey siliceous slates of the upper Barents Formation. Around Tvihyrningen this formation is approximately 400 m thick. The strata thicken northwards and reach a thickness of approximately 1000 m in Fugelhukfjellet (ATKINSON 1956, 1960).

C. *Barents Formation*

The Barents Formation, here as with ATKINSON's (1956) Barents Group, refers to a sequence dominated by siltstones which lies between the Fugelhuk and Conqueror Formations. In the Grampianfjella the rocks are uniform. However, to the west of Scotiafjellet the constituent facies are different. The Barents Formation lies beneath Fugelhuk strata and is exposed in the centre of the island, west of Scotiafjellet, on the lower slopes of Tvihyrningen north across Geddesflya to Normandalen, in a narrow band toward Ossianbekken, and widening out in an arc to the west coast. In this area the top of the formation is

marked by the appearance of black–dark grey, often siliceous, slates which lower down include more silty bands. These pass down into sandstones with frequent slate pebbly bands. Below are thin quartzites and black slate laminae. These overlie a characteristic grey metallic slate with 2–3 mm pyrite "blebs". Below this is a sequence of banded siltstones which exhibits many minor folds and whose true thickness it is not easy to estimate, though it does not appear to exceed 100 m. The lowest part of this formation is marked by flaggy fine-grained sandstones which are frequently calcareous. The transition to the underlying Conqueror Formation is marked by a sequence of green pelitic quartzites containing a black limestone and impersistent pebbly quartzites. West of Scotiafjellet this sequence is poorly developed and does not contain the limestone. North of Conquerorfjellet it is much thicker and appears to be at its maximum development in the area west of Richardlaguna. Thickness is estimated at 500 m. Part of ATKINSON's Larsen Group is a Klippe of Barents slates on Alfred Larsentoppen.

Sutorfjella Conglomerate Member

HOEL (1914) mentioned these conglomerates and commented on their similarity to the Red Bay Devonian conglomerate of north Spitsbergen. CRAIG (1916) similarly likened them to the lower Old Red Sandstone of Scotland. TYRRELL (1924), reviewing these observations, compared them rather with the Tertiary conglomerates of Thomsonfjella. ATKINSON (1956, 1960) concluded that these rocks are interbedded with strata of the Barents Formation and so belong to it. KRASIL'SHCHIKOV (personal communication and 1973) expressed uncertainty about their age but favoured TYRRELL's view.

This conglomerate dips 60°SW and can be traced across the two Sutors. It strikes parallel to the shore at 165° for just over a kilometre northwards before disappearing out to sea. It is underlain by green pelitic bands interbedded with dolomitic quartzites very similar to those at the top of the Conqueror Formation.

The conglomerate itself contains clasts of a number of underlying formations, the dominant rock type being a brown-weathering pale grey quartzite, frequently cut by quartz veins which are not related to the jointing of the conglomerate itself. In a number of horizons clasts are of a green cleaved siltstone identical to that of the matrix. Subordinate clasts include quartzites not unlike those seen in the lower Barents Formation itself and the Grampian Group as a whole. A less common clast is a black mudstone with quartz dolomite veining of the type characteristic of two of the Scotia Formations, and this gives evidence for the order of events in the Forland Complex. The conglomerate has a slaty cleavage parallel to that of the adjacent slate belonging to the Grampian Group. The clasts themselves are also cleaved, also parallel to that of the rock as a whole. It is inconceivable, therefore, that this Member could be of any other than Barents age.

The boulders, especially the quartzites, are often well-rounded and have red oxidised skins suggesting subaerial erosion and transport. Some have a double skin in which the oxidised layer is superimposed by a green reduced layer and

this, together with the generally green matrix, confirms that the deposition environment was aqueous and reducing. The boulders show that the typical white quartz veins were formed before erosion so that some stresses possibly associated with uplift had already operated. This is consistent with a major tectonic fault scarp situation.

D. *Conqueror Formation*

This formation unites a distinctive sequence of quartzites and slates. The name is adopted from ATKINSON (1956, 1960). Although well exposed in the north-facing slopes of Conquerorfjellet, it is more fully developed further north along the strike. The passage from Barents to Conqueror Formations is taken as coinciding with the green pelite and quartzite sequence, which is well developed in Petuniadalen up onto the Ytterryggen system and can be traced as far north as the Sutorfjella. Below this quartzite follows a sequence of slates, dark grey when fresh, alternating with dark–light grey weathering quartzite. Below these the quartzites become more brown in colour when weathered and are lighter grey when fresh. A number of pebbly calcareous bands occur and in particular a 2 m conglomerate band. The latter is traceable for a distance from Normandalen, where it is thrust out north through Conquerorfjellet–Ytterryggen–Margaretfjellet and further north. Below this is a thick slate with thin quartzitic bands, towards the base marking the top of the Utnes Formation. The Conqueror Formation in the vicinity of the type area is about 500 m thick. Further from Ytterryggen, towards the northern end of Dyerlaguna, it thickens to about 850 m.

E. *Utnes Formation*

This formation represents the transition from the Roysha Formation of the Scotia Group to the Conqueror Formation of the Grampian Group. This is isolated here for the first time and although exposed on the western slopes of Conquerorfjellet is seen at Utnes. The passage down from the Conqueror Formation is marked by a thick grey slate with thin quartzite bands. Lower down the quartzites become more pyritic and the slate blacker with occasional calcareous bands. The passage downwards into the Roysha Formation is marked by the appearance of a soft black carbonaceous slate. This formation is no more than 80 m thick.

2. SCOTIA GROUP

As the name suggests this group occupies the region of Scotiafjellet–Scotiadalen. The rocks also outcrop in the strip north of the Thomsonfjella, on the eastern slopes of the Grampianfjella toward the region of Richardlaguna where they widen out considerably. TYRRELL (1924 and MAJOR et al. 1956) first isolated this group and referred to it as the Mt Scotia Series. It occurs both around Scotiafjellet and in Scotiadalen and we use ATKINSON's (1956, 1960) name Scotia Group. Previous workers have not applied any systematic scheme to divide it. It is redefined here as constituted by the Roysha, Kaggen and Baklia Formations.

A. *Roysha Formation*

The choice of this name for the upper part of the Scotia Group is arbitrary and this formation is best developed slightly to the north of the western slopes of Conquerorfjellet. It lies conformably below the Utnes Formation of the Grampian Group, the uppermost unit being a very soft black carbonaceous slate. The major part of the formation consists of an alternation of sequences dominated either by grey dolomitic siltstones interbedded with thin black slates or by black carbonaceous slates with occasional grey siltstones. The true thickness of this sequence is difficult to determine as tight-folding thickens to an unknown degree. A conservative estimate would not exceed 400 m.

