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Winfried K. Dallmann

Notes on the geology of Prins Karls Forland

Review and results of geological mapping and investigations in 2012-14

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Address:

Winfried K. Dallmann
Department of Geosciences
UiT The Arctic University of Norway
P.O. Box 6050, Langnes, NO-9037 Tromsø

Framsenteret/Fram Centre, P.O. Box 6606, Langnes, NO-9296 Tromsø
www.npolar.no, post@npolar.no

Cover photo: Northwestern coast of Prins Karls Forland, view from Horneflya towards Fuglehukfjellet

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Abstract

Three geological field seasons on Prins Karls Forland (PKF) were carried out in 2012, 2013 and 2014 by the Norwegian Polar Institute, mainly in the northern and central parts of the island. Work has not been continued since and will probably not be completed by the involved scientists. This report summarises the new map data as well as preliminary results and interpretations and provides a basis for future research and mapping.

Our work focussed on careful remapping of the island and on controversial issues in the previous literature. Emphasis was put on basement-related topics, which were supposed to have much higher potential for finding new results than the better investigated Palaeogene strata in the northeast of the island.

The metamorphic basement of PKF is subdivided into a northern and a southern tectonic block with basically very different stratigraphic records, although both are presumably of Neoproterozoic age. Only the northern block has been re-investigated in detail so far. It is made up of two contrasting lithostratigraphic groups, the older Grampianfjella Group (metapsammitic) and the Scotiafjellet Group (calcareous/metapelitic). The lower section of the former is amended with the carbonate-prone Craigtoppane Formation and various scattered, correlated units, as well as chloritic lithologies possibly representing a meta-igneous unit. This unit is deformed into a retrogressed shear zone separating the Grampianfjella Group from the underlying, high-grade Pinkie unit. The shear zone represents a thrust contact established during the Ellesmerian Orogeny.

As for the Palaeogene deposits, major new results concern merely the basal conglomerates, of which the Sutorfjella conglomerate (NW PKF; earlier suggested Neoproterozoic, Devonian or Palaeogene age) with some certainty now is correlated with the Selvågen Formation (NE PKF). It therefore represents the initial stage of graben development in the De Geer Transform Fault Zone between Greenland and the Barents Shelf.

New light is also cast on the structural development. The considerably elongate shape of the island, situated between and parallel with the Forlandsundet Graben and the continental margin, is caused by its position in the De Geer Transform Fault Zone. Significant faulting is linked to the transform margin (mainly Eocene) and the superimposed rifted margin (mainly Oligocene) of Svalbard, but restricted to the brittle deformation regime.

The ductile fabric of the basement, expressed by penetrative foliations, isoclinal folding and ductile shear zones/thrusts, characterises mainly the pelitic and calcareous lithologies. Newly published results suggest that these may be related to the Ellesmerian Orogeny, although Caledonian elements cannot be excluded.

Brittle and semi-brittle deformation, including map-scale folding of the island, is entirely assigned to Palaeogene deformation, including fold-thrust tectonics related to the early Eocene West Spitsbergen Fold Belt and the Eocene-Oligocene transform movement in the De Geer Transform Fault Zone. There is a system of overlapping and attenuating, stacked thrust faults, combined with a change in predominant vergence from easterly to westerly directions across a NNW-SSE striking axial zone, reminiscent of a flower-like structure. This suggested transpression could have occurred during the time of fold belt formation in Spitsbergen, but has to be elaborated by further work.

The cross-cutting young, brittle fault system relates to later graben formation and deposition of the mostly late Eocene Buchananisen Group. This occurred in trantensional and interveningly transpressional settings during transform movement in the De Geer Transform Fault Zone. This is overprinted by the youngest tensional movements thought to have occurred during initial sea-floor spreading across the De Geer Transform in the early Oligocene. The youngest Paleogene strata exposed on the eastern side of the Forlandsundet Graben, is supposed to have been deposited at this stage.

Published vitrinite reflectance and other exhumation-related data are seen in context with the elaborated structure, resulting in a tentative conceptual model, which will have to be reconsidered and refined after more field data have been collected.

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Introduction and objective

During three field seasons (2012, 2013, 2014), the Norwegian Polar Institute (NPI) carried out geological field work on Prins Karls Forland (PKF). The author worked during these years at the Institute. The aim was to increase our understanding of the geological structure of the island, its tectonic setting and history, as well as its possible correlation with the geology of western Spitsbergen. Special attention was given to the island's position in the De Geer Transform Fault zone between Greenland and the Barents Shelf during the North Atlantic rift in the Palaeogene. The ultimate output of the work was supposed to be a geological map as part of NPI's geological mapping programme, as well as relevant scientific publications. Work was discontinued from 2015 onward.

This report aims at providing the preliminary results and putting them into a context with previous work. Future continuation of these efforts should be based on the attained knowledge and data; double work should be avoided. As the results are not considered to be mature for publication in the form of complete maps or scientific articles, they are summarised and compiled here in a report for the benefit of future research and mapping.

Field cooperation with scientists from the University of Uppsala, Sweden, and the AGH University of Science and Technology, Kraków, Poland, during the field seasons 2013 and 2014 is highly acknowledged. Their contributions to the geological map, which were provided with the goal of being incorporated into NPI's final geological map, are used here with references to the respective field geologists. Other contributions are referred to as pers. comm.

The main objectives of this report are bedrock-related and include structural geology, stratigraphy and interpretations of the geological development in terms of plate tectonics and orogenesis, as well as to sum up all available map data. Other observations during field work (for instance, concerning Quaternary geology, ore geology, etc.) are included as additional notes at the end. Rock analyses have so far not been carried out, except for those referred to, mainly authored by our cooperation partners. The observed field relations are illustrated by photos.

Previous work

Early exploration (pre-World War II)

The earliest published geological descriptions from Prins Karls Forland (PKF) are those of individual localities of basement rocks (previously called "Hecla Hoek") from Drasche (1874) and Nordenskiöld (1876). Lee (1908) investigated black basement limestones collected by W.S. Bruce and found bryozoan and a number of brachiopod fossils leading to the assumption that Carboniferous and Permian sediments occured on the island.

W.S. Bruce, who joined the Prince of Monaco expeditions of 1906 and 1907, discovered the occurrence of Tertiary sediments in eastern Prins Karls Forland (Bruce 1907, 1908). These were further described by Nathorst (1910) and Hoel (1912).

The first detailed descriptions were made by Craig (1916), who joined the Scottish Spitsbergen Expedition in 1914. He subdivided the geological record of the island into metamorphic basement ("Hecla Hoek"), the "Sutor conglomerates" and Tertiary sediments. He also re-investigated Bruce's samples and stated that most of them were erratic blocks and not *in situ*. Craig considered the basement to be of Silurian age due to a ressemblance with the Silurian sucession of Bjørnøya. The Sutor conglomerate was considered to be clearly younger than the "Hecla Hoek" rocks and probably of Devonian age.

Holtedahl (1914) subdivided the basement into (from older to younger) Northern Grampian, Mt. Scotia and Ferrier Peak 'series', thus forming the basis for the present subdivision. Their age was suggested to be Ordovician on the basis of resemblance with the Ordovician strata of Bjørnøya and Spitsbergen.

The pre-glacial platform and raised beaches of PKF were firstly described by Peach (1916).

The work of Hoel (1920) about Svalbard's coal and ore deposits contains a note on the iron ore in northern PKF.

For early geographical and general observations see also Wordie (1921) and Tyrrell (1921).

Tyrrell (1924), from the University of Glasgow, provided the first complete and detailed geological survey of Prins Karls Forland. He described the basement as "intricately folded and intersected by great thrust planes and shatter-belts". He recognised a different tectonic regime in the Ferrier Peak series (Southern PKF) from that of the Northern Grampian / Mt. Scotia series (Northern PKF). The latter were described as the most tectonised, showing easterly to north-easterly vergence and overfolding. Age relations were considered more uncertain. The Ferrier Peak series was thought to have a fault boundary with the northern basement. He saw little evidence for the Mt. Scotia series to overlie the Northern Grampian series with a primary boundary and suggested instead a thrust contact. Tyrrell provided detailed lithological and structural descriptions of individual localities and sections in both the basement and the Tertiary sediments to the extent that they should be carefully read and considered in a modern context. Though not having seen the Sutor conglomerate, Tyrrell suggested it might be of Tertiary age based on the obvious presence of Tertiary sediments on the island.

Frebold (1935) summarised the state of knowledge at that time, based on Tryrrell (1924).

The Cambridge scholar environment (1950s to 1990s)

D.J. Atkinson published a number of articles on various works funded by the Harvard University, Cambridge, during the decade following his Ph.D. thesis at the University of London (Atkinson 1954). His first short article discussing the occurrence of chloritoid in high-strain zones in the basement (Atkinson 1956) was followed by a comprehensive analysis of the tectonic framework considered by him as entirely Caledonian (Atkinson 1960). Like Tyrrell (1924), he subdivided the island's basement into a northern and a southern tectonic block along a roughly N-S trending line passing through Scotiadalen. He further subdivided the Grampian and Ferrier Peak series and inferred the presence of thrust sheets in the succession, although – as opposed to Tyrrell – with a SW-ward thrust direction.

He defined several thrust sheets, which, however, were poorly mapped. He also established a sequence of structural events. Astonishingly though, he did not refer to the quite detailed previous descriptions by Tyrrell (1924) at all.

In a subsequent article, Atkinson (1962) discussed the tectonic control on Tertiary sedimentation concluding with a "taphrogeosynclinal" tectonic environment paralleling the Caledonian structural trend. A first, rough stratigraphic subdivision of the Tertiary rocks (Selvågen conglomerate and McVitie Formation) was introduced. His subsequent work (Atkinson 1963) dealt with the Tertiary rocks of Svalbard as a whole. He argued for a younger Tertiary age of the rocks on PKF than those of the Central Tertiary Basin of Spitsbergen on the basis of the overall tectonic development of the archipelago.

The next effort in investigating the basement geology was done by two Ph.D. students from the University of Cambridge; A. Morris (1979) and G.M. Manby (1978). While Morris mapped and structurally and petrologically analysed the Geikiebreane area of the southern tectonic block, Manby did so with the southern part of the northern block. One result was the stratigraphic subdivision of the former Ferrier Peak series into ten formations (Morris 1979), and that of the Grampian and Scotia series into five and three formations, respectively (Manby 1978). The model of southwest-verging thrusts and folds in a Caledonian complex, recumbent, polyphase fold system was refined. The sequence of structural events was further elaborated.

W. Brian Harland having been the mentor of the Cambridge scholars for decades, established a stratigraphic correlation of the basement rocks of PKF and Spitsbergen, where the Ferrier Group (former Ferrier Peak series) was thought to correlate with the Vendian tilloids of Spitsbergen (Comfortlessbreen Group), while the Scotia and Grampian groups (in this age order) were considered as younger, probably of Early Palaeozoic age (Harland et al. 1979). The Sutor conglomerate was seen as a part of the pre-Caledonian succession.

Subsequent studies were carried out by Morris (1981, 1982) on greenschist facies metamorphism and deformation mechanisms in the Ferrier Group, and by Manby (1983a) on the occurence of primary scapolite in the higher-grade Pinkie Group (Harland et al. 1979) as well as a reappraisal on chloritoid formation (Manby 1983b). In a more comprehensive article, Manby (1986) further elaborated his model for the polyphase deformation of the northern tectonic block. Although he defined a Mid-Cenozoic, co-axial folding event overprinting the main Caledonian structural framework, corresponding in age to the Tertiary West Spitsbergen Fold-Thrust Belt, it was not clarified in the article how this event relates to the regional folds mapped and seen in the area.

Morris (1989) defined the tectonic boundary between the northern and southern basement blocks of PKF as the Scotiadalen Fault and related it to the dextral transform motion between the Greenland and Barents margins during the opening of the North Atantic Ocean. However, it was neither mapped nor properly investigated.

Harland et al. (1993), within a review of the Vendian geology of Svalbard, merely summarised the basement stratigraphy of PKF including a short discussion of its depositional ages.

Harland (1999) in his book "The Geology of Svalbard" summarised the decades-long work in Svalbard by the Cambridge scholar environment, including that on PKF, and discussed it in the context of other work (see below).

Cooperation between the universities of Cambridge and Münster led to a review of the fossil content of the Tertiary rocks of Svalbard, including PKF, by Lehmann (1978).

Cooperation between the Havard University, Cambridge, and the Norwegian Polar Institute resulted in the identification of Late-Neoproterozoic fossils in the Scotia Group (Knoll & Ohta 1988, Knoll 1992). The age was first indicated to be of late Vendian (now: late Ediacaran), later re-determined as early Vendian (now: late Cryogenian to early Ediacaran).

Soviet-Russian investigations (1960s and 1970s)

Soviet-Russian geological research in Svalbard was quite active during these decades, but only few of their reports and subsequent publications were concerned with PKF. Livšic & Panov (1965) mapped the Tertiary succession f in some detail and defined four new formations substituting Atkinson's (1962) McVitie Formation, which were lithologically and sedimentologically described (Livšic 1967). Livšic's later work (1973, 1974) dealt with the Tertiary succession and platform structure of Svalbard as a whole, while adding plant and mollusc fossil findings on Sarsøyra (Spitsbergen side of Forlandsundet Graben) to the ealier known data.

Norwegian Polar Institute (1968-1999)

In the framework of a geological mapping programme for an overview map of the Svalbard archipelago, the Norwegian Polar Institute carried out field mapping on PKF between 1968 and 1975. This work formed the basis of rough maps to the scale of 1:500 000 (Flood et al. 1971; Hjelle & Lauritzen 1982).

Hjelle et al. (1979), based on their earlier mapping, introduced an independent stratigraphic subdivision of the basement rocks with descriptive, lithological names. They also proposed a tentative correlation with the basement stratigraphy of adjacent parts of Spitsbergen, with the suggested Vendian tillitoid horizons as markers. The equivalents of the Scotia and Grampian groups were considered to be of Mesoproterozoic (Middle "Hecla Hoek") age, with the Scotia Group as the oldest.

Gjelsvik (1988, unpubl.) provided a detailed lithological and structural description of the Sutor conglomerate and favoured a Devonian age of the deposits.

Hjelle et al. (1999) edited the Kongsfjorden map sheet to the scale of 1:100 000. It contains the northern part of PKF and is based on a synthesis of the results from the Münster theses (see below) and the older NPI material. A new, local stratigraphic nomenclature based on lithologies was applied.

Dallmann (1999) in his "Lithostraphic Lexicon of Svalbard" reviewed and fomally defined the Tertiary formations of PKF on the basis of available logged type sections.

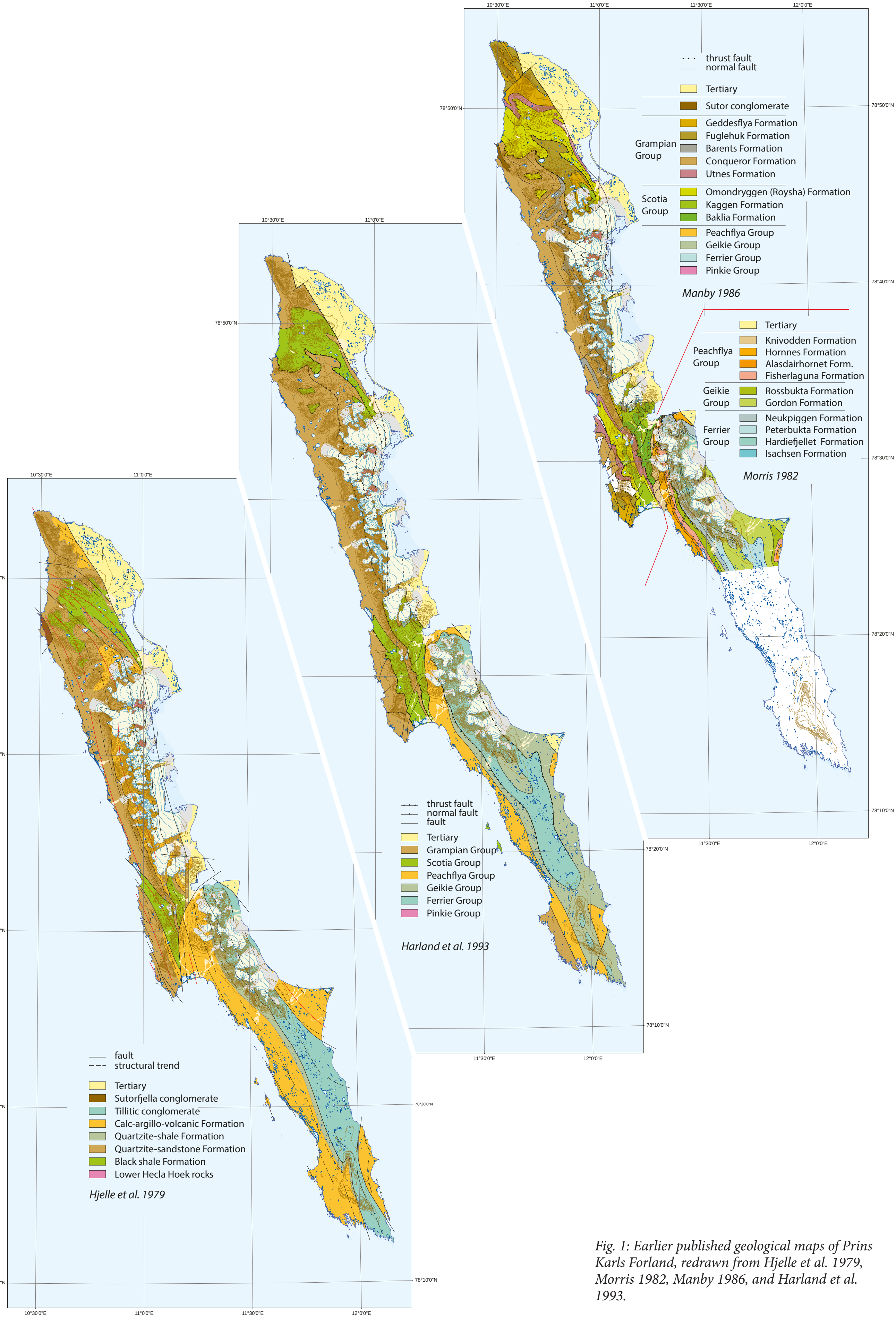


Fig. 1: Earlier published geological maps of Prins Karls Forland, redrawn from Hjelle et al. 1979, Morris 1982, Manby 1986, and Harland et al. 1993.

Universities of Kiel and Münster (1986-2000)

The Universities of Kiel and Münster let students map and investigate areas on PKF as part of their master theses. Kubisch (1986), Magnus (1986), Pagels (1986) and Wollenburg (1986) from Kiel each studied one or two formations of the Tertiary succession under the supervision of J. Thiede. Klee (1990), Mersmann (1990) and Post (1990) from Münster studied areas within the basement in the central part of northern PKF under the supervision of F. Thiedig and K. Piepjohn. Doubtful Early Palaeozoic fossils were found in conglomerate pebbles of what now is called the Macnairrabbane Window.

Piepjohn et al. (2000) published a structural analysis and elaborated a sequence of structural events in the basement area mapped through the Münster theses. Consistent with Tyrrell (1924), but opposed to the Cambridge work (see above), he postulated a northeastern vergence of both the Caledonian and the Tertiary structures. He also described the Sutor conglomerate and tentatively assigned a Devonian age to it.

Other work

The work listed below is concerned with the Forlandsundet Graben and its Tertiary sedimentary fill. Apart from the above-mentioned contributions, no newer work on the basement geology of PKF has to our knowledge been carried out.

Borehole

A cored stratigraphic borehole in the context of hydrocarbon exploration was drilled at Sarstangen (UTM 33X 422846-8741814) by the companies Terratest A/S and Norsk Polarnavigasjon A/S in 1974. It reached 1113 m depth, went mainly through coarse conglomerates with finer clastic interbeds (Sarstangen and Sarsbukta formations), meeting the metamorphic basement at 1050 m (notes from confidential conversations). Details have not been published.

Thesis

The most comprehensive work on the Tertiary sediments in the Forlandsundet Graben was written as a *cand. real.* thesis (hovedoppgave) by Rye Larsen (1982) from the University of Bergen. Based on the stratigraphic subdivision by Livšic (1967, 1973, 1974), adding one formation, he presented a careful description and analysis of the sediments and their structural position, ending up with the interpretation of a series of alluvial to submarine fan deposits in a basin (Forlandsundet Graben) overlying the active transform plate boundary between the Barents and Greenland shelves.

Fossil ages of the Tertiary sediments

All of the fossil ages that have been used to determine the age of the Tertiary sediments in the Forlandsundet Graben are from the Sarsøyra/Sarsbukta and Kaffiøyra area on the Spitsbergen side of the graben. Manum (1960) described the first dinoflagellates indicating an Eocene-Oligocene age. Plant fossils, which were unknown from the Central Tertiary Basin, were found by Manum (1962). Livšic, based on plant and mollusc findings (1967, 1973, 1974), as well as Atkinson (1963) assigned a Late Eocene to Early Oligocene age, while Zastawniak (1981) determined a Late Paleocene to Early Eocene age from the presence of Metasequoia and Trochodendroides remains. Feyling-Hanssen & Ulleberg (1984) argued for a most probable Middle to Upper Oligocene age based on foraminifer findings. A Late Eocene to Early Oligocene age was also proposed based on dinoflagellates for the Tertiary sediments at near-by Renardodden (Head 1984). Manum & Throndsen (1986) added new dinoflagellate findings and reviewed earlier age discussions, concluding with a Late Eocene age of the sediments at Sarsbukta. Dallmann (1999) reviewed the lithostratigraphic units applying the mostly accepted, although not formation-wise defined Late Eocene to Early Oligocene age.

Manum & Throndsen (1986) also reported vitrinite reflectance data of Rm=0.3 (max. 2 km overburden) from Sarsbukta, while values on PKF were considerably higher, Rm=4 (6-8 km overburden).

Forlandsundet Graben

A number of publications between 1981 and 1995 by authors from various universities, other research institutes and oil companies, were concerned with the structure and development of the Forlandsundet Graben. The overall goal of these investigations was to reconstruct the development of the plate boundary between the Greenland and Barents margins during the opening of the North Atlantic.

Wójcik (1981) mapped and investigated the Sarsøyra and Kaffiøyra area on the Spitsbergen side of the graben and described 15 selected localities covering basement, Tertiary and Quaternary with fault contacts and primary unconformities. The mapped fault system was analysed and subdivided into syn-sedimentary, post-sedimentary and Quaternary movements.

Steel et al. (1985), reviewing a vast amount of data, discussed the development of Palaeogene basins in and around Svalbard in the context of plate boundary development with a complex strike-slip history involving both transtension and transpression. The Forlandsundet Graben was interpreted to be situated within the West Spitsbergen Fold-Thrust Belt as a late-orogenic collapse structure in a transpressional to transtensional setting.

Lepvrier (1990) carried out a structural analysis of a limited amount of field data, resulting in a sequence of events from dextral transpression (20° E) with the initial generation of a pull-apart basin in a releasing bend of the plate boundary, then orthogonal compression (70-80° E; similar to the Central Tertiary Basin) and final minor NNW-SSE to N-S extension.

Kleinspehn & Teyssier (1992) pointed out the complexity of development of the basin during transform movement, considering the depositional contacts with the basement, SW-ward increasing vitrinite reflectance, faults affecting the graben fill at various stages of sediment consolidation, as well as locally observed ductile fabrics and generation of mica in the graben fill. Extension that gave the present graben structure its final shape was considered to be a late tectonic overprint. The authors opposed earlier pull-apart basin models due to inconsistencies with the basin geometry, but blamed the lack of sufficient data, including exact age data, for the unability to solve the question of the origin of the basin.


Fuglehuken
Carmichaelpynten
McVitiepynten
Forlands-
flaket
Flåvatnet
Stormneset
Heemskerckneset
Richardlaguna
Ferskvass-
bukta
Niggbukta
Vernodden
PRINS
CO-
KARLS
FORLAND
Kapp Sietoe
Blokkvatnet
Rottenburgpynten
Fuhrmeisterstranda
Murraypynten
Murraybreen
Millerbreen
Fallbreen
Grimaldi-
bukta
Buchananisen
Skurvodden
Mickeryholmen
Trocaderostranda
FLAKET
A
A'
B
B'
40'
11°

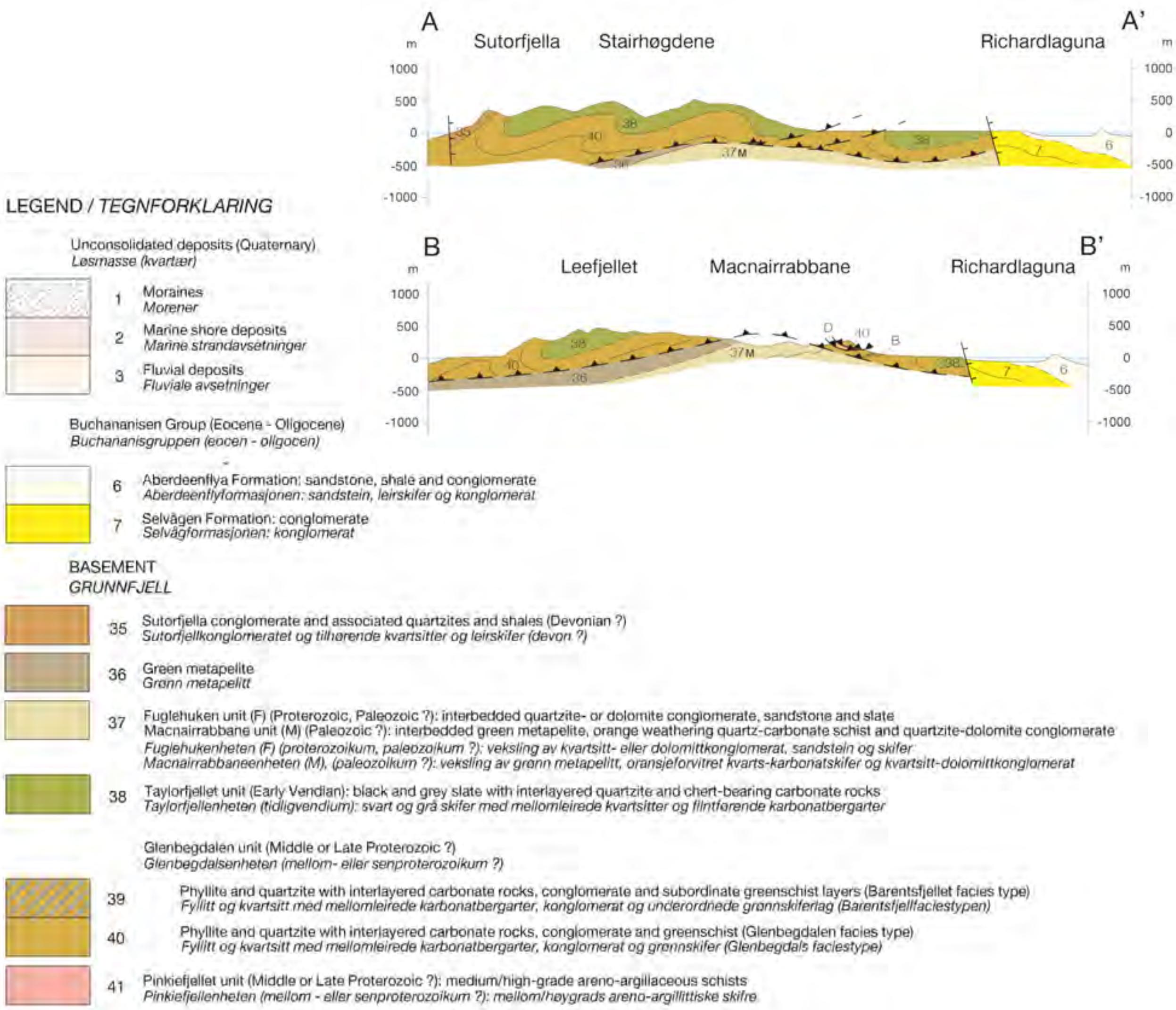


Fig. 2: Geological map (left) and vertical cross sections (right) of the northern part of Prins Karls Forland, excerpt from Norwegan Polar Institute's map by Hjelle et al. (1999). Scale 1:100 000.

