Hecla Hoek rocks of Oscar II Land and Prins Karls Forland, Svalbard

By AUDUN HJELLE, YOSHIHIDE OHTA and THORE S. WINSNES

Contents

Abstract

The Hecla Hoek succession of the present area is strongly disturbed by the Tertiary diastrophism and most lithologic units are separated by faults. Five lithologic units have been distinguished in the Upper and Middle Hecla Hoek Supergroup, and three separated blocks of Lower Hecla Hoek Supergroup are also recognized. All correlations are based on lithologic characteristics and structural interpretation. The stratigraphic position of peculiar glaucophane schist–bearing formation is still a problem.

The metamorphic grade of the rocks generally increases with stratigraphic depth, from the green schist facies in the upper part to the upper amphibolite facies in the lower part, and the stilpnomelane–, chloritoid– and staurolite–bearing assemblages characterize the intermediate P/T type metamorphic facies series. This progressive metamorphism was achieved during the main Caledonian orogeny when the axial plane cleavages of isoclinal folds developed. A thermal matamorphism followed the regional metamorphism and a late deformation with

chevron folds superposed on the metamorphic rocks. The Tertiary movement with the stress from SW caused open gentle folds and thrust faults associating with local retrogressive metamorphism. The formation of the Forlandsundet graben is later than the thrust movement.

Introduction

Low grade Hecla Hoek meta-sedimentary rocks occur widely along the west coast of Oscar II Land and on Prins Karls Forland. These two areas are separated by the Forlandsundet Tertiary graben. The geologic structures of these rocks are very complicated as discussed by WEISS (1953) and ATKINSON (1960) and consequently many difficulties are encountered in attempts to restore the stratigraphy of these areas. This article presents a preliminary geological map, stratigraphic divisions and general structures, based on the field surveys carried out by many geologists of Norsk Polarinstitutt since 1955.

Prins Karls Forland.

T. GJELSVIK: 1968, 1970, 1971, 1972, 1973, 1974, mostly northern area, some in the middle part.
A. HJELLE: 1972, middle part.
Y. OHTA: 1972, northern part.
T.S. WINSNES: 1972, southern part.

North of St. Jonsfjorden, Oscar II Land.

E. TVETEN: 1968, from Uversbreen to Aavatsmarkbreen.
T.S. WINSNES: 1967, west side of Kongsvegen to Engelskbukta.
1972, Haraldfjellet to Carlsfjella, and southern part of Prins Heinrichfjella.
1975, Løvenskioldfonna and Haaken Mathiesenfjella.
A. HJELLE: 1972, southern part of Prins Heinrichfjella and Ankerfjella.
Y. OHTA: 1972, from Konowfjellet to Gaffelbreen.

South of St. Jonsfjorden, Oscar II Land.

H. MAJOR: 1955, Daudmannsøyra — Trygghamna — Venernbreen area.
T. SIGGERUD: 1965, around Copper Camp, St. Jonsfjorden.
Y. OHTA: 1973, from the west coast to Vegardfjella, and in the north of Eidembreen.
T.S. WINSNES: 1975, Sparrefjellet.

Besides these data, the works of TYRRELL (1924), WEISS (1953), and ATKINSON (1956, 1960, and 1963) are referred to.

It is hoped that this article can open a discussion on this problematic Hecla Hoek area of Svalbard.

Stratigraphy

The area of Hecla Hoek rocks is divided into two by the Forlandsundet Tertiary graben: Prins Karls Forland in the west and Oscar II Land in the east (Fig. 1). Each of these areas is divided into three, and six lithostatigraphic

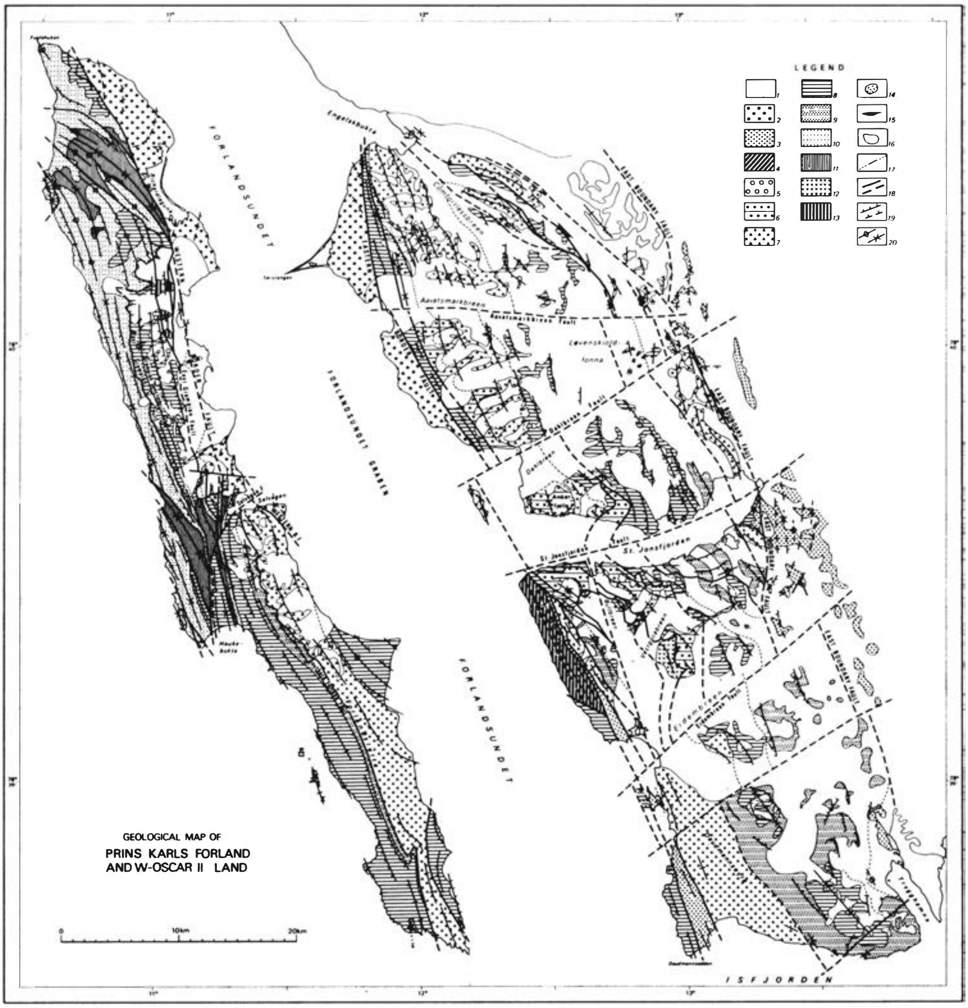

Fig. 1. *Geological map of Prins Karls Forland and the western part of Oscar II Land.*

Legend: 1: glacier and moraine, 2: Tertiary rocks, 3: Permo–Carboniferous rocks, 4: Devonian, 5: Sutor Conglomerate, 6: Bulltinden Formation, 7: Tillitic Conglomerate, 8: Calc–argillo–volcanic Formation, 9: Quartzite–shale Formation, 10: Quartzite–sandstone Formation, 11: Black shale Formation, 12: Vestgötabreen Formation, 13: Lower Hecla Hoek rocks, 14: basic instrusive rocks, 15: dolomite and serpentinite along faults, 16: exposure border, 17: lithologic border, 18: fault, 19: structural trend, 20: anticline and syncline.

sections have been established (Fig. 2). The stratigraphic columns from the northern part of Prins Karls Forland and the southern side of St. Jonsfjorden are summarized from many geologic profiles, while the rest were synthesized from a few sections.

The formation names already proposed by previous authors are followed with some modifications. No new names are proposed but the rock units are distinguished by their dominant lithology. Eight lithologic units, hereinafter termed formations, have been distinguished.