B. *Kaggen Formation*

This formation lies below the Roysha Formation and consists of tight isoclinally folded slate-phyllonites. They outcrop in a widening band south of Scotiafjellet, over much of the lower slopes of the east Thomsonfjella, Krokodillen and Buchananryggen. They continue northwards, widening out west of Richardlaguna. The extent of folding and sliding hinders the elucidation of the complete sequence. The stratigraphy of the formation has been compiled from observations at a number of localities, none of which exhibits the full complement of rocks. Correlation between the various localities is purely lithological, based on distinctive green and purple striped slates, grey slates with quartzites, and chloritoid bearing slates. The name Kaggen is chosen from the ridge where one of the thickest sequences is exposed. Briefly, the formation consists of dark bottle-green slates and various shades of green–grey slates, often with a striped effect. The upper part of the sequence is best exposed on the ridges between Alanfjella and Scotiafjellet, from Normandalen across to Omondryggen; southwards are exposed light and dark grey variegated slates with abundant chloritoid in the darker layers. Below these are grey slates followed by a light green slate containing many large chloritoid porphyroblasts easily seen in hand specimens. Below these are a series of green and purple slates which outcrop particularly well in the south-eastern foothills of the Thomsonfjella–Scotiadalen area. Below these are grey–green to dark grey slates with an increasing incidence of quartzite bands towards the base. This formation is estimated to be 300 m thick.

C. *Baklia Formation*

The lower part of the Scotia Group is exposed in the region of the lake just east of Scotiadalen, called Baklia. The passage from black slates with quartzite to a black carbonaceous slate sequence marks the transition from the Kaggen into the Baklia Formation. The upper part of this formation is dominated by black slates. However, within these slates is a very variable sequence of grey-orange dolomite limestones. These limestones are characterised by the presence of intraformational breccias which appear to show a decrease in clast size eastwards. The lower part of the formation exhibits an alternation of grey, frequently cherty, dolomitic siltstones with black slates. The bottom of the ormation is taken as the level of appearance of a quartzite sequence which is

frequently conglomeratic with green and black slaty laminae. Below this lies a sequence of brown-weathering grey slates and then a black slate with dolomitic cherty limestones. Below this the Knivodden Formation proper begins (part of the Peachflya Group). The whole of this sequence is conformable and is probably not more than 300 m thick.

3. PEACHFLYA GROUP

This group lies directly below the Scotia Group and is a subdivision of what TYRRELL named the Ferrier Peak series, more nearly ATKINSON's Kerr Group. Kerr is not appropriate because rocks of the Scotia and Barents groups outcrop in the vicinity of Kerrlaguna, whereas most of Peachflya (the strandflat of the west coast) is occupied by the lithologies described below. Each of the four formations is distinct: Knivodden (incompetent chloritoid phyllites); Hornnes (siliceous-phyllite, sandstone-quartzite, limestone alternation); Alasdairhornet (volcanic suite); Fisherlaguna (blue phyllites).

A. *Knivodden Formation*

Phyllites constitute the bulk of the Knivodden Formation which forms a wide band in the west of Peachflya. They are generally incompetent and structureless, although occasionally some bedding lamination and five broad compositional divisions can be distinguished. The top of the formation is marked by a dark grey to black siliceous phyllite, often with pyrite growing along the cleavage planes. Above this the rocks become much less siliceous and consist almost entirely of altered clay minerals with chloritoid laths growing in the matrix. Towards the base thin arenaceous layers occur, and the lowest phyllite unit is generally coarser than those above it.

Initially, these rocks were all finely laminated argillites but metamorphism and deformation have destroyed most of the sedimentary characteristics, imprinting a slaty cleavage produced by pressure solution and new mineral growth. Clay mineral crystallinity measurements indicate temperatures of 300°C during metamorphism.

B. *Hornnes Formation*

Lying below these phyllites is a 350 m sequence of sandstone-quartzites, limestones and phyllites which constitute the Hornnes Formation, named from the locality of its best developed coastal section. Essentially, this formation is made up of dark siliceous phyllites with thin (10 cm) layers and lenses of sandstone, containing a number of more massive sandstone-quartzite bands up to 4 m thick. In total there are about eight of these bands. In addition, there are three limestone horizons. The uppermost is very dark, almost black, and crystalline with thin convolute layers of dolomitic limestone. This member varies in thickness from 10 m to 40 m. The dark colour of the limestone is produced by a high carbon content and this, together with the fine banded nature of the dolomite, suggests a possible algal origin for the rock, although any organic structures have been destroyed by deformation. Near the base is a

2 m limestone layer, laminated, crystalline and dolomitic. The base itself is marked by a fairly substantial limestone which is usually pale in colour and contains some silici-clastic material, but is mainly composed of crystalline calcite-dolomite laminae. A basic sill intrudes this rock wherever it is exposed. Again, the calcite-dolomite banded nature of parts of this member contain significant amounts of carbon as thin discontinuous partings which could be of organic origin.

C. *Alasdairhornet Formation*

At the top of the Alasdairhornet Formation (190 m) is a transition rock consisting of alternating layers of carbonate material and volcanogenic material. Most of this formation consists of banded and welded tuffs with some basic flows, while the base is a reworked sediment of volcanogenic and silici-clastic material. The name Alasdairhornet is taken from the ridge along which good exposures occur. Most of the banding appears to be primary, but the mineralogy has been greatly altered. Retrograde metamorphism (retrograde from primary igneous) has chloritised and sepentinised most of the rock leaving occasional relict pyroxenes. Relict amygdales filled with quartz, feldspar and calcite occur in a thin flow near the base of the formation.

D. *Fisherlaguna Formation*

The lowest formation (350 m) in the Peachflya Group is the Fisherlaguna Formation, consisting of incompetent phyllites which have a characteristic blue sheen on cleavage surfaces, and contain very thin sandstone lenses and occasional pressure solution quartz pods. The formation is generally poorly exposed because of its incompetent nature. It has been named after Fisherlaguna for convenience since it outcrops there, but nowhere in the area mapped is there a well exposed section.

4. GEIKIE GROUP

The Geikie Group consists of two formations: Rossbukta (quartzite and phyllite) and Gordon (limestone). The boundary between the two is transitional but distinguishable. The group outcrops with limited exposure to the east of the Peachflya Group. Thrusting between the overlying Peachflya, the Geikie, and the underlying Ferrier groups has greatly reduced the outcrop width of this group to the west of the southern Grampians. A more complete section is seen east of the mountains and on parts of the Forlandsletta, though the exposures on the Forland are poor and widely separated. The name Geikie is employed for this group since it includes the extensive limestone and sandstone formations (Geikie and Gordon Groups) that Atkinson (1960) thought to be older than the Ferrier Group. In the present study it has been found that these rocks form a stratigraphic sequence both with each other and with the Peachflya Group, but not with the Ferrier Group.

A. *Rossbukta Formation*

The younger, Rossbukta, Formation consists of 300 m of dark mainly siliceous phyllites becoming increasingly calcareous towards the base. The top

is marked by a change from the overlying blue phyllites to more cohesive brown phyllites. Within these phyllites are a number of impure, coarse, crystalline sandstones. Sorting is generally poorer near the top of the formation where the phyllites contain numerous thin lenses of sandstone and sand-sized particles with a matrix of assorted clay minerals and clay-silt-sized particles. A fairly well exposed section of these rocks occurs along part of the shore of Rossbukta and in patches inland, so this name was chosen for the formation. Where these rocks lie close to the thrust which separates them from the Ferrier Group they are partly mylonitised and massively quartz veined.

B. *Gordon Formation*

This formation is dominantly limestone and dolomite comprising 470 m but the base is thrust.