Gabrielsen et al. (1992) focussed on the convergent structural features in the Tertiary sediments on PKF which were thought to indicate that the trough initially developed under local transtension in an overall transpressional environment along the transform plate margin. Later subsidence created large-scale drag structures along the graben margins after the transition into an overall transpressional regime. The authors reconfirmed the need of better age control on the sediments in order to pinpoint deformational events in time.

Nøttvedt et al. (1992, abstract) focused on the stratigrahy indicating that the present margins of the depositional trough on PKF are late structures formed by backstepping of the marginal fault system; the original basin was considered to be much wider. Structures point to an overall shearing rather than a post-orogenic collapse regime. The conglomerates at the eastern margin (Sarsøyra/Kaffiøyra) were seen to represent a late-stage infill decoupled from the main basin stratigraphy.

Krasil'ščikov et al. (1995) mapped the largely Quaternary-covered eastern graben margin from Sarstangen to Daudmannsodden by carrying out a geomagnetic survey. Subsurface structures were found to outline a boundary fault pattern consistent with a left-stepping, dextral en echelon arrangement overprinted by a later transverse fault system.

Diverging issues and interpretations in previous work

Previous works show strongly diverging interpretations, both when it comes to the stratigraphy and the structure of the basement, as well as the structural evolution of the Forlandsundet Graben. The following problems were identified from the previous literature prior to the recent field seasons. These issues were addressed in particular during field work, in addition to a careful remapping of the area.

Up and down in the basement stratigraphy of northern PKF

The Cambridge scholar environment (Manby 1978, 1986; Harland et al. 1979, 1993; Harland 1999), as well as Hjelle et al. (1979) considered the Scotia Group older than the Grampian Group (Fig. 1). These authors started their work in the strongly deformed Scotiadalen area. Piepjohn (responsible for the PKF part on NPI's A7G map sheet – Hjelle et al., 1999) and Piepjohn et al. (2000) argued for the opposite. Piepjohn's experience was only based on work in the northern part of northern PKF.

Age of basement formations

The age of the basement formations is extensively discussed in the description of Norwegian Polar Institute's A7G map sheet (Hjelle et al. 1999) on the basis of earlier work. Earlier interpretations vary from Early Palaeozoic (Holtedahl 1914; Craig 1916; Harland et al. 1979) to mostly Neoproterozoic (Hjelle et al. 1999) or a range from one to the other (Harland et al. 1993). One has to keep in mind that the interpreted up-and-down of the succession played an important role after the determination of Ediacaran microfossils in the Scotia Group (Knoll & Ohta 1988, Knoll 1992). It would be important to find further age indications and to verify or reject suggested stratigraphic correlations with other units in Svalbard.

Age of the Sutorfjella conglomerate

The age of the Sutor conglomerate has been proposed to be Proterozoic to Early Palaeozoic (Atkinson 1956; Harland et al. 1979, 1999), Devonian (Craig 1916; Gjelsvik 1888; Hjelle et al. 1999; Piepjohn et al. 2000) or Palaeogene (Tyrrell 1924; Rye Larsen 1982).

Fuglehuken – Macnairrabbane correlation

A lithological correlation of the Fuglehuken and Macnairrabbane units is suggested by some authors (Hjelle et al. 1979, 1999), while there is uncertain fossil indication that the Macnairrabbane unit is of Early Palaeozoic age (Piepjohn et al. 2000). The Fuglehuken unit, on the other hand, seems to underly the entire succession of the Grampian Group (Figs. 1, 2). Both their age and mutual structural relation are confusing and should be clarified.

Detailed subdivision of the Grampian Group

The Grampian Group has been subdivided in detail by Manby (1978) and Harland et al. (1993). Different units have quite similar descriptions suggesting that these subdivisions only apply locally. Still, they were extended to the entire northern block of PKF. The description of Hjelle et al. (1999) suggests that lateral variations are more distinct than the vertical development (Fig. 2). New field work should cast more light on this issue.

Thrust nappes and structural directions

Some previous works show thrust boundaries in places, where other works show primary contact relations (Figs. 1, 2). The most striking example is the Northern Grampian Thrust (Manby 1978, 1986; Harland 1993), which does not exist on Norwegian Polar Institute's map (Hjelle et al. 1999). New field work should pay particular attention to this issue. Also reports on the vergence of thrusting and folding diverge. While Atkinson (1956), Hjelle et al. (1999) and Piepjohn et al. (2000) report easterly to northeasterly thrust vergences, the Cambridge group (Manby 1978, 1986; Harland et al. 1993) reports westerly to southwesterly vergences and thrust directions. Do these reports address different structures in different areas, or are they divergent interpretations?

Age of fold and thrust structures

There is a general consensus that ductile structures and metamorphic mineral assemblages in the basement rocks are of Caledonian age. However, no age determination has ever been provided. It is less clear all over the literature, which of the large-scale folds and thrusts were thought to belong to the Caledonian Orogeny and which to the Cenozoic deformation, although Manby (1978, 1986) and Piepjohn et al. (2000) attempted a classification in their respective areas of investigation.

Boundary relations between the northern and southern structural blocks of PKF

Many authors have indicated that PKF is subdivided into two tectonic units divided by a north-south trending line across Scotiadalen (Tyrrell 1924; Atkinson 1956; Morris 1989). Hjelle et al. (1979) indicate such a tectonic boundary along the valley, but tentatively correlate the basement stratigraphies to the north and south of the boundary with each other. Manby (1978, 1986), Morris (1979, 1982, 1989) and Harland et al. (1993) did not correlate any stratigraphy across the Scotiadalen line (Fig. 1). Manby (1978), however, pointed out the existence of klippen consisting of lithologies from the southern block on the mountains of the northern block (Thomsonfjella). The structural and stratigraphic relations between these two tectonic blocks need to be clarified.

Tectonic setting of the Forlandsundet Graben

The complex development and lack of data for a proper interpretation of the tectonic and structural history of the Forlandsundet Graben have been pointed out by several authors (Kleinspehn & Teyssier 1992; Gabrielsen et al. 1992; Nøttvedt 1992), who oppose earlier interpretations as extensional collapse (Steel et al. 1985) or pull-apart origin (Lepvrier 1990). While the potential of finding more and better data in the Palaeogene sediments may be limited, one should continue to look for clues in the Palaeogene deformation of the adjacent basement.

Three NPI expeditions 2012-14

Field work in Prins Karls Forland (PKF) was carried out under the auspices of the Geological Mapping Programme of Svalbard to the scale of 1:100 000, for wich the Norwegian Polar Institute has the official mandate. The island Prins Karls Forland is covered by two map sheets (A8, southern two thirds of PKF, and A7, Kongsfjorden and northernmost third of PKF). The geological map A7 was published by Hjelle et al. (1999), but parts of the basement geology of PKF were not fully understood and correlations within the map sheet include compromises. None of the participating geologists in the recent expeditions had been to the area before. For this reason it was decided to start field work in this northern part of the island to become familiar with the stratigraphy and to gain control of the stratigraphic correlations and the structure of the area before proceding southward into more complex and disputed areas.

Work was planned to concentrate mostly on the basement-related issues, which were considered to be less understood and to have a higher potential in solving imminent problems through field mapping and on-site studies. Still, problems related to the Forlandsundet Graben and Palaeogene transform movement had to be addressed, simply because some of the related structures are cross-cutting the basement and – as it turned out – might be of high importance for the overall structure of the island.

A short overview of field work during the three recent summers is given below (Fig. 3). For more details the internal field reports (Geological field work in Prins Karls Forland 2012; 2013; 2014, all by W.K. Dallmann, Norwegian Polar Institute) can be consulted.

In summary, the first and third expeditions were quite successful, while bad weather hampered work during the second expedition.

Field work in 2012

Participants

Winfried Dallmann, geologist, Norwegian Polar Institute

Synnøve Elvevold, geologist, Norwegian Polar Institute

Tommaso Trentini, student of geology, field assistant (Univ. of Ferrara, Italy)

Markéta Šamánková, student of geology, field assistant (Univ. of Brno, Czech Republic)

Logistics

Equipment was delivered by *R/V Lance* to camp site on 26 June.

Partcipants arrived by helicopter from Longyearbyen on 29 June.

Field transportation was mainly on foot and by inflatable boat (one Zodiak Mark III).

A helicopter was at disposal for field work during two separate days.

Partcipants left by helicopter to Longyearbyen on 29 July.

Equipment was collected by *R/V Lance* from camp site on 5 August.

Photo 1: Camp site at Vernodden, July 2012.

Camp site (Photo 1)

West coast of PKF, 750 m northeast of Vernodden.

Position: 78° 48.29' N / 10° 31.26' E.

It was planned to move the camp after two weeks, but this was cancelled because remapping of the northern area needed more time.

Weather conditions

Generally good, few strong winds and very little rain. Fog or low clouds did not hamper field work, but high waves often prevented the use of the inflatable boat. During the two days when the helicopter was at disposal, there were some restictions due to the weather: On the first day strong winds prevented landing on high ridges; on the second day emerging sea fog demanded an early return to the camp.

Results overview

Ramapping of the area north of Glenbegdalen and west of Macnairrabbane, Sildresletta and Aberdeenflya;

Revision of basement stratigraphy in the area;

Determination of primary vs. thrust contacts;

Collection of data for question of correlation between Fuglehuken and Macnairrabbane units;

Observations of metamorphic gradients;

Review of the geology of the Sutor(fjella) conglomerate;

Observations of Quaternary geological features.

Field work in 2013

Participants

Norwegian – Polish – Swedish collaboration:

Winfried Dallmann, geologist, Norwegian Polar Institute

[Synnøve Elvevold, geologist, Norwegian Polar Institute – supposed to arrive later, cancelled due to bad weather]

Jerzy Czerny, geologist, AGH Kraków, Poland

Photo 2: Camp site at the southern coast of Selvågen, August 2013.

Jarosław Majka, geologist, Univ. of Uppsala, Sweden

Karolina Kośmińska, student of geology (AGH Kraków, Poland)

Grzegorz Ziemniak, student of geology (AGH Kraków, Poland)

Iwona Klonowska, student of geology (Univ. of Uppsala, Sweden)

Logistics

Heavy equipment was delivered by *R/V Lance* to camp site in the middle of July.

Partcipants and remaining equipment arrived by *R/V Lance* from Longyearbyen on 11 August.

Field transportation was mainly on foot and by inflatable boats (two Zodiaks Mark III).

Partcipants left by helicopter to Longyearbyen on 28 August (before schedule, due to bad weather).

Equipment was collected by helicopter to Longyearbyen / Ny-Ålesund on 28 August.

Camp site (Photo 2)

East coast of PKF, south side of Selvågen.

Position: 78° 32.61' N / 11° 18.65' E.

Weather conditions

The weather conditions were quite bad, with strong winds and exceptionally much rain. Damage to tents on the third day, one storage tent lost in storm. For large parts of the time no meaningful work could be carried out. Only one beautiful day. Temperatures were relatively high, around 8-10° C.

Results overview

Mapping of the area around Grimaldibukta and Buchananryggen, some small areas around Selvågen and western Doddsfjellet to Alasdairhornet;

Investigation of the fault line in Scotiadalen;

Remapping of some graben margin faults and lower part of Palaeogene stratigraphy;

Structural observations in the Grimaldibukta area.

Field work in 2014

Participants

Norwegian – Polish – Swedish collaboration:

Winfried Dallmann, geologist, Norwegian Polar Institute

Synnøve Elvevold, geologist, Norwegian Polar Institute

Jarosław Majka, geologist, Univ. of Uppsala, Sweden

Maciej Manecki, geologist, AGH Kraków, Poland

Jerzy Czerny, geologist, AGH Kraków, Poland

Karolina Kośmińska, student of geology (AGH Kraków, Poland)

Grzegorz Ziemniak, student of geology (AGH Kraków, Poland)

Aleksandra Puławska, student of geology (AGH Kraków, Poland) (arrived when Dallmann, Elvevold and Majka left)

Logistics

Heavy equipment was delivered by *R/V Lance* to camp site on 7 July.

Partcipants and remaining equipment arrived by helicopter from Longyearbyen on 22 July.

Field transportation was mainly on foot and by inflatable boats (two Zodiaks Mark III).

A helicopter was stationed in camp from 1 to 5 July, and at disposal on 12 July.

Some partcipants left by helicopter to Longyearbyen on 15 August, the others on 31 August by boat.

Equipment was returned by boat to Longyearbyen together with the remaining participants.

Camp site (Photo 3)

East coast of PKF, north side of Selvågen.

Position: 78.55° N / 11.26° E.

Weather conditions

Generally good, few strong winds and little rain – except for the first few days and a short period in the middle of August. Temperatures were normal to low, 3-7° C, occasionally down to 0° or up to 10° C.

Photo 3: Camp site at the northern coast of Selvågen, July 2014.

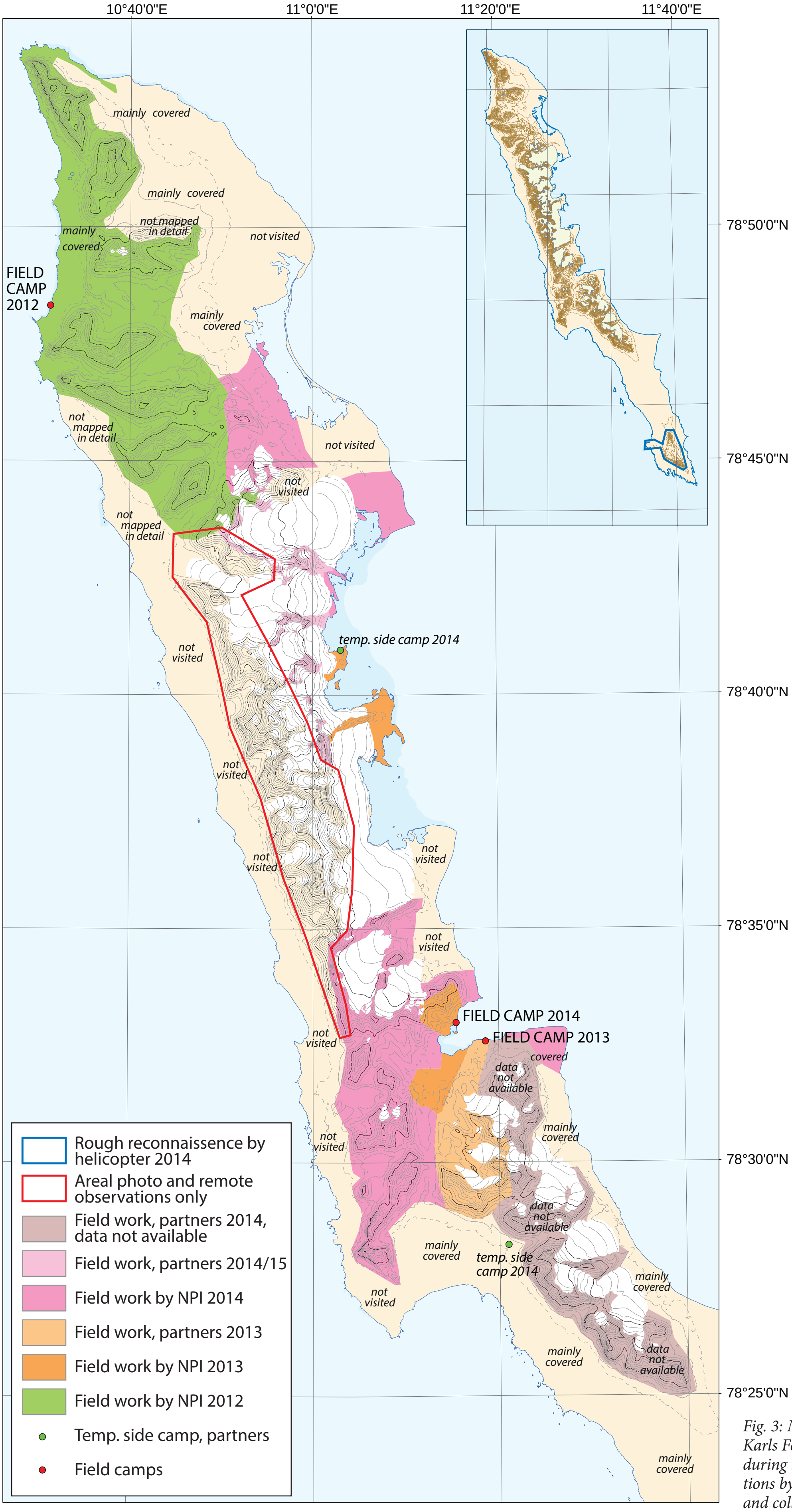


Fig. 3: Map of northern and central Prins Karls Forland showing working areas during the three geological field expeditions by the Norwegian Polar Institute and collaboration partners.

Results overview

Mapping of the following areas:

- Macnairrabbane and plain towards Richardlaguna
- Murraybreen – Djevletommelen
- Selvågen – Thomsonfjella – Krokodillen (except for eastern coastal plain)
- Selvågen – Tvihyrningen – Scotiadalen (except for western coastal plain)
- Mountain area around Geikiebreane

Stratigraphic observations in basement rocks;

Structural investigation of fold and thrust patterns, as well as major fault lines;

Investigation of the Pinkiefjellet unit and adjacent carbonate formations (by Polish and Swedish collaboration partners);

Observations of Forlandsundet Graben structures;

Observations of Quaternary geological features.

Geological outline of Prins Karls Forland

This geological outline is based on previously known data (see Section *Previous work* above), modified under consideration of the results from the recent expeditions. The stratigraphic names used herein are older names and new names defined by us, with the corrected spelling according to the rules and recommendations for naming stratigraphic units in Norway (Nystuen 1986, 1989; Dallmann 1999). The main difference is that full geographic locality names like they appear on modern maps must be used instead of abbreviated ones, for instance Grampianfjella Group instead of Grampian Group and Scotiafjellet Group instead of Scotia Group. For references, if not provided here, see *Previous work*.

Tectonic setting

Prins Karls Forland (PKF) is a markedly elongate island, 80 km long in NNW-SSE direction and only 5-12 km broad. It is situated west of, and parallel to, the western coast of Spitsbergen, and separated from it by the shallow strait Forlandsundet. The latter constitutes a Palaeogene depositional basin and a graben structure. Palaeogene sediments occur on the eastern side of the island. The bulk of the bedrocks are metamorphic basement. The elongate shape and parallel orientation of the island with the present continental margin, the western boundary of the Barents Shelf, strongly suggests that its origin is connected with the De Geer Transform Fault between Svalbard and the Greenland Shelf during the opening of the North Atlantic Ocean during the Eocene (Myhre et al. 1982) (Fig. 4).

In general terms, PKF is an uplifted block of metamorphic basement between the continental margin to the west and the Forlandsundet Graben to the east. Its northern and southern submarine continuations are roughly mapped by seismics (Eiken 1994) and gravimetry (Olesen et al. 2010), but their basement geology is unknown. The island is subdivided into two quite different basement regimes, separated by the curved though roughly north-south trending Baklia Fault Zone (Scotiadalen Fault of Atkinson 1960; Morris 1989) (Figs. 5-9).

Basement lithologies

The northern basement block consists mainly of two distinct lithostratigraphic groups, the Grampianfjella Group and the Scotiafjellet Group, the latter containing microfossils of Ediacaran age (Knoll & Ohta 1988, Knoll 1992). We consider the Grampianfjella Group to be older and to have a depositional contact with the Scotiafjellet Group (in contrast to some previous work), it is supposed to be Neoproterozoic. There is no documented stratigraphic correlation with basement rocks on adjacent Spitsbergen, yet there is some lithological ressemblance with the Aavatsmarkbreen and Sarsøyra formations just east of the Forlandsundet Graben, although these are reported to contain Early Palaeozoic fossils (see age discussion by Hjelle et al. 1999).

The Grampianfjella Group consists mainly of metapsammites, quartzites and slates, occasionally calcareous, with interbeds of conglomerates at lower levels and phyllitic formations at upper levels. The Scotiafjellet Group consists mainly of thick, black, calcareous

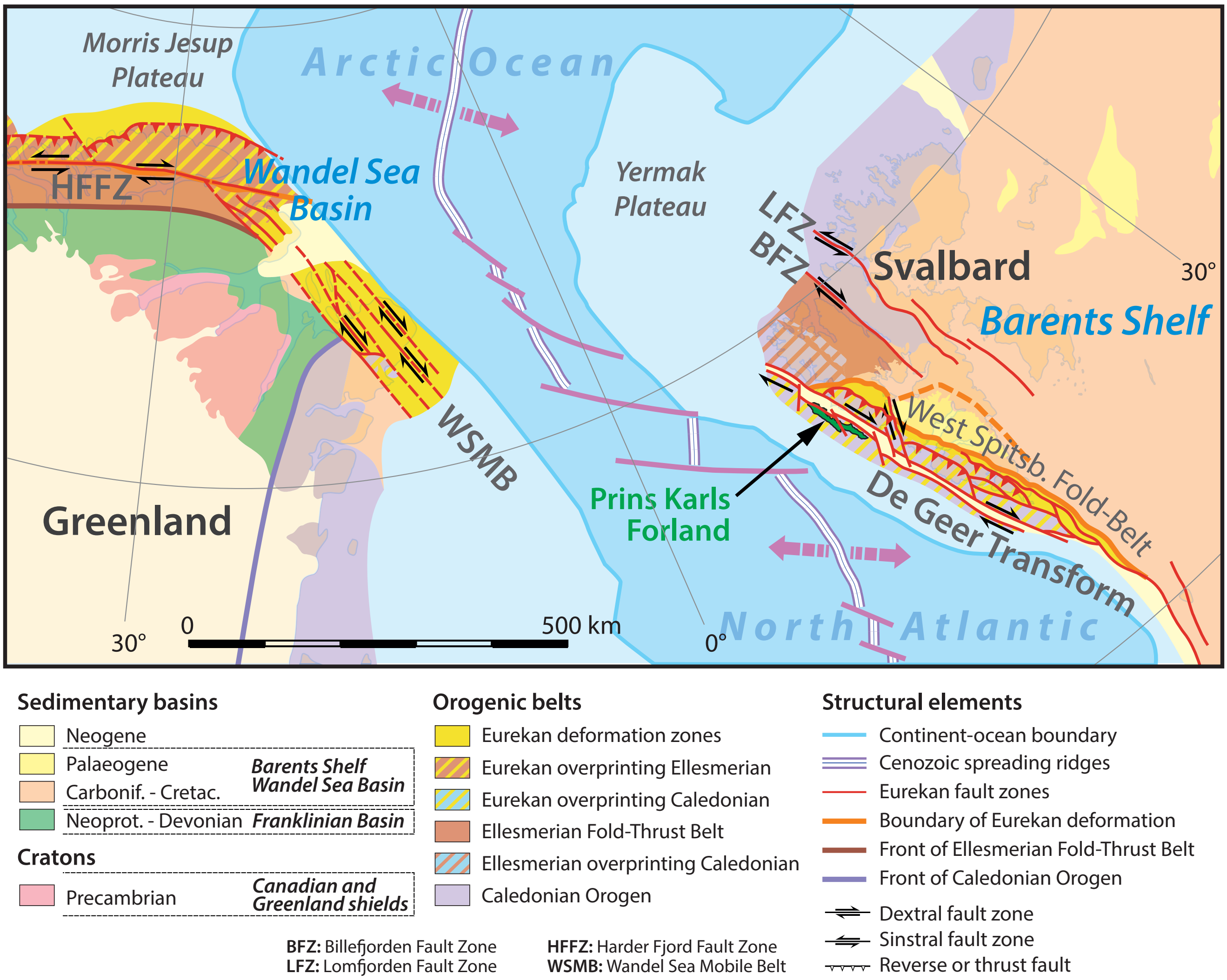


Fig. 4: Tectonic map of the transition from the North Atlantic to the Arctic Ocean, modified from Piepjohn et al. (2016). Prins Karls Forland is situated in the De Geer Transform Fault Zone, which was the lateral link between the initial spreading ridges in the two oceans during the Eocene. Rifting across the transform fault started in the Oligocene and converted the transform margin into a rifted margin.

metapelites and marbles overlain by slates and metapelites with subordinate intercalations of metapsammites (Figs. 12-13).

Different lithologies occur in the central eastern area of the northern block, from the Grimaldibukta area to Richardlaguna. Higher-grade quartzites and micaschists, locally with garnet, comprise the Pinkie unit. Thus unit occurs at Bouréefjellet and Veslefingeren, in tectonic contact with lower-grade rocks. The transition zone between the Pinkie unit and the "normal" stratigraphy consists of tectonised limestones (Craigtoppane Formation). A zone of chloritic phyllites, which may represent retrograde igneous rocks, occurs in a tectonised zone close to Richardlaguna (Figs. 5-9).

The southern basement block, earlier assigned to the "Ferrier Group" is now subdivided into several stratigraphic groups (Morris 1978, 1979) (Figs. 5-9), of which the Ferrierpiggen Group consists mainly of diamictites and seems to correlate with the Early Ediacaran diamictites of southern Spitsbergen (Slyngfjella conglomerate). The overlying Geikie Group (marble and phyllites) are reminiscent of the Höferpynten carbonates in southern Spistbergen. The uppermost Peachflya Group (various phyllites with intercalated quartzites, carbonate rocks and occasionally greenschists) may correspond to the Gåshamna phyllites in southern Spitsbergen (suggested correlations: J. Czerny, pers. comm. 2013). These possible correlations should be kept in mind when discussing the origin of the basement blocks of PKF.

Palaeozoic metamorphism and deformation

The basement complex shows overall greenschist-facies metamorphism, with a slight increase from north (chlorite-grade) to south (biotite-grade) (Tyrrell 1924; Atkinson 1960). Morris (1983) estimated PT conditions of 0.6 GPa and 500° C, which corresponds to a burial depth of ca. 20 km and Barrovian-type metamorphism. Manby (1986) indicated a wider range of 0.4-0.75 GPa and 380-560° C without commenting on the previously suggested north–south gradient. This regional metamorphism is related to a penetrative slaty cleavage and isoclinal folding and has conventionally been thought to be of Caledonian age, but without any existing age determination neither on PKF nor other low-grade rocks in the Southwestern Basement Province of Svalbard.