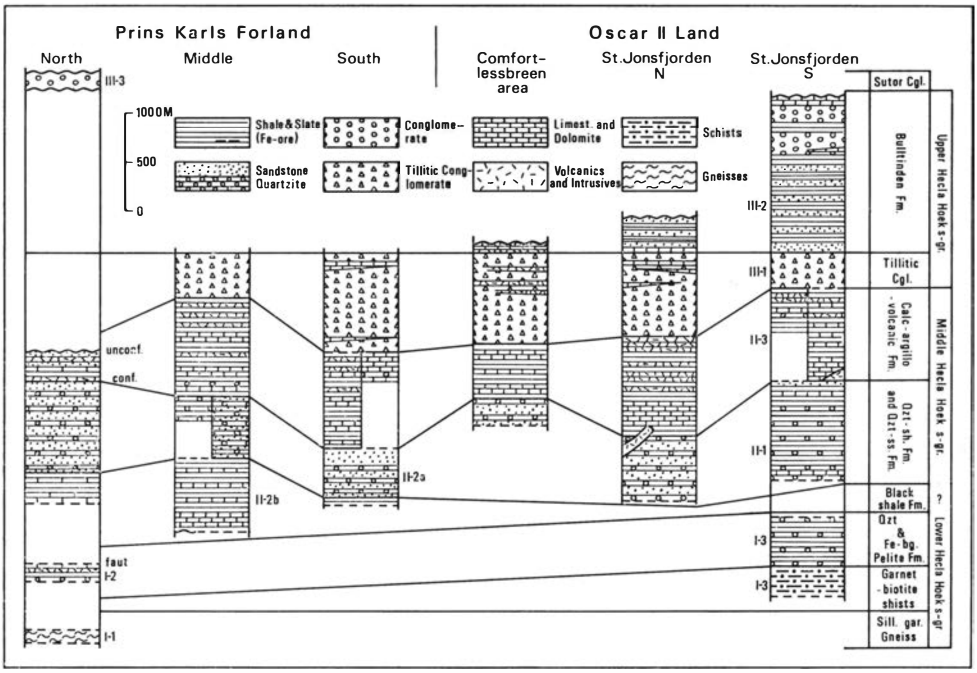

Fig. 2. *Lithostratigraphic columns of the Hecla Hoek successions in Prins Karls Forland and Oscar II Land. The numbers: I–1, II–1a etc., refer to the description in the text.*

In spite of the short distance across the Forlandsundet graben, the correlation of these formations between the west and east is not straightforward. The most reliable correlation is the Tillitic Conglomerate, which we consider to be the glacial deposit of Vendian age, widely occurring all over Oscar II Land and in the southern part of Prins Karls Forland. However, many other formations are separated by faults and their stratigraphic positions are mainly based on structural interpretations and on the comparisons of their lithology with those of other areas of western Spitsbergen.

The succession above the Tillitic Conglomerate of the Upper Hecla Hoek Supergroup was grouped into one formation. Three formations are considered to be of the Middle Hecla Hoek Supergroup and three isolated successions are assumed to be of the Lower Hecla Hoek Supergroup. The observed thicknesses are: Upper Hecla Hoek 2,500 m and Middle Hecla Hoek 3,500 m. The lower Hecla Hoek rocks, – 1,000 m, occur as small fault blocks.

LITHOSTRATIGRAPHIC DESCRIPTION

Lithological characteristics of each formation are described, based mainly on field observations, supported by some microscopic work (Figs. 1 and 2).

I. *Lower Hecla Hoek rocks*

These rocks are distinguished by their notably higher degree of metamorphism. The occurrences are always bounded by faults.

I–1 *Sillimanite-garnet-biotite gneisses at the Bourėefjellet, middle Prins Karls Forland*

These rocks occur along the eastern foot of Bourėefjellet with a thickness of about 150 m. The rocks are dark, dense and schistose, having alternations of calcareous and pelitic layers of cm to dm thicknesses. Mylonitic texture is evident in the matrix. Sillimanite occurs as relics in small prismatic grains enclosed in the bundles of sericite. Garnet grains are idiomorphic and often helicitic with numerous inclusions of plagioclase, potash feldspar, biotite and quartz. Pale brown large flakes of biotite occur on the mylonitic matrix of quartz and feldspars. Epidote, clinozoicite, sphene, tourmaline and calcite are common accessories. These rocks form a wedge-like block, bounded by a steep fault on both the east and the west side, extending parallel to the Western Border Fault of the Forlandsundet Tertiary graben (Fig. 1).

I–2. *Iron-ore-bearing pelites*

On the southern faces of Bourėefjellet, a slate rich, 150 m thick, succession with very gentle structure occurs. Many quartzite layers are interbedded and a brecciated limestone of green and white tints occurs in the upper part. Amphibolite lenses are intercalated in the middle part. Between the limestone and amphibolites, an iron-ore bed of 3 m thickness occurs, being composed of dense layered magnetite and hematite.

The slate-rich succession is cut by steep faults both in the west and the east, and extends to the south at least for 2–3 km as a narrow zone of about 1 km width. This succession can be correlated to the iron-ore-bearing rocks east of Recherchebreen, south of Bellsund.

I–3. *Garnet-biotite schists and quartzite-shale alternation*

These rocks occur along Svartfjellstranda and are separated from the main Hecla Hoek region in the east by a narrow fault zone of Late Paleozoic rocks. The rocks are divided into two members; the Garnet-biotite schist of 300 m thickness in the east, and the Quartzite-shale alternation with a thickness of 500 m in the west along the shore. The schistosity and bedding of both members are nearly vertical, and the border of these two shows rapid but gradational change. Due to the high grade metamorphic assemblages, the Garnet-biotite schist Member is considered to be in the lower position. The quartzite of the upper member is pure and banded with pink, grey, and white beds. This colour distinguishes it from that of the Quartzite-shale Formation (see II–1). These rocks form a NNW-SSE trending zone parallel to the eastern border of the Forlandsundet Tertiary graben.

I–4. *Vestgötabreen Formation: the glaucophane schist and associated rocks*

This rock unit was named the Vestgötabreen suite by Horsfield (1972), and occurs from Bulltinden to Motalafjella for 10 km as a narrow thrust schuppen a few hundred meter thick. The original definition of this suite by Horsfield was coarse-grained glaucophane bearing garnet-muscovite-schists, but this is modified here to include all rocks closely associating in the thrust zone, such as: epidote-actinolite greenstone, serpentinite, glaucophane-bearing schists, eclogite, muscovite-quartz-schist, calcareous schist and dolomite, and the name is changed into the Vestgötabreen Formation.

This formation is sandwiched between rocks of the Bulltinden Formation (see III–2). The rock association of the Vestgötabreen Formation: frequent alternation of quartz schist and impure limestone with a large amount of meta-basites, represent typical eugeosynclinal shallow sea deposits. The stratigraphic position of this formation is problematic, correlative successions are the Calc-argillo-volcanic Formation (II–3) of the present area in the Middle Hecla Hoek succession and the Eimfjella Formation of Hornsund in the Lower Hecla Hoek succession.

II. *Middle Hecla Hoek rocks*

The stratigraphic positions of two formations presented below are unknown by direct evidences, but are supposed to be of Middle Hecla Hoek Supergroup from lithologic comparisons.

II–1. *The Quartzite-shale Formation*

This formation occurs in two areas: 1) from Wollertoppen, north of St. Jonsfjorden to the south and west of Lexfjellet, north of Isfjorden, and 2) along the ridges of the southern part of Prins Karls Forland.

The lower border of this formation is probably a fault contact with the Tillitic Conglomerate at the southeastern edge of Gunnar-Knudsenfjella and at the northwestern edge of Vegardfjella, and at the western tip of Carlsfjella, south and north of St. Jonsfjorden, respectively.

This formation is composed of an alternation of quartzite and shaly sandstone. The quartzite is pure and dominant in the lower part of the succession, with beds of 0.5 to 10 m in thickness, occupying about 1/3 of the succession. Some quartzite layers on the ridge west of Charlesbreen show pink and grey coloured bands similar to the Quartzite-shale alternation Member of the I–3. Quartzite-rich successions also occur further to the south, in Stortrollet and the foothills of the mountains from Kinnefjellet to Protektorfjellet in the northern side of Isfjorden.

The shaly rocks of the Quartzite-shale Formation consist of individual beds thicker than the quartzite, up to 30 m thick. The dark shale increases in the upper part. Here three or four layers of black oolitic limestone; less than 5 m in thickness, occur on the ridge between Anna-Sofiebreen and Gunnarbreen.

In the southern Prins Karls Forland, the upper part of the formation is exposed, being composed of homogeneous flaggy siliceous shale and some quartzite beds.

A minor gabbro stock cuts this formation around Donpynten on the northern shore of Isfjorden.

II–2. *The Quartzite-sandstone Formation and the Black shale Formation in Prins Karls Forland*

Two formations, the Quartzite-sandstone apparently underlying the Black shale Formation, occur above the Calc-argillo-volcanic Formation west and north of Prins Karls Forland. The conformable relation of the Quartzite–sandstone Formation to the underlying one was observed at three localities and this formation can apparently be considered younger than the Calc–argillo–volcanic Formation and older than the Tillitic Conglomerate.

However, the rocks conformably underlying the Tillitic Conglomerate are phyllites and limestones similar to the rocks of the Calc-argillo-volcanic Formation. From the structural interpretation of the Grampianfjella, the Calc–argillo–volcanic Formation occurring in the northern Prins Karls Forland is the upper limb of an overturned syncline. Thus, there is a possibility that these two formations may be inverted and older than the Calc–argillo–volcanic Formation. This problem is still an open question and may be solved by a detail study of the sedimentary structures of these two formations.

II–2a. The Quartzite–sandstone Formation

This is a more than 900 m thick alternation of quartzite and sandstone and occurs along the west coast from Kaldneset to Utnes, and over the whole northern part of Prins Karls Forland. In the Grampian area, the lower boundary with the Calc–argillo–volcanic Formation is cut by the steep west dipping West Grampian Fault (Fig. 1). The quartzite is less than a half of the whole succession and always sandy and impure. Dark alternating layers of fine– to medium–grained sandstone, occasionally conglomeratic, and silty stones often show turbidite structures. Graded beddings are occasionally observed, but the up–down relations observed are not sufficient to determine whether this formation is overturned or not. Some thin layers of conglomeratic quartzite with angular limestone pebbles are characteristic in the lower part of this formation.