The topmost member is a calcareous phyllite with schistose partings in places. This is almost continuous with the lowest phyllite of the Rossbukta Formation, the difference being marked by the amount of calcareous material present. A 3–4 m layer of massive dolomite lies within these phyllites and the base is masked by a thin, laminated, crystalline limestone with carbonaceous laminae.

The base of the Gordon Formation is made up of a limestone series including thin silty beds, but consisting mainly of dolomite-limestone laminated horizons, massive dolomite bands, intraformational breccias and carbon-rich beds. In common with most of the limestones in the area, the possibility of organic origin arises with these rocks. In this case the evidence is somewhat stronger since the presence of pisolite-like structures indicates algal mat conditions during formation. Deformation and recrystallisation have, however, obliterated most of the finer structures.

5. FERRIER GROUP

This name was used by Tyrrell (1924 and Major et al. 1956) for the oldest of his three series, and again by Atkinson (1960). We redefine this group as comprising four formations: Neukpiggen, Peterbukta, Hardiefjellet and Isachsen. They are typically schistose mixtites, of biotite grade, that we interpret as distal flyschoid marine tillites. There are at least two tillite horizons – which is characteristic of the Varangian ice age. The rare occurrence of stromatolites and oncolites in the stones is also a Varangian characteristic. This group is a tectonic unit which is stratigraphically discontinuous at top and bottom. Neither the top of the upper mixtite nor the base of the lower is seen because the rocks occur as a nappe.

A. *Neukpiggen Formation*

Calcareous mixtites make up the highest formation (300 m) whose stratigraphic top is not seen. Calcareous mixtite schists contain fragments of dolomite and granite varying in size from 10 mm to 0.3–0.4 m across and 50–100 mm fragments of limestone. Near the top of the formation 1–4 m thick dolomite pebble beds occur in fairly rapid succession and for about 50 m below this there are occasional pebble beds of similar thickness. Towards the base of this upper

mixtite formation the schist contains numerous 50–500 mm bands of crystalline limestone and there is one apparently discontinuous dolomite-marble bed up to 3 m thick. This formation is also thrust to the north of Scotiadalen and was there included in ATKINSON's informal Larsen Group.

B. *Peterbukta Formation*

This formation (160 m) is fairly well sorted and strongly schistose metagreywacke, distinguished by lack of large clasts. We name it from the bay where it is best exposed.

C. *Hardiefjellet Formation*

The mainly mixtite formation (120 m) consists of siliceous schists with occasional calcareous partings and 50–500 mm sandstone bands. In addition to the mixtites there are some pebble beds about 1 m thick. In general this formation is very similar to the upper mixtites but here they are darker in colour, more siliceous and higher grade. In places the schistosity is very strong, with mica flakes up to 5 mm across and small biotite crystals growing throughout the matrix.

D. *Isachsen Formation*

This formation of dark green biotite schist, with brown interlayers and numerous pressure solution-quartz segregations, is the lowest of the group. Thin layers of mixtite material do occur, about 1 m thick, but most of the rocks are fine-grained, thinly laminated (10–20 mm at the most) and fairly well-sorted. ATKINSON informally used this name for a group with metavolcanics which we cannot match exactly because of different structural interpretation. Nevertheless beds about 1.2 m thick of volcanic, possibly tuffaceous strata are dispersed throughout the formation, of which 150 m are exposed and the base is not seen.

6. FORMATIONS NOT YET FITTED INTO SEQUENCE

A. *Pinkie Formation*

The Pinkie Formation, one of ATKINSON's informal groups, is confined to the area between Bouréefjellet and Monacofjellet. On the southeastern spur of Bouréefjellet this formation structurally overlies a sequence of Geddesflya type siltstones and thin quartzites. To the west the Pinkie Formation is in turn overthrust by a sequence of Conqueror quartzites. The formation is readily distinguished by metavolcanics and a high grade of metamorphism; it includes quartz-biotite schists, feldspathic-magnetite-biotite schists, felsites and a calcareous brecciated slate with much biotite. The latter, described by Atkinson, is not part of the Scotia Group, being dynamically or cataclastically deformed. This formation may represent a more easterly facies of the upper Grampian Group thrust westwards, or because of its high metamorphic grade it could represent rocks older than the Ferrier Group.

III. Oscar II Land

This is a much larger area and our work has been more extensive, with mapping on a scale of 1:50,000 except for the eastern part where maps and sections to a scale of 1:25,000 were done by A. CHALLINOR. Not only is there a greater variety of strata here than in Prins Karls Forland but also more structural complexity, so that we are less certain of the relationships between the sequences worked out in the different areas. Nevertheless, the succession has survived some testing and the tillite formations, first noted by us in 1958 and 1959 (HARLAND 1960), and fossiliferous formations discovered by us in 1968 and 1969, give some stratigraphic control. We define the formations in sequence from the top (see Table 2).

We use HOLTEDAHL's (1913) observations and attempt to name formations with his observations in mind. We follow ORVIN (1934) exactly for the sequence of older rocks in Brøggerhalvøya and this account adds little to his. We have related our units to the main stratigraphic groups noted by the Birmingham expeditions of 1951 and 1958 (BAKER, GARRETT and other private communications; WEISS 1953, 1958; and *Polar Record 5* (37/38) 340, *6* (44) 527–28, *9* (62) 463); and by BARBAROUX 1966 and CHALLINOR 1967.

Table 2.

Sequence of older strata in Oscar II Land

Group	Formation	Dominant lithology	Thickness in metres
Bullbreen	Holmesletfjella	flyschoid calc slates	500
[0.7 km]	(Bulltinden Mbr)	conglomerates & slumped beds	
	Motalafjella	limestone	200
[0.5 km]	Sarsøyra	limestones and slates	
Comfortlessbreen	Engelskbukta	mixtite	500
[2–4 km]	Annabreen	quartzite	2–4000
	Haaken	mixtite	
St. Jonsfjorden	Alkhorn	limestone	1000
[3.8 km]	Løvliebreen	quartzites & volcanics	1000
	Moefjellet	dolomites	800
	Trondheimfjella	various	1000
Kongsvegen	Nielsenfjellet (& Müllerneset)	schistose psammites	1500–2000
[3.1 km]	Steenfjellet	marbles	100
	Bogegga	schistose pelites	1500
Vestgötabreen Fm.			250

Our main debt, however, is to C. B. WILSON who in one season in 1958 covered a large part of the area and set up the first possible sequence for Oscar II Land. The intended joint visit in 1959 by CBW and WBH was prevented by his untimely death. His manuscript and reconnaissance map were used subsequently by our expeditions and we believe also by the Norsk Polarinstitutt to whom the work was sent.

1. BULLBREEN GROUP

This unit, outcropping at the western end of St. Jonsfjorden, contains fossils of Palaeozoic age. Although strongly folded and cleaved, it shows only slight metamorphism, so that the fossils and sedimentary structures are well preserved. The group is a combination of the Holmesletfjella and the Motalafjella Formations. The whole group appears as overthrust sheets in a small Klippe at Ankerfjella (north of St. Johnsfjorden) and more extensively around Bullbreen to the south.