The Pinkie unit has recently revealed detrital zircon ages of 950-1050 Ma, thus assigning a Neoproterozoic age to their protoliths. The rocks of the Pinkie unit were metamorphosed under amphibolite facies conditions at 0.8-1.0 GPa and 560-630° C and mylonitised at ca. 500-550° C and 0.9-1.1 GPa. *In situ* monazite dating record the metamorphism at ca. 359-355 Ma (Latest Devonian to Earliest Carboniferous ; Kośmińska et al. 2020). These results place the highest-grade tectonothermal processes known from PKF in the Ellesmerian Orogeny, which in return questions the anticipated Caledonian age of the greenschist-facies metamorphism and related ductile deformation in the remaining parts of the basement complex.

The observed ductile thrusts are related to the Palaeozoic orogenic deformation, for instance above the Macnairrabbane Window (Piepjohn et al. 2000). Other thrusts are cataclastic, semi-brittle and are associated with map-scale (10s of metres to kilometre-sized) folds, which refold the main ductile foliation and schistosity. They have NNE-directed vergence in northern PKF, with some bimodal transition zone in Grampianfjella, and WSW to SW-directed vergences in central and southern PKF (Figs. 6-11). While according to Manby (1978, 1986) most of the map-scale folds belong to the ductile, Palaeozoic orogeny, Piepjohn et al. (2000) considered the folds to define a subsequent, semi-brittle event. They assigned them to a late-Caledonian phase due to their interpretation of the overlying Sutorfjella conglomerate which thought to be of Devonian age. Taking into account the now-believed Palaeogene age (correlation with the Selvågen Formation), they might as well belong to the Eurekan (Palaeogene) deformation.

Palaeogene tectonic framework

Eurekan deformation occurred in the Palaeogene in connection with the opening of the North Atlantic, when the southwestern part of Spitsbergen was uplifted and thrust over the Central Tertiary Basin to the ENE forming the West Spitsbergen Fold-Thrust Belt in the early Eocene. Simultaneously, or immediately after, the De Geer Transform Fault developed between the spreading Arctic and North Atlantic oceans, displacing Svalbard and the Barents Shelf in a dextral sense in relation to Greenland until the end of the Eocene (e.g. Myhre et al. 1982). When the spreading axis rotated anti-clockwise, spreading was initiated across the De Geer Transform Fault from the Oligocene onward (Fig. 4).

The position and movement of PKF, or its two separate tectonic blocks, during this transform phase is unknown. However, the extremely elongate shape of the island, its high uplift rate (Manum & Throndsen 1986), the presence of a young strike-slip fault (Morris 1989) and the development of the Forlandsundet Graben, with its complex transpressive-transtensive tectonic history (e.g., Steel et al. 1995, Kleinspehn & Teyssier 1992, Gabrielsen et al. 1992), indicate its position and deformation within the De Geer Transform Fault zone. The semi-brittle folds and thrusts might easily be thought to have developed during early stages of transpression, possibly in connection with the West Spitsbergen Fold-Thrust Belt (Steel et al. 1985). Preliminary models are discussed later in this report.

Forlandsundet Graben

The oldest sediments of the Forlandsundet Graben, the Selvågen conglomerates, are not dated, but underly the finer clastic infill of probably late Eocene to early Oligocene (see Section *Fossil ages of the Tertiary sediments* under *Previous work*). The Selvågen conglomerates represent early stages of basin development and fill a gradually developing topographic relief, indicated by the uneven distribution and thickness. There is no indication that any of the visible faults were syndepositional, so the basin may have been much wider than the present outcrop (Kleinspehn & Teyssier 1992). The Sutorfjella conglomerate on the western side of PKF shows similar characteristics and is now thought to belong to the same event of basin formation, either in continuation of the Selvågen conglomerate, or in a separate trough. The age of these conglomerates may be distinctly older than the overlying formations, but younger than all of the underlying folds and thrusts in the basement on which they are deposited above an angular unconformity (e.g., Rye Larsen 1982).

The overlying sediments (Sesshøgda, Reinhardpynten, Krokodillen, Marchaislaguna and Aberdeenflya formations) show to a large extent a lateral facies variation from alluvial (S) to shallow marine dominated environment (N), although vertical facies development can locally be observed (Rye Larsen 1982).

The conglomerates on the eastern side of Forlandsundet, the Sarsbukta and Sarstangen conglomerates, are the only well dated sediments in the trough (late Eocene to possibly early Oligocene; Livšic 1967, 1973, 1974; Manum & Throndsen 1986). They are thought to represent a late transtensional or extensional phase of subsidence and may be the youngest of the trough sediments (Nøttvedt et al. 1992).

The structural development of the trough is not completely understood. It is complex and involves periods of transtension and transpression, and local refolding of the already consolidated sedimentary fill. The present extensional graben structure represents the latest overprint, associated with large-scale flexuring and drag folding along major marginal faults (Kleinspehn & Teyssier 1992; Gabrielsen et al. 1992; Nøttvedt et al. 1992). Seismic lines show that the basement of the present graben structure occurs at ca. 1-2 km depth (Gabrielsen et al. 1992) (Figs. 10 and 11).

Quaternary peculiarities

The Quaternary geological history of the island is not a subject in this report, but attention is drawn to the extensive occurrence of well-developed raised beaches, both on Forlandsletta and on the strandflats in the northern part of the island. The post-glacial marine limit is slightly above 30 m (Forman 1990).

A pecularity is the relative abundance of large rock glaciers along the coastal mountain sides of the island, especially in certain bedrock formations like the Grampianfjella Group of the basement and the Reinhardpynten and Krokodillen formations of the Palaeogene succession (Figs. 7-9).

Another notable observed feature is thick accumulations of peat deposits under birds' cliffs, especially the one under the southern mountain side of Sutorfjella.

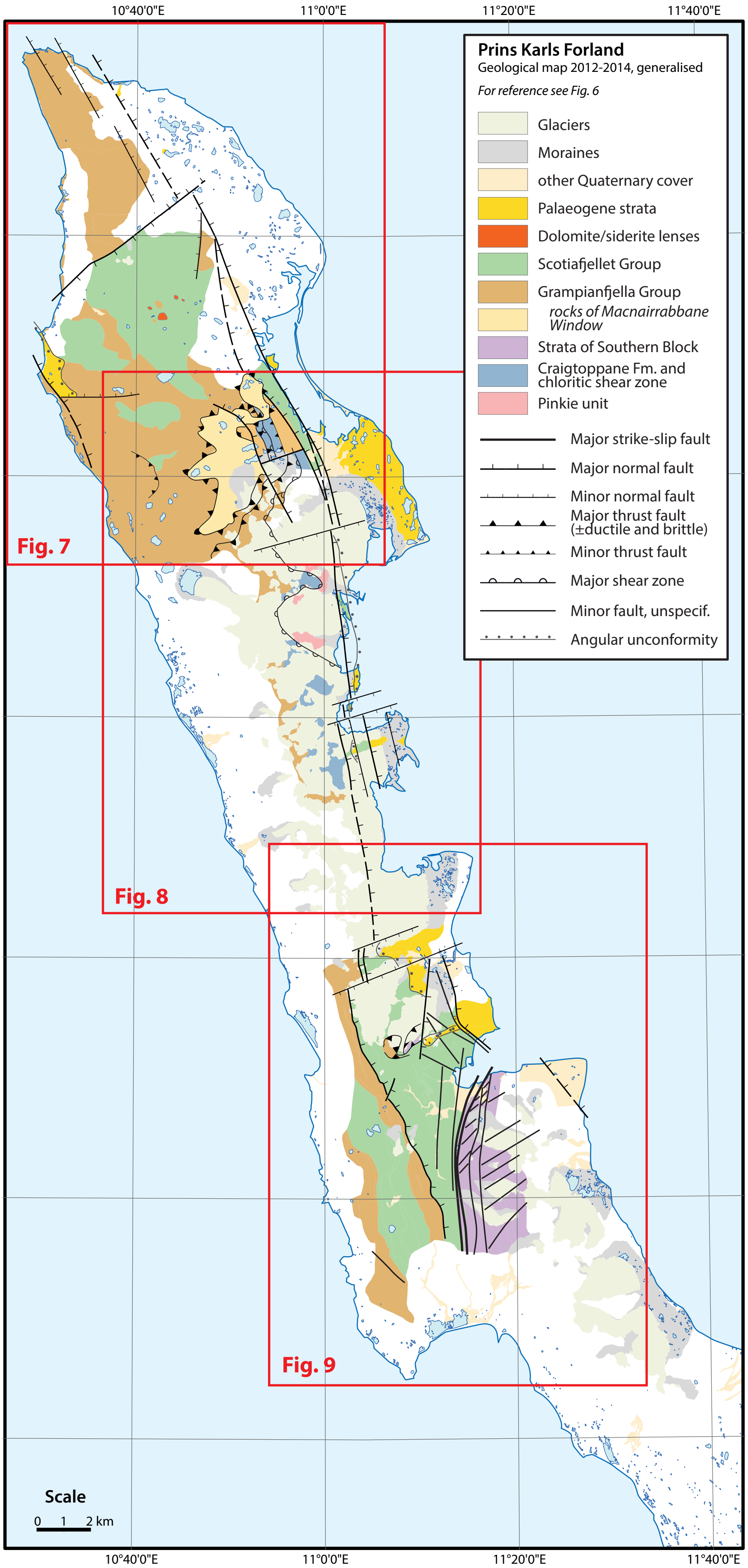


Fig. 5: Geological overview map of the area mapped in 2012-2014. Red frames indicate the position of detailed maps (Figs. 7-9).

Legend for geological map: Remapped parts of Prins Karls Forland (Figs. 7, 8 and 9)

Preliminary compilation from field work 2012-2014.

Contributing geologists:

W. Dallmann, S. Elvevold, J. Czerny, M. Manecki, J. Majka, K. Kośmińska, G. Ziemniak, I. Klonowska

Quaternary

Unconsolidated material (Pleistocene - Holocene):

1 Moraines

2 Marine deposits

3 Glaci-fluvial deposits

Palaeogene

Buchananisen Group (Eocene - Oligocene ?):

4 *Aberdeenflya Formation (Oligocene ?):* conglomerate, sandstone, siltstone, claystone

5 *Marchaislaguna Formation (Oligocene ?):* conglomerate, sandstone, siltstone, claystone

6 *Krokodillen Formation (Eocene ?):* silty claystone, sandstone

7 *Reinhardpynten Formation (Eocene ?):* sandstone, siltstone

8 *Sesshøgda Formation (Eocene ?):* conglomerate, sandstone, siltstone, claystone

9 *Selvågen Formation (Eocene ?):* coarse conglomerate; S Sutorfjella conglomerate

10 Large dolomite and siderite lenses, secondary precipitations

Neoproterozoic

Scotiafjellet Group (latest Neoproterozoic):

11 *Taylorfjellet and Kaggen formations, undifferentiated*

12 *Kaggen Formation:* predominantly slate, subordinate quartzite, dolomitic quartzite, locally metapsammite

13 light, massive quartzite

14 porous, sericitic sandstone and rusty slate

15 *Taylorfjellet Formation:* recrystallised carbonate rocks (often with chert bands/nodules)

16 *Baklia facies I:* calcareous slate, locally dark quartzite, dark slate and light limestone

17 *Baklia facies II:* black carbonaceous slates with layers of dark grey dolomite (often with chert bands/nodules)

18 *Omondryggen facies:* recrystallised, dark grey limestone (often with chert bands/nodules)

Grampianfjella Group (late Neoproterozoic):

19 *Utnes Formation:* phyllitic slate, locally rusty (with intercalated, yellow-weathering, recrystallised limestone in northern PKF)

20 *Conquerorfjellet Formation:* metapsammite and quartzite, slate, locally polymict conglomerate, recrystallised carbonate rocks and chlorite schist; quartzitic lead horizon (yellow band)

21 calcareous lithologies incl. marble bands alternating with metapelite

22 *Fuglehuken Formation:* metapsammite, slate, and calcareous, orange-weathering polymict pebble conglomerate

23 *Craigtoppane Formation:* recrystallised carbonate rocks

Suggested correlatives:

C (West of Richardlaguna): carbonate-rich clastic rocks with layers of polymict conglomerate and quartz-carbonate-chlorite schist

S (North of Kapp Sietoe): recrystallised carbonate rocks, intercalated metapsammites

F (Northwest of Carmichaelpynten): laminated dolomite, intercalated with quartzitic metapsammites, quartz-pebble conglomerate and calcareous metapelites

Rocks in Macnairrabbane Window:
(suggested equivalents of Grampianfjella Group)

24 Chlorite-carbonate schist, locally pebbly

25 Quartzite and metapsammite with layers of oligomict, orange-weathering dolomite conglomerate

26 Quartz- and carbonate-rich phyllite

27 Massive dolomite

28 Phyllite

Peachflya Group (late Neoproterozoic):

29 *Hornnes Formation*, upper part, and *Knivodden Formation*: dark, rusty phyllite and quartzite, one black marble marker horizon (green line), upper part greyish and greenish phyllite

30 *Hornnes Formation*, lower calcareous part: yellow marble, dolomite, quartzite, locally with greenschist

31 *Alasdairhornet Formation:* greenish, calcareous phyllite, quartz- and carbonate-rich phyllite, locally greenschist

32 *Fisherlaguna Formation:* grey phyllite with interbeds of quartzite/metapsammite

Geikie Group (late Neoproterozoic):

33 *Rossbukta and Gordon formations*, undifferentiated: grey and black calcite marble, quartz- and carbonate-rich phyllite, phyllite

Ferrierpiggen Group (late Neoproterozoic):

34 Undifferentiated, mainly diamictite

Pinkie unit (earliest Neoproterozoic >960 Ma)

35 Quartz-biotite schist, laminated quartzite, mica schist with or without garnet, subordinate scapolite-bearing rock, augen gneiss, garnet-amphibolite

Unknown correlation and age

36 Quartzite and greenstone

37 Shear zone: chloritic rocks with marble, metapsammite, greenschist and retrogressed gabbro

Geological symbols

dashed versions indicate assumed position

- Rock boundary
- Angular unconformity
- Fault, unknown type of displacement
- Fault, normal
- Fault, reverse or thrust
- Anticline
- Anticline, overturned
- Syncline
- Flexure
- 10 Strike and dip (value)
- Horizontal bedding
- Vertical bedding
- 10 Overturned bedding (value)
- Mineral occurrence
- Front line of rock glacier
- A A' Position of cross section (Fig. 11)

Scale 1 : 75 000
contour interval: 50 m
(25 m line in lowland)

0 1 2 3 km

Fig. 6: Legend for the detailed geological maps, Figs. 7-9.

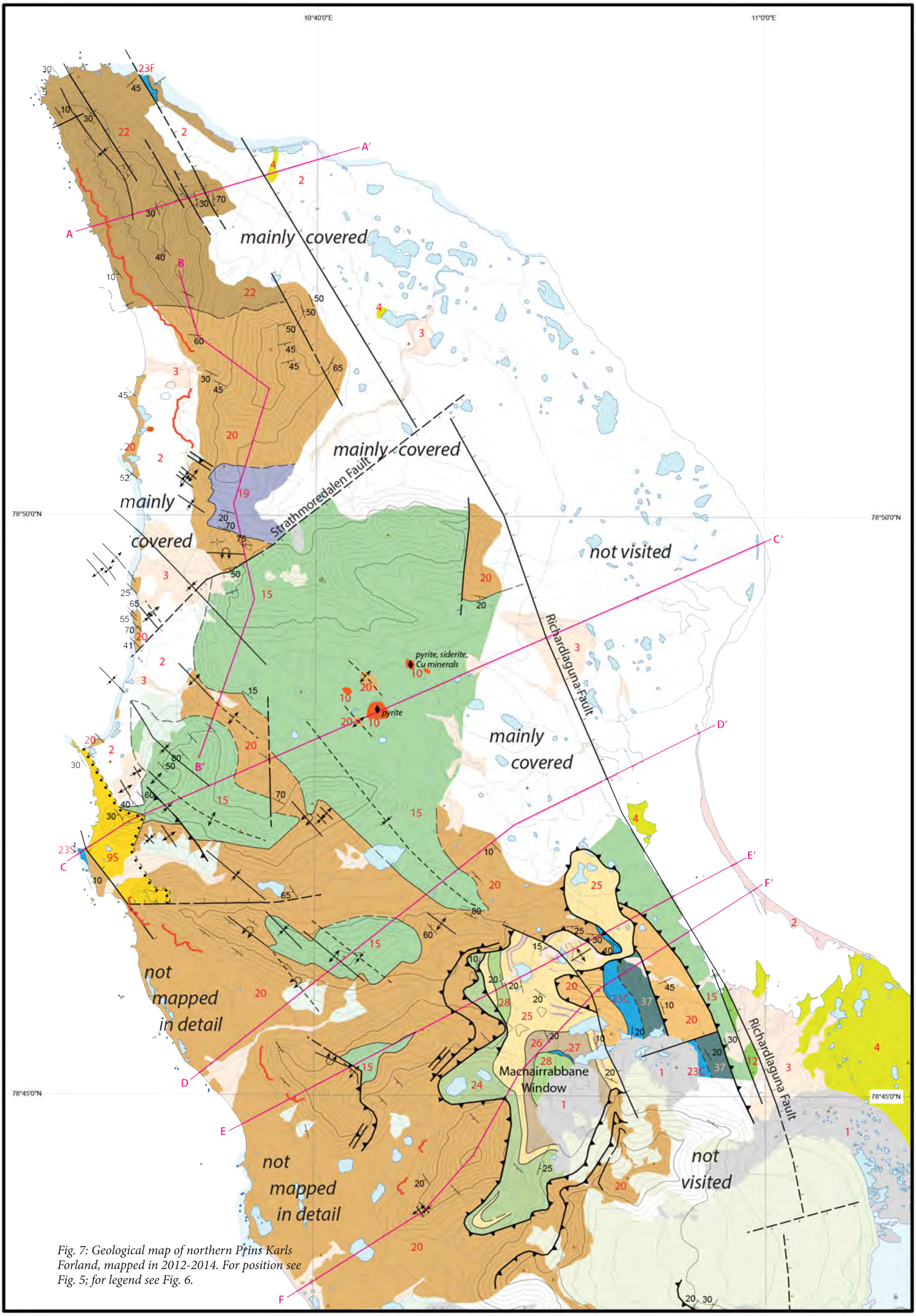


Fig. 7: Geological map of northern Prins Karls Forland, mapped in 2012-2014. For position see Fig. 5; for legend see Fig. 6.

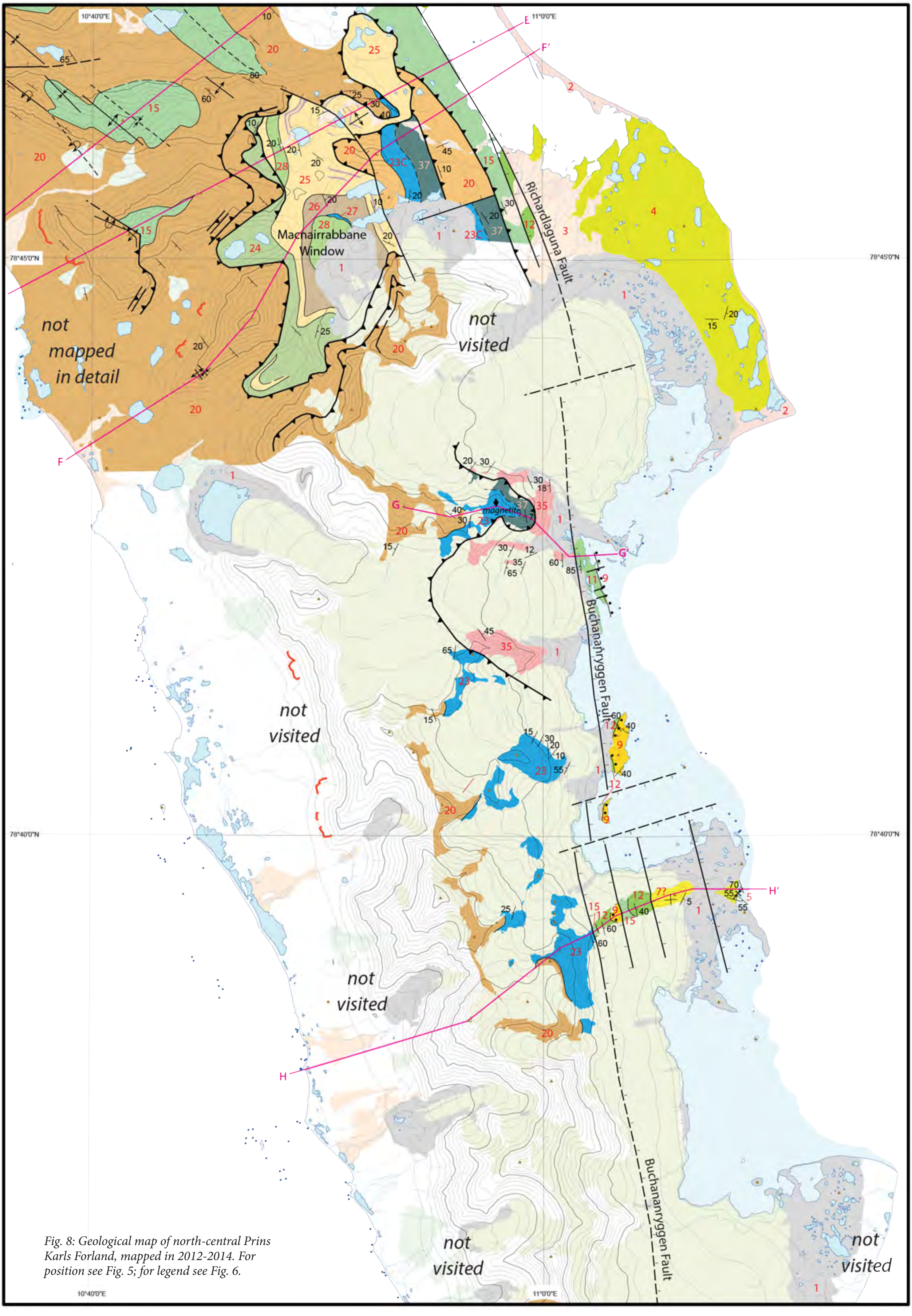


Fig. 8: Geological map of north-central Prins Karls Forland, mapped in 2012-2014. For position see Fig. 5; for legend see Fig. 6.

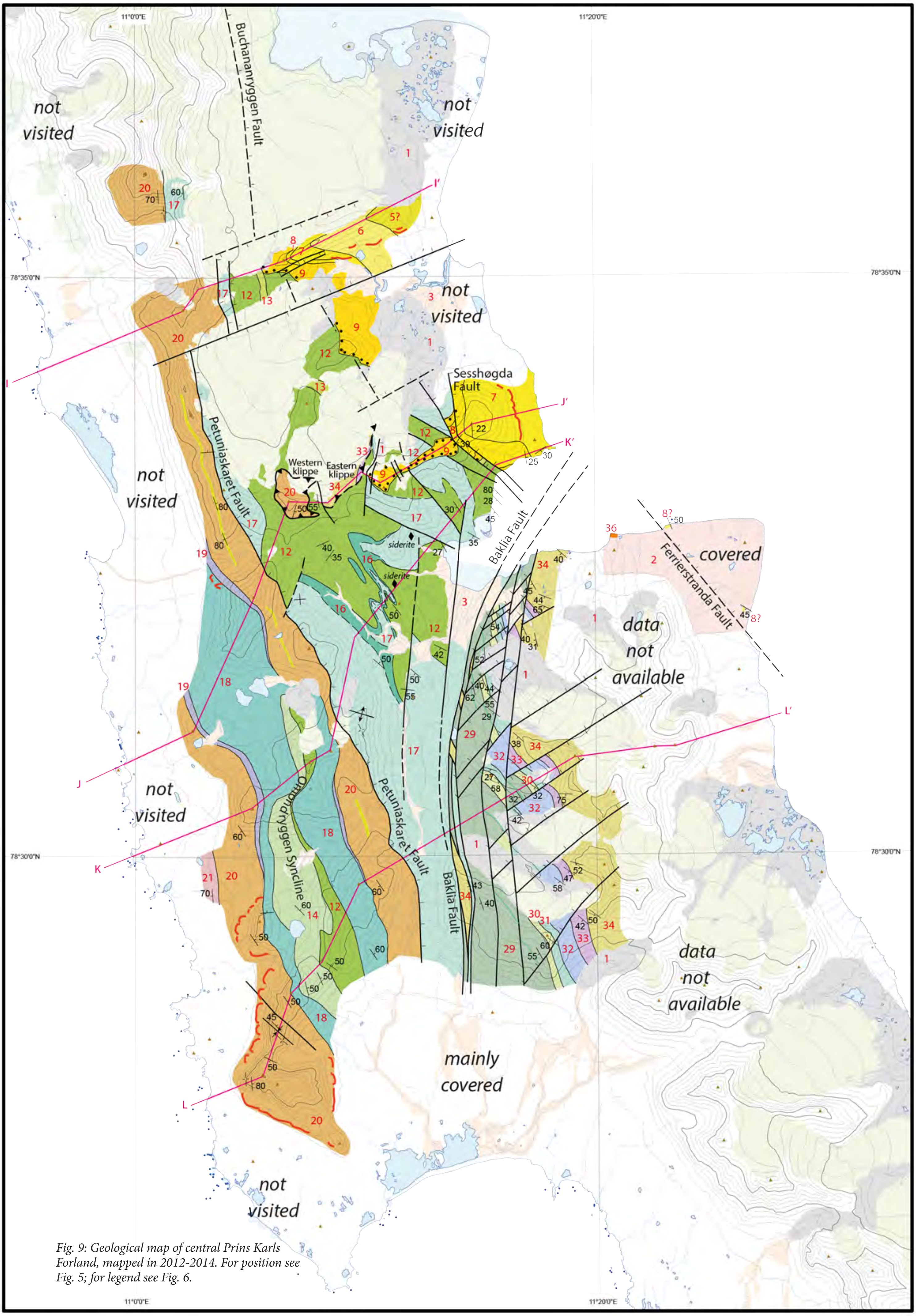
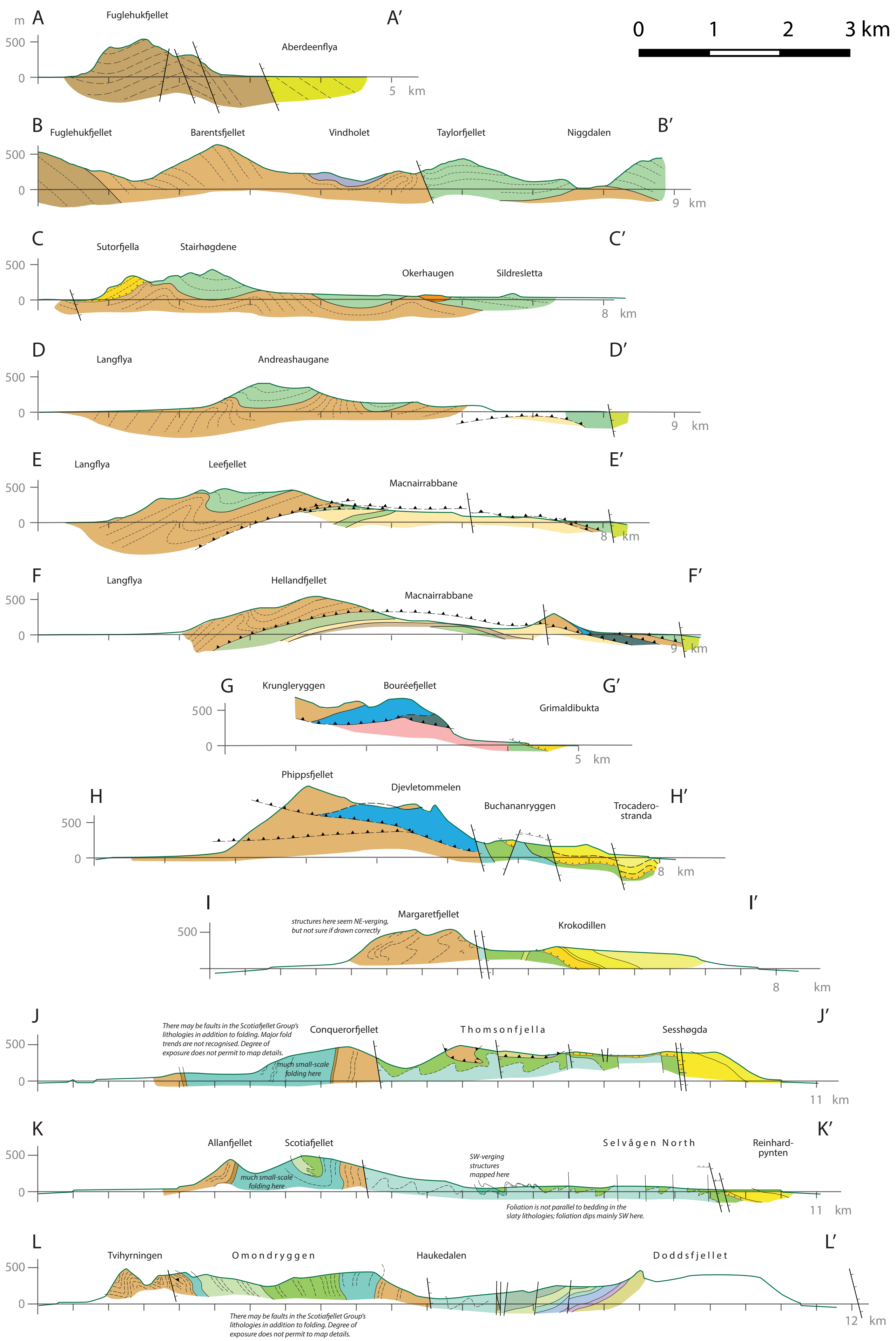


Fig. 9: Geological map of central Prins Karls Forland, mapped in 2012-2014. For position see Fig. 5; for legend see Fig. 6.