II–2b. The Black shale Formation

In the northern part of Prins Karls Forland, a distinct black formation apparently overlies conformably the Quartzite–sandstone Formation. The rocks comprise calcareous black shale, partly slate, and impure limestone. Characteristic siliceous concretions of irregular rod shape, 1–5 cm across, often occur in the shale. Some of them show weak concentric pattern around the margins, and may be relics of organic structures.

This formation extends to the south to Haukedalen, central part of Prins Karls Forland, together with the Quartzite–sandstone Formation. The thickness is 550 m in the north and 750 m in the central area.

This is apparently the uppermost formation of any regional significance in Prins Karls Forland. However, if the structural assumption of an overturned syncline in Grampianfjella is accepted, this becomes the lowest succession below the Quartzite–sandstone Formation which may be correlated to the Quartzite-shale Formation (II–1) in Oscar II Land.

II–3. *The Calc–argillo–volcanic Formation*

This formation is commonly composed of grey banded limestone in the lower part, black shale or slate in the middle and green phyllite with meta–volcanics and –intrusives in the upper part in general. The successions observed in five separated localities show large variations as outlined below:

1) The largest outcrop of this formation is a NNW–SSE zone from Engelskbukta to Trygghamna, north of Isfjorden, 5–9 km wide and 80 km long. In the northern part of this zone, Trondheimsfjella, several limestone layers alternate with slate in the lower part, the middle part is shale, and a few relatively thick limestones (up to 100 m) and shale occur in the upper part of the succession. Observed thickness is 550 m.

Along the northern side of St. Jonsfjorden, this formation was observed with a slate of 80 m thickness and a limestone–rich succession of more than 100 m thickness in the lower part, about 100 m thick black slate in the middle, and grey–green phyllites of about 300 m thickness in the upper part. The lower limestone extends to the north around Løvenskioldfonna. Two small basic instrusive bodies, hornblende gabbro and porphyrite, occur in the lower slate and they may be feeder of the eruptive rocks which are now represented by the green phyllites in the upper part of this formation.

To the south of St. Jonsfjorden, the limestone–rich character of this formation continues to Isfjorden. The limestone is prominent in the lower and upper parts and shale dominates in the middle part of the succession. A thick light coloured, banded dolomitic limestone on the ridges of Kinnefjellet and Lexfjellet to Protektorfjellet, conformably overlying the Quartzite–shale Formation (II–1), is the lower part of this formation.

A remarkable volcanic complex occurs on the top of Gunnar–Knudsenfjella. It is composed of basalt lava, varicoloured viscular agglomerates and green phyllites, and the total thickness is up to 150 m. The thickness decreases rapidly north– and southwards and the complex grades laterally into thin layers of green phyllites. The green phyllite horizons below the limestone of the mountains west of Trygghamna and the hornblende gabbro stock around Donpynten are the southern extremities of this basic rock unit.

The basic rocks show coarse–grained gabbroic textures when they occur in the lower part of the present formation and in the Quartzite–shale Formation below, while they are made up of extrusive rocks and green phyllites in the upper part of this formation. This volcanic member is the only comparable rocks with the epidote–actinolite greenstones of the Vestgötabreen Formation (I–4).

2) The second occurrence of this formation is in the western part of Oscar II Land; along the Forlandsundet Tertiary graben in the north of St. Jonsfjorden and along the fault zone of Permo–Carboniferous rocks south of St. Jonsfjorden.

In the northern localities, the exposure is very poor and the observed rocks are mostly grey dolomitic limestone with black slate, and the estimated thickness is 550 m north of Dahltoppen to the north of Aavatsmarkbreen. At the shore south of Andreasbreen, from the Tertiary graben fault and 1.5 km eastwards, green phyllite alternates with grey and black phyllites and quartzite and calcareous rocks are subordinate. The total thickness here is estimated to maximum 450 m. A serpentinized green phyllite occurs close to the Eastern Border Fault (Fig. 1).

To the south of St. Jonsfjorden, the Calc–argillo–volcanic Formation occurs along the shore between Thorkelsenfjellet and Bulltinden and is composed of thin alternation of grey limestone, quartzitic sandstone and green phyllite. A narrow fault zone of green phyllite follows along the eastern side of Thorkelsenfjellet and Svartfjella. The thickness is 200 m.

The limestone–rich succession along the western shore of Daudmannsøyra has some dark and green phyllites, and can be correlated with this formation.

3) Southern part of Prins Karls Forland

Green phyllite and shaly rocks are dominant in Scotiadalen and Haukedalen, with a few layers of white limestone, while the limestone intercalations become very frequent to the south on Forlandsletta and in Vestflya in the lower part of the formation. These limestone beds form the isolated mountain peaks around the southern tip of Prins Karls Forland. The middle part of the succession is shaly and the upper part is rich in green and dark chocolate coloured phyllites. The width of the occurrence is more than 5.5 km from the middle of Forlandsletta to Forlandsøyane, however, the steep dipping structures certainly include many structural imbrications. The thickness is estimated to be about 1,000 m here. The transition to the lower formation is observed to be gradational along the ridges of the southern Prins Karls Forland and the upper boundary is also gradational to the overlying Tillitic Conglomerate.

A similar phyllite–rich succession occurs as a wedge–shaped zone in the middle of Omondryggen in the west, and is considered the upper part of this formation. The phyllite grades into the apparently overlying Quartzite–sandstone Formation, while the lower calcareous part is cut by steep faults in the east. The main rocks here are black phyllite and various calcareous rocks, occasionally with glossy, coal–rich surfaces, both with some green phyllite intercalations.

4) Grampianfjella in the central Prins Karls Forland

The Calc–argillo–volcanic Formation is folded into a large overturned syncline along the main ridge of Grampianfjella and outcrops along the eastern steep slopes (Fig 3, B and C sections). The succession is rich in dark slate with many limestone beds in the lower part, but the detail is unknown because of poor accessibility.

5) The Laurantzonfjellet area and the eastern foothills of Barentsfjellet and Fuglehukfjellet

The overturned syncline of the central Prins Forland plunges gently north and the overturned upper limb of the present formation extends down below the surface. An incomplete tectonic window occurs north of Laurantzonfjellet, where this formation is composed of green phyllite, shale and sandstone with a thin layer of white limestone. The exposed thickness in 250–300 m.

A green phyllite and shale–sandstone succession occurs along the Western Border Fault in the northern–most part of Prins Karls Forland, apparently underlying conformably the Quartzite-sandstone Formation. These rocks are considered to be the upper part of the present formation and the exposed thickness is about 150 m.

II–4. *The successions just below the Tillitic Conglomerate*

Concordantly underlying successions below the Tillitic Conglomerate have been observed in several localities, having somewhat different lithologies. All these are thought to belong to some part of the Calc–argillo–volcanic Formation.

II–4a. The limestone succession in southeastern Prins Karls Forland

A 300 m thick limestone occurs along the eastern foothills of Methuenfjellet as the core of a local anticline. The contact to the overlying Tillitic Conglomerate is observed in the west to be concordant. The limestone is shaly and phyllitic with some occasional quartzite beds. The general nature of the succession is unknown, because of poor exposure on the strand–flat, but gives the impression of being similar to the lower part of the Calc–argillo–volcanic Formation.

II–4b. The phyllite succession of Vegardfjella, southeast of St. Jonsfjorden

The rocks here are mostly black and green phyllites, shaly sediments of volcanogenic origin, with a few thin beds of partly oolitic limestone. These phyllites occur concordantly below the Tillitic Conglomerate and are overlain with an unconformity by a varicolured conglomerate of Late Paleozoic age. The exposed thickness is 420 m.

II–4c. The phyllite succession in Svartfjella, southwest of St. Jonsfjorden

Similar phyllites as those of the Vegardfjella area occur here under the Tillitic Conglomerate, where the shaly phyllite is associated with three thin beds of grey limestone. Some leucocratic injection veins, less than 10 cm thick, occur in the phyllite with pinch–and–swell structures. The observed thickness of the succession is 250 m here.

III. *Upper Hecla Hoek rocks*

The rock succession from the Tillitic Conglomerate and above are grouped into two formations, and the Sutor Conglomerate of unknown stratigraphic position is also described here.

III–1. *The Tillitic Conglomerate*

This formation occurs in the western part of Oscar II Land as a 6–7 km wide zone from Engelskbukta to Dahlbreen and a narrow wedge–shaped zone along eastern side of the Late Paleozoic rock zone in Svartfjella, widening to the south in Daudmannsøyra, north of Isfjorden. This formation also occurs further to the east along the western side of Osbornebreen, inner–most St. Jonsfjorden. The same rocks are seen in the southern part of Prins Karls Forland along the eastern slopes of the ridge from Doddsfjellet to Methuenfjellet. The thickness is more than 1,000 m in both Oscar II Land and Prins Karls Forland.