A. *Holmesletfjella Formation*

The uppermost unit is of calcareous siltstones, argillites and polymict conglomerates. It was so named by HARLAND (1960), but misplaced as older than the Comfortlessbreen Group. The siltstones weather to a pale buff colour, often with grey bands, and contain various sedimentary structures including graded bedding, ripple marks and trace fossils. Massive conglomerates occur but are very variable in thickness and composition. Two separate conglomerate beds occur on Ankerfjella but on Motalafjella there is only a single unit, several hundred metres in thickness with thin limestone intercalations. The conglomerate is designated the Bulltinden Conglomerate Member for convenience in reference because of its fauna. However, within the Holmesletfjella Formation, to the SE of that mountain, is a thin tilloid associated with conglomerates. This was first thought (WBH) to be evidence of Varangian age and when a Palaeozoic age was established an Ordovician tillite was suspected, but on a recent visit (WBH and APM) this interpretation could not be established.

There is apparent stratigraphic conformity between the Holmesletfjella and Motalafjella Formations. In the latter are poorly preserved fossils, but better specimens have been recovered from limestone clasts in the Bulltinden conglomerates.

Bulltinden Conglomerate Member

Thick conglomerates form a substantial but variable part of the Holmesletfjella Formation. This conglomerate member has long been known. HOLTEDAHL referred to it (1913) and his description clearly related it to Bulltinden, so we chose this name. He found oolitic boulders of the Alkhorn Formation on it. WILSON described the conglomerate and tentatively correlated it with the Haaken schists but with misgivings, noting that the clast content cannot be matched (WILSON and HARLAND 1964). WINSNES (1965) took a similar view, as did FLOOD, NAGY and WINSNES (1971) in mapping the whole group as Eo-Cambrian.

However, in 1968 WTH and WBH suspected fossils in the limestone clasts; in 1969 WGH collected fossils from the conglomerates in Motalafjella chiefly from a locality on northern Motalafjella. The assemblage was tentatively identified by C. L. FORBES of the Sedgwick Museum as late Ordovician or early Silurian. In 1971 WBH revisited the locality and made a further collection from a slightly different facies of penecontemporaneously slumped limestone. This later collection contains a similar but less diversified fauna which may not be much older than the member. These two collections have since been examined by C. T. SCRUTTON who considered that the fossils from the conglomerates are of Silurian aspect and probably of either Wenlock or Ludlow age. The collection from the slumped limestones lacks the more diagnostic forms found in the conglomerate but contains at least one coral in common and nothing that conflicts with a Silurian age for that horizon. Further details of these faunas will be published elsewhere (SCRUTTON, HORSFIELD and HARLAND 1976).

Other clasts in the Bulltinden Member conglomerates are of marble lithologies similar to the Alkhorn Formation varieties, including some which were folded before inclusion in the conglomerate. Dolomite clasts are less common than in the Comfortlessbreen tillites and contain no stromatolites. There are no granite clasts but one or two pebbles have been found of retrogressed schists similar to those in the Vestgötabreen Formation. This absence of extra-basinal lithologies and the closely-packed and well-sorted distribution of clasts offer no support to interpretation as a tillite. It is considered that the conglomerates formed in a shallow marine environment during a phase of Silurian faulting, possibly with metamorphism and folding.

B. *Motalafjella Formation*

This consists of pale grey, massive limestones (200 m), well exposed in an overturned nappe structure on Motalafjella. Here it structurally overlies the Vestgötabreen Formation of coarse-grained glaucophane schists and metamorphosed basic intrusives (HORSFIELD 1972). An unfaulted lower boundary has not been found and mapping suggests that this horizon has acted as a zone of décollement, with the limestones becoming more crystalline and dolomitic towards this zone.

2. SARSØYRA FORMATION

The marbles and argillites of this formation were first described by HOLTEDAHL (1913). They were named by WILSON (Ms) the Sarsøyra Beds from the coastal plains on which they occur. It was later suggested that they were Cambro-Ordovician in contrast to all the other rocks (W9 of HARLAND 1960). The formation borders the Forlandsundet Fault Complex and its upper and lower relationships are probably tectonic; indeed, it is not clear whether or not the constituent units are an unbroken sequence. For the present one formation is assumed. It is at least 500 m thick and four members are recognized.

A. HOLTEDAHL's "Heller, massiger Kalk" (1913, p. 59) is strongly sheared and grades into dark grey calcareous shales. No dolomitization has been observed. Because of this we do not follow HOLTEDAHL nor WILSON in correlat-

ing this formation with the dolomites north of Engelskbukta (the Moefjellet Formation).

B. Black, purple and green cleaved argillites form another variable unit distinguished by HOLTEDAHL. They are not so metamorphosed as the pelites of the Comfortlessbreen Group not far to the east. HOLTEDAHL (1913, p. 58) described them as ". . . meistens grün bis fast schwartz gefärbte, gerade spaltbare Schiefer vor, denen einige sehr bitumenreich sind und einen fast schwarzen Strich haben". Some have a soapy feel suggesting chlorite or talc.

C. Calcareous conglomerates and breccias form the next member. The clasts are small and show considerable flattening. Quartzites, dolomites and limestone clasts are found in a calcareous matrix. In two specimens collected from limestone clasts in the stream section north of Aavatsmarkbreen small fragments of fossils were found (by WTH) in 1969. One was part of a simple coral. This could be Ordovician or Silurian.

D. Semi-pelites and greenstones are also associated in the lowermost member.

The westernmost outcrops of this formation appear to be scattered within the plain of Sarsøyra. WILSON suggested that they belonged to a horst. WTH noted slumped blocks in the Tertiary sequence and considered they were all allochthonous. WBH accommodates both viewpoints by postulating a submerged system of Tertiary fault scarps with some blocks sliding a little way from their now submerged horst-like structure. This is typical of a step-faulted graben margin.

3. COMFORTLESSBREEN GROUP

This group is characterized by tillite formations. WILSON in 1958 described the Haaken schists which we thought might be tillites, and this view was confirmed in 1959 when the Comfortlessbreen Formation was named (W7 of HARLAND 1960). Subsequent correlation shows the group to be equivalent to parts of BAKER's Variable Group (private communication). WILSON also named the Annabreen Quartzites. We subsequently had difficulty in determining the sequence with a threefold division of two tillites and a quartzite formation. Where least tectonically disturbed the quartzite appeared in the middle. It is common in tillites of Varangian age for there to be two glacial episodes and this is not quite clear in Prins Karls Forland. We also distinguish here the units already recognised as follows and so define the group:

A. Engelskbukta (tillite) Formation
B. Annabreen (quartzite) Formation
C. Haaken (tillite) Formation

The whole sequence appears to be 3 to 4 km thick but is in places thickened by folding and elsewhere reduced by faulting. Some of the characteristics of the upper and lower tillite are the same, namely: they are thick, calcareous, clastic possibly flyschoid turbidites with dispersed stones of varied composition and up to a metre or more in diameter but more commonly only a few centimetres across. They are usually of dolomite, limestone, quartzite or granite, in that order of decreasing frequency. The carbonate clasts are occasionally stroma-

tolitic and oncolitic. The clast composition is similar to that of Varangian tillites elsewhere in Spitsbergen and the Arctic. Varangian tillites generally follow a sequence of stromatolitic and pisolitic dolomites and limestones. The matrix is altogether different from that in Ny Friesland and Nordaustlandet and the sequence is thicker and suggests a mobile environment. Sedimentary structures, however, cannot easily be observed because of intense flattening and elongation with schistosity and subsequent chevron folding.