Fig. 11 (right): Vertical cross sections through the mapped area. Positions indicated in Fig. 7-9.

Fig. 10: Tentative tectonostratigraphic interpretation of northern and central Prins Karls Forland, based on mapping and investigations in 2012-2014.



m A
Fuglehukfjellet
A′
Aberdeenflya
500
0
5 km
0 1 2 3 km
B
Fuglehukfjellet
Barentsfjellet
Vindholet
Taylorfjellet
Niggdalen
B′
9 km
C
Sutorfjella
Stairhøgdene
Okerhaugen
Sildresletta
C′
8 km
D
Langflya
Andreashaugane
D′
9 km
E
Langflya
Leefjellet
Macnairrabbane
E′
8 km
F
Langflya
Hellandfjellet
Macnairrabbane
F′
9 km
G
Krungleryggen
Bouréefjellet
Grimaldibukta
G′
5 km
H
Phippsfjellet
Djevletommelen
Buchananryggen
Trocadero-
stranda
H′
8 km
I
structures here seem NE-verging, but not sure if drawn correctly
Margaretfjellet
Krokodillen
I′
8 km
J
There may be faults in the Scotiafjellet Group's lithologies in addition to folding. Major fold trends are not recognised. Degree of exposure does not permit to map details.
Conquerorfjellet
much small-scale folding here
Thomsonfjella
Sesshøgda
J′
11 km
K
Allanfjellet
Scotiafjellet
much small-scale folding here
SW-verging structures mapped here
Selvågen North
Reinhard-
pynten
K′
Foliation is not parallel to bedding in the slaty lithologies; foliation dips mainly SW here.
11 km
L
Tvihyrningen
Omondryggen
Haukedalen
Doddsfjellet
L′
There may be faults in the Scotiafjellet Group's lithologies in addition to folding. Degree of exposure does not permit to map details.
12 km

stratigraphic unit	description acc. to Harland	thickn. (Harland)	correlations, notes
Grampian Group name goes back to Tyrrell 1924	siliciclastic, flyschoid succession	**>3500 m**	Quartz-sandstone Fm. (Helle et al. 1979) Psammo-pelitic unit (Knoll & Ohta 1988) Glenbegdalen unit (Hjelle et al. 1999)
Geddesflya Formation	3: mainly quartzites w. dolomite, banded siltstone, breccias, thin siltstones, slates 2: slate-pebble breccias w. banded siltstones 1: thinly bedded quartzites and banded siltstones	>1800 m	
Fuglehuk Formation	massive bedded quartzite, interbedded with banded siltstone	400-1000 m thickens N-ward	
Barents Formation	4: siltstones, locally grading into black to dark-grey slates 3: folded and banded siltstones 2: flaggy, calcareous sandstones 1: green pelitic quartzites with black limestones and pebbly quartzite	500 m	
Conqueror Formation	transitional boundary with Barents Formation 4: quartzites and slates 3: dark-grey slates alternating with quartzites 2: pebbly calcareous beds 1: thick slates with quartzite bands	850 m	
Utnes Formation	transition between Conqueror and "Roysha" formations	80 m	
Scotia Group name goes back to Tyrrell 1924	dark (graphitic) carbonaceous slates with impure carbonate rock and quartzite beds, oolitic; chert nodules, microfossils	**<1000 m**	Black shale Formation (Helle et al. 1979) Black carbonate-pelite unit (Knoll & Ohta 1988) Taylorfjellet unit (Hjelle et al. 1999)
Omondryggen ("Roysha")* Formation	soft, black carbonaceous slate, interbedded with dolomite siltstone	400 m	All these authors place Scotia Group on top of Grampian Group
Kaggen Formation	slate phyllonites, tight isoclinally folded; with a distinct green and purple striped section suggestig a minor volcanic component, metamorphosed to chlorite	300 m	*Knoll & Ohta describe a basal conglomerate with clasts from Grampian Group*
Baklia Formation	5: black slates with quartzites 4: black carbonaceous slate succession with grey-orange dolomitic limestones with intraformational breccias 3: grey, often cherty dolomitic siltstones with black slates 2: quartzites, often conglomeratic, with green and black slaty laminae 1: dolomitic, cherty limestone	200-300 m	** "Roysha" Fm. is a misspelling of the place name Røyshaugen (abbreviated Røysha. on the map), later changed to Omondryggen Fm.*

Fig. 12 (above and right page): Lithostratigraphic table for the metamorphic basement of Prins Karls Forland according to the work of the Cambridge scholar environment, summarised from Manby 1978; Morris, 1979; Harland et al. 1979, 1993; Harland 1999.

stratigraphic unit	description acc. to Harland	thickn. (Harland)	correlations, notes
Peachflya Group	grey and green phyllites, often siliceous, limestone and sandstone beds; tuff and basic lava flows in the middle part	**940 m**	Calc-argillo-volcanic unit (Hjelle et al. 1979)
Knivodden Formation	incompetent chloritoid phyllites (pale grey, dark grey and pale green)	400 m	
Hornnes Formation	alterations of siliceous phyllite, sandstone and quartzite, limestone	350 m	
Alasdairhornet Formation	volcanic suite: banded and welded tuffs with some basic lava flows; thin carbonate interbeds near top and base with reworked volcanogenic and siliciclastic material	190 m	
Fisherlaguna Formation	incompetent dark, bluish phyllites	350 m	
Geikie Group	phyllite, upward decreasingly calcareous, ends up with 3-4 m dolomite unit, impure sandstone beds	**>770 m**	Kerr Group (Atkinson 1954, 1956) Ferrier Peak Series (Tyrrell 1924)
Rossbukta Formation	dark siliceous phyllite, upward increasingly calcareous	300 m	
Gordon Formation	calcareous phyllite with 3-4 m massive dolomite/lime-stone laminated horizons, with intraformational breccias, carbonaceous beds, pisolitic limestones	470 m	
Ferrier Group	schistose diamictites; biotite grade metamor-phism	**>730 m**	Tillitic conglo-merate unit (Hjelle et al. 1979)
Neukpiggen Formation	calcareous and chloritic schist and phyllite with discontinuous psammite, marble and conglomerate beds; dispersed dolomite and quartzite clasts; granite clasts up to 40 cm long; marble clasts up to 10 cm long	300 m	
Peterbukta Formation	pink and grey, weathered psammitic schists, grey calcareous schists, dark pellitic schists; discontinuous beds of crystalline psammites and dolomites, ortho-conglomerate, intraformational conglomerates; outsize clasts occur throughout	160 m	
Hardiefjellet Formation	upper division: pale, calcareous siliceous schists, lower division: dark green schists; darker in colour and higher metamorphic grade than Neukpiggen Formation	120-500 m	
Isachsen Formation	dark green quartz-chlorite schists with brown inter-layers; thin layers of diamictite, laminated, sorted; 1-2 m thick tuff layers occur throughout; base not exposed	>150 m	
Alfred Larsen-toppen unit	isolated klippe; upper 20 m: orange-weath. coarse dolomitic psammite w. dispersed stones of grey dolomite (more numerous than formations above); lower unit rich in granitoid boulders		
Pinkie Group	fault-bounded thrust slice, unknown stratigraphic position; highest metamorphic grade in PKF; garnet-biotite schist, biotite-bearing phyllite and amphibolite; magnetite/hematite ores	**>200 m**	

stratigraphic unit	lithology	notes
Buchananisen Group	**Clastic sedimentary rift succession**	**Palaeogene strata**
Aberdeenflya Formation	conglomerates, sand-, silt- and claystones	*subdivision adopted from Rye Larsen (1982)*
Marchaislaguna Formation	conglomerates, sand-, silt- and claystones	
Krokodillen Formation	claystones, sandstones	
Reinhardpynten Formation	sandstones, siltstones	
Sesshøgda Formation	conglomerates, sand-, silt- and claystones	
Selvågen Formation	coarse conglomerates	
Scotiafjellet Group	**Carbonate- and metapelite-domin. succession**	**Neoproterozoic strata of the northern tectonic block**
Kaggen Formation	slates, phyllites, subord. metapsammites	*subdivision revised according to current research*
Taylorfjellet Formation	dark or grey limestones and calcareous slates	
Baklia facies	black carbonaceous slates	*stratigraphic names adopted from Manby (1986), Harland et al. (1993), Hjelle (1999)*
Omondryggen facies	dark limestones and carbonaceous slates	
Grampianfjella Group	**Metapsammite-dominated succession**	
Utnes Formation	rusty or calcareous phyllites	*rocks of Macnairrabbane Window are suggested to correlate with Grampian-fjella Group*
Conquerorfjellet Formation	metapsammites, slates	
Fuglehuken Formation	metapsammites, pebble conglomerates	
Craigtoppane Formation	recrystallised carbonate rocks	*Craigtoppane Fm.: new name*
Pinkie unit	**High-grade metamorphic rocks** micaschists, gneisses, amphibolites	*tectonic thrust unit*
Peachflya Group	**Metapelite-dominated succession**	**Neoproterozoic strata of the southern tectonic block**
Knivodden Formation	phyllites and quartzites	
Hornnes Formation	marbles, quartzites and greenschists	*subdivision adopted from Morris (1982)*
Alasdairhornet Formation	greenish calcareous phyllites and greenschists	
Fisherlaguna Formation	phyllites with some metapsammites	
Rossbukta Group	**Carbonate- and metapelite-domin. succession**	
undifferentiated	marbles and phyllites	
Ferrierpiggen Group	**Diamictite-dominated succession**	
undifferentiated	tilloid rocks	

Fig. 13: Revised lithostratigraphic table for Prins Karls Forland, based on the present work. For previous interpretation see Fig. 12. Subdivision of the Palaeogene Buchananisen Group from Rye Larsen (1982).

Stratigraphy

As stated above, the stratigraphic successions of northern and southern PKF are lithologically quite different, although they may be quite similar in age. Their age relation is still a matter of debate (see below, Section *Age discussion*); the lithostratigraphic nomenclatures are kept totally apart (Figs. 12, 13). For geographical names see Fig. 17.

Basement of northern PKF

Stratigraphic framework

In the northern tectonic block, the question of top and bottom of the stratigraphy of the basement rocks is most fundamental. Up-and-down criteria are hard to find, and, if present, they are equivocal (for instance, presumed water-escape structures pointing in opposite upward directions, Photo 12).

Atkinson (1960) said that there is some faint indication for the Scotiafjellet Group being younger than the Grampianfjella Group, but he also said that that deformation is so strong that it easily could have erased the primary relations.

The majority of previous works (Manby 1978, 1986; Hjelle et al. 1979; Harland et al. 1979, 1993; Harland 1999) assigned the youngest age to the Grampianfjella Group, overlying the Scotiafjellet Group (Fig. 12). The reason is apparently a tentative correlation of these units with the Ordovician-Silurian Bullbreen Group in Oscar II Land, Spitsbergen, where some of the formations have distant similarities, although such a correlation has never been documented. The rather complicated interpretation of the structure of the basement by Manby (1978, 1986) as refolded Caledonian fold nappes may be a consequence of this believed stratigraphic order. Their stratigraphic interpretation needed a mechanism to turn the succession upside-down.

The first work proposing an opposite stratigraphic order was that of the study group from the University of Münster (Piepjohn et al. 2000), which also is adopted on the Norwegian Polar Institute's map sheet Kongsfjorden (Hjelle et al. 1999). When we worked without preconceptions in the northern part of PKF (north of Murraybreen), like Piepjohn's group did, it seemed clear that the Scotiafjellet Group overlies the Grampianfjella Group (Photo 4). The contact appears primary and there are no indications of a thrust as inferred by the previous authors (Fig. 1). Likewise, nothing suggests that the entire northern PKF should be completely inverted.

The Ediacaran age of some samples from the Scotiafjellet Group (Knoll & Ohta 1988, Knoll 1992) outrules the tentative correlation with the Palaeozoic Bullbreen Group on Spitsbergen, which was proposed by Harland et al. (1993).

As will be shown below (*Structure of the basement*) we propose an alternative interpretation of the basement structure, where the existence of recumbent fold nappes is not needed. As a result of these circumstances, we suggest a stratigraphic order shown in Fig. 13. See the following sections for stratigraphic order within these groups.

The tectonically bounded, higher-grade metamorphic Pinkie unit at Grimaldibukta is suggested to keep its name unchanged, because the Norwegian translation of the geographical name, Veslefingeren, is too different from the English "Pinkie" and not recognisable for non-Norwegian speakers.

In the following, the previously known stratigraphic units of the northern block are described from bottom to top. Major problems in the lower parts of the stratigraphy have been discovered and tentatively correlated during the recent expeditions, and so far not been mapped continuously. These are treated in a subsequent section (*Stratigraphic relations in the lower part of the Grampianfjella Group*).

Photo 4: Scotiafjellet Group (dark limestones and marls) overlying Grampianfjella Group (light-coloured metapsammites) at the northern valley side of Gjelet. The orange colours are weathered material from secondary dolomite veins.

Grampianfjella Group

Manby (1978, 1986) proposed a very detailed formation subdivision of the "Grampian" Group. This subdivision was made in the Scotiafjellet area in central PKF. The lithologies of the individual formations are quite alike, no distinctive parameters are mentio-=ned apart from some colour variations and thickness variations of quartzite versus slate beds, and some irregular occurrences of calcareous lithologies, etc. (Figs. 1, 12).

We were not able to confirm this subdivision in the field. From our experience these subdivisions vary a lot from area to area. The bulk of the group contains alternations of metapsammites and slates with varying ratios, while subordinate lithologies like massive quartzites, phyllites, greenish metapelites, calcareous rocks and conglomerates occur locally and not within distinctly traceable members.

Three formations, however, can possibly be adopted for our map: the Fuglehuken, Conquerorfjellet and Utnes formations. We propose to apply the names of these three units with modified definitions, while other lithological variants may be considered to be of local character.

1. Fuglehuken Formation

The Fuglehuken Formation (Manby 1978) is different from the use of the name by Hjelle et al. (1999). The latter version comprises Manby's Fuglehuken and Geddesflya formations in the very north of the island. These are metapsammites, quartzites, slates and occasionally quartz conglomerates with interbedded, often brownish-coloured carbonate and polymict pebble conglomerates. We could not confirm Manby's twofold subdivision at Fuglehukfjellet, nor could we confirm the presence of these rocks in the mountains at Geddesflya. According to our view the Fuglehuken Formation (in the sense of Hjelle et al. 1999) lies below the Conquerorfjellet Formation and is the lowermost unit of the Grampianfjella Group exposed in the northern part of PKF. It has a conformable, folded contact towards the overlying Conquerorfjellet Formation (Fig. 7).

The main lithology consists of two types of metapsammites: 1) dense, whitish quartzites and 2) grey, somewhat porous metapsammites, locally brownish weathering. Both can be massive (10s of metres thick intervals) or intercalated with grey slates or phyllites at cm to m scale (Photos 5-7).

Frequently, metre-thick layers and lenses of pebble conglomerates occur. They are mostly matrix-supported, occasionally clast-supported, with grit-sized, up to 5 cm large pebbles of quartz, slate and subordinate marble clasts. The matrix is quartz-rich, sandy. These conglomerates make an intraformational impression and are not distinguishable from the distance.

Another sort of conglomerates with prevailing dolomite clasts is clearly visible from the distance due to its orange-brown weathering colour. They are polymict (dolomite, quartz, slate and others). Bed thicknesses vary between centimetres and metres (Photo 8). These conglomerates are best accessible along the northeastern slopes of Fuglehukfjellet, but occur also at the steep mountain face on the southeastern slope. These orange-brown weathering conglomerates are the most distinguishing feature of the Fuglehuken Formation.

2. Conquerorfjellet Formation

The Conquerorfjellet Formation (Manby 1978) seems to represent the bulk of the Grampianfjella Group along the ridge Grampianfjella and most of the western coastal plain, as well as southward on both sides of the Omondryggen Syncline (Fig. 9). In addition, we have mapped its continuation in northern PKF between Strathmoredalen and Fuglehukfjellet (Figs. 7-9), where it reappears below the overlying carbonate lithologies of the Scotiafjellet Group that make up Taylorfjellet and Stairhøgdene.

Piepjohn et al. (2000) and Hjelle et al. (1999) made a distinction between the Barentsfjellet (north of Sutordalen) and Glenbegdalen (Sutordalen and southward) facies based on the allegedly higher amount of green phyllites in the southern facies. This, however, cannot be confirmed based on the present mapping, although there seems to be a slight increase in the metamorphic gradient southward, where slates become phyllitic. Green phyllites and greenish quartzites were actually only seen in the north close to the saddle of Strathbegdalen above the top of the Fuglehuken Formation.

The lower boundary of the Conquerorfjellet Formation is only seen in southern Fuglehukfjellet. A large part of the succession (ca. 1800 m) is exposed in Barentsfjellet, but assumably not quite to its upper boundary with the Taylorfjellet Formation. The two formations are here separated by the SW-NE striking Strathmoredalen Fault. The succession at Barentsfjellet starts above metapsammites and polymict pebble conglomerates of the Fuglehuken Formation (A) and contains the following succession (Photo 9):

B: Yellowish-black laminated slate and brownish-weathering, thinly foliated slate, light-grey psammitic slate and fine-grained quartzite;

C: Greenish, thinly but distinctly bedded quarzite with transitions to quartzitic slate;

D: Light-grey quartzite;

E: Greenish, quartz-rich, flaggy slates with dolomite laminae and greenish quartzitic interbeds;

F: Pink to reddish, impure quartzite or metapsammite with intercalated polymict pebbel to boulder conglomerate (Photo 10);

G: Massive, grey quartzite, quartzitic slate, slate, and almost paper-shale-like slate in alteration (Photo 11);

H: Massive grey quartzite and quartzitic slate;

I: Thinly bedded succession of dark-grey slate and yellow-weathering limestone;

J: Rusty grey slate and intercalated beds of limestone, partly resembling the limestones of the overlying Taylorfjellet Formation (Scotiafjellet Group) but lighter coloured, with a network of quartz veins.

The Taylorfjellet Formation (K) occurs across the Strathmoredalen Fault and has not been seen in contact with the Grampianfjella Group in this place. The units I and J form an overturned anticline just next to the fault.

Using the lithological subdivision of Manby (1978) in a broad sense, units B-H correspond to the Conquerorfjellet Formation, while units I and J are the Utnes Formation.

Photo 5: Typical cliff consisting of metapsammites of the Fuglehuken Formation, Fuglehukfjellet. (Compare Fig. 158 for faults in this cliff.)

Photo 6: Thick alteration of quartzitic metapsammite and slate, Fuglehuken Formation at Fuglehuken.

Photo 7: Thin alteration of quartzitic metapsammite and slate, Fuglehuken Formation at Fuglehuken.

Photo 8: Polymict conglomerate, Fuglehuken Formation at Fuglehuken.

At Stormneset west of Barentsfjellet, load marks ressembling an assumed Bouma sequence with water-escape structures was seen in a quartzite-slate succession, which are consistent with a normal way up of the stratigraphy (Photo 12b). Other water-escape structures in the vicinity are inconclusive with respect to up-down criteria (Photo 12a).

South of the Strathmoredalen Fault the upper part of the Conquerorfjellet Formation can be seen below the Taylorfjellet unit, especially from Niggdalen into the cirque of Stairhøgdene. There the banded slate-limestone facies (Utnes Formation) occurs at lower elevations, and quartzite-shale successions at upper elevations in Niggdalen. Two separate exposures of a clast-supported, polymict conglomerate occur to the N and SW of Okerhaugen surrounded by exposures of Taylorfjellet limestones, possibly in anticlinal crests (or, less probably, along hidden faults) (Fig. 7). Contact with the limestone is not exposed.

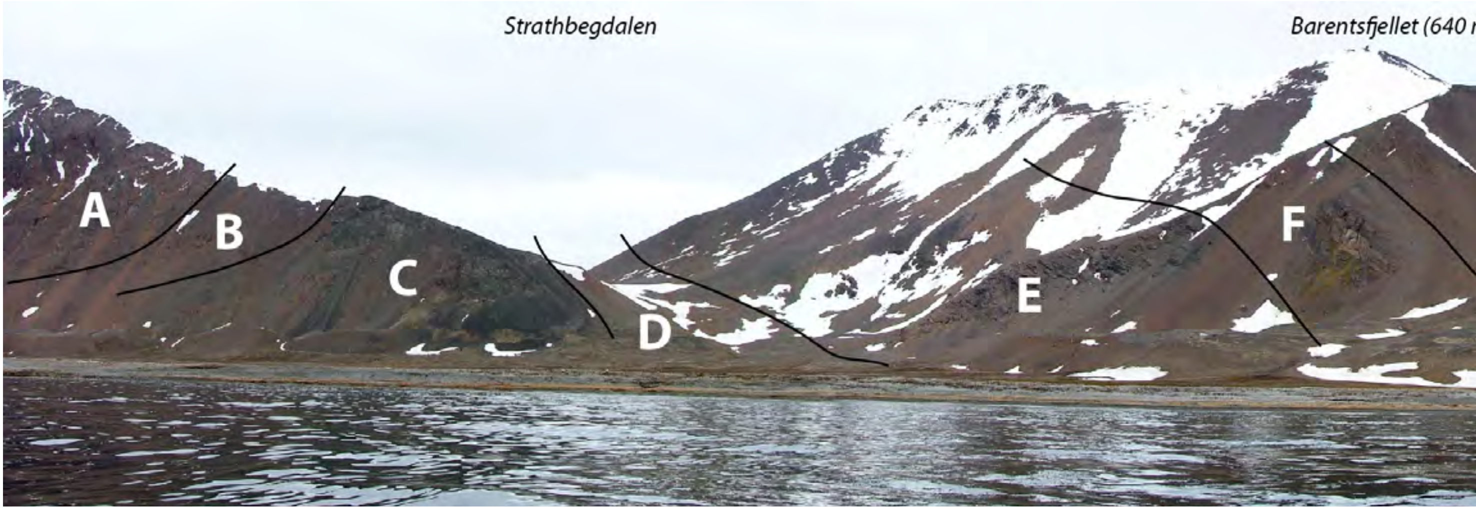


Photo 9: Panoramic section of the Grampianfjella Group from the southern tip of Fuglehukfjellet (left) along the western side of Barentsfjellet to Vindholet (right) with indicated lithologies (listed on page 30). A: Fuglehukfjellet Formation; B-J: Conquerorfjellet Formation; K: Scotiafjellet Group (fault contact).


Photo 10: Polymict conglomerate with dolomite-bearing matrix, middle part of Conquerorfjellet Formation (unit F on Photo 9).

In Sutordalen the Conquerorfjellet Formation is poorly exposed, but quartzitic metapsammites and slates seem to dominate. The upper part (east end of western lake) is rusty slate and thin layers of yellow weathering carbonate (Utnes Formation). The clast-supported, polymict conglomerate occurs also here at quite high levels of the unit (Photo 13).

In the valleys farther south (Gjelet, Glenmoredalen, Glenbegdalen), quartzites, quartzitic metapsammites and slates are abundant throughout the succession. The valley bottoms are only occasionally exposed, but often show probable *in situ* material in blocks and stones. Zones of brownish-yellowish weathering carbonate rocks (Utnes Formation) occur especially on the foreland plain (locally also real marble, like observed in front of Glenbegdalen), but occasionally also in the higher parts of the valleys. The banded limestone succession and the rusty slates with carbonates succession have not been observed here. The boundary with the overlying Taylorfjellet limestones seems to be primary in the entire area.


Photo 11: Slate with quartzite interbeds in the Conquerorfjellet Formation (unit G on Photo 9).

Photo 12: Sedimentary structures in metapsammites of the Conquerorfjellet Formation. A and B: water-escape structures; B: suggested Bouma sequence indicating turbidites. Up-down criteria are ambiguous.