The upper boundary is conformable with the overlying Bulltinden Formation in Prins Heinrichfjella, north of St. Jonsfjorden. This formation overlies different rocks presumably of the Calc–argillo–volcanic Formation (II–4a–c). Although the contacts are obliterated by strong schistosity, these evidences indicate that the base of this formation may show an angular unconformity.

This formation is mainly composed of characteristic schistose conglomerates with numerous grey dolomite pebbles. Some thin dolomitic limestone beds occur in the upper part. Many thin layers of green phyllite have been recorded in the upper part in Haaken Mathiesenfjella, west of Comfortlessbreen.

Besides the boulders of dolomite, grey limestone and quartzite are common among the pebbles and boulders and the limestone occasionally contains stromatolite and oolite. Pebbles of granitic rocks are rarely found. The pebbles and boulders are strongly flattened and elongated, some are more than 1 m long. They are scattered and show very poor sorting, and a few to about 10 pieces per 1 m^2 are observed in the schistosity plane. The matrix of the rocks is a calcareous and siliceous shale with large amounts of dolomite, calcite and sericite. Quartz, albitic plagioclase, graphite and opaques are subordinate.

From the scattered and unsorted occurrences of pebbles and boulders in the fine-grained matrix, the rocks of this formation are considered as glacial sediments of Vendian age.

III–2. *The Bulltinden Formation*

This formation was defined by HORSFIELD (1972). The type locality is Bulltinden, western Holmesletfjella and Motalafjella in the south of St. Jonsfjorden. The lower boundary is a low angle fault and no depositional contact has been found in this area. The formation is composed of three members; a frequent alternation of coarse-grained, often conglomeratic, sandstone and shale in the lower part, very coarse conglomerate and shale in the middle and a limestone in the upper part.

In the lower member, the sandstone is relatively well sorted and occupies more than half of the succession. The conglomeratic nature of this sandstone distinguishes it from those of the other formations below. The alternating shale often shows well developed laminar structures. The thickness of this member in Holmesletfjella is about 1,000 m.

The conglomerate of the middle member is moderately sorted, the thickness of the sorted units is several metres, from coarse-grained sandstone to polymict boulder conglomerate. The pebbles and boulders are sub-rounded to round, up to 1.5 m across. Boulders of grey limestone and brown dolomite are abundant with subordinate quartzite, sandstone, shale, black slate, chlorite phyllite, quartz schist, schistose amphibolite, meta-diabase, garnet-mica schist and skarn. These pebbles and boulders are scarcely deformed. Two beds of conglomerate are present in the southern part of Motalafjella, the lower bed is more than 200 m thick and the upper one 150 m. Between these two beds a 100 m thick dark shale occurs. This shale has well developed laminations of shale and silt, and numerous thin sandstone layers.

A grey limestone of 10 m thickness occurs in the middle member on the northeastern edge of Motalafjella. This unit is composed of conglomeratic limestone with angular breccias and dense grey limestone, and the latter includes many fossils of Lower Paleozoic age. The rocks are only slightly recrystallized, and brachiopods, cephalopods, gastropods, stromatolites, crinoids, table and horn corals have been collected. An upper Ordovician to lower Silurian age is suggested by a brief preliminary examination.

The conglomerate is very well developed in Bulltinden. A conglomerate with such large boulders suggests that this is an intermontane deposit at the foots of a rapid raising hinterland.

A distinct grey limestone of 50 m thickness occurs above the middle member in the area from Bulltinden to Motalafjella. HORSFIELD (1972) excluded this from the Bulltinden Formation. However, doubtful fragments of brachiopods were found in a scree block directly lying on this limestone in Motalafjella and, therefore, this limestone is included in the Bulltinden Formation as its upper member. The limestone sandwiches the Vestgötabreen Formation and is seen on the ridge of southwestern Holmesletfjella with the associated black shale above.

The Bulltinden Formation occurs across St. Jonsfjorden to the north, in Ankerfjella and Prins Heinrichfjella, on the northern side of Aavatsmarkbreen where it forms part of a syncline whose western limb is cut by a steep fault (Fig. 3, section F). The conglomeratic rocks here are mostly schistose and are often accompanied by sandstone and quartzite beds. Intercalated limestone beds are occasionally observed in the lower part on the slopes of Ankerfjella and the northern side of Aavatsmarkbreen. Poorly preserved fossil-like fragments were found at a locality in Ankerfjella. Although most rocks are obliterated by strong schistosity, the lower boundary with the Tillitic Conglomerate is considered to be conformable in Prins Heinrichfjella.

III–3. *The Sutor Conglomerate*

A remarkable conglomerate occurs at Sutorfjella on the west coast of Prins Karls Forland. This was firstly described by ATKINSON (1960). The conglomerate is very coarse with sub-angular boulders up to a few metres across, very poorly sorted and have a green or dark brown coloured matrix of coarse-grained sandstone. White quartzite boulders with dark reddish weathered crust are notable. The quartzitic conglomerate with angular limestone breccias from the Quartzite–sandstone Formation (II–2) below are also included as pebbles and cobbles. This formation overlies the Quartzite–sandstone Formation by a low angle fault, and its stratigraphic position is unknown.

SUMMARY OF STRATIGRAPHY

Due to a strong deformation and faulting during Tertiary, most rock units in the present area are separated by tectonic breaks which make stratigraphic correlations difficult.

TYRRELL (1924) made the first classification of the rock successions in Prins Karls Forland and his divisions generally agree with those of the present paper. ATKINSON (1956 and 1960) made further sub-divisions, but his descriptions are

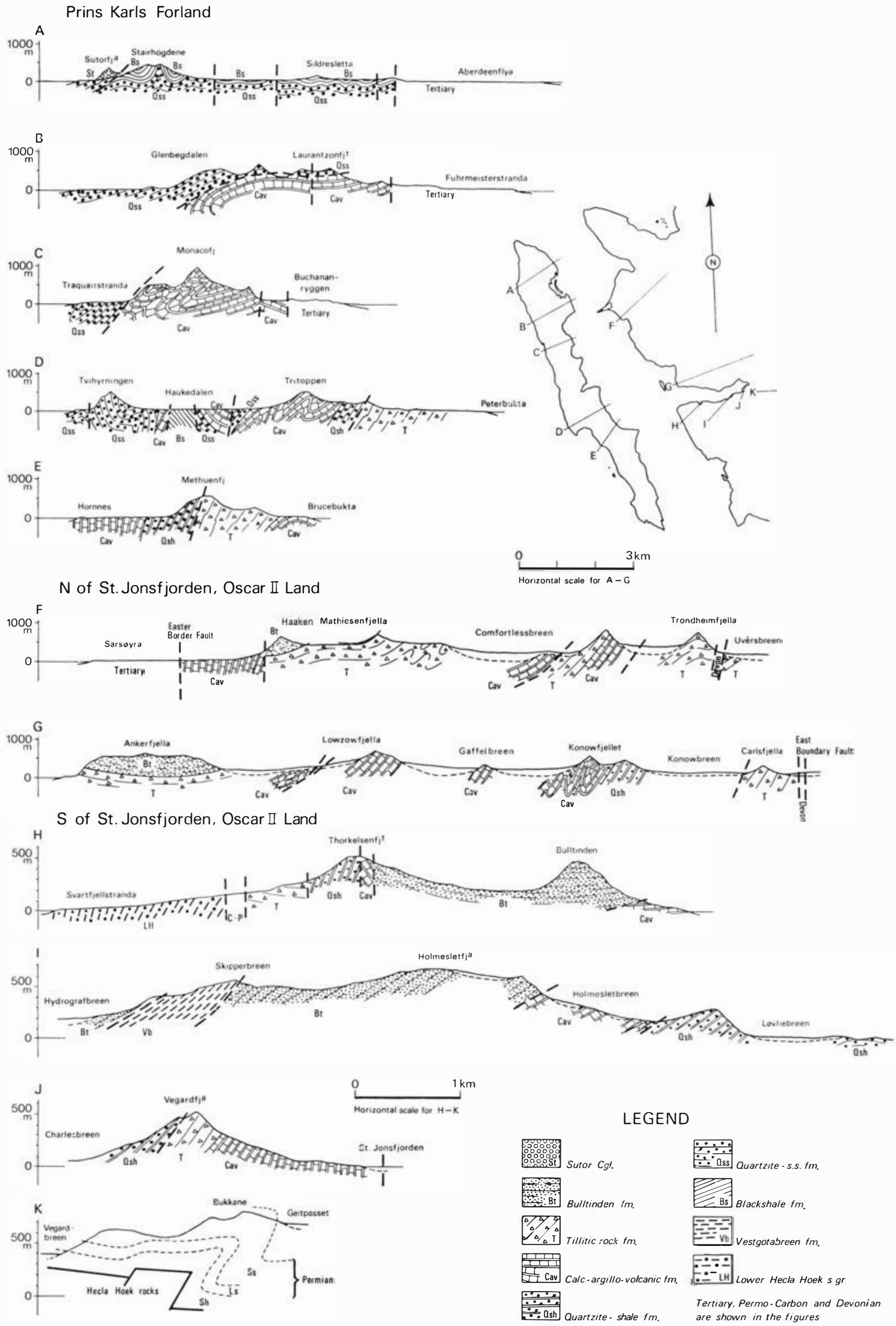

Fig. 3. *Geologic profiles from Prins Karls Forland (A–E) and Oscar II Land (F–K).*

mainly concerned with the structural units and not based on the lithology. Therefore, it is difficult to make correlations with his divisions, but an attempt is shown in Table 1.