In these respects the tillite formations parallel those of Prins Karls Forland and Nordenskiöld Land rather than those further to the east. However, higher grades of metamorphism are evident as, for example, at Carlsfjella, Svartfjella and Eidembukta where biotite and garnet in a somewhat gneissose texture are found. The more usual grades are chlorite-sericite assemblages.

A. *Engelskbukta Formation*

This name is proposed here to distinguish this upper unit from the lower unit already named (Haaken). The formation is seen in situ very conveniently on the south cliff on Engelskbukta. Bands, up to a metre thick, of unsorted orthoconglomerate are restricted to this unit.

B. *Annabreen Formation*

So named by Wilson (W8 of Harland 1960), this unit was renamed by Challinor (we think mistakenly) and classed as early Carboniferous (Cutbill and Challinor 1965). It consists of massive pink, brown and white weathering quartzites with no clasts. The granular texture typifies the kind of metamorphism associated with presumed Precambrian rocks. Quartzites and semi-pelites may show a fine compositional banding.

C. *Haaken Formation*

Dolomitic boulders, including stromatolitic and oncolitic structures, are common in this formation. Larger clasts, including the quartzites, are also more evident than in the Engelskbukta Formation.

4. ST. JONSFJORDEN GROUP

Two pairs of formations constitute this group. The upper pair (Alkhorn and Løvliebreen) directly underlie the Comfortlessbreen Group with sedimentary contact. The lower pair (Moefjellet and Trondheimfjella) are isolated by faults but are inferred in the position suggested with breaks of unknown magnitude above and below. The group is unified because the two pairs have been confused, while the tillites above and the much more highly metamorphosed rocks of the Kongsvegen Group beneath are distinct.

A. *Alkhorn (Limestone) Formation*

This is essentially a limestone formation that everywhere underlies the Haaken tillites of the Comfortlessbreen Group and overlies quartzites of the Løvliebreen Formation. The name (Alkhornkalk) is taken from Holtedahl

(1913 and MAJOR et al. 1956) who described the lower part of the sequence at Alkhornet (Type 3 a thick dolomitic limestone and Type 2 a phyllite and shaly marble, 80–100 m). From studies in the same region south of St. Jonsfjorden the Birmingham expedition surveyed this unit as thin "upper calcareous group, 765 m" (BAKER, private communication). C. B. WILSON independently described the Dahlbreen limestone from north of St. Jonsfjorden (W6 of HARLAND 1960) and we have referred to it by that name until now, when we acknowledge HOLTEDAHL's prior contribution.

The formation contains a wide range of lithologies but very little dolomite (which distinguishes it clearly from the lower Moefjellet Formation). Banded pale and dark marbles of a distinctive variety are present and also fine grained tinted marbles, calc-argillites, grits, breccias, and conglomerates. No stromatolites have been observed but oolitic and pisolitic textures, which may be algal (oncolites), are common. These are often visible as dark spots where they have been replaced by chert (c.f. HORSFIELD 1973).

B. *Løvliebreen Formation (1000 m)*

The formation is named after the glacier on the southern side of St. Jonsfjorden. It corresponds to the dark quartzites of HOLTEDAHL (1913) at the bottom of his Alkhornet sequence and to the "massive quartzite bodies occurring in the eastern part of Holmesletfjella and in Gunnar Knudsenfjella" of WEISS (1953). In both localities there are interbedded pelites and volcanic rocks. The formation occurs in a recumbent syncline south of St. Jonsfjorden and the base is not seen, so that 1000 m may be an underestimate of its thickness. Two members are distinguished:

(i) *Upper*: massive quartzites with intercalated pelites. The dark quartzites are cut by thin white quartz veins. In thin section they are equigranular and pure with rounded or sutured outlines. The pelites are dark, fine-grained, and fissile.

(ii) *Lower*: the volcanic rocks (e.g. ot Gunnar Knudsenfjella) weather dark brown, green and purple. They are fine-grained and contain amygdales but have no glassy shards, crystallites or spherulites and no pillow structures. These metavolcanics are probably widespread in the inland areas of southern Oscar II Land, judging by their extensive occurrence in glacial moraines.

C. *Moefjellet Formation*

The formation was named by C. B. WILSON from one of the jagged dolomite peaks on Løvenskioldfonna and was the fifth in his system (W5 of HARLAND 1960). It is a massive dolomite, uniform, unfoliated and difficult to subdivide. In colour it is typically a cream-weathering grey rock, often a quartzite with gritty surface texture. Veining and internal small-scale brecciation are often seen on weathered surfaces. Small-scale banding may be due to alternating cream and grey dolomitic or cherty layers in dolomite. No organic structures have been seen.

The formation lies above the Trondheimfjella Formation at Trondheimfjella but its upper relationship is faulted. Its lower stratigraphic position is inferred because there is no break in the sequence Comfortlessbreen–Alkhorn–Løvliebreen. Interjacent strata could be missing. A minimum thickness of 800 m is suggested and the thrusting has produced an outcrop of variable width.

The formation outcrops north and south of Engelskbukta, but it is possible that marbles at Eidempynten and Daudmannsodden are correlative.

D. *Trondheimfjella Formation*

This is a mixed formation of interbedded marbles, quartzites, and pelites with calcareous conglomerates towards the base. It is well exposed along the northeast face of Trondheimfjella which runs east from Engelskbukta and was so named by WILSON (W4 of HARLAND 1960). Part of ORVIN's (1934) "dolomites and limestones at Forlandsundet" is included.

The formation passes concordantly upwards into the Moefjellet Formation but its lower boundary is faulted. Its thickness is not less than 1000 m. Faulting brings it into close contact with rocks of Carboniferous age. CHALLINOR's Bjørvigfjellet Formation on the northern side of Engelskbukta can therefore be correlated in some detail with this and the overlying Moefjellet Formation.

It is divided into three members:

(i)	Thin orange-weathering bands of calcareous conglomerates in a sequence of quartzites, psammites and massive dolomites	c. 200 m
(ii)	Dark phyllitic semi-pelites and psammites with minor quartzites and calcareous beds	c. 300 m
(iii)	Marble flags	500 m

Although it is suggested that this formation overlies the Kongsvegen Group the basal conglomerates do not contain typical Kongsvegen-type clasts.

5. KONGSVEGEN GROUP

This name (HARLAND, WALLIS and GAYER 1966) groups the formations that ORVIN (1934) first defined. He set up 11 units. 1–9 he named the "Quartzite and Mica Schist series"; 10 the "Steenfjell Dolomite"; and 11 the "Bogegg Mica Schist", underlain by "Dolomites and limestones at Forlandsundet". ORVIN considered the sequence inverted so that unit 1 would be the youngest. WILSON took the opposite point of view, (W1–3 of HARLAND 1960). HARLAND et al. (1966) and CHALLINOR (1967) confirmed ORVIN's order because of the overturned Carboniferous unconformity, and introduced the name Nielsenfjellet (sic) Formation for units 1 to 9 and modified ORVIN's two names to match the current place names. We accept ORVIN's division of units 1–11 with the original names of ORVIN and CHALLINOR. But ORVIN's fourth unit (CHALLINOR's Bjørvigfjellet Formation) we here identify with the Trondheimfjella Formation described above.