From Krungleryggen southwards to Grampianfjella the Conquerorfjellet Formation appears to consist of more massive quartzitic lithologies, although this may be due to the repetition by and folding above thrusts (see *Structure of the basement*). This area has not been mapped in detail yet. All along Grampianfjella the formations seem quite uniformly massive from a distance, but they are cut by thrust faults (Photos 133-141). Neither the upper nor the lower boundaries seem to be exposed.

The Grampianfjella Group exposures continue into central PKF in the NNW-SSE striking zone east of the Omondryggen Syncline (Photo 14) and reoccur on its western flank (Photo 15). Rocks of the

Photo 13: Clast-supported, polymict conglomerate; upper part of Conquerorfjellet Formation, Sutordalen.

Scotiafjellet Group seem to form a fold core between the eastern and western fold limbs made up of rocks of the Grampianfjella Group (see *Structure of the basement*) (Fig. 9).

Up to more than 100 m thick rusty phyllites (Utnes Formatin) occur in many places towards the boundary with the Scotiafjellet Group on both fold limbs, suggesting that the primary stratigraphy is roughly preserved. The eastern limb is cut by a large down-to-east displacing, brittle fault in the east (Grampianfjella Fault). The western limb is not yet mapped on the coastal plain.

The main lithologies in the Omondryggen area are massive quartzites and metapsammites with slaty sections similar those in northern PKF. A prominent white quartzite occurs quite often in the central part of the eastern fold limb, and is also observed at Gourlayfjellet in the western limb. It can be traced with some interruptions from at least west of Alfredbreen southwards to Normanndalen. At Petuniaskaret the quartzite layer shows minor offsets (few to 10 m) along small E-W striking faults, particularly well visible north of the mountain pass (Photo 14). It also occurs in the pass northeast of Ossianvatna and at the pass in Normanndalen.

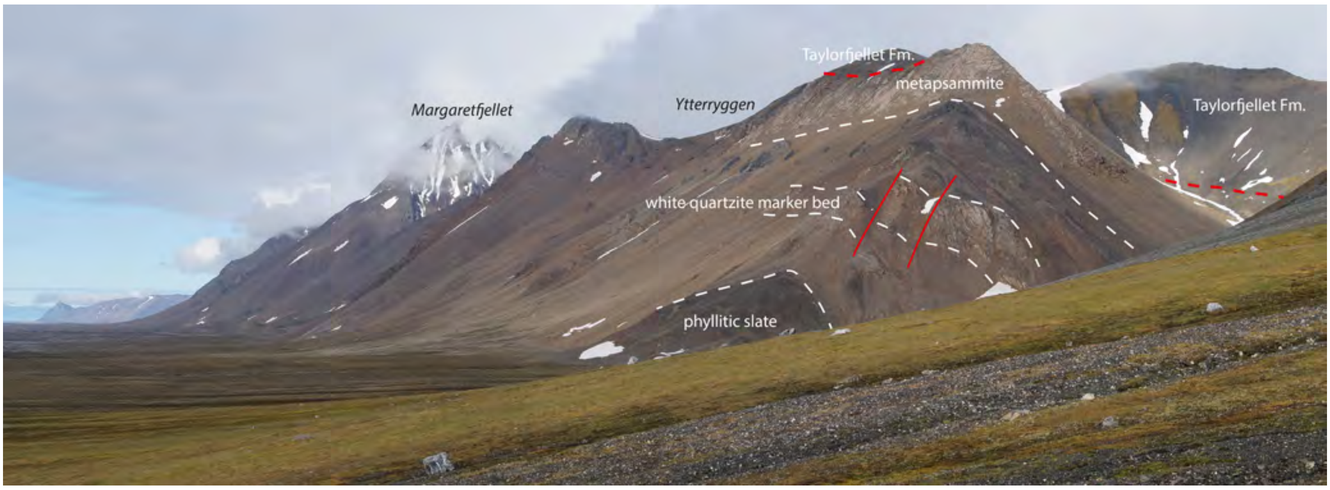


Photo 14: Typical section through the Conquerorfjellet Formation of central Prins Karls Forland at Petuniaskaret, looking northward along the eastern flank of the Omondryggen Syncline. The Taylorfjellet Formation to the right has a fault contact with the Conquerorfjellet Formation (Petuniaskaret fault segment).

Photo 15: Typical section through the Conquerorfjellet Formation of central Prins Karls Forland at Tvihyrningen, looking northwestward in the western flank of the Omondryggen Syncline.

3. Utnes Formation

The Utnes Formation (Manby 1978) is defined as the lithological transition between the Grampianfjella and Scotiafjellet groups, consisting of grey slates and phyllites, siliceous to calcareous, often rusty (probably from pyrite content), darkening in colour towards the overlying calcareous beds of the Scotiafjellet Group (Photo 9). According to our observations, opposing Manby's map (Fig. 1), this formation does not occur everywhere at the group transition. Often the contact is sharp, while in many places it is covered by scree; if present, the Utnes Formation must be very thin in these places.

On top of the overturned anticline at Vindholet (Photo 9), the Utnes Formation is an alternation of (partly rusty) slates and grey, often yellow-weathering, sometimes cross-bedded limestones (Photo 16). At the ridge between the anticlinal crest and Vindholet, this succession is several 10s of metres thick and consists of several metres thick slates with metre-thick limestone intervals.

Also in other areas similar lithologies occur below the first black slates of the Taylorfjellet Formation, usually with quartzite or metapsammite layers on top. This can be seen both in Mackenziedalen and in the cirque of Stairhøgdene. In the latter place, the alternations – where exposed in the river gorges – are thinner, with decimetre-thick slate and limestone beds, preferrably showing fining-upward successions (Photo 17).

The presence of limestones in the upper levels of the Grampianfjella Group may be the reason why Hjelle et al. (1979, 1999) mapped the calcareous Taylorfjellet Formation (Scotiafjellet Group)

Photo 16: Rusty slates with limestone interbeds in the upper part of the Conquerorfjellet Formation at Vindholet (unit J on Photo 9).

Photo 17: Limestone-slate alternations in the upper part of the Conquerorfjellet Formation, Niggdalen (unit I on Photo 9).

Photo 18: Rusty slates of the Conquerorfjellet Formation, canyon between Conquerorfjellet and Røyshaugen (unit J on Photo 9).

continuously between Taylorfjellet, Stairhøgdene and St. Andreashaugane. Manby's (1978, 1986) mapping is more correct here, although he did not indicate the presence of the Utnes Formation. Though carbonate lithologies and rusty slates occur in many other places close to the basis of the Taylorfjellet Formation, they are not continuous and, due to poor exposure, it is not possible to show them correctly on the map.

The Utnes Formation reoccurs below the Taylorfjellet Formation on both sides of the Omondryggen Syncline in central PKF, where it also was mapped by Manby (1978). Here it is less calcareous then in northern PKF and consists to a larger extent of rusty slates (Photo 18), although Manby described limestone intervals also from here. Southward towards Haukebukta the formation attenuates and disappears.

Scotiafjellet Group

Manby (1978, 1986) subdivided the Scotiafjellet Group into three formations, from allegedly older to younger, the Baklia, Kaggen and Omondryggen "formations" (Figs. 1, 12). Unfortunately, these three formations never occur in stratigraphic order within one single tectonic unit; only the Kaggen Formation occurs together with one of the others, respectively. Both the Omondryggen and Baklia units are dark and calcareous, the former with a higher percent of dolomites and a lesser percent of non-calcareous lithologies like slates and psammites (Photos 19-22).

Exceptionally, all three formations, though thinned, seem to occur together at Buchananryggen (close to Grimaldibukta), but boundaries cannot be studied here. Manby's map image is an interpretation based on the assumption that the Omondryggen "Formation" is the oldest. A complicating fact is that the Omondryggen and Baklia "formations" contain quite similar lithologies and are not easy to distinguish everywhere.

The basic lithology of all these formations is the same: dark, muddy limestones (locally lighter-coloured dolomites), often with a network of quartz veins, locally with chert nodules, and dark marls. The very similar facies on the map sheet A7 Kongsfjorden (Hjelle et al 1999) is called Taylorfjellet Formation, because it was not possible to decide, which one of Manby's subdivisions (Baklia or Omondryggen) it correlates to.

In central PKF, the Baklia "Formation" occurs only east of the Western Forlandsundet Fault (Photo 19), while the Omondryggen "Formation" occurs in the fold core of the Omondryggen Syncline (Fig. 9, Photo 20). The Baklia type association of rocks has a softer topography than the Omondryggen type.

Our own mapping did not reveal any indication of these two units being situated at different stratigraphic levels with the Kaggen Formation in between. The map is consistent with all these carbonate rocks being one formation, which we have renamed Taylorfjellet Formation. To express the differences between the eastern and western occurrences, Manby's formation names can be kept for the distinction of a western and an eastern facies type; Omondryggen type facies in the west and Baklia type facies in the east. In northern PKF (north of Murraybreen) it is not easy to subdivide these facies types, partly due to the lack of good continuous sections (Photos 21, 22). The Kaggen Formation does seemingly not exist there.

Photo 19: Typical slope face consisting of dark calcareous slates (Baklia facies) of the Taylorfjellet Formation, Scotiafjellet, central PKF, seen from the east.

Photo 20: Typical slope face consisting of dark recrystallised limestones (Omondryggen facies) of the Taylorfjellet Formation. Conquerorfjellet, central PKF, seen from the west.

1. Taylorfjellet Formation

The bulk of the formation (Baklia type facies), consists of black calcareous slates, probably altered marls, with thick sections or individual layers of dark-grey dolomite, often with chert nodules and bands (Photo 23). Massive black dolomites with a network of quartz veins are also common. Locally, in a central position of the formation, intraformational breccias (Photo 24) are observed.

The Omondryggen facies, which occurs predominantly in the major syncline west of the Western Forlandsundet Fault, is dominated by the more competent dolomitic varieties, both lighter-coloured cherty and darker-coloured with the quartz vein network (Photo 25). Non-calcareous lithologies were not observed.

Photo 21: Typical slope face consisting of dark calcareous slates (Baklia facies) of the Taylorfjellet Formation, Taylorfjellet, northern PKF, seen from the southwest.

In northern PKF, the Taylorfjellet Formation also contains these two dolomitic rock types, with a clear abundance of the darker type, as well as a higher portion of black calcareous slates. Typical trends have not been observed due to the poor exposure in many of the weathered, black mountain slopes.

On the top of Taylorfjellet some light-coloured rocks were seen from the distance but have not been visited or identified.

In the northern Scotiadalen-Finneryggen area the upper few tens of metres of the Taylorfjellet Formation (Baklia type) include a local member starting with calcareous slates (appear almost as phyllites) with marble bands, followed by a few tens of metres thick light-coloured, banded marble and a carbonate-free, dark grey to almost black quartzite to quartz slate with transitions to quartz phyllites (also a few tens of metres). These lithologies are either local and attenuate, as they do not occur at Ytterryggen nor in the eastern part

Photo 22: Typical exposure profile of the Taylorfjellet Formation in northern PKF at Taylorfjellet, seen from Vindholet.

Photo 23: Limestone interbeds of the Baklia facies, with chert nodules and bands, Taylorfjellet Formation, northeast of Finneryggen.

Photo 24: Intraformational conglomerate in the Baklia facies of the Taylorfjellet Formation, east of Røyshaugen (central PKF).

Photo 25: Recrystallised limestone (marble) with network of quartz veins, Omondryggen facies of the Taylorfjellet Formation, Conquerorfjellet west.

of Finneryggen. They may occur on the eastern side of the promontory north of Thomsonfjella but have only been observed there from a distance (Fig. 18, colour 16; Photos 192, 193, p. 92-93). They have alternatively been cut out by early, ductile thrusts, which would not be easy to detect in the field in these mainly phyllitic lithologies. They certainly do not occur in northern PKF.

2. Kaggen Formation

The bulk of the Kaggen Formation consists of greyish slates (Photos 26-29). Layers of quartzite and quartz-carbonate rock, a few metres in thickness, occur, and even a layer of angular quartz conglomerate (northern coast of Selvågen). The slates are locally darker, but usually not calcareous. A characteristic horizon (a few metres thick or less) of purple and chloritic-green banded slate occurs in the middle of the formation and is found in many places throughout the area (Photo 30). The compositional banding (primary bedding) is often highly oblique to the main foliation, thus the frequently observed repetitions of the purple and green slate may be due to tight folding (see structural description).

In the Omondryggen Syncline, the facies of the Kaggen Formation shows a different development. The normal grey slates occur on the eastern limb of the syncline, while the western limb consists mainly of a slightly porous, sericitic metapsammite with some intercalated rusty slate (Photo 31). It is possible that this metapsammite stratigraphically overlies the slate and that the map pattern is a result of faulting in the synclinal core, where the western limb (which again should consist of slate) is cut out. Future, detailed investigations may suggest that this rock unit should represent an individual formation.

A light-grey to yellowish quartzitic sandstone occurs at two places adjacent to Alfredbreen, which are contiunous in strike, 1) on the pass between Kaggen and Geddesfjellet, and 2) on the pass between Margaretfjellet and Krokodillen,. Its thickness is in the order of 100 m. Such a thick quartzitic sandstone has not been observed elsewhere in the formation.

The Kaggen Formation occurs extensively in central PKF and continues northward in the down-faulted, marginal tectonic blocks of the Forlandsundet Graben (Krokodillen, Buchananryggen, Grimaldibukta), where it attenuates tectonically just south of Richardlaguna.

The so-far unidentified light-coloured rocks seen from the distance on the top of Taylorfjellet might possibly represent a northern continuation of the formation.

Photo 26: Typical metapelites of the Kaggen Formation, slate with intrafolial folds, at Kaggen.

Photo 27: Typical metapelites of the Kaggen Formation, slate with crenulation cleavage crosscutting the primary layering, northern coastal section at Selvågen.

Photo 28: Metapelites of the Kaggen Formation with small-scale kink folds, northern coastal section at Selvågen.

Photo 30: Kaggen Formation with purple-green layers, foliation at angle with colour banding, northern coastal section at Selvågen.

Photo 29: Metapelites of the Kaggen Formation with large kink folds, northern coastal section at Selvågen.

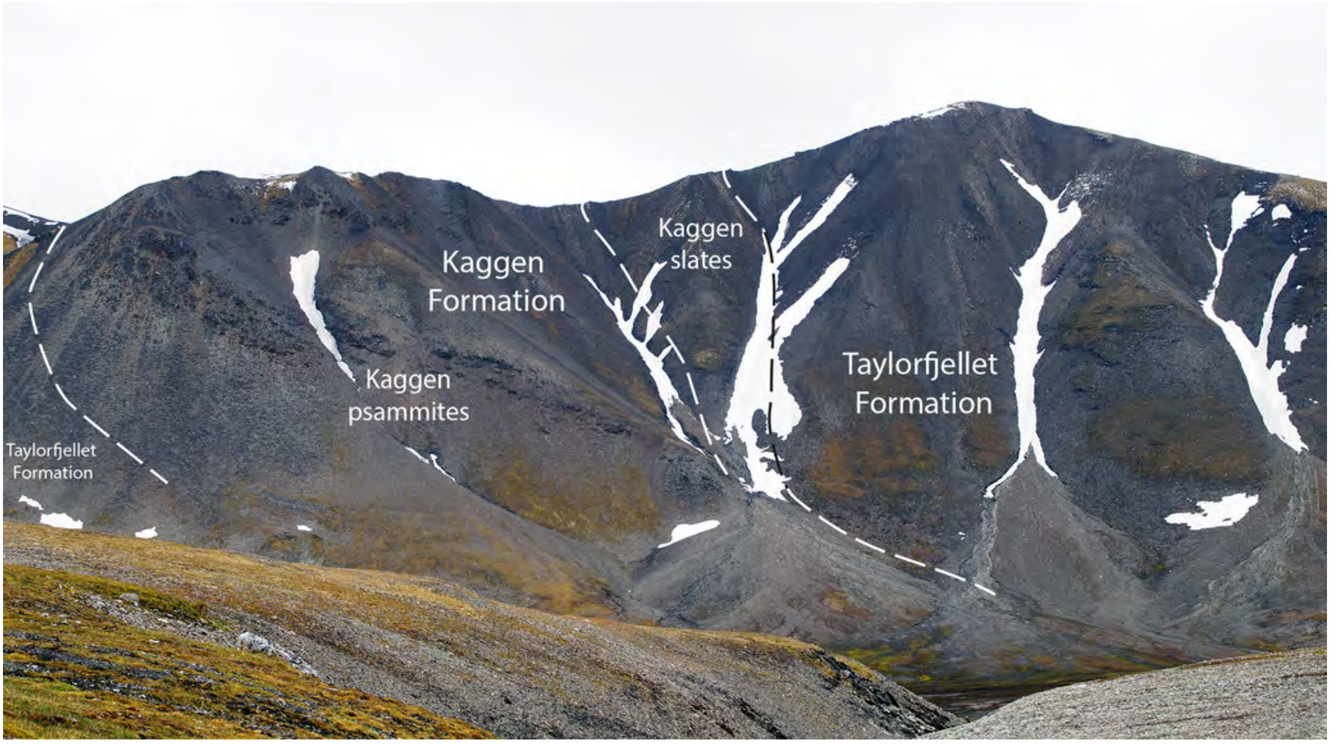


Photo 31: Kaggen Formation, folded metapsammite in the Omondryggen Syncline, pass between Allanfjellet and Scotiafjellet, seen from the south.

Stratigraphic relations in the lower part of the Grampianfjella Group

The structurally lowest sections of the Grampianfjella Group occur in a zone close to the boundary with the higher-grade Pinkie unit (see below) and in the Macnairrabbane Window. The former boundary is a tectonic shear zone, in which different lithologies occur (the carbonate-prone Craigtoppane Formation and a chlorite-schist-dominated unit), while the window occurs below a thrust fault and has an unknown stratigraphic relation to the remaining parts of the Grampianfjella Group.

1. Lithologies of the Macnairrabbane Window

The Macnairrabbane Window (Piepjohn et al. 2000) is a structural window providing insight into an underlying thrust sheet (see section *Structure of the basement*) (Photo 32).

This structural window was neither recognised by Manby (1978, 1986), Hjelle et al. (1979) nor Harland et al. (1993), and was first mapped by Piepjohn et al. (2000) and, based on Piepjohn's work, shown on the map by Hjelle et al. (1999) (Fig. 2). On these maps it had a smaller geographical extent than recently revealed (Figs. 5, 7). The window extends farther to the northeast than previously thought. No good outcrops exist in the extended part, however. Topography in combination with the orientation of the overlying thrust fault strongly suggest its northeastern continuation. The overall appearance of the rocks (see below) is in concordance with this interpretation.

The bulk of the Macnairrabbane succession consists of quartzite and quartzitic to arkosic metapsammite, occasionally with layers of (quartz) phyllite or carbonate-bearing phyllite (Photo 33).

These metapsammitic rocks contain sections of pebble conglomerates, sometimes several layers closely above each other. Layers may be lense-shaped. The matrix is orange carbonate, while the clast composition is oligomict (dolomite and some quartz). The clast size is from millimetres up to 4-5 cm, rounded or stretched (Photos 34-36). The conglomerates differ in appearance from those in the Fuglehuken Formation and other conglomerates in the Grampianfjella Group.

A chlorite schist unit extends for at least 4.5 km along the entire western part of the Window below the main thrust. The previously assumed volcanic origin (Hjelle et al. 1979, 1999) does not seem to be plausible. Most of the rock has a distinct lamination with carbonate laminae or thin beds, several mm thick. Other, more massive layers contain beds of quartzite (not only vein quartz) and dolomite pebbles (Photos 37, 38) which indicate a metasedimentary origin.

Other lithologies occur in the southeast of the window, stratigraphically below the metapsammites: A quartz-carbonate phyllite, a few tens of metres thick, and below that a phyllite. Locally in between them there is a layer, outcropping at 300 m of length, of probably boudinaged, yellow dolomite lenses, each of them some tens of metres long.

Hjelle et al. (1999) shortly discussed a possible correlation of the strata of the Macnairrabbane Window with the Fuglehuken Formation without resulting in any conclusion. There is no basis for any direct correlation. The typical Fuglehuken conglomerates are absent at Macnairrabbane, while the Macnairabbane conglomerates are different: They are easily recognised on weathered surfaces, while strongly recrystallised. On a fresh surface, matrix and carbonate boulders often have obscure boundaries or are not even distinguishable, more reminiscent of intraformational conglomerates. They

Photo 32: Overview of the Macnairrabbane Window, viewing eastward from the mountain pass east of Gjelet. The valley bottom consists of the window's rocks. The exposures in the foreground are the metasedimentary chlorite schists (unit 24 on map, Fig. 7). The trust lies in the lower ranges of the mountain sides.

Photo 33: Barren quartzite landscape characterises most of the Macnairrabbane Window.

Photo 34: Quartzites with intercalated lenses of orange-coloured conglomerates in the Macnairrabbane Window.

Photo 35: The conglomerates of the Macnairrabbane Window are mostly oligomict (dolomite and quartz pebbles) and have a dolomitic matrix.

Photo 36: Close-up photograph of an orange-weathering dolomite conglomerate with stretched pebbles.

are oligomict (dolomite and quartz pebbles), but not polymict like most of the Fuglehuken conglomerates.

Two secondary circumstances, not the lithologies themselves, make the unit appear different from the Grampianfjella Group in general, but may at the same time suggest that they are part of it: 1) There is abundant orange-coloured, secondary carbonate precipitation in fissures and cracks almost everywhere, which give the area a peculiar, rusty stain; 2) there is almost no vegetation on these rocks, a fact that underlines the orange staining of the area and makes it appear more different from the surrounding Grampianfjella rocks than it actually is, petrographically. These circumstances may be due to the fact that most of the area is extensively fractured because it immediately underlies a surface-parallel, eroded semi-brittle thrust plane (Photo 32). In addition, it may have been covered with dead ice until more recently than the other relatively flat areas of PKF, so vegetation has not yet established itself to the same extent.

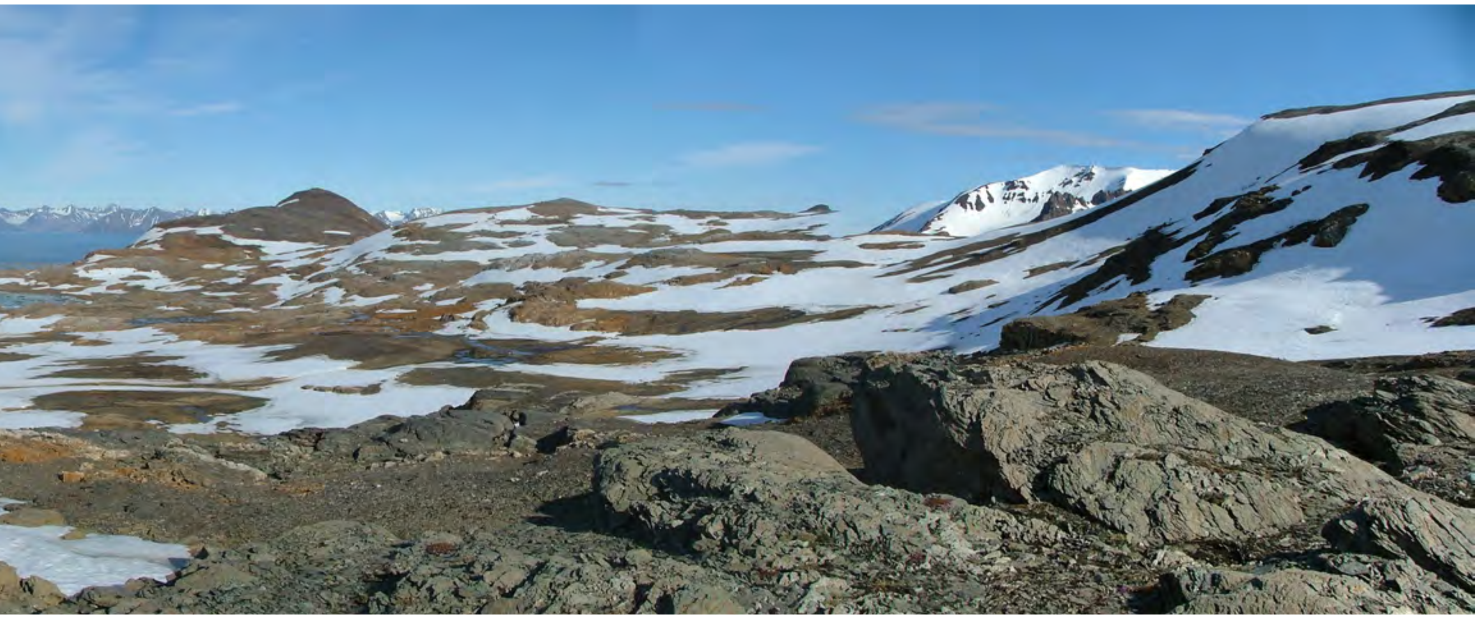


Photo 37: The western area of the Macnairrabbane Window displays a carbonate-laminated greenish rock of sedimentary or pyroclastic origen.

Photo 38: Locally, the greenschist of the Macnairrabbane Window contains streched conglomerate pebbles of dolomite and metasedimentary quartzite in a massive greenish matrix.

2. Craigtoppane Formation

In the Murraybreen-Buchananisen area, a new calcareous stratigraphic unit is distinguished, which was earlier assigned to the Pinkie unit (Harland et al. 1979). It occurs at eastern Krungleryggen and Bouréefjellet, eastern Rudmosefjellet, Veslefingeren (former "Pinkie") and Kasinoet. It also builds up the mountains Djevletommelen, Klørne, Neglene and Craigtoppane (Fig. 8) and has an approximate thickness of up to ca. 500 m.

Due to the very rough topography of these mountains it has only been visited at a limited amount of localities. The easiest accessible locality is at the western end of Buchananryggen, where a major Palaeogene normal fault separates it from Scotiafjellet Group lithologies to the east.

There is most probably a primary contact with the metapsammites and quartzites of the overlying Grampianfjella Group inferring that the Craigtoppane Formation may stratigraphically underly the Grampianfjella Group (M. Manecki, J. Majka, K. Kośmińska, pers. comm. 2014). At Veslefingeren and Bouréefjellet, the formation is thrust over the higher-grade rocks of the Pinkie unit, constituting a broad shear zone (see *Greenschist-metagabbro zone*).

The sequence in the Murraybreen-Buchananisen area consists of two distinct subunits. The following description is from an informal report by M. Manecki, J. Majka and K. Kośmińska (pers. comm. 2014):

The lower part is formed by banded grey and black dolomites. Typical examples crop out on northern slopes of Craigtoppane (Photos 39, 40). The bands are cm-dm thick, the grey bands are softer, yellow weathering, and contain various amounts of calcite. The black bands are harder and may contain some quartz. The foliation is usually parallel to the bands. The rocks are strongly deformed and isoclinal folds are common (Photo 41). The black bands show often brittle deformation, while white bands are ductile deformed. Brittle cracks within black bands, filled with white secondary calcite, in most cases do not continue into the white bands (Photo 40).

Photo 39: A variety of light and dark banded carbonate rock in the lower part of the Craigtoppane Formation on Bouréefjellet. Photo: Maciej Manecki.