The Tillitic Conglomerate can be correlated well over the whole western Spitsbergen, and the correlation of the Bulltinden Formation with the Sørkapp Land Group is certain. However, the correlations of the other older formations are still tentative and based on general lithologic similarities and the grade of metamorphism. The correlations of the Quartzite-sandstone Formation and the Black shale Formation of Prins Karls Forland are the most problematic since these are based on the structural interpretations.

The important points concerning the stratigraphy are summarized below:

1) The Bulltinden Formation, presumably Ordovician to Silurian, includes the youngest succession of Upper Hecla Hoek Supergroup in Svalbard and is an intermontane mollasse of the Caledonian orogeny.

2) The Tillitic Conglomerate, a Varangian glacial deposit, is the best key for regional correlation. A clino-unconformity is estimated at the base of this formation.

3) Two volcanic horizons have been distinguished in the studied area: in the upper part of the Tillitic Conglomerate and in the upper part of the Calc–argillo–volcanic Formation. The holo-crystalline basic rocks in the lower part of the Calc–argillo–volcanic Formation and the Quartzite–shale Formation are considered to be the feeders and instrusives related to the volcanism in the upper Calc–argillo–volcanic Formation of the Middle Hecla Hoek succession.

The basic rocks of the Eimfjellet Group in Hornsund are the third basic igneous activity in the Hecla Hoek succession of western Spitsbergen.

The Vestgötabreen Formation may be correlated to one of the older two.

4) The Quartzite–shale Formation of Oscar II Land and the Quartzite-sandstone Formation of Prins Karls Forland are correlated to the Slyngfjellet Conglomerate of southwestern Spitsbergen. If this is the case, the conglomeratic nature of these two formations are far less than the Slyngfjellet Conglomerate and their lithologies are similar to that of the Veteranen Group of Lomfjorden Supergroup in Ny Friesland, although their thickness is about 1/4 of the latter.

The Black shale Formation below the Quartzite-sandstone Formation may belong to the Lower Hecla Hoek succession.

5) The high grade metamorphic rocks including biotite, garnet, sillimanite are certainly of the Lower Hecla Hoek succession. The iron-ore-bearing slate in central Prins Karls Forland is correlated to the similar succession below Slyngfjellet Conglomerate in the east of Recherchebreen, south of Bellsund.

Table 1.

		Hornsund (Birkenmajer 1974)	Bellsund (Hjelle 1969) south	Bellsund (Hjelle 1969) north	Oscar II Land (present paper)	Prins Karls Forland present paper	Prins Karls Forland Tyrrell 1924	Prins Karls Forland Atkinson 1960	Ny Friesland (Harland et al. 1966)	
Upper Hecla Hoek	Hornsund Supergr.				Bulltinden Fm.				Hinlopenst. Supergr.	
Upper Hecla Hoek	Hornsund Supergr.	Sørkapp Land Gr.							Hinlopenst. Supergr.	Oslobreen Gr.
Upper Hecla Hoek	Hornsund Supergr.	Sofiekammen Gr.							Hinlopenst. Supergr.	
Upper Hecla Hoek	Hornsund Supergr.	Gåshamna phy.	Bellsund–Dunderdalen tillite	Kapp Linné Tillite Lågneset Tillite	Tillitic Cgl.	Tillitic Cgl.	Ferrier Peak Series	Ferrier Gr. Geikée Gr. Gordon Gr.	Hinlopenst. Supergr.	Polarisbreen Gr.
M. Hecla Hoek	Sofiebogen S-gr.	Höferpynten dol.	Konglomeratfj. shale–quartzite volcanics calc beds	Lågneset–Kapp Martin green–grey shale Lågnesrabbane calc beds	Calc–argillo–volcanic Fm.	Calc–argillo–volcanic Fm.			Lomfj. S-gr.	Akademikerbreen Gr.
M. Hecla Hoek	Sofiebogen S-gr.	Slyngfjellet Cgl	Konglomeratfjellet Conglomerate	Kapp Martin Cgl.	Quartzite-shale Fm.	Quartzite-sandstone Fm. (conglomeratic)	North Grampian Series	Fuglehuken Gr.	Lomfj. S-gr.	Veteranen Gr.
Lower Hecla Hoek	Torellbreen S-gr.	Deilegga Gr.	East of Recherche-breen calc. phy.+ iron-bed calc. qtz.			Black shale Fm. Pelite with Fe-ore	Mt. Scotia Series	Scotia Gr. Barents Gr.	Stubendorffbr. S-gr.	Planetfjella Gr.
Lower Hecla Hoek	Torellbreen S-gr.	Eimfjellet Gr.			(Vestgötabreen Fm.?) Quartzite-shale alternation Gar–bi–schist Sill–gar–bi–gneiss				Stubendorffbr. S-gr.	Harkerbreen Gr.
Lower Hecla Hoek	Torellbreen S-gr.	Isbjørnhamna Gr.							Stubendorffbr. S-gr.	Finnlandveggen Gr.

6) The Sutor Conglomerate resembles the basal Devonian conglomerate elsewhere in the northern Spitsbergen as well as the Tertiary basal conglomerate on the eastern ridges of Grampianfjella, and no definite correlation of this conglomerate can be made at the present stage.

Geologic structures

Complicated nappe structures were proposed by ATKINSON (1960) in Prins Karls Forland, and the mesoscopic structural elements were studied by WEISS (1953) in the south of St. Jonsfjorden. A new tectonic interpretation has been proposed by HARLAND and HORSFIELD (1974) based on the studies mentioned above and the work on Brøggerhalvøya by CHALLINOR (1967) and others. In the present paper, the simplest possible interpretations are adopted. The observed structures are summarized below in retroactive order (Figs. 5 and 4).

THE STEEPLY DIPPING TRANSVERSE FAULTS OF ENE–WSW STRIKE

These faults cross cut the general strike of the regional structures of both Tertiary and Caledonian origin.

a) *The Selvågen Fault:* The Western Border Fault of NNW–SSE strike is dislocated and rotated slightly between the north and the south side of Selvågen, and a local fault of SW–NE strike is assumed here. This fault may converge into the fault in Scotiadalen, which is considered to be a branch of the Western Border Fault.

A E–W striking minor fault was observed from Magdabreen to Alfredbreen in the southeast of Grampiafjella.

b) *The Dahlbreen Fault:* The Eastern Border Fault goes into the sea at Snippen, northwestern entrance of Dahlbreen, while Hermansenøya to the west of the southern extension of the fault is composed of the Tillitic Conglomerate. Besides, the syncline axis of the Ankerfjella is displaced to the west in Prins Heinrichfjella. Thus, a transverse fault is assumed along the northern part of Dahlbreen.

These local displacements show that the ENE–WSW striking steep faults are later than the border faults of the Forlandsundet Tertiary graben. Another four steeply dipping faults of similar strike are supposed in the southwestern part of Oscar II Land (Fig. 3).

Faults with similar trends are known elsewhere along the west Spitsbergen Tertiary folded zone south of Isfjorden. This young trend is one of the most distinct fracture trends all over Svalbard and is manifested by the direction of shore lines and major fjords.

THE TERTIARY GRABEN

Faults of NNW–SSE trend are important structures in western Spitsbergen and bound the graben structures along the west coast.

The Western and Eastern Border Fault are typical in that they are almost vertical and diverge only locally. Three steep faults branch off from the Western Border Fault west of Richardlaguna in the northern Prins Karls Forland. They curve gently to a NW–SE trend in the north, which suggests that a horizontal SW–NE component of stress was present during the early time of graben formation.

The N–S striking steep faults along Scotiadalen and Haukedalen are also branches of the Western Border Fault. These faults produced step-wise movements of the wedge-shaped blocks enclosed by them. Some steep faults west of Scotiafjellet and Omondryggen are of the same origin.

The Eastern Border Fault also diverges in the south of St. Jonsfjorden and encloses a narrow zone of Late Paleozoic rocks from Svartfjella to the east of Daudmannsodden. Here the Eastern Border Fault is located some distance offshore to the west.