We also include in this group the Müllerneset Formation from south of St.

Jonsfjorden which we correlate with the Nielsenfjellet Formation; it probably includes the outcrop at Kulmodden in western Brøggerhalvøya.

The group forms a distinct mountain range extending 30 km as the backbone of Brøggerhalvøya. It is overthrust from the south and a fundamental fault there could be concealed.

A. *Nielsenfjellet Formation*

This is ORVIN's (1934) "Quartz Mica Schist series" and was named by CHALLINOR (1967). Typically this is seen southeast of Ny-Ålesund in dark mountain ridges. It comprises monotonous dark phyllitic semi-pelites interspersed with paler, dolomitic quartzite bands. ORVIN suggested a thickness of 2500 m but that is probably taken from Brøggerhalvøya which is not a typical section and shows some repetition. The figure of 1500 m is derived from the more constant width to the southeast. On the other hand the Müllerneset Formation which we correlate with it is not less than 2000 m so we conclude 2 km to be a reasonable estimate.

B. *Steenfjellet Formation*

This formation (ORVIN 1934) consists of a prominent 100 m band of grey and creamy-orange marbles separating the Bogegg and Nielsenfjellet Formations. It is coarse-grained and slightly foliated, with a well-developed, internal, passive folding. The formation is locally cut by thrusting. It is the thickest and most prominent of the pale bands that occur in the overlying Nielsenfjellet Formation. It is cut out by thrusting at Veslebreen and Holtafjella. The foliation of the marble is accentuated by parallel muscovite and differential weathering of quartz-dolomite and calcite rich layers.

C. *Bogegg Formation*

CHALLINOR (1967) modified the spelling to Bogegga to conform to the official spelling of the place name but we use the name as first defined by ORVIN (1934 and MAJOR et al. 1956) – the "Bogegg mica-schist". It is a varied sequence of schistose and gneissose psammites, pelites, semi-pelites, pale dolomitic marbles, pink feldspathites and dark amphibolites. It is well exposed in the Edithbreen area and forms dark ridges with occasional thin paler bands. It is divisible into three members:

(i) Pelites and semi-pelites with intercalated orange-weathering quartzites, marbles and psammites. The pelites and semi-pelites are biotite schists with quartzo-feldspathic bands and lenses, and occasional small garnets. The marbles are coarse-grained and gritty with slight muscovite schistosity and comprise half the bulk of the member .. .. 500 m

(ii) Dark feldspathic and garnetiferous semi-pelite with quartzo-feldspathic bands. The unit is characterized by large quartzo-feldspathic segregations up to 2 m in diameter, with muscovite, and by ptygmatic structures .. .. 400 m

(iii) Gneissose porphyroblastic feldspathites and semi-pelites with schistose garnetiferous pelites, subordinate dolomites and impersistent concordant amphibolites. The feldspathites weather greenish-grey and typically develop an augen structure .. .. 600 m

The coarser schistosity and more prominent deformation of this formation relative to the structurally lower Nielsenfjellet Formation supports the view that this is the oldest of the three formations.

D. *Müllerneset Formation*

This formation consists of 2000 m of phyllitic and schistose pelites and semi-pelites with psammites and white quartzites. It is typically seen around Müllerneset, south of St. Jonsfjorden, and occupies the Svartfjellstranda coastal plain west of the thrust strip of Carboniferous and Permian rocks, and Dineley (1958) suggested it was of this age. We correlate it, however, with the Nielsenfjellet Formation, and the tectonic setting is similar to that at Kulmodden west of Brøggerhalvøya.

6. VESTGÖTABREEN FORMATION

This is a suite of metamorphic rocks of blue schist facies, of which some lithologies at least are derived from basic igneous rocks. It occurs in a narrow zone about 10 km long by a few hundred metres wide which runs parallel to the regional NW–SE strike. Rocks of this suite were first discovered as loose blocks by C. B. Wilson in 1957. In 1962 D. G. Gee located a source on Motalafjella and in 1968/9 W. T. Horsfield located further outcrops on ridges to the north of Vestgötabreen (Horsfield 1972). Exposures are therefore situated only on steep craggy ridges about 10 km inland from Forlandsundet.

The zone along which these outcrops run is associated with considerable brecciation, iron and copper mineralisation, and runs parallel to several low angle faults which dip to the west. To the west lie sheared marbles and to the east massive metamorphosed greenstone. We cannot correlate this suite of rocks but they are probably older than the Bulltinden conglomerates, and probably suffered metamorphism at around 470 M.y.; however, since their occurrence is restricted to the area of Bullbreen Group rocks, they may well originally have been Palaeozoic rocks.

IV. Correlation and Conclusion

The main object of this paper is to outline the stratigraphic sequences as we understand them. There is no space to consider their palaeogeological implications. Our final task, to compare and correlate these sequences, is attempted in Table 3 and the notes below.

(1) The fauna of the Bulltinden Conglomerate Member is of Wenlock or Ludlow age.

Table 3.

Correlation of older strata between Prins Karls Forland and Oscar II Land

The symbols (in brackets) used in this table serve as a key to the units on the geological map Fig. 1. Thickness in km of combined sequence = 16.5 to 18 km.

Prins Karls Forland			Oscar II Land			
Group		Formation		Formation	Group	
Grampian 3.6	(B)	Geddesflya Fugelhuk Barents (Sutorfjella Mbr) Conqueror Utnes		Holmesletfjella * (Bulltinden Mbr) Motalafjella	Bullbreen 0.7	(B)
Scotia 1	(S)	Roysha C Kaggen Vg Baklia C	M* C V	Sarsøyra	0.5	(S)
Peachflya 1.3	(P)	Knivodden Vg Hornnes Alasdairhornet V Fisherlaguna				
Geikie 0.77	(G)	Rossbukta Gordon M				
Ferrier 0.73	(T)	Neukpiggen T Peterbukta Hardiefjellet T Isachsen (Vg) T	T T	Engelskbukta Annabreen Haaken	Comfortlessbreen 3 to 4	(T)
			M V M	Alkhorn o Løvliebreen Moefjellet Trondheimfjella	St. Jonsfjorden 3.8	(J)
			M	Müllerneset and Nielsenfjellet Steenfjellet Bogegg	Kongsvegen 3.1	(K)
		Pinkie V	V	Vestgötabreen		

* fossil horizon
T tillite horizon
—— tectonic break
o oncolite horizon
C carbon or bitumen
M marble
V volcanic horizon
Vg volcanogenic