Photo 41: Carbonate schist with isoclinal folds on the northeastern slope of Craigtoppane. Fold axes plunge gently (pencil). Photo: Maciej Manecki.

The upper part is formed by a calcareous rock type with a peculiar, cataclastic fabric. It is a dark grey or yellow weathering carbonate rock with angular fragments of marble or calcite-rich phyllite, cemented by a network of white calcite veins up to 1 mm thick (Photos 42, 43). The clasts are usually 0.5–2.0 cm in size. The rock is layered at a cm to several metres scale parallel to the foliation. Layers with chert bands and lenses occur (Photo 44). Quartzite bands may be intercalated. This massive carbonate rock builds up the mountains from Djevletommelen in the south through the south-eastern walls of Craigtoppane, the upper parts of Bouréefjellet and the southern slopes of Laurantzonfjellet in the north (Fig. 8).

The following anecdote illustrates the peculiar appearance of these rocks: Because of the often striped pattern at Kapp Sietoe we called this lithology informally "zebra rock" in 2012. At our first meeting with the geologists from Uppsala/Kraków who had visited eastern PKF in 2012 and who later joined our expeditions, we learned that they had found similar rocks and called them "shitty rock", "ugly rock" or "James Bond rock" (from the quotation "shaken, not stirred"). The latter expression became the one widely used in the field.

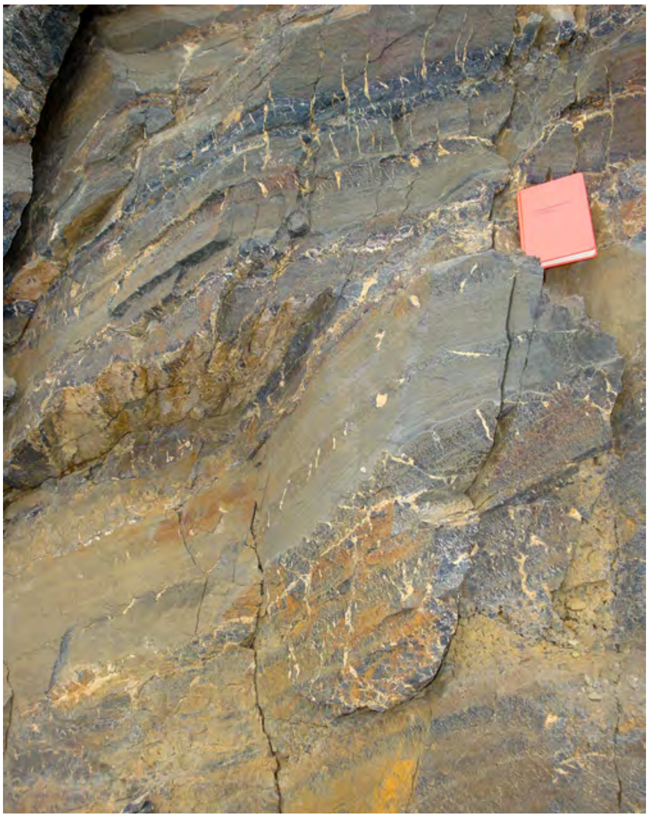


Photo 40: Another variety of light and dark banded carbonate rock in the lower part of the Craigtoppane Formation on Bouréefjellet. Black layers show brittle deformation cracks filled with light-coloured calcite, while light layers are more ductile deformed. Photo: Maciej Manecki.

Photo 42: Higher parts of the Craigtoppane Formation on Bouréefjellet consist of a banded marble with a fragmented matrix. Photo: Maciej Manecki.

Photo 43: The typical patched, fragmented marble of the Craigtoppane Formation, here an erratic block on Buchananryggen, most probably derived from the Craigtoppane Formation in the adjacent mountain Djevletommelen.

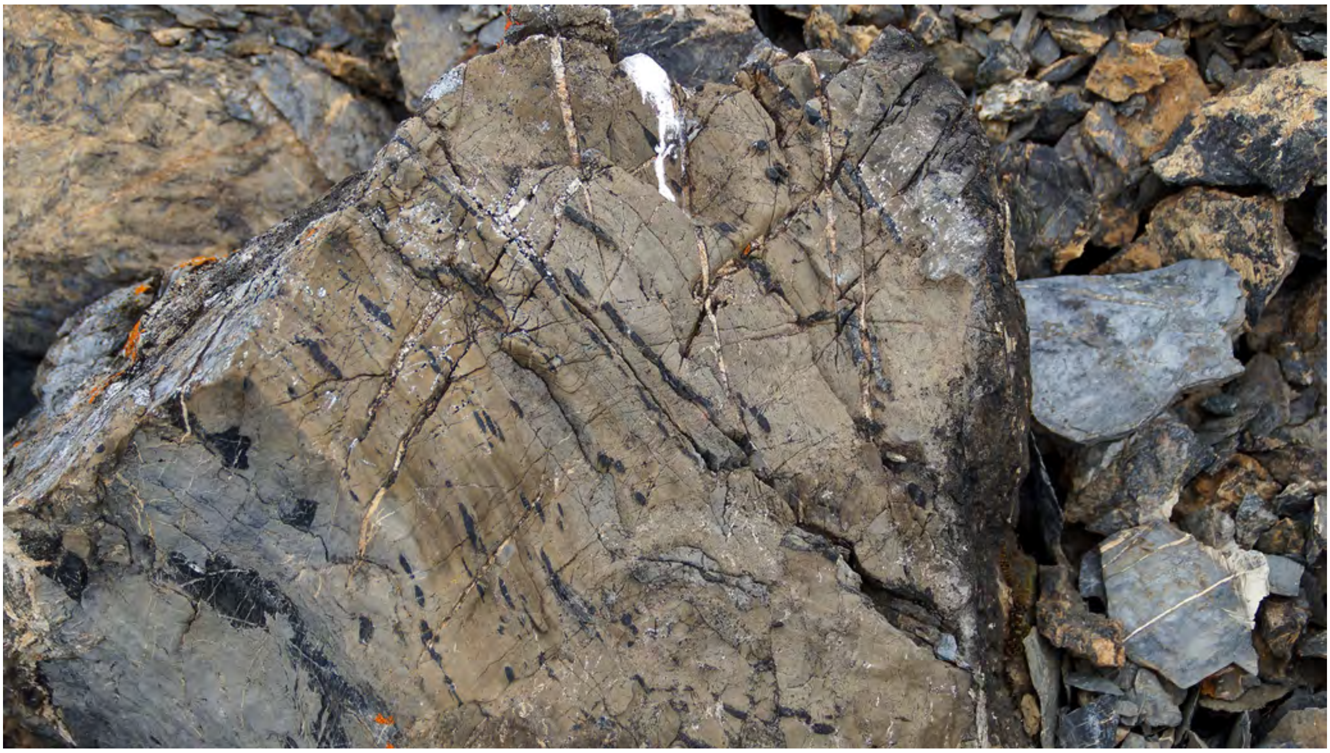


Photo 44: Carbonate rock with chert bands and lenses from the Craigtoppane Formation at Djevletommelen, just across the Western Forlandsundet Fault Zone from Buchananryggen.

On top of Bouréefjellet, the cataclastic carbonates are capped by laminated dolomitic marbles containing chert (jasper; Photo 45), interbedded with slates and laminated brown quartzites. Boudins of meta-mafic bodies (several metres in size) and discontinuous layers of massive magnetite ore (up to several metres thick) can be found within the laminated quartzites and slates (see *Greenschist-metagabbro zone*). On the top of Bouréefjellet, a large magnetite body occurs in these rocks. The richest analysed specimens had 40 % magnetite and 20 % hematite (Commissioner of Mines, pers. comm. 2012; Chapter 11 in Dallmann 2015). Another magnetite body was found at the southwestern side of the mountain (M. Manecki, pers. comm. 2014).

Photo 45: Carbonate with flattened, stretched chert lenses near the top of Bouréefjellet, Craigtoppane Formation. Photo: Maciej Manecki.

Photo 46: Patchy carbonate rock at Kapp Sietoe, reminiscent of the Craigtaoppane marbles (compare Photo 43).

3. Possible correlatives of the Craigtoppane Formation

In the lowland area between Laurantzonfjelet and Richardlaguna, in contact with the Conquerorfjellet Formation, an approximately 80 m thick succession of carbonate-rich clastic rocks with layers of polymict conglomerate and quartz-carbonate-chlorite schist occurs, upward grading into a unit of similar thickness with predominant chlorite schist in alteration with metapsammites (signature 23C in Fig. 7; see also *Greenschist-metagabbro zone*).

These are overlain by metapsammites of the Coquerorfjellet Formation. The unit seems to be a lateral continuation of the Craigtoppane Formation, although they here are structurally sandwiched between slices of Conquerorfjellet Formation. The abundant thrusts and shear zones in the area may provide a structural solution (see Section *Structure of the basement*). Unfortunately, the southern and eastern parts of Laurantzonfjellet are not mapped in detail yet. They are expected to reveal the stratigraphic relation between these calcareous units.

Carbonate lithologies at a low stratigraphic level in the Grampianfjella Group can also be seen in one northeastern coastal exposure (1 km NW of Carmichaelpynten, signature 23F in Fig. 7): laminated dolomite, dark-medium grey with light grey laminae. It is intercalated with quartzitic metapsammites, quartz-pebble conglomerates and calcareous metapelites. The exposure is isolated and tectonised by brittle faulting, seemingly cut off from the more westerly exposures by a fault, meaning that its continuity with – or stratigraphic position within – the adjacent Fuglehuken Formation is doubtful.

Photo 47: Close-up of the patchy carbonate rock at Kapp Sietoe.

Photo 48: Close-up of the patchy carbonate rock at Kapp Sietoe, a slightly foliated variety.

Photo 49: Cataclasite derived from the patchy carbonate rock at Kapp Sietoe in the fault separating it from the Sutorfjella conglomerate.

Photo 50: Carbonate rock at Kapp Sietoe, reminiscent of the Craigtaoppane marbles (compare Photos 39-40).

Photo 51: Boundary between the patchy carbonate rock and the metapsammites at Kapp Sietoe.

Photo 52: Metapsammite bodies with a peculiar boundary relation to the surrounding metapelites at Kapp Sietoe.

Southeast of Carmichaelpynten, laminated epidote-chlorite schists occur. All these lithologies trigger associations with the chlorite schist succession at Richardlaguna and may represent the same stratigraphic level.

On Langflya, the western strandflat south of Sutorfjella, carbonate lithologies (coarse-grained marbles) were locally seen in isolated exposures, but have not been mapped. They are also indicated on the NPI map sheet (Hjelle et al. 1999). If no major unrecognised thrust faults occur between here and the exposed mountain sides, this area is stratigraphically situated in the lower part of the Conqueror Formation and may form the transition with an underlying carbonate-prone succession.

Rocks reminiscent of the Craigtoppane carbonates occur north of Kapp Sietoe (signature 23S in Fig. 7) in northwestern PKF, where they show a striped to patchy pattern of white and dark-grey calcite, intercalated with various metapsammites (Photos 46-48). The rocks form locally a cataclasite in a Palaeogene fault zone (Photo 49) separating it from the Sutorfjella conglomerate. Its texture is decreasingly deformed from the fault towards a black mudstone with an irregular pattern of white calcite veins and patches (Photo 50). In the stratigraphic transition zone with the overlying metapsammites (Grampianfjella Group; Conquerorfjellet Formation?), metre-scale layers and irregular bodies of a yellowish-weathering psammite are situated within the calcareous rock (Photos 51, 52).

4. Greenschist-metagabbro zone

In connection with the carbonate-prone successions in the lower part of the Grampianfjella Group, zones of chlorite schist and other basic lithologies occur. The northernmost occurrence is an isolated outcrop of the above-mentioned epidote-chlorite schist southeast of Carmichaelpynten, which suggests being a stratigraphic equivalent of the chlorite-prone lithologies southwest of Richardlaguna.

In the latter area, there is a ca. 100 m thick succession of chloritic phyllite (Photo 53), which contains large lenses (metres to tens of metres) of a very dense, dark-greenish-brown chlorite-rich rock with Fe-rich, rusty weathering crusts (retrogressed mafic rocks?, Photos 54-55), and a strongly sheared dark limestone bed with quartz boudins and rods (Photo 56). The chloritic phyllites alternate with metapsammites in the vicinity of the boundary with the overlying Conqueror Formation (Photo 53). Occurrences of altered, aphanitic mafic rocks have also been described from the top area of Bouréefjellet (M. Manecki, pers. comm 2014).

These lithologies strike into the eastern parts of Laurantzonfjellet and Bouréefjellet, where they are not yet mapped.

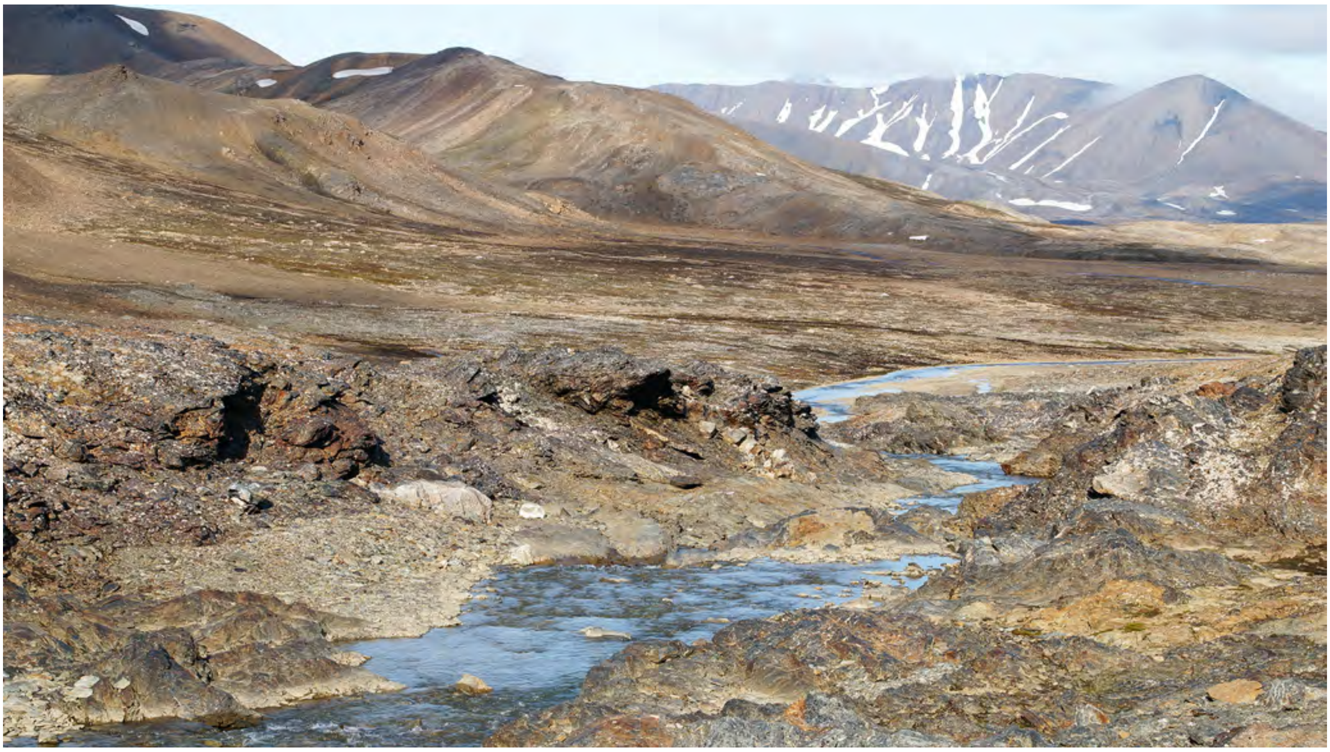
A 20 cm large, rounded metagabbro boulder found in 2012 in the outer part of Glenbegdalen was suggested to have been brought there by a local glacier from the adjacent mountain top areas. Strongly sheared chlorite schists have been described from the slopes of Laurantzonfjellet and Bouréefjellet in a similar setting, where they contain lenses of undeformed metagabbro with a magmatic, poikilitic texture (Maraszewska et al. 2016). The age of these gabbros is not known, but they are likely to be tectonically emplaced in the shear zone during the Ellesmerian Orogeny (U-Pb zircon dating, Kośmińska et al 2015, 2016, 2020). The tectonostratigraphic relation between the chloritic shear zone and the carbonate-prone Craigtoppane Formation in this area is still to be sorted out.

Photo 53 (left): Alternating slates and chlorite schists in the lowermost stratigraphic unit of the Grampianfjella Group, close to Richardlaguna.

Photo 55: Greenschist-metagabbro zone between Brodden and Richardlaguna; massive chlorite rock, possibly retrograded mafic intrusions.

Photo 56: Sheared calcite marble, exceptionally interlayered with chlorite schists of the greenschist-metagabbro zone.

Photo 54 (below): Greenschist-metagabbro zone, lowermost Grampianfjella Group, between Brodden and Richardlaguna. The dark hills are made up massive chlorite rock, possibly retrograded mafic intrusions.



5. Stratigraphic trends

The base of the Grampianfjella Group (Fig. 14) is only exposed at Bouréefjellet and Veslefingeren, where it overlies the higher-grade Pinkie unit with a tectonic, sheared contact (see *Structure of the basement*). In this location, the lowermost lithologies of the Grampianfjella Group are the carbonate-prone Craigtoppane Formation and associated chlorite schists, which seem to define tectonic shear zones. From the map pattern and the above descriptions it is reasonable to presume that these lithologies continue northward into the southern and eastern slopes of Laurantzonfjellet and farther northward into the area between Richardlaguna and Brodden. Here, the marbles of the Craigtoppane Formation are replaced by other carbonate-prone lithologies, while the chlorite schists are still prominant. The partly undeformed metagabbro lenses appear as altered, chloritised metagabbro bodies.

In several other localities, where a low stratigraphic level in the Grampianfjella Group is represented, carbonate-prone lithologies occur – at Carmichaelpynten, at Kapp Sietoe and on Langflya. The Kapp Sietoe occurrence has strong similarities with the fractured marbles of the Craigtoppane Formation. Also at the lowermost stratigraphic levels of the Macnairrabbane Window, quartz-carbonate schists and a local dolomite layers occur. Sheared chlorite rocks occur at Carmichaelpynten.

Photo 57: Carbonate conglomerates in the metapsammites above the Craigtoppane Formation at Millerbreen, a possible equivalent of the Macnairrabbane rocks? Photo: Jarosław Majka.

Photo 58: Quartz conglomerates in the metapsammites above the Craigtoppane Formation at Millerbreen. Photo: Jarosław Majka.

In the Fuglehuken Formation, also here underlying the Conquerorfjellet Formation, the abundance of carbonate-rich polymict conglomerates is prominent, while similar conglomerates in the Macnairrabbane Window and in the stratigraphically lower part of the Conquerorfjellet Formation at Millerbreen (Photos 57, 58) seem to be oligomict (K. Kośmińska, pers. comm. 2018). The conglomerates at Macnairrabbane (Photos 35, 36) and Millerbreen look a lot alike.

Thus, there are common trends in all these areas, but with significant local variations. The common features are the downward increasing presence of carbonate-prone lithologies with underlying chlorite schists or chlorite content in clastic rocks containing more or less retrogressed mafic bodies (Fig. 14).

The Fuglehuken Formation occupies a stratigraphic position between the carbonate-prone lithologies and the Conquerorfjellet Formation only in northernmost PKF. However, given the fact that

(1) the orange-weathering, carbonate-prone conglomerates are their main distinguishing feature, and that

(2) the conglomerate composition may vary laterally from polymict to olimict,

they may correlate with the lower conglomerate-bearing sections of the Conquerorfjellet Formation in the Macnairrabbane Window and at Millerbreen.

Pinkie unit

Harland et al. (1979) defined the "Pinkie Formation" in the mountain area between Bouréefjellet and Monacofjellet, characterised by higher-grade metamorphism and the alleged presence of metavolcanics. It was described as a thrust sheet between formations of the Grampianfjella Group. Hjelle et al. (1999; "Pinkiefjellet unit") specified an approximate thickness of 700 m. The carbonate-prone lithologies of the Craigtoppane Formation were included in the unit, which made its geographical extent and thickness considerably larger than what it is according to the present definition. After having recognised the primary contact of the carbonate succession with the overlying Conquerorfjellet Formation, the extent of the Pinkie unit now is confined to the higher-grade lithologies in the lower part of Bouréefjellet and the ridge of Veslefingeren (= original British name "Pinkie") (Photo 59, Fig. 8). These lithologies are mainly quartz-biotite schists, laminated quartzites and garnet-bearing mica schists.

M. Manecki, J. Majka and K. Kośmińska (pers. comm. 2014) describe the lithologies of the unit as follows: The lowermost part comprises laminated quartzites with laminae enriched in carbonate. Upward in the profile, carbonate laminae disappear and the rocks turn into a laminated quartzite. They are overlain by dark aphanitic rocks containing quartz and biotite and possibly plagioclase and/or amphibole. In the higher part of the profile, the dark siliciclastic rock contains garnet and white mica. Higher up, staurolite-garnet bearing schists occur which contain both white micas and biotite. Kyanite appears in the overlying schists. Amphibolites and amphibole-bearing schists probably comprise the uppermost part of the section. The mineral composition confirmed by preliminary microscopic observations suggests that these rocks were subjected to at least amphibolite facies metamorphism. There is an apparent metamorphic zoning from chloritoid through staurolite and up to

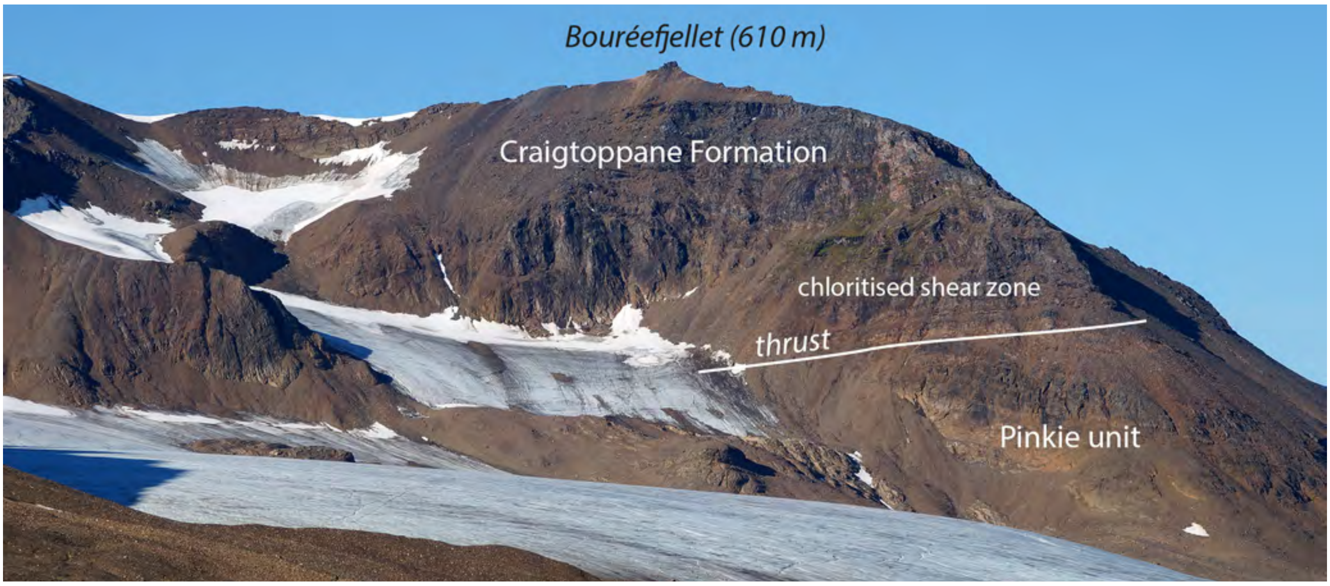


Photo 59: The Pinkie unit and overthrust basal succession of the Grampianfjella Group, starting with the chloritic shear zone and the Craigtoppane Formation.

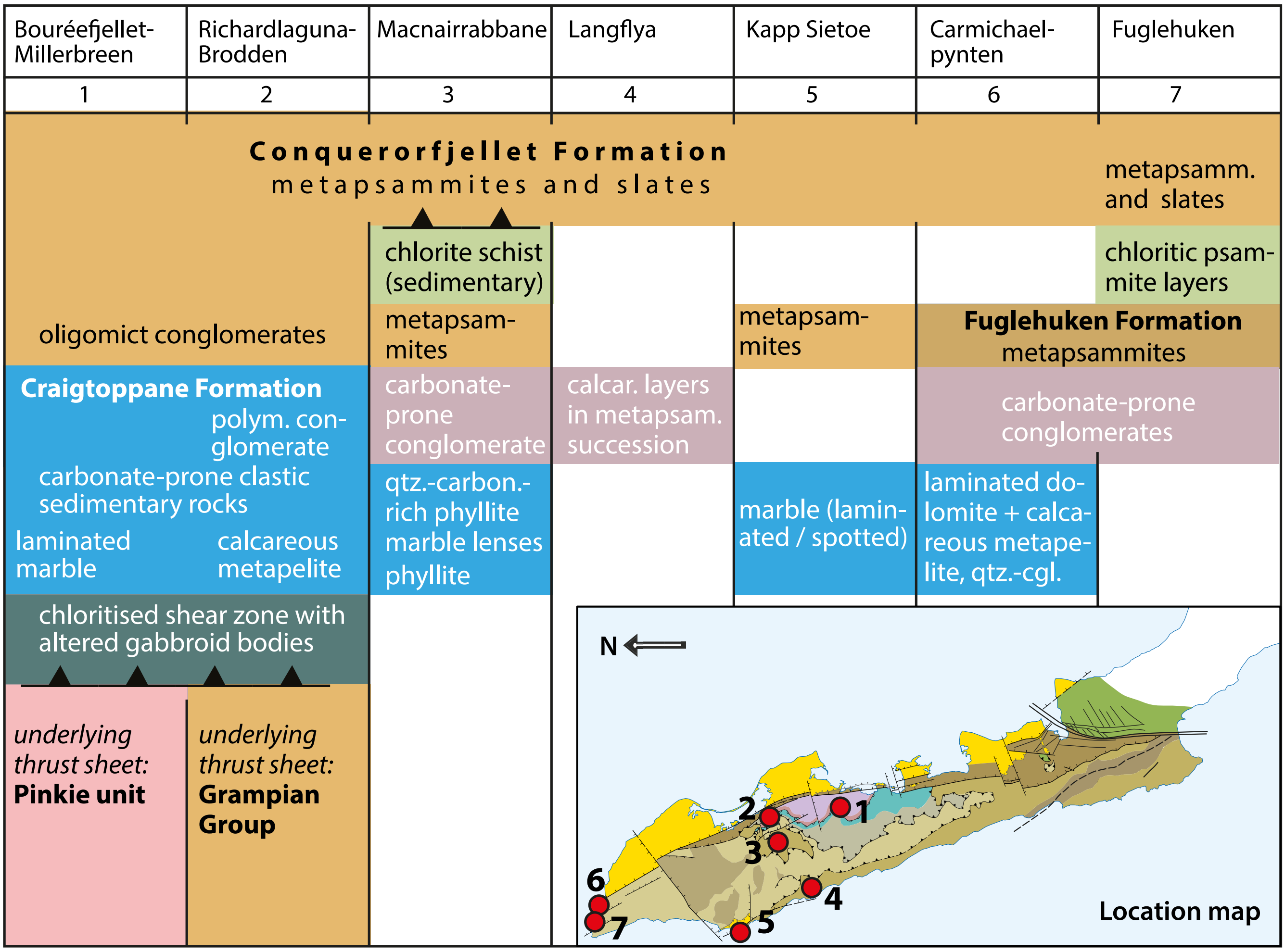


Fig. 14: Lithostratigraphy of the lower part of the Grampianfjella Group and tentative correlation of seven localities in northern Prins Karls Forland.

kyanite zone. The Barrovian-type metamorphic assemblages and ductile D1 structures are strongly overprinted by pervasive D2 mylonitic pattern (Faehnrich et al. 2016).