It is noteworthy that the rocks of high metamorphic grades occur within the fault zones of both the Western and the Eastern Border Fault: the sillimanite–garnet–biotite gneisses (I–1) and the iron–ore–bearing pelite (I–2) along the Western Border Fault and the garnet–biotite schist (I–3) along the Eastern Border Fault. Dolomite and serpentinized greenrocks occur along these faults as discontinuous, squeezed-out thin bodies along the Eastern Border Fault from Kaffiøyra to Sarsøyra and along a splay fault from Richardlaguna to Balfourfjellet in northern Prins Karls Forland.

A steep fault of similar strike is supposed to occur along Bullbreen.

The fault bounding the Hecla Hoek rocks to the east from Kongsvegen to Trygghamna, the East Boundary Fault, is steep and has similar strike as the graben faults. Although initiated earlier, this fault was certainly reactivated during the period of graben formation. The occurrence of Devonian rock along this fault is noteworthy.

The Forlandsundet Tertiary graben is considered to be formed in Eocene–Miocene time (HARLAND and HORSFIELD, 1974 and BIRKENMAJER, 1972) and extends offshore western Spitsbergen. Another graben occurs around Øyrlandsodden and Sørkapp Land, and all these structures are parallel to the Spitsbergen Fracture Zone some 150 km offshore to the west along the continental margin. These graben structures are younger than the main folding phase of the Tertiary orogeny.

MAIN TERTIARY OROGENY

Low to moderately westward dipping faults and regional folds with NNW–SSE axial trend were formed during the Tertiary orogeny and are the main elements of tectonic architecture of western Spitsbergen.

The youngest structures formed during this period is open folds of NNW–SSE strike, which are observed in the northern part of Prins Karls Forland. Most folds are gentle and shallow with 1–2 km wave length and a few hundred metres in amplitude, and almost concentric style with vertical axial plane. Some of the folds are asymmetric conical folds with axial planes dipping steeply to the west. Axial surface cleavages are weakly developed locally in the eastern part of Barentsfjellet. The anticlines tend to have acute crests which turn into thrust faults with steep westward dip. This suggests that the development of these folds preceeded the formation of the graben faults. The N–S and NNW–SSE striking minor fold axes (Fig. 4–A) correspond to these folds in the middle and northern Prins Karls Forland. These open folds refolded the overturned syncline of Grampianfjella in the northern part of Prins Karls Forland and are therefore younger than the main phase of strong folding and thrusting. An open syncline in Ankerfjella belongs to this young deformation.

Typical fold structures of the main Tertiary orogeny are represented by the overturned syncline of Grampianfjella, middle Prins Karls Forland (Fig. 3 section C). Although the details are not known because of the unaccessible steep cliffs, the syncline core was observed from a distance and can be reconstructed from associated minor folds of dm wave length with moderately westward dipping axial planes. The main axis of the syncline plunges very gently to the north and the overturned upper limb is roughly horizontal in northern Prins Karls Forland, and the axial plane has very gentle dip to the west.

In the western part of middle Prins Karls Forland, a steep westward dipping fault, the West Grampian Fault, is present in the overturned upper limb, and separates different lithologic units. This fault disappears somewhere around Laurantzonfjellet in the north. The eastern limb of the syncline is cut by the moderately westward dipping East Grampian Fault along the eastern foothills of Grampianfjella. From this fault splay a few faults around Bouréefjellet enclosing the highly metamorphosed deeper rocks. The Southern Forland Fault is the extension of the East Grampian Fault and the Calc–argillo–volcanic Formation to the west of the fault is supposed to include some imbrications of tight folds which are southern extensions of the overturned syncline of Grampianfjella.

In Oscar II Land, all lithologic units occur in zones with a NNW–SSE trend, bounded by low to moderately westward dipping faults. These faults are reverse, mostly less than 45°, and brought the older rocks up upon the younger ones. They were later cut by the graben border fault in the western part. Local tight folds accompanying weak cleavages produced by the thrust movement were observed around the faults: in the west of Comfortlessbreen, in Konowfjellet, eastern ridge of Ankerfjella and west of Piriepynten.

The large scale thrust structures of Oscar II Land are certainly comparable to the major structures of Prins Karls Forland, judging from the common axial trend and thrusting from the same SW direction. Structural imbrications are of a larger scale in Oscar II Land than in Prins Karls Forland.

The Carboniferous to Triassic rocks east of the Hecla Hoek region have been folded in step–style folds with the NNW–SSE axial trend with small wavelengths and partly overturned to the east in the western part like in the Osbornebreen–Charlesbreen–Trollheimen area (Fig. 3, Section K), and large step folds with a long flat western limb in the eastern part like in the Borebreen–Wahlenbergbreen–Kongsvegen area. These folds of the sedimentary blankets are considered to be the reflections of the thrust block movements of the underlying Hecla Hoek rocks as seen in western Oscar II Land. Mesozoic dolerites are involved in these folds elsewhere.

The arc–shaped zone of crystalline schists and phyllites of Brøggerhalvøya and Holtafjella has harmonious thrust structures (CHALLINOR, 1967) with the present Hecla Hoek rocks, and also involves the coal-bearing Tertiary strata at Ny-Ålesund.

From the structural evidence in the younger rocks, some gentle folds and thrusts of the present area are considered to be caused by Tertiary deformation preceeding the formation of the Forlandsundet graben. Although some of them may be of Caledonian origin, they were reactivated during the Tertiary orogeny. This main phase of Tertiary orogeny occurred sometime in the Paleogene Tertiary period and is probably related to the relative motion between the Greenland and the European plate during the early opening of the Norwegian–Greenland Sea. The tectonic transport from SW to NE is opposite to what ATKINSON (1960) discussed, and the dextral strike slip movement is represented by a gentle swing of westward dipping faults from a NNW–SSE to a NW–SE trend as seen in the northern part of Prins Karls Forland, around Comfortlessbreen and in the southern side of St. Jonsfjorden.

THE MESOZOIC DOLERITES

A few small dykes of dolerite cut the Tillitic Conglomerate northwest and southeast of Løvenskioldfonna, Oscar II Land. Sheets of dolerite with various thicknesses occur in the Permo–Carboniferous rocks east of the Hecla Hoek region. No systematic trend can be distinguished.

This igneous activity marks the end of the stable platform period from Late Carboniferous to Middle Mesozoic, and the beginning of Tertiary movements which are connected with the opening of Northern Atlantic.

THE LATE PALEOZOIC ROCKS

A narrow downfaulted zone of Permo–Carboniferous rocks, a few hundred metres wide, occurs from Svartfjella to Kapp Scania along the western shore of Oscar II Land. Two more small occurrences were found along the fault from Trondheimfjella to Kregnestoppen.

Some hundreds of pieces of angular blocks of doubtless Permo–Carboniferous rocks occur on a small hill to the northeast of Svartfjella, on the amphibolites of the Vestgötabreen Formation. These blocks cannot be regarded as a glacial drift, and the occurrence is problematic.

These Permo–Carboniferous rocks indicate that the Late Paleozoic shallow sea sediments, probably together with the Mesozoic ones, once covered the whole area of Oscar II Land.

DEVONIAN ROCKS

A conglomerate with grey and red limestone pebbles and red sandstone has been seen at the eastern tip of Haraldfjellet, west side of Osbornebreen. Another fault slice of Devonian rocks with fossils was found at Kregnestoppen, northeast of Løvenskioldfonna. These are in fault contact with the Tillitic Conglomerate and have a lithology which resembles that of the Devonian rocks in northern Spitsbergen. The eastern occurrence is along the N–S striking East Boundary Fault of the Hecla Hoek region, and the northern extension joins the Devonian rocks of Lovénøyane in Kongsfjorden (GJELSVIK 1974). This suggests that one of the faults bounding the Devonian graben in the northern Spitsbergen might pass along the East Boundary Fault of Hecla Hoek region in the middle Spitsbergen.

TWO PHASES OF CALEDONIAN DEFORMATION DISTINGUISHED FROM THE MESOSCOPIC STRUCTURAL ELEMENTS (FIG. 4)

All Hecla Hoek rocks, even those of the early Paleozoic Bulltinden Formation, show strong cleavages, developed parallel to the axial surfaces of small tight folds. The regional fold structures are represented by the lithologic units of some hundreds of metres in thickness, and the cleavages also show the same folded structures. This means that the cleavages were involved in the Tertiary regional folds and are consequently older than the Tertiary deformations.

The mesoscopic structural elements from Oscar II Land are summarized in Figs. 4–B and 4–C. The axial crests of the folded beddings were lost by strong cleavages in most cases, and the measurable beddings are mostly sub–parallel to the cleavages. Therefore, these two planar elements were counted together in the diagrams.