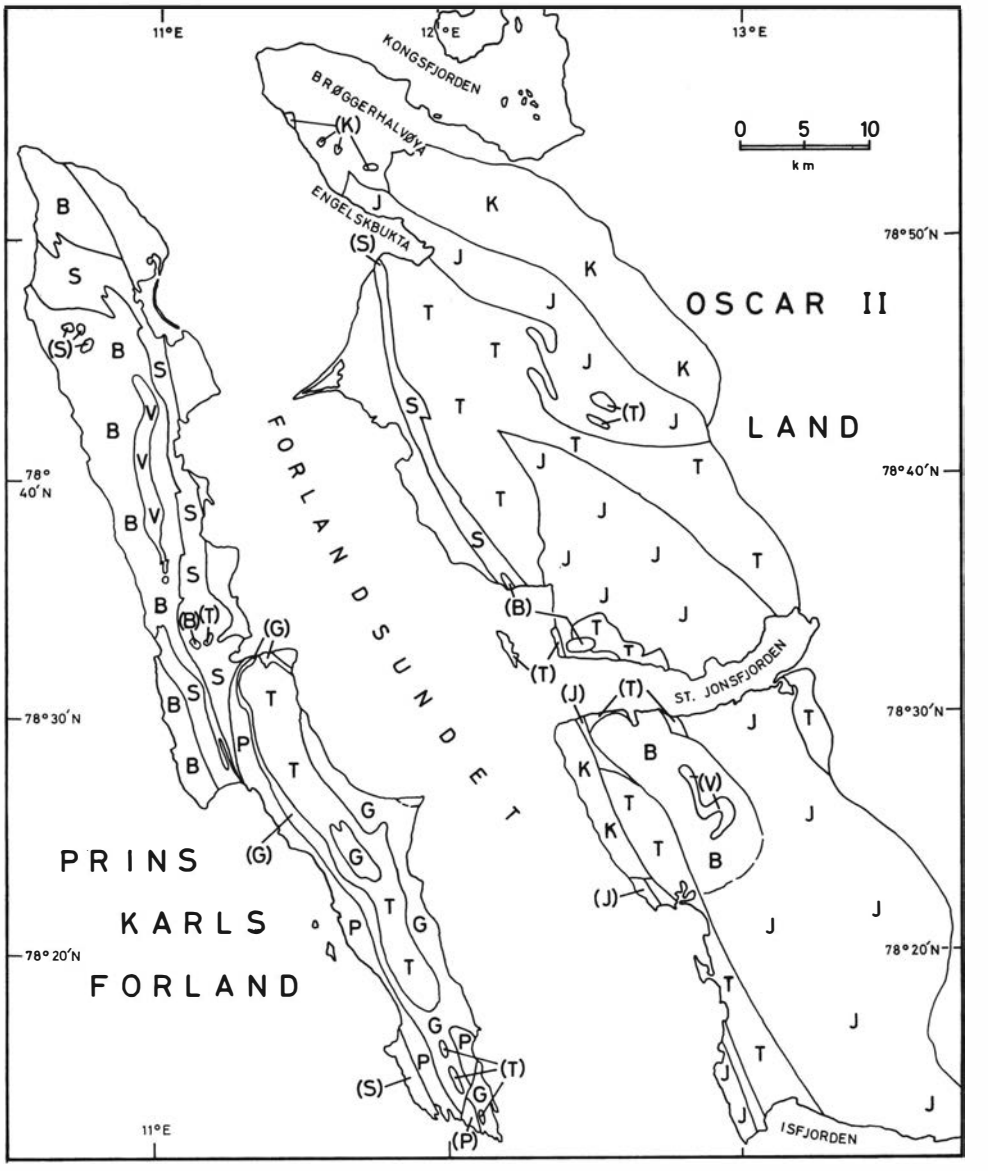

Fig. 1. *Map of central western Spitsbergen to show the larger outcrop areas of the stratigraphic groups as described in this paper.*

(2) The Bullbreen Group and the Grampian Group are analogous.

(i) Both the Barents Formation and the Holmesletfjella slates and siltstones are turbidites and their colouring is similar.

(ii) Each has remarkably coarse and locally developed conglomerates, namely the Sutorfjella and the Bulltinden Conglomerate Members. Both are formed from the rapid erosion of uplifted areas, though the Sutorfjella conglomerate is limited in extent and thickness compared with the Bulltinden. The clast compositions are different also. The Sutorfjella clasts

all appear to derive from post-Varangian rocks, whereas the Bulltinden conglomerate derives from late Riphean and early Palaeozoic limestones up to at least Wenlock age. The latter would therefore appear to result from more widespread and deeper erosion. Nevertheless, both situations are highly mobile and could indeed be synorogenic.

(3) The varied strata of the Sarsøyra Formation, with limestones, multicoloured slates and a rich carbon content, are reminiscent of the Scotia Group, i.e. the slates might compare with the Kaggen Formation and suggest a volcanic episode. The fossil reported suggests at earliest a mid-Ordovician age, and if the correlation suggested here is correct then these rocks would be older than the Bullbreen Group, i.e. pre-Devonian, probably pre-Ludlow.

(4) The tilloids of the Ferrier and Comfortlessbreen Groups correlate and probably represent the Varangian ice age, partly because each reveals two distinct tillite formations and each contains stones with stromatolites and oncolites.

(5) The underlying carbonate formation is not stromatolitic, but in both Oscar II Land and Nordenskiöld Land oolites and pisolites (oncolites) are found in limestones (Horsfield 1973) that, it has been suggested, correlate in time with the late Riphean Akademikerbreen Group. This is a reasonable time correlation, but the facies are very different.

(6) In the tectonically unstable area under consideration conglomerates are not infrequent but need not have been very extensive, so we do not value them for long distance time correlation. For example, we would not feel confident to match any part of our sequence with the Draken conglomerates of Ny Friesland.

(7) It may be significant that possibly the oldest rocks in each sequence, though tectonically isolated, are metavolcanics (Pinkie and Vestgötabreen).

V. Summary

We have established two sequences which are somewhat complementary. They are positively linked by the tillites and this enables us to add up the thickness for the whole. In doing so we have given throughout the most conservative thicknesses. Moreover, at several places the sequences are incomplete, so strata are probably tectonically removed. The sequence as a whole is no less than 18 km thick and probably more than 20 km. This ranges in age probably from Mid or Late Riphean through to Wenlock or Ludlow time. The facies indicates tectonic mobility almost throughout, with flyschoid and conglomeratic rocks and with several volcanic episodes. There is sufficient unity within this area and sufficient contrast from neighbouring sequences to justify naming a distinct geosyncline.

We have considered regional names, but they have been pre-empted (e.g. Forlandsundet, West Spitsbergen). Therefore, personal names have been considered; and in view of his outstanding contribution to the elucidation of the older rocks of western Spitsbergen we propose to commemorate Olav Holtedahl by referring to the Holtedahl Geosyncline.

Acknowledgement

Three of us (WTH, GMM and APM) were supported by studentships and a major part of the field costs was provided by a Research Grant financed by the Natural Environment Research Council. WBH also received a grant from the Royal Society for this field work. The expedition members over many years who have supported the work in the field are named in the Polar Record accounts listed in the Introduction. The writing of this paper was made possible by help from several and especially K. HEROD with text and references; C. A. G. PICKTON with the figure and P. KEARSLEY who typed the usual five drafts.

References

ATKINSON, D. J., 1956: The occurrence of chloritoid in the Hecla Hoek formation of Prince Charles Foreland, Spitsbergen. *Geol. Mag.* **93** (1): 63–71.

— 1960: Caledonian Tectonics of Prins Karls Forland. Int. geol. Cong. 21st Session, Copenhagen 1960. Section 19: 17–27.