Lithological succession (M. Manecki, J. Majka and K. Kośmińska, pers. comm. 2014):

Thrust contact with Craigtoppane Formation (Grampianfjella Group)

Amphibolites and amphibole-bearing schists

Garnet-mica-bearing schists with staurolite and/or kyanite (Grt+Bt+Ms+Pl±St±Ky+Tur+Ilm+Q)

Garnet-amphibolites (gneisses with garnets) (Grt+Bt+Ms+Pl+-Q±Amph)

Gneisses with plagioclase augen (Bt+Mica+Pl+Q ?)

Dark gneisses (biotite-rich ?)

Laminated quartzites

Scapolite-bearing rocks

Quartzites with carbonate-rich laminae

Chloritoid-mica-bearing schists (Cld+Chl+Mica+Plag+Q)

Manby (1983b, 1986), based on scapolite-bearing samples from Veslefingeren, indicated biotite-almandine facies metamorphism in the PT range of 380-560° C and 0.4-0.75 GPa. Recent work revealed three progressive zones of Barrovian-type metamorphism at 560-630° C and 0.8-1.0 GPa (Kośmińska 2015, Kośmińska et al. 2016, 2020). Monazite dating showed growth from an early prograde stage at 359 Ma old (latest Famennian) to peak conditions at 355 Ma (Earliest Carboniferous) and thus determines the age of its deformation to the Ellesmerian Orogeny. Detrital zircon dating gave a maximum protolith age of 950-1005 Ma, thus assigning a probable Neoproterozoic age to the protoliths (Kośmińska et al. 2015).

Basement of southern PKF

A detailed stratigraphy of southern PKF was proposed by Morris (1978, 1979). It can be traced across the entire mountain area around Geikiebreane and reoccurs south of the almost completely covered Forlandsletta at Persiskammen and Salfjellet. The strata are generally younging upwards, starting with Neoproterozoic diamictites (tilloids) (Photos 60, 61). The established stratigraphy is in agreement with recent obsevations, although it might be practical to move the boundary between the Hornnes and Knivodden formations for the purpose of easier mapping (Fig. 13; J. Czerny, pers. comm 2013).

New map data that so far are availbale to us, are restricted to the vicinity of the Baklia Fault Zone (mapped by J. Czerny and G. Ziemniak, 2013) (Fig. 9). Subsequent work by the same workers in 2014, which covers large parts of the Geikiebreane area, is not compiled yet. During a helicopter-based reconnaissence trip to the area south of Forlandsletta during the same field season, several formations from the the Geikiebreane area were recognised there, and it seems that there is no room for additional strata below or above the established succession (Fig. 15, Photos 62-65).

Photo 60: Diamictites reminiscent of the Ferrierpiggen Group in the eastern klippe on Thomsonfjella.

Photo 61: Close-up of a diamictite reminiscent of the Ferrierpiggen Group in the eastern klippe on Thomsonfjella.

Photo 63: Chloritoid phyllite of the Knivodden Formation at Aitkenodden intensely sheared and folded (locality 110 in Fig. 15).

Photo 64: Quartz-carbonate-mica schist at Persiskammen (locality 111 in Fig. 15).The succession also contains diamictites and is thought to belong to the Neukpiggen Formation of the Ferrierpiggen Group.

Photo 62: Chloritoid phyllite of the Knivodden Formation at Aitkenodden (locality 110 in Fig. 15).

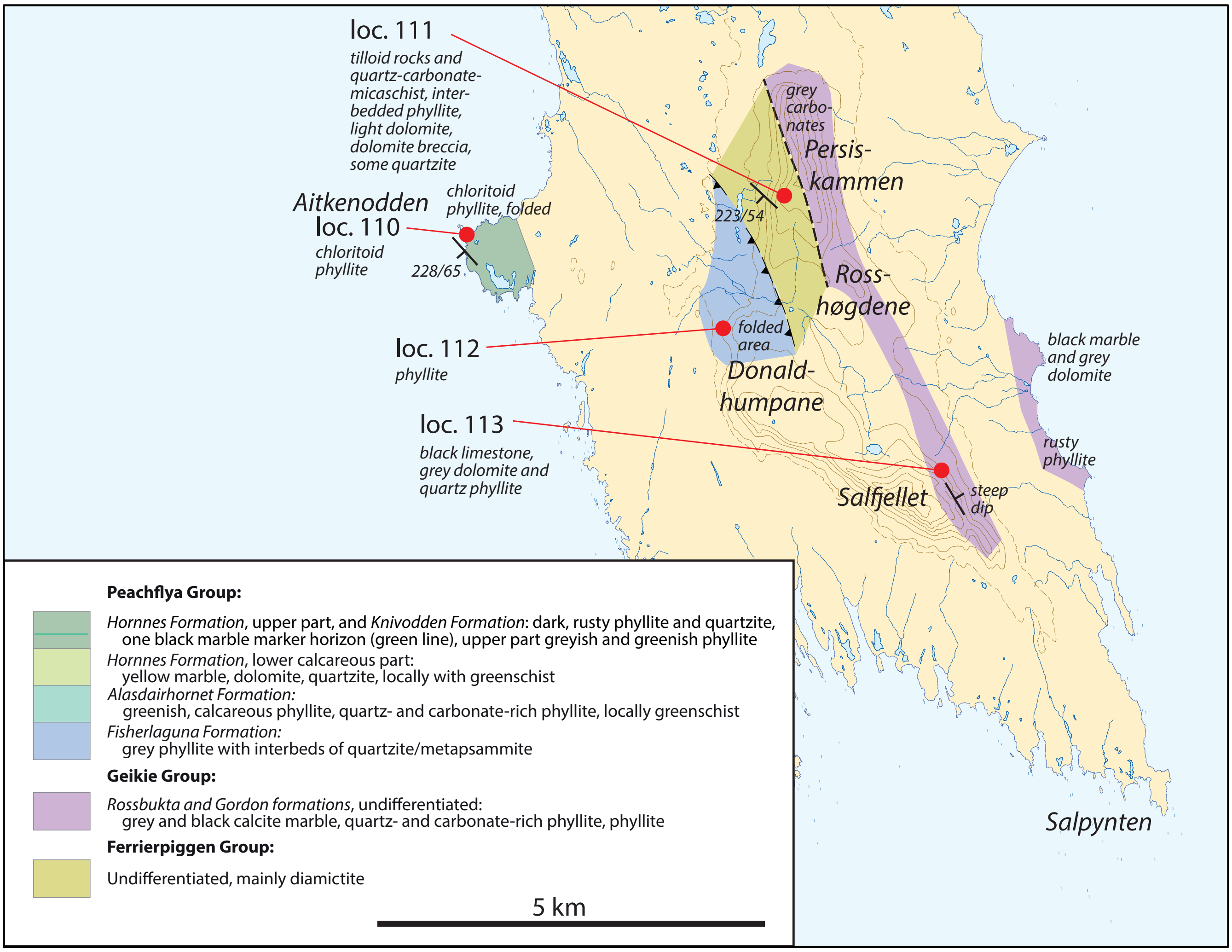


Fig. 15: Stratigraphic observations from a reconnaissence trip to southern Prins Karls Forland.

Photo 65: Salfjellet with steeply east-dipping marbles and other carbonate rocks belonging to the Geikiebreane Group (loc. 113 in Fig. 15).

The stratigraphy of the southern tectonic block of PKF is subdivided into Ferrierpiggen Group, Geikiebreane Group and Peachflya Group, and is unique to this area. Certain similarities with the Sofiebogen Group of southern Spitsbergen occur (J. Czerny, pers. comm. 2013).

The Ferrierpiggen Group (lowest level): mainly diamictites, presumably tillitic rocks;

Geikiebreane Group (middle level): recrystallised carbonate rocks;

Peachflya Group (highest level): various phyllitic rocks with calcareous sections and with intercalated metapsammites, as well as greenschists. For details see Fig. 13.

Aspects of basement correlation

A correlation of any stratigraphic units between PKF and Spitsbergen is not straightforward. However, distinct similarities exist between the stratigraphy of southern PKF and the Sofiebogen Group of southern Spitsbergen (Birkenmajer 1992), while possible correlatives of that group farther north (Dallmann et al. 2002) could possibly be candidates (e.g., Daudmannsodden and Lågnesbukta groups), though comparative work would need to be done.

The Ferrierpiggen Group consists mainly of diamictites, presumably tillitic rocks, and seems to correlate with the early Ediacaran diamictites of southern Spitsbergen (Slyngfjella conglomerate). There, these overly the 640 million years old Torellian unconformity (Majka et al. 2014) and may thus represent the youngest Neoproterozoic glaciation. The overlying Geikiebreane Group is reminiscent of the Höferpynten carbonates in southern Spitsbergen, which overly the Slyngfjella conglomerate. The uppermost Peachflya Group may tentatively correspond to the Gåshamna phyllites in southern Spitsbergen (J. Czerny, pers. comm. 2013).

This tentative correlation would place the stratigraphy of southern PKF around the Cryogenian-Ediacaran boundary, which means above the 640 Ma old Torellian unconformity. A similar age ("Lower Vendian") was indicated for the basement of northern PKF, at least for the Scotiafjellet Group, by Knoll (1992). These very different stratigraphies within a quite close age range could indicate that the southern and northern parts of the PKF basement are derived from places far apart and juxtaposed during the Caledonian, Ellesmerian and/or even the Eurekan orogenies, the latter along the Baklia Fault.

In order to test Harland's et al. (1979, 1993) correlation of the Grampianfjella Group (and initially also the Scotiafjellet Group) with the Ordovician-Silurian Bullbreen Group in Spitsbergen, a short excursion to the southern shore of Engelskbukta was undertaken, where the Aavatsmarkbreen Formation (Waddams 1983) provides a good coastal section. The Aavatsmarkbreen Formation was correlated with the Bullbreen Group by Ohta et al. (1995) based on findings of Early Palaeozoic fossils (Scrutton et al. 1976; Armstrong et al. 1986). Laminated and massive quartzites occur at Engelskbukta, which resemble some of the Grampianfjella lithologies, especially at Fugle-huken (Photos 66-69). These are interbedded at a hundred-metres scale with dark, muddy marbles, locally displaying a network of quartz vein. Also this lithology occurs in PKF, but never interbedded with the quartzites. In short, the main lithologies exist, but not the diagnostic associations from PKF. A lithological correlation might thus be possible, but not obvious. A possible correlation would have to overcome the problem of different age interpretations.

Although the evidence of an early Ediacaran age of the Scotiafjellet Group (Knoll 1992) may be quite weak due to the possibility that the fossils may be redeposited, a major obstacle for the Bullbreen

Photo 66: Coastal cliff at Engelskbukta (Spitsbergen, east of Forlandsundet) displaying the Aavatsmarkbreen Formation. The formation has been correlated with the Orovician-Silurian Bullbreen Group and with the Grampianfjella Group on PKF, leading to age discrepancies.

Photo 67: Alternating metapsammites and metapelites in the Aavatsmark-breen Formation in the coastal cliff at Engelskbukta.

Photo 68: Dark calcareous succession in the coastal cliff at Engelskbukta, Aavatsmarkbreen Formation.

Photo 69: Folded, distinctly layered metapsammite in the Aavatsmarkbreen Formation in the coastal cliff at Engelskbukta.

correlation is the different order of the main lithologies. While the main northern PKF lithologies go from psammites to carbonate, the Bullbreen Group goes from carbonate to conglomerate and then to psammites. Even though the way-up of one of the successions may be mistaken, the major Bulltinden conglomerate between the carbonate and clastic successions of the Bullbreen Group has no equivalent in PKF.

Another fact is complicating the situation even more. Although the stratigraphies north and south of the Baklia Fault are completely different, there is a klippe of diamictites (Neukpiggen Formation, Ferrierpiggen Group) from the southern stratigraphy emplaced on top of the Kaggen Formation from the northern stratigraphy in Thomsonfjella (Fig. 9; Photos 144-150). The correlation was done by Manby (1978) and reconfirmed during recent field work (J. Czerny, pers. comm 2014). Any tectonic model explaining the juxtaposition of the northern and southern stratigraphies would need to have room for thrusting part of the southern basement onto northern basement during a convergent phase (see below).

The Palaeogene

Our work has particularly dealt with the basement rocks of PKF, while observations of the Palaeogene succession mainly served puposes of detailed mapping. We have no reason to modify the stratigraphy, which was developed by Atkinson (1962), Livšic (1967), Rye Larsen (1982) and Dallmann (1999) (see *Previous work – Other work*). However, the detailed distribution, structure and some boundary relations differ locally from previous maps (Kubisch 1986; Magnus 1986; Pagels 1986; Wollenburg 1986; unpublished Norsk Hydro field reports 1989-1991; Hjelle et al. 1999). We refrain from giving a summary of earlier stratigraphic descriptions, which is provided by the Lithostratigraphic Lexicon of Svalbard (Dallmann 1999). The sections below are limited to specific observations that deviate from or amend earlier descriptions.

Sutorfjella conglomerate

In the formalised nomenclature (Dallmann 1999) the name of the unit is Sutorfjella conglomerate, replacing the earlier used "Sutor conglomerate" (Craig 1916) and "Sutorfjella conglomerate member" (Harland et al. 1979).

The Sutorfjella conglomerate is the only stratigraphic unit on the western side of PKF, which is distinctly younger than the basement rocks, overlying the latter with an undisputed angular unconformity. The conglomerate forms the northern and southern peaks of Sutorfjella, topographically interrupted by the Quaternary-covered, east-west trending valley Sutordalen. It dips ≤30° WSW, steeper than the slopes (Photo 70), and flattens out on the coastal foreland to the west, where it grades into openly folded sandstones (Photo 71), and then is cut off sharply by a NNW-SSE striking, brittle normal fault. This fault strikes into the sea in the NNW and into the foreland plain at Langflya, where it cannot be traced due to extensive Quaternary cover. We found the previous maps (Gjelsvik 1987; Hjelle et al. 1999; Piepjohn et al. 2000) roughly correct, but made a few minor corrections (Fig. 7).

The main objective of our field work was to make up our mind about the disputed age of the conglomerate. Craig (1916) considered it to be clearly younger than the "Hecla Hoek" (basement) rocks and probably of Devonian age. Though not having seen it, Tyrrell (1924) suggested it might be of Tertiary age because of the obvious presence of Tertiary sediments on the island. Atkinson (1954) and Harland et al. (1979, 1997) assigned it to the pre-Caledonian succession, though younger than the unconformibly underlying rocks. Gjelsvik (1987) and Klee (1990) made detailed descriptions and favoured a Devonian age. Due to the lack of additional evidence, this opinion was uncritically adopted by Hjelle et al. (1999) and Piepjohn et al. (2000). Rye Larsen (1982) in his voluminous thesis on the Tertiary rocks of PKF did not investigate the Sutorfjella conglomerate, but, obviously after a visit, proposed a Palaeogene age due to its striking similarity with the Selvågen Formation on the eastern side of the island.

The main reason for the frequently represented opinion that the conglomerate is "old" (Devonian or older) seems to be its "old" appearance in contrast to other Cenozoic conglomerates in Svalbard. Both clasts and matrix are normally foliated, though there is no foliation that has affected both together. Clasts have pre-depositional cleavage and veining (Photos 72, 73). Foliation in the matrix has generally an acute angle with the lithological bedding, where shaly layers are intercalated (Photo 74). The matrix is shaly, greenish or exceptionally greyish. Clasts are compositionally and texturally immature, have all sizes up to ca. 50 cm and represent the lithologies of the surrounding basement.

The conglomerate seems to represent debris flow deposits, composed of stacked lobes (Photos 75, 76). The ≤30° dip angle of the depositional streams may represent the original angle of deposition in the (submarine?) talus cone of a slope or at a fault scarp. The depositional angle flattens away from the slope, where clasts are mostly absent; the matrix becomes the bulk lithology of a greenish to reddish arkosic sandstone with a banded or patchy colour distribution and abundant quartz veins. This sandstone is weakly folded in a very open syncline at a 10s-of-metres scale (Photo 71).

Photo 70: Sutorfjella conglomerate, northern peak seen from the south. The white line traces the angular unconformity above rocks of the Grampianfjella Group.

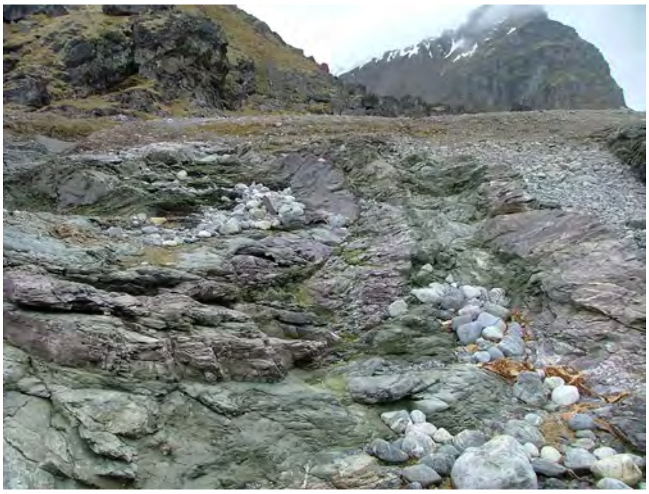


Photo 71: Sutorfjella conglomerate in the background; greenish and reddish sandstones in front belong to the same sedimentary succession and are weakly folded.

Photo 72: Sutorfjella conglomerate with a breccia clast.

Photo 73: Sutorfjella conglomerate with a foliated clast.

Photo 74: Sutorfjella conglomerate with foliated matrix, acute angle between the foliation and the lithological bedding, where shaly layers are intercalated.

Photo 75: The ≤30° dip angle of the depositional lobes of the Sutorfjellet conglomerate may represent the original slope angle during deposition in a (submarine?) talus cone of a slope or at a fault scarp.

Photo 76: The Sutorfjella conglomerate may represent debris flow deposits, composed of stacked lobes, which now are controlling differential weathering.

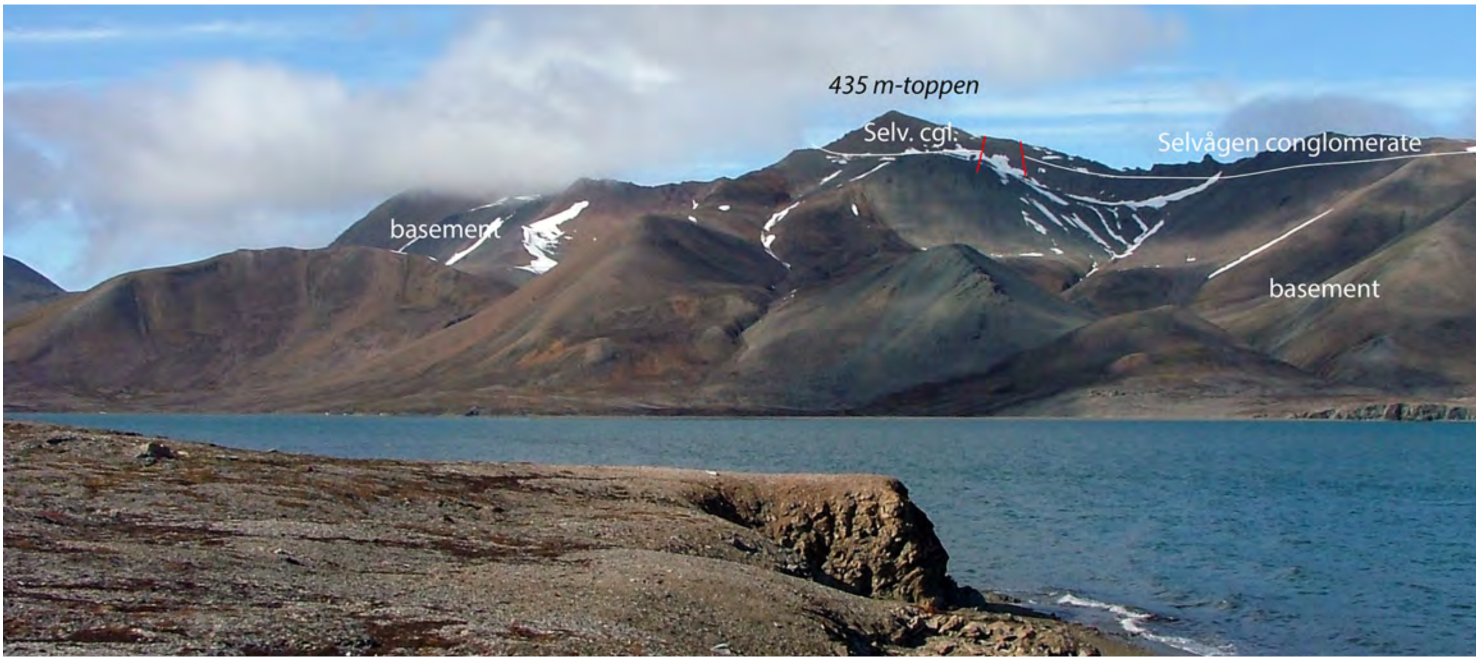


Photo 77: Northward view across Selvågen showing basement and overlying Selvågen conglomerate, down-faulted at two normal faults in the east, where overlying younger Palaeogene sediments occur. The main graben boundary fault, the Western Forlandsundet Fault Zone, is situated far away to the west (left).

The "old" appearance of the rocks is further caused by the greenish colour and the often strong foliation of the matrix where bending around the clast. Provided that the matrix may be redeposited material from the wider surroundings without any growth of green minerals, but suffering a significant overburden that resulted in a distinct foliation, this "old" appearance may not have any bearing on the real depositional age.

When mapping the Palaeogene deposits on the eastern coast of PKF and after having studied the Sutorfjella conglomerate, we found that the similarity between the basal conglomerates (Selvågen Formation) and the Sutorfjella conglomerate was striking. The description of the lithology and texture of the Sutorfjella conglomerate fits in detail with that of the Selvågen Formation. Also the Selvågen Formation fills the morphological relief of the basement surface and seems to be part of an uninterrupted depositional sequence with the overlying formations (Rye Larsen 1982). Although there is no direct age evidence for any of these sediments on the western side of Forlandsundet, it is reasonable to assume a Palaeogene age in correspondence with the dated graben fill on the eastern side (Feyling-Hanssen & Ulleberg 1984). However, there might still be a significant age gap between the basal conglomerates and the overlying sediments, and also between individual exposures of conglomerates. It is thus probable that the Sutorfjella conglomerate, although derived from roughly the same period of differential uplift and subsidence, may have been deposited in a separate trough. It should therefore keep its local stratigraphic name.

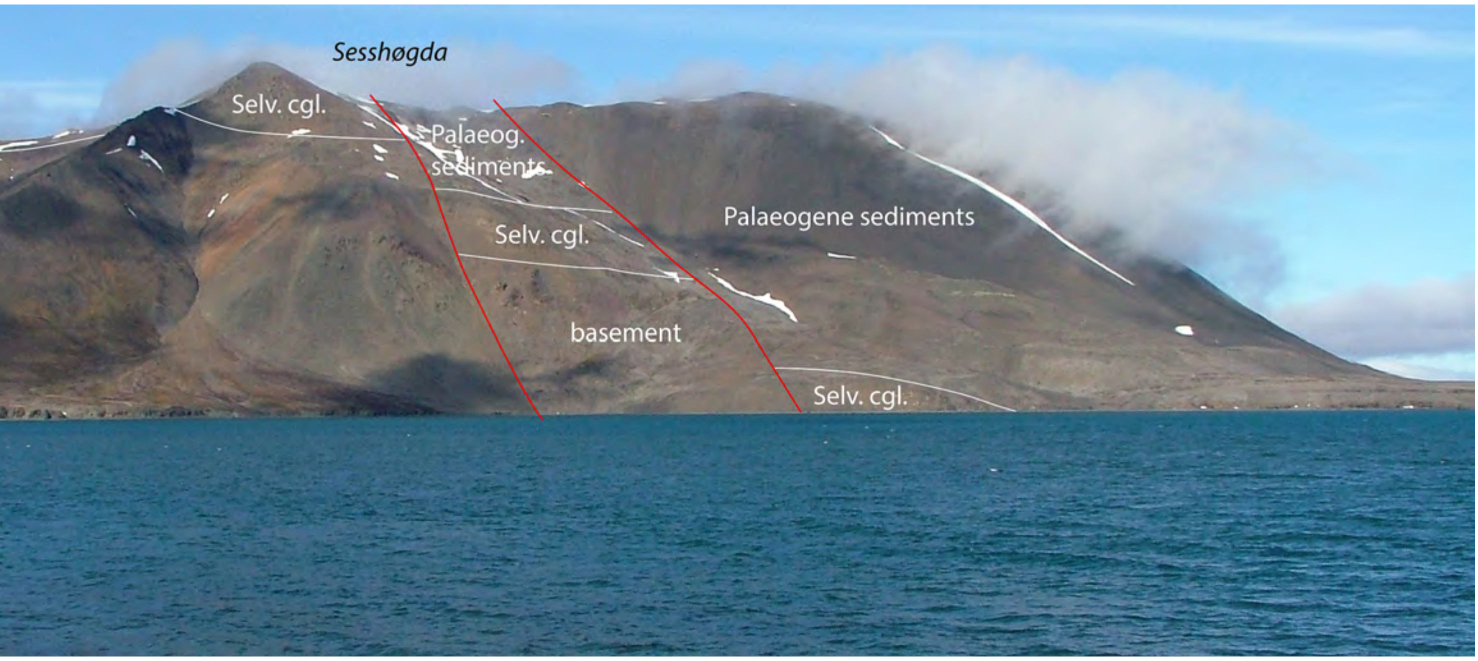
Rye Larsen (1982), confirmed by Manum & Throndsen (1986), reported quite high vitrinite reflectance values, especially from the Selvågen area of up to 4.01, which correspond to an overburden of 5-10 km, provided a normal geothermal gradient. Assuming that the geothermal gradient in northwestern Svalbard was relatively high due to the vicinity of the Yermak hot spot (Amundsen et al. 1987), an overburden in the upper range of that depth interval may be suggested. This would explain the strong foliation bending around the clasts, which give the conglomerate the tectonised, "old" appearance.