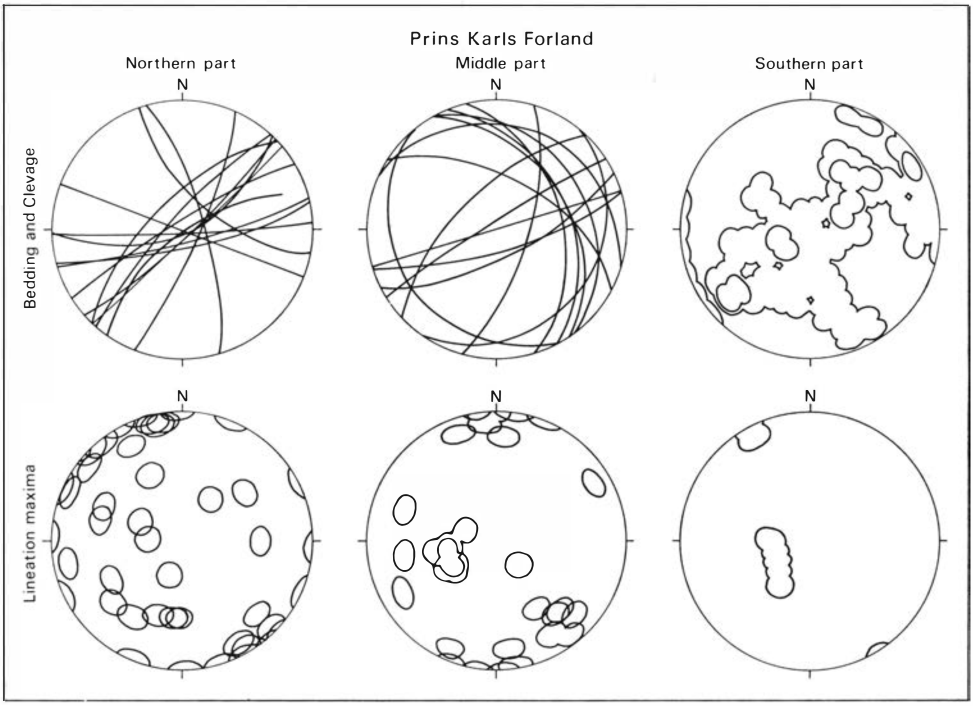

Fig. 4a. *Fabric diagrams of the mesoscopic structural elements.*

A. Summaries of the planar and linear structural elements from Prins Karls Forland. The girdles are drawn from the maximum of the bedding–cleavage diagrams of the subareas from the northern and middle parts of Prins Karls Forland, while the southern part is shown by a common contoured diagram. The maxima and sub-maxima of lineations from the subareas are projected in the lineation maxima diagrams.

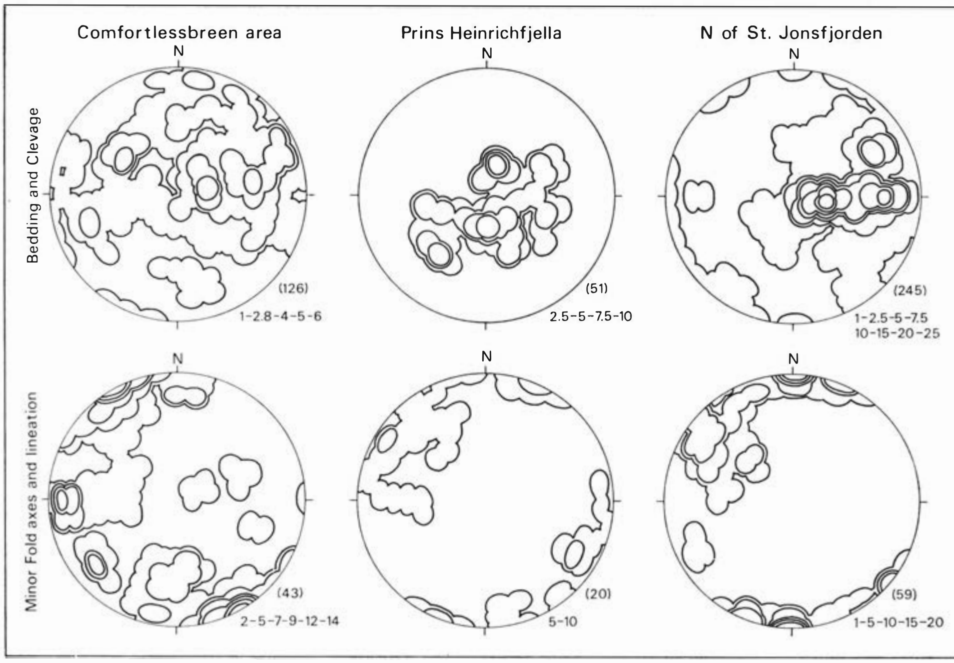

Fig. 4b.

B. Fabric diagrams from northern Oscar II Land.

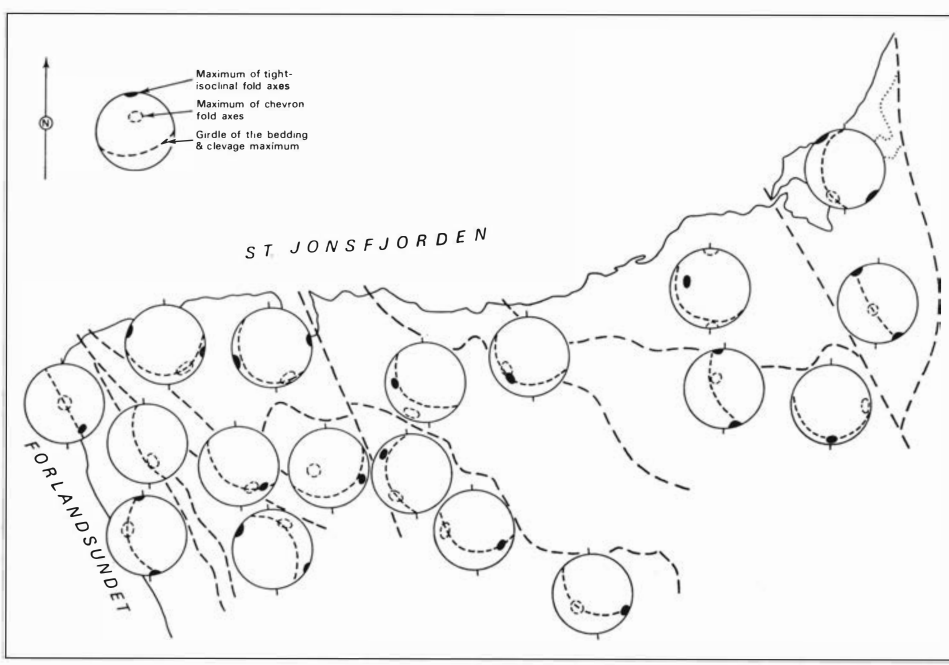

Fig. 4c.

C. Simplified fabric diagrams from the southern side of St. Jonsfjorden.

Two types of minor fold axes were distinguished in the area south of St. Jonsfjorden: 1) younger chevron folds and 2) older tight–isoclinal folds. In most diagrams of Fig. 4–C, the maxima of observed fold axes of both types are projected on or near the girdle, while they deviate distinctly from the girdle in a few diagrams. This discrepancy indicates that the present bedding–cleavage structures do not have their original trend, but are rotated by the later Tertiary movements. The rotation of both types of minor fold axes by the Tertiary deformations is evident since the trend of fold axes maxima changes from one sub–area to another in a thrust block. Weiss (1953) concluded that the N–S striking lineations are younger than the E–W striking ones and are of Tertiary origin, but our detailed analysis shows that both must be older than the Tertiary movements.

In the southern part of Prins Karls Forland, Atkinson (1956) associated the younger lineations of NE–SW strike, the chevron- and kink–folds, with the a–lineation of his nappe movement. But, chevron– and kink–type folds are not likely to be a–lineations, and the scattering and rotation of statistical maxima of these fold axes (Fig. 4–A) strongly suggest that these are older than the Tertiary deformation which is represented by N–S to NW–SE striking lineations.

In St. Jonsfjorden no comparable lineation corresponding to the two types of minor folds in the Hecla Hoek rocks was seen in the Permo–Carboniferous rocks involved in the Tertiary deformation, which means that both chevron– and tight–isoclinal folds were formed prior to Lower Carboniferous.

The tight–isoclinal folds always associate the cleavages and all metamorphic minerals occur under the control of cleavages and fold axes. Therefore, the folds represent the main recrystallization phase in the regional metamorphism. The axes of the tight–isoclinal folds have a more consistent trend than the chevron fold axes. This gives them an impression of being the youngest of the two types. However, the chevron folds evidently deformed the axes and axial planes of the tight–isoclinal folds and are definitely younger. The small scattering of the tight–isoclinal fold axes is due to the similarity in axial trend between these and that of main Tertiary deformation.

The N–S to NW–SE striking minor folds in the northern half of Prins Karls Forland (Fig. 4–B) are caused by the Tertiary deformation. To distinguish Tertiary structural elements from the more intense Caledonian ones is very difficult in the Hecla Hoek rocks of western Spitsbergen.

PRE–CALEDONIAN EVENTS

Lack of a major calcareous Cambro–Ordovian succession in this area may be due to either a structural missing or tectonic events during early Paleozoic as proposed in Hornsund by Birkenmajer (1972).