BAKER, B. H., C. L. FORBES, and M. F. W. HOLLAND, 1952: Fossiliferous strata at Kapp Scania, Daudmannsøyra, Vest Spitsbergen. *Geol. Mag.* **89** (4): 303–304.

BARBAROUX, L., 1966a: Contribution à l'Étude tectonique de la Presqu'ile de Brøgger (Spitsberg). *Bull. Soc. géol. France*, **7**e *ser.* **8**: 560–566.

— 1966b: De l'étude statistique des blocs erratiques, rive sud du Kongsfjord, Spitsberg. *Centre National de la Recherche Sci. Recherche Cooperative sur Programme* (*Spitsberg* 1964 *et premières observations* **1965**). Lyon, Audin. **42**: 239–44.

BRUCE, W. S., 1910: The Exploration of Prince Charles Foreland, Spitsbergen, during 1906, 1907 and 1909. *Brit. Ass. Advmt. Sci.*, Sheffield 1910, Rept. Section E. 2 pp.

CHALLINOR, A. C., 1967: The structure of Brøggerhalvøya, Spitsbergen. *Geol. Mag.* **104** (4): 322–336.

CRAIG, R. M., 1916: Outline of the Geology of Prince Charles Foreland, Spitsbergen. *Trans. Edinb. geol. Soc.* **10**: 276–288.

CUTBILL, J. L., and A. CHALLINOR, 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* **102** (5): 418–439.

DINELEY, D. L., 1958: A review of the Carboniferous and Permian rocks of the west coast of Vestspitsbergen. *Norsk geol. Tidsskr.* **38** (2): 197–219.

DRASCHE, R. V., 1874: Petrographische-geologische Beobachtungen an der West-Küste Spitzbergens. *Tschermaks. Min. Mitt.* (3). Wien 1874: 261–268.

FLOOD, B., 1969: Sulphide mineralizations within the Hecla Hoek complex in Vestspitsbergen and Bjørnøya. *Norsk Polarinst. Årbok* 1967: 109–128.

FLOOD, B., J. NAGY, and T. S. WINSNES, 1971: Geological Map, Svalbard. 1:500,000. Sheet 1G: Spitsbergen Southern Part (Map with explanatory notes). *Norsk Polarinst. Skirfter* Nr 154A. Oslo 1971.

HARLAND, W. B., 1960: The development of Hecla Hoek rocks in Spitsbergen. *Int. geol. Cong. 21st Session, Norden* 1960. *Report Pt.* **19**: 7–16. (Discussion Pt. **27**, p. 194, 1963.)

HARLAND, W. B., J. L. CUTBILL, P. F. FRIEND, D. J. GOBBETT, D. W. HOLLIDAY, P. I. MATON, J. R. PARKER, and R. H. WALLIS, 1974: The Billefjorden Fault Zone, Spitsbergen: the long history of a major tectonic lineament. *Norsk Polarinst. Skrifter* Nr. 161. 72 pp.

HARLAND, W. B., and W. T. HORSFIELD, 1974: The West Spitsbergen Orogen. Mesozoic-Cenozoic belts. **In**: Data for Orogenic Studies (Ed. A. M. SPENCER). *Geological Society of London Special Publication* No. 4: 747–755.

HARLAND, W. B., R. H. WALLIS, and R. A. GAYER, 1966: A Revision of the Lower Hecla Hoek Succession in Central North Spitsbergen and Correlation Elsewhere. *Geol. Mag.* **103** (1): 70–97.

HEINTZ, A., and TH. SIGGERUD, 1965: A note on the stratigraphy of Goldschmidtfjella, Oscar II Land. *Norsk Polarinst. Årbok* 1963: 251–253.

HOEL, A., 1914: Exploration du Nord-Ouest du Spitsberg enterprise sous les auspices de S.A.S. le Prince de Monaco par la Mission Isachsen. Troisième Partie: Géologie Resultats des Campagnes Scientifiques accomplies sur son yacht par Albert 1er Prince Souverain de Monaco. *Fasc.* **42**: 1–68.

HOLTEDAHL, O., 1913: Zur Kenntis der Karbonablagerungen des Westlichen Spitsbergens. II. Allgemeine stratigraphische und tektonische Beobachtungen. *Skr. Vidensk. selsk. Christiania.* 1. *Math. Naturw. kl.* Nr. 23: 1–91.

HORSFIELD, W. T., 1972: Glaucophane schists of Caledonian age from Spitsbergen. *Geol. Mag.* **109** (1): 29–36.

— 1973: Half-moon oolites from the Hecla Hoek of Nordenskiöld Land, Spitsbergen. *Norsk Polarinst. Årbok* 1971: 55–58. Oslo 1973.

KRASIL'SHCHIKOV, A. A., 1973: [Stratigraphy and Palaeotectonics of the Precambrian and early Palaeozoic of Spitsbergen] Stratigrafia i paleotonika dokenbrija – rannego Paleozoja Spicbergana. [Scientific Research Institute for Geology of the Arctic] *Naucna issledovatelskij institut geologii Arktiki, NIIGA*, [Transactions] *Trudy.* **172** (Ed. V. N. SOKOLOV), 1–120.

LEE, G. W., 1908: Notes on fossils from Prince Charles Foreland, brought home by Dr William S. Bruce in 1906 and 1907. *Proc. R. phys. Soc. Edinb.* **17** (4): 149–166.

MAJOR, H., W. B. HARLAND, and H. STRAND, 1956: *Svalbard. Lexique Stratigraphique International* **1**: Europe; Fasc. 1: Artique, 1d, 49–95. CNRS, Paris.

ORVIN, A. K., 1934: Geology of the Kings Bay Region, Spitsbergen, with special reference to the coal deposits. *Skr. Svalb. og Ishavet* Nr. 57. 195 pp.

SIGGERUD, THOR, 1962: The iron occurrence at Farmhamna, Vestspitsbergen. *Norsk Polarinst. Årbok* 1960: 86–89.

SCOTTISH SPITSBERGEN SYNDICATE: Manuscript Repts. by various authors housed at the Scott Polar Research Institute, Cambridge.

SCRUTTON, C. T., W. T. HORSFIELD, and W. B. HARLAND (1976): A Silurian fauna from western Spitsbergen. *Geol. Mag.* **113** (6): 519–523.

TYRRELL, G. W., 1924: The Geology of Prince Charles Foreland, Spitsbergen. *Trans. roy. Soc. Edinb.* **53**. Part 2 Nr. 23: 443–78.

WEISS, L. E., 1953: Tectonic features of the Hecla Hoek Formation to the south of St Jonsfjord, Vestspitsbergen. *Geol. Mag.* **90**: 273–286.

— 1958: The structure of the Trygghamna-Vermlandsryggen area, Isfjorden. *Norsk. geol. Tidsskr.* **38** (2): 218–219.

WILSON, C. B., and W. B. HARLAND, 1964: The Polarisbreen Series and other evidences of Late Pre-Cambrian Ice Ages in Spitsbergen. *Geol. Mag.* **101** (3): 198–219.

WINSNES, T. S., 1965: The Precambrian of Spitsbergen and Bjørnøya. **In**: *The Geologic Systems. The Precambrian.* **2** (Ed. K. RANKAMA). Interscience Publishers (Wiley), London: 1–24.