The Selvågen area

The Selvågen area provides the only relatively complete stratigraphic section of the Palaeogene of the Forlandsundet Graben, the Buchananisen Group (Dallmann 1999). From base to top, the Selvågen, Sesshøgda, Reinhardpynten, Krokodillen and Marchaislaguna formations (Livšic 1967) occur in a generally ENE-ward younging succession. Depositional formation boundaries can be observed in the outcrops on Sesshøgda and/or Krokodillen.

The conglomeratic Selvågen Formation constitutes the base of the succession in all places, where a primary contact with its basement is exposed – Thomsonfjella/Sesshøgda (Photos 77, 78), Geddesfjellet (Photo 79) and Krokodillen (Photo 81), between the two latter ridges almost continuously exposed in front of the glacier Alfredbreen (Photos 80, 82). The conglomerate is measured to be 170 m thick in the stratotype on Thomsonfjella (Rye Larsen 1982) (Photos 77, 78), where the upper boundary is not exposed. The thickness decreases eastward to ca. 50 m in the small fault block on Sesshøgda (mapped by us), where the upper boundary is exposed. To the north, at Geddesfjellet, a thickness of ca. 500 m can be estimated from the map image (Fig. 9, Photo 79). At Krokodillen, the thickness is again small and significantly varying (Photo 81). The variation may be caused by a predepositional morphological relief and/or by syndepositional faulting – related to the first phase of the faulting event that eventually led to the subsidence of the Forlandsundet Graben.

The Sesshøgda Formation (sandstone, pebbly sandstone and fine-grained conglomerate) occurs above the Selvågen conglomerates in the two eastern fault blocks at Sesshøgda, 59-120 m thick (Rye Larsen 1982). In contrast to the Selvågen conglomerate, it is always distinctly bedded. It is not exposed between Sesshøgda and Krokodillen, where it reoccurs with a thickness of less than 50 m (Photo 83).



The Reinhardpynten Formation (monotonous shales with pyrite concretions and fine-grained sandstones) make up the eastern slope of Sesshøgda to Reinhardpynten (>210 m thick, Rye Larsen 1982) and the middle part of Krokodillen. In the latter place the thickness seems distinctly less, although not yet mapped properly, while it is overlain by the Krokodillen Formation (similar shales without pyrite concretions and with distinct, coarser-grained, massive sandstones) (Photo 84). The Krokodillen Formation may be a time-equivalent, lateral replacement of the upper part of the Reinhardpynten Formation.

Isolated outcrops of massive sandstones are present in the northern part of Sessflya. Rye Larsen mapped these as Marchaislaguna Formation (heterogeneous formation with sandstone, pebbly sandstone, conglomerate, shale), which from here should continue into the coastal exposures of Andenesstranda. Sandstones on the eastern end of the Krokodillen ridge (Photo 81) may be the basal layers of the Marchaislaguna Formation. We did not visit these outcrops.

South of Selvågen, on eastern Selvågflya and northern Ferrierstranda (both sides of the cape Dawespynten), only two small outcrops of Palaeogene rocks were found, both close to the suggested western boundary fault. The southeastern outcrop (bank of a small stream) shows dark, flaggy siltstones with plant remains and beds of dark-grey, fine-grained sandstone. The northwestern coastal outcrop shows shales, flaggy siltstones, massive light-coloured, fine-grained sandstone with crossbedding, gritstone and pebble conglomerate layers. Strikingly, the outcrop contains small-scale isoclinal folds, reminiscent of some of the deformation at Trocaderostranda (see section below). The outcrops may tentatively belong to the Sesshøgda Formation (Photo 85).

Photo 78: View from the 435 m-peak (see Photo 77) to the east along Thomsonfjella. The Selvågen conglomerate overlies the basement, which consists mostly of the Kaggen Formation.

Photo 79: Geddesfjellet seen from the north, showing Selvågen conglomerate overlying basement (Kaggen Fm.). The conglomerate forms a flexure, probably above a hidden fault. Sesshøgda in the background, moraine in front.

Photo 80: Selvågen conglomerate behind the coastal strandflat between Geddesfjellet and Krokodillen, covered with young moraine in the background.

Photo 81: Palaeogene succession of the mountain Krokodillen, viewed northward from the eastern slope of Geddesfjellet.

Photo 82: Selvågen conglomerate facies in the area between Krokodillen and Geddesfjellet.

Photo 83: Sesshøgda Formation in a small E-W striking graben structure, southwestern Krokodillen (see Photo 81).

Photo 84: Sandstone subcrops on the coastal plain Sessflya, representing either Reinhardpynten or Krokodillen Formation.

Photo 85: Small outcrop of the Sesshøgda Formation east on Selvågflya, 2.5 km west of Dawespynten, gritstone to fine pebble conglomerate. This is the northernmost of only two Paleogene outcrops that have been found south of Selvågen.

Trocaderostranda

Palaeogene strata occur along a ca. 400 m long, almost continuously exposed coastal cliff at Trocaderostranda (Photo 86). Fifty m away from the shore, quartz-mica schists are exposed on the coastal plain, suggesting a north-south trending Palaeogene fault to run in north-south direction just behind the cliff.

The sedimentary facies of the strata is distinctly twofold. The major part of the outcrop, starting in its southern end, is an alternating succession of medium-grained quartz sandstones, dark, fine-grained flaggy sandstones, and occasionally conglomerates (Photos 87-89). No fossils were found, not even plant fossils, but mudflakes are common (Photo 88). In a few places, trace fossils (circular burrows) were observed (Photo 90).

The upper part of the succession displays a distinctly different facies. The contact with the lower part is not exposed and may be either primary or faulted. The rocks are mainly flaggy siltstones, with intercalated 10-30 cm thick quartzitic sandstone interbeds (Photo 91). The siltstones are heavily bioturbated (Photo 92).

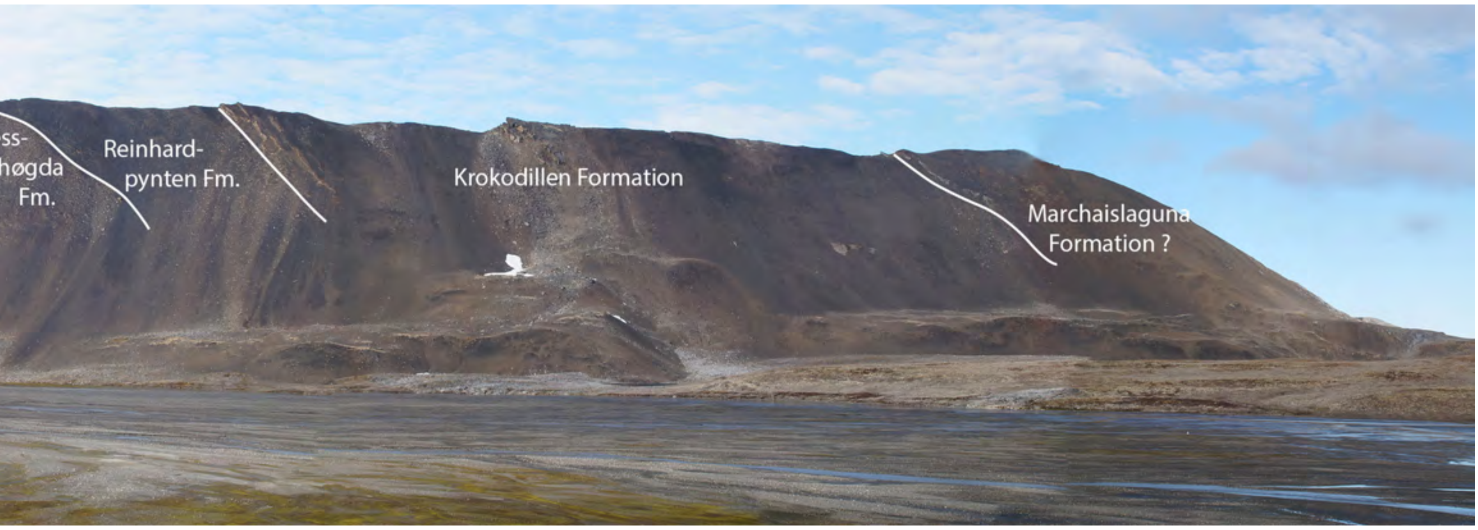


Photo 86: The 400 m long, folded Palaeogene section at Trocaderostranda displaying the Marchaislaguna Formation.

Photo 87: Marchaislaguna Formation in the lower part of the Trocaderostranda section: medium-grained, dense sandstones alternating with thin, flaggy sandstones.

Photo 88: Marchaislaguna Formation in the lower part of the Trocaderostranda section: polymict, upwards fining conglomerate, the only conglomerate in the section.

Photo 89: Marchaislaguna Formation in the lower part of the Trocadero-stranda section: gritstone with mudflakes.

Photo 90: Marchaislaguna Formation in the lower part of the Trocadero-stranda section: fine-grained sandstone with circular burrows.

Photo 91: Marchaislaguna Formation in the upper part of the Trocadero-stranda section: flaggy siltstones with 10-30 cm thick quartzite interbeds.

Photo 92: Marchaislaguna Formation in the upper part of the Trocadero-stranda section: bioturbated, flaggy siltstones.

The rocks were assigned to the Marchaislaguna Formation by Livšic (1967). Rye Larsen (1982) questions the vertical formation subdivision, discussing the possibility of a lateral facies development from Reinhardpynten to Aberdeenflya in an elongate basin with S-N sediment transport along the basin axis, involving several of the upper formations. Trocaderostranda is characterised by coarser, more shallow-marine delta fan deposits with several fine-grained conglomerates, compared to lateral equivalents at Peter Winterbukta and on Aberdeenflya.

A pecularity of this exposure is the intensive convergent deformation of the rocks, which is discussed in *Structures and tectonics*

Buchananryggen

The west-east trending ridge Buchananryggen, west of Trocaderostranda, displays a splendid section through the western margin of the Forlandsundet Graben (Fig. 8), with several tectonic blocks displaying graben and horst structures (see *Structures and tectonics*). Two separate, minor fault blocks expose Palaeogene strata between basement units (Photo 159).

The western fault block is a minor graben, ca. 500 m across. It contains carbonate-rich lithologies of the Scotiafjellet Group overlain by typical Selvågen conglomerate. The base of the conglomerate is not directly exposed.

The eastern fault block contains monotonous, shaly to almost slaty rocks with some intervals containing thin quartzitic sandstones (Photo 93). The rocks are not metamorphic, but have possibly suffered some increased temperature. In unpublished reports by Norsk Hydro (1989-1991), they were tentatively assigned to the Neoproterozoic basement, while students from the University of Münster related them to the Marchaislaguna Formation (Kubisch 1986; Pagels 1986; Wollenburg 1986). We observed feeding traces and burrows in some stratigraphic sections at the western end of the outcrop (Photos 94-96). The rocks resemble the Reinhardpynten Formation at Krokodillen, but may represent a different facies in the depositional system discussed by Rye Larsen (1982; see above).

Grimaldibukta

Selvågen conglomerate occurs in the northern continuation of the western minor graben on Buchananryggen in several places around the bay Grimaldibukta (Fig. 8); on Grimaldiholmen, Craighalvøya and a coastal section that only recently has appeared under the retreating front of the glacier Fallbreen in the northwest of Grimaldibukta. We have observed depositional contacts at the base of the conglomerates on Craighalvøya and in the northwestern outcrops. Grimaldiholmen (not visited, but observed with binoculars) structurally links up Craighalvøya with the exposure on Buchananryggen.

On Craighalvøya and in the northwestern exposure, minor (metre-scale) faults have disrupted the boundary, but primary contacts are preserved in several places. There are sections with undeformed or only slightly sheared depositional contacts (Photos 97-99).

On Craighalvøya, boulders in the basal part of the conglomerate are various recrystallised carbonate lithologies such as typical representatives of the Craigtoppane Formation and mica schists, gneisses, and quartzites from the Pinkie unit. This confirms that the cong-

Photo 93: Flaggy sandstone facies of the Palaeogene block on eastern Buchananryggen, most probably Reinhardpynten Formation.

Photo 94: Feeding traces in the Palaeogene sandstones on eastern Buchananryggen.

Photo 95: Feeding traces in the Palaeogene sandstones on eastern Buchananryggen.

Photo 96: Bioturbation in the Palaeogene sandstones on eastern Buchananryggen.

Photo 97: Erosional unconformity below the Selvågen conglomerate on Craighalvøya, Grimaldibukta. The underlying basement consists of metapelites of the Kaggen Formation.

Photo 98: *Sheared erosional unconformity below the Selvågen conglomerate on Craighalvøya, Grimaldibukta.*

Photo 99: *Primary sedimentary unconformity between the Selvågen conglomerate and foliated basement rocks on Craighalvøya, Grimaldibukta.*

Photo 100: *Facies of the Selvågen Formation on Craighalvøya: angular to subrounded, clast-supported, polymict conglomerate.*

Photo 101: *Boulders in the Selvågen conglomerate on Craighalvøya: patchy carbonate rock of the Craigtoppane Formation (centre).*

Photo 102: *Boulders in the Selvågen conglomerate on Craighalvøya: folded, banded, quartzitic metapsammite (centre).*

Photo 103: *Boulders in the Selvågen conglomerate on Craighalvøya: gneiss, possibly from Pinkie unit.*

Photo 104: *Boulders in the Selvågen conglomerate on Craighalvøya: grey quartzite with network of quartz veins.*

Photo 105: *Boulders in the Selvågen conglomerate on Craighalvøya: biotite gneiss, possibly from Pinkie unit.*

Photo 106: Boulders in the Selvågen conglomerate on Craighalvøya: pink quartzite.

lomerate boulders are derived from the local underground and surroundings (Photos 100-106).

Aberdeenflya – Fuhrmeisterstranda

Very few observations of Palaeocene strata have been made in this area. At the northern end of Aberdeenflya, 1.5 km southeast of Carmichaelpynten and 500 m from the shore, a minor, metre-sized conglomerate exposure was found. It is situated close to the western boundary fault of the Forlandsundet Graben. It is a mature, finer-grained (up to 2-3 cm large clasts) conglomerate similar to those in the Sesshøgda and Marchaislaguna formations. From there to the shore, only monotonous, thin-bedded, light-coloured sandstones of the Aberdeenflya Formation (Rye Larsen 1982) are exposed. The same type of sandstones also occur west and south of Richardlaguna in close vicinity to the boundary fault, seemingly without the occurence of conglomerates in between.

Structure and tectonics

Constraints for structural development

Based on the assumed late Neoproterozoic age of the basement units and the fact that at least the southern part of PKF has clear lithostratigraphic similarities with the late Neoproterozoic of southern Spitsbergen, it must be anticipated that the basement of PKF was affected by the same tectonic events as known from the Southwestern Basement Province of Spitsbergen.

There is a possibility that the northern half of the island is derived from a more distant stratigraphic domain and was juxtaposed with the southern half during a later tectonic event. Nevertheless, it would probably still belong to the wider North Atlantic realm of continuous Neoproterozoic strata, which is found both in northeastern Greenland and eastern Svalbard (Gee & Tebenkov 2004; Gee et al. 2008) and thus cannot be expected to have a very different tectonic history.

Tectonic events recorded in Svalbard and/or northern Greenland and that could be thought to also have affected the basement of PKF, are as follows (if not specified below, see Ramberg et al. 2008; Henriksen 2008; Dallmann 2015) (Fig. 10):

Event A) Late Neoproterozoic extension and volcanism related to rifting of the Iapetus Ocean;

Event B) Early Caledonian convergence and terrane accretion on the Laurentian side of the Iapetus Ocean in the Early–Middle Ordovician — high-P metamorphism from a subduction and suture zone best known from Motalafjella, western Spitsbergen (Bernard-Griffiths 1993; Gasser & Andresen 2012), as well as barrow-type metamorphism from the Pearya Terrane, northern Ellesmere Island (Trettin 1991);

Event C) Late Caledonian convergence and continent–continent collision in the Late Silurian-Early Devonian, juxtaposing Laurentia and Baltica – high-grade metamorphism and granite intrusions known from northeastern and northwestern Svalbard (e.g., Johansson et al. 2002); age of post-Torellian low-grade metamorphism of southwestern Svalbard is poorly documented (Majka 2017);

Event D) Post-Caledonian collapse, in part combined with transtension, throughout the Devonian – known from northwestern Svalbard, no metamorphism;

Event E) Ellesmerian oblique and/or orthogonal convergence and mountain building in the latest Devonain to earliest Carboniferous – known from northwestern Svalbard – no metamorphism seen in Spitsbergen (Dallmann & Piepjohn 2020) – first documented Ellesmerian high-grade metamorphism in PKF (Kośmińska 2015; Kośmińska et al. 2016, 2020);

Event F) Mid-Carboniferous transtensional rifting with formation of graben or halfgraben structures;

Event G) Late Paleocene to early Eocene continental convergence across the De Geer Fault, forming the West Spitsbergen Fold Belt;

Event H) Late Eocene transform margin (De Geer Transform Fault) separating the North-American and Eurasian continental margins, both transtensional and transpressional settings possible;

Event I) Oligocene to recent rifted-continental-margin development across the abandoned De Geer Transform Fault.

The fact that the basement is separated by the Baklia Fault into two structural blocks of unknown age relations and an unknown original distance between the depositional areas, opens for a somewhat diverging tectonic history of the two provinces prior to their juxtaposition. There is a significant constraint, however: A klippe of rocks from the southern stratigraphic province occurs on mountains belonging to the northern block — consequently (see above, Section *Aspects of basement correlation*), juxtaposition must have occurred before the thrusting event. Two possible scenarios evolve from this:

1) They could have been laterally juxtaposed from distant places by strike-slip within the De Geer Fault zone.

2) Alternatively, the two blocks may display a considerable vertical, stratigraphic offset and were separated by high-angle faulting during some early activity of the Baklia Fault. In this case, the northern block is supposed to be younger, because the overthrust klippe should represent the underlying strata.

Both scenarios could have occurred during one of the Palaeozoic events, or an early phase of Event G.

Apart from the klippe, the only stratigraphic reference for deformational ages in the basement of PKF is the presence of Eocene-Oligocene strata in eastern PKF and on Sutorfjella, which allows for a number of deformational structures, including the development of the Forlandsundet Graben, to be assigned to the events H and I.

The considerably elongate shape of the island, situated between and parallel to the Forlandsundet Graben and the continental margin, is caused by its position in the De Geer Transform Fault. Significant faulting is linked to the transform margin (mainly Eocene) and the superimposed rifted margin (mainly Oligocene) of Svalbard. The distinctly higher vitrinite reflectance values from Palaeogene rocks of PKF (see above; Rye Larsen 1982; Manum & Throndsen 1986) compared to Spitsbergen indicate late, post-depositional uplift of the island (late phase of Event H, or Event I).

Lateral displacement (map-view morphology) between the northern and southern structural blocks along the Baklia Fault, which also dissects the marginal faults of the Forlandsundet Graben (Fig. 10), links some late faulting to Event I (mainly Oligocene).

The above constraints are important to keep in mind when discussing and interpreting the detailed structural record below.

Structure of the basement of northern PKF

Main structural characteristics

The basement rocks display folds, shear zones and thrusts, which distinctly pre-date late, brittle faulting. The structural trend is roughly NW-SE to NNW-SSE, sometimes subparallel with the young marginal graben faults, sometimes forming an acute angle with them (Fig. 10).

The bulk of the strata of northern PKF consists of the mostly psammitic Grampianfjella Group and the overlying calcareous-metapelitic Scotiafjellet Group, which are – as discussed above – considered to have maintained their original, upward-younging stratigraphic succession. Competent lithologies have preserved primary bedding, while incompetent lithologies are sheared and folded under ductile, low-grade metamorphic conditions (chlorite zone). Locally, ductile high-strain zones occur, which also have affected psammitic and psephitic lithologies.

Semi-brittle folding and thrusting has affected the entire succession, refolding the ductile fabric and dominating the overall macroscopic structure. Folds and thrusts occur in all sizes up to kilometre-scale and verge perpendicularly to the main structural trend into both directions. North of Grampianfjella NE-directed structures prevail, while SW- to WSW-verging structures are predominant to the south. In the transitional area at Grampianfjella, both directions are superposed.

At least three thrust nappes subdivide the entire succession in to a tectonostratigraphy, each of them displaying the two lithostratigraphic groups. The uppermost of them contains additional, higher-grade units at the bottom in the Grimaldibukta area.

A tectonic window, the Macnairrabbane Window, in the middle nappe comprises Grampianfjella lithologies that probably display the underlying lower nappe. The middle nappe attenuates distinctly eastward and may even pinch out completely at Søre Buchananisen (Figs. 8, 10). The nappe boundaries in Grampianfjella have been traced roughly on aerial photographs, so that their outcrop pattern may be revised after detailed mapping in the future.

One small klippe on Thomsonfjella (close to the Baklia Fault) contains a lithology belonging to the southern PKF lithology and demands specal attention when sorting out the order of major tectonic events (see below).

A complicated structure, here preliminarily called the "Omondryggen Syncline", follows the regional NNW-SSE trend in the southwestern part of the northern block. It seems to have a complex internal geometry, which is not yet understood due to poor exposure and limited time spent in the field there.

Close to the eastern coast at Murraybreen, Fallbreen and Nordre Buchananisen, in the upper nappe, the Grampianfjella Group seems to overlie the older rocks of the Craigtoppane Formation. The latter, in return, overlies the higher-grade metamorphic rocks of the Pinkie unit with a thick, ductile, sheared contact (Maraszewska et al. 2016). The Craigtoppane Formation and suggested stratigraphically equivalent lithologies as well as the shear zone itself seem to continue northward into the area southwest of Richardlaguna, where they occur close to the eastern side of the Macnairrabbane Window.

Unfortunately, for the time being, sufficient data from the basement of southern PKF are not available for comparison.

Earlier interpretations

There is some discrepancy from earlier work (Manby 1978, 1986; Morris 1981; Piepjohn et al. 2000) concerning the sequence of structural development and the assignment of the observed structures to individual tectonic events. The age of the observed structures has been interpreted differently. Manby (1978, 1986) defined his D1 phase to have developed a syn-metamorphic, penetrative foliation axial planar to F1 folds and major thrusts. Map-scale fold nappes as well as upright box folds of 100s-of-metres scale (Photo 127) were assigned to D1. Manby's D2 phase, coaxial but not coplanar with D1, reactivated thrusts and gave rise to crenulation folds. He assumed these to be of Caledonian age with respect to similar anticipations from Spitsbergen. The D3 phase affected merely the Palaeogen rocks and was responsible for a large-scale flexuring of the basement complex.

Morris (1981) described a similar, ductile and syn-metamorphic D1 fabric with a penetrative slaty cleavage, which was supposed to be responsible for nappe overfolding and imbricate, tectonic sheets assigned to the Caledonian Orogeny. The large-scale folds of 100-500 m amplitude (Photo 127), in contrast to Manby's interpretation, were assigned to a later overprint by the coaxial D2 phase of possible Palaeogene age.

Piepjohn et al. (2000), working only in northern PKF between Macnairrabbane and Sutorfjella, saw two phases of m-scale isoclinal folding with deviating axial trends responsible for a slaty cleavage (S1) and an overprinting crenulation cleavage (S2). They did not report any fold nappes or other large-scale features assigned to this assumed early Caledonian deformation. Their D3 phase was seen as responsible for the semi-brittle map-scale folding (Photo 128) apparent in the area, associated with a locally developed S3 pencil cleavage. These structures pre-dated the Sutorfjella conglomerate, thought by them to be of Devonian age, and therefore supposed to be late Caledonian structures. Their post-Sutorfjella, Palaeogene D4 phase was the thought to be responsible for late thrust faulting (Macnairrabbane Window), spaced fracture cleavages and open folding (Photo 71; both affecting the Sutofjella conglomerate).

Our re-introduction of a Palaeogene age of the Sutorfjella conglomerate would open for the possibility of a Palaeogene age of both Piepjohn's et al. (2000) D3 and D4 phases.

In order not to get confused by the various use of phase designations, we will in the following sections subdivide deformation into 1) early ductile deformation (assigned to Palaeozoic orogenies), 2) later semi-brittle convergent deformation (assigned by us to the Palaeogene Eurekan Orogeny) and 3) late brittle extensional and strike-slip faulting (assigned by us to the syn- to post-sedimentary development of the Forlandsundet Graben).

Ductile structures

The psammites and conglomerates have locally preserved their primary bedding (Photos 7, 10, 12); thin pelitic interbeds display a foliation defined by – from macroscopic observations to judge – a low-grade mineral assemblage with sericite and chlorite. In psammitic-pelitic alternations, minor intrafolial, isoclinal folds are observed (Photos 107, 131). No attempt has been made to verify Piepjohn's et al. (2000) subdivision into two interfolial phases (see above).

No foliation is seen in massive carbonate rocks, but intercalated, competent lithologic bands like chert layers may be boudinaged and veins show ptygmatic folds (Photo 108). Heterogeneous carbonate rocks show intensive, irregular shearing and folding at small scale (Photo 109) and large-scale (Photo 110) – it is not clear whether these structures were formed at the same time as the early ductile structures, or alternatively formed during a younger, semi-brittle event.

Non-calcareous, metapelitic lithologies mainly occurring in the Kaggen Formation, display a penetrative foliation. When primary bedding is seen, the bedding is either shear-folded (Photo 111) or cut obliquely by the foliation (Photos 112, 113).

Map-scale isoclinal repetions of strata have not been observed, apart from a refolded syncline in the Finneryggen area (close to Selvågen) that has been mapped in the Scotiafjellet Group (Fig. 9). The superimposed folds refold the main foliation and are probably younger, but the primary syncline may be near isoclional, with the main, ductile foliation equalling the shear foliation of the structure.

High-strain zones have been seen in several places. They are parallel with the penetrative foliation and seem to belong to the same deformational episode. They are easy to detect where they affect psammitic and psephitic rocks, which elsewhere are less deformed and show primary bedding. One of these zones occurs in coastal exposurs just south of Kapp Sietoe, seaward of a younger fault separating it from the Sutor conglomerate. The host lithology is most likely the Conquerorfjellet Formation and consists of quartz schists with conglomeratic layers. The zone is several metres thick and displays a strong foliation with cross-cutting shear bands, elongate and boudinaged pebbles and quartz rods (Photos 114-117).

Another high-strain zone occurs at the thrust contact above the Macnairrabbane Window, where it has been observed in both the upper reaches of the valleys Glenmoredalen (Photo 118), Glenbegdalen (Photos 38, 119) and Gjelet (Photos 120-123). In the two former places, it displays calcareous greenschists with stretched and boudinaged quartz pebbles belonging to the lithology of the lower nappe in the window. At Gjelet, the zone is observed in the psammitic lithologies of the overlying nappe (Conquerorfjellet Formation). Here it displays strongly sheared slates (Photo 120), boudinaged psammitic layers within slates (Photos 121-122), locally refolded and overprinted by a well-developed crenulation cleavage (Photos 123-124). The orientation of the shear zone is roughly parallel with the lithological boundary between the rocks of the window and rocks of the overlying nappe. These observations suggest