An unconformity at the base of the Tillitic Conglomerate is suggested by the different underlying rocks. The occurrence of a few granitic rock pebbles in the conglomerate indicates the existence of crystalline basement in the vicinity somewhere. However, the grade of metamorphism is progressive downwards in the stratigraphic sequence and the biotite isograd was reached in parts of the Tillitic Conglomerate.

The Quartzite–shale Formation and the Quartzite–sandstone Formation, which can be correlated to the Slyngfjellet Conglomerate at the base of Middle Hecla Hoek succession, have no distinct conglomerate as in the southern area of western Spitsbergen.

Mainly due to the strong disturbances from the Tertiary deformation, the analysis of pre–Caledonian events is very difficult in this part of Spitspergen.

Metamorphism

The phyllitic cleavages, formed as axial surface cleavage of the tight-isoclinal folds, are associated with progressive metamorphic mineral assemblages, while the younger structures as the chevron folds and the shear cleavages along the Tertiary disturbance zones are accompanied by retrogressive metamorphism only. Therefore, the metamorphic recrystallization of the Hecla Hoek rocks of this area is mainly of Caledonian origin.

The grade of metamorphism increases with stratigraphic depth. In the uppermost unit, the Bulltinden Formation, detrital muscovite and biotite are well preserved in the sandstone, while small flakes of sericite represent strongly crenulated microfolds and secondary cleavages in the shaly rocks. Detrital muscovite is preserved in the stratigraphic sequence down to the level of the Tillitic Conglomerate. Recrystallized chlorite and sericite occur in large amouts in the grey and green phyllites of the Calc–argillo–volcanic Formation. Chloritoid occurs in the phyllites of this formation in the middle and southern part of Prins Karls Forland (ATKINSON 1956).

The holocrystalline basic rocks in the Quartzite–shale Formation and the Calc–argillo–volcanic Formation are affected by post– or late–magmatic alteration and most mafic constituents have been converted into (biotite)–actinolite–epidote–chlorite–rutile–opaque aggregates. Quartz occupies irregular interstitial spaces and the plagioclase is totally dusty. The metamorphic assemblages of these rocks are characterized by (biotite), epidote, actinolite, chlorite and stilpnomelane of brown and green varieties.

The rocks of the Tillitic Conglomerate in St. Jonsfjorden have chlorite–sericite–bearing assemblages, while those of the southern Prins Karls Forland, east of Doddsfjellet, have biotite. Thus, the biotite isograde is not exactly parallel to the boundary of the lithologic units. Anyway, the biotite isograde was attained and typical nemato– and grano–blastic textures were achieved by recrystallization around the base of the Upper Hecla Hoek succession in the present area.

The rocks just below the Tillitic Conglomerate are essentially chlorite–sericite and graphite phyllites on the northern shore of Vegardfjella, eastern St. Jonsfjorden. The green phyllites at this locality are partly of spotted texture with albite poikiloblasts, some of which show S-shaped outline which represents syntectonic growth. The green schists in the same stratigraphic position southeast of Svartfjella show banded structures with boudinaged leucocratic layers of aplitic rock. Chessboard plagioclases of albitic composition and quartz are the main constituents in the leuco-layers and the matrix is the same as surrounding fine–grained schistose rocks. Although the occurrence is limited to a small area, one may suggest an introduction of quartz–dioritic materials into this structural level. This resembles the granitization described from Hornsund by BIRKENMAJER and NAREBSKI (1960), although it is there of the Lower Hecla Hoek succession.

Highly metamorphosed rocks are correlated to Lower Hecla Hoek. The garnet–biotite schists of Svartfjellstranda show two stages of recrystallization: the older with helicitic garnet and lepidoblastic biotite and muscovite, and the younger represented by large flakes of pale brown biotite growing regardless of the cleavages. The chevron and kink type minor folds made very weak local cleavages at the crests and have no progressive recrystallization. Therefore, these two phases of metamorphic recrystallization probably belong to the Caledonian main deformation phase, the older is syntectonic and the later is late– or post–kinematic thermal recrystallization. Later growth of biotite is also evident in the sillimanite–garnet–biotite gneiss of Bouréefjellet, Prins Karls Forland. Sillimanite and garnet are granulated relics enclosed in chlorite and sericite aggregates and many mylonitic fractures cut the granoblastic matrix. The large biotite flakes occur on the mylonitic matrix and were crushed and altered by the fractures formed during the Tertiary movements.

ATKINSON (1956) reported staurolite from the east of Monacofjellet, Grampianfjella. It is likely to conclude, from the occurrences of stilpnomelane and chloritoid in the lower grade rocks and staurolite, almandine–garnet and sillimanite in the higher grade ones, that the Hecla Hoek rocks of this area were metamorphosed under the conditions which correspond to the intermediate temperature/pressure facies series, in a range from greenschist facies to upper amphibolite facies.

The glaucophane–bearing rocks and eclogite of the Vestgötabreen Formation have different characteristics from the other Hecla Hoek rocks and will be discussed in a seperate article of this issue (OHTA, this volume).

Acknowledgements

The authors wish to express their thanks to Dr. T. GJELSVIK, Messrs T. SIGGERUD, H. MAJOR of Norsk Polarinstitutt, and Mr. E. TVETEN of Norges Geologiske Undersøkelse, for the information from their field surveys. Acknowledgement is also due to our field assistants, to the technical staffs of the institute, and to Dr. Y. KRISTOFFERSEN for the improvement of English.

References

ATKINSON, D.J., 1954: The geology of Prince Charles Foreland and adjacent parts of northwestern Spitsbergen. Ph.D. thesis, London Univ.

— 1956: The occurrence of chloritoid in the Hecla Hoek Formation of Prince Charles Foreland, Spitsbergen. *Geol. Mag.* **93**: 63–71.

— 1960: Caledonian tectonics of Prins Karls Forland. *21st Intern. Geol. Congr.* **21** (19) :17–27.

— 1963: Tertiary rocks of Spitsbergen. *Bull. Am. Ass. Petrol. Geol.* **47** (2): 302–323.

BIRKENMAJER, K., 1972: Tertiary history of Spitsbergen and continental drift. *Acta Geol. Polonica* **22**: No. 2: 193–218.

— 1975: Caledonides of Svalbard and plate tectonics. *Bull. Geol. Soc. Denmark* **24**: 1–19.

BIRKENMAJER, K. and NAREBSKI, W., 1960: Precambrian amphibolite complex and granitization phenomena in Wedel-Jarlsberg Land, Vestspitsbergen. *Studia Geol. Polonica* **4**: 37–82.

CHALLINOR, A., 1967: The structure of Brøggerhalvøya, Vestspitsbergen. *Geol. Mag.* **104**: 322–336.

DINELEY, D.L., 1958: A review of the Carboniferous and Permian rocks of the west coast of Vestspitsbergen. *Norsk Geol. Tids.* **38**: 197–217.

GJELSVIK, T., 1974: A new occurrence of Devonian rocks in Spitsbergen, *Norsk Polarinst. Årbok* 1972: 23–28.

GOBBETT, D.J. and C.B. WILSON, 1960: The Oslobreen series, Upper Hecla Hoek of Ny Friesland, Spitsbergen. *Geol. Mag.* **97**: 441–460.

HARLAND, W.B., 1969: Contribution of Spitsbergen to understanding of tectonic evolution of North Atlantic region. *Am. Ass. Petrol. Geol., Memoir* **12**: 817–851.

HARLAND, W.B. and C.B. WILSON, 1956: The Hecla Hoek succession in Ny Friesland, Spitsbergen. *Geol. Mag.* **93**: 265–286.

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**: 70–97.

HARLAND, W.B. and W.T. HORSFIELD, 1974: West Spitsbergen orogeny in Mesozoic–Cenozoic belts. Date for orogenic studies (ed. A.M. SPENCER), *Geol. Soc. London special publication* No. 4: 747–755.

HJELLE, A., 1962: Contribution to the geology of the Hecla Hoek Formation in Nordenskiöld Land, Vestspitsbergen. *Norsk Polarinst. Årbok* 1961: 83–95.

— 1969: Stratigraphical correlation of Hecla Hoek successions north and south of Bellsund. *Norsk Polarinst. Årbok* 1967: 46–51.

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

LOWELL, J.D., 1972: Spitsbergen Tertiary orogenic belt and the Spitsbergen Fracture zone. *Bull. Geol. Soc. Am.* **83**: 3091–3102.

MAJOR, H. and T.S. WINSNES, 1955: Cambrian and Ordovician fossils from Sørkapp Land, Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 106: 1–47.

SMULIKOWSKI, W., 1968: Some petrological and structural observations in the Hecla Hoek succession between Werenskioldbreen and Torellbreen, Vestspitsbergen. *Studia Geol. Polonica* **21**: 97–161.

TYRRELL, G.W., 1924: The geology of Prince Charles Foreland, Spitsbergen. *Trans. Roy. Soc. Edinburgh* **53** (2) (No. 23): 443–478.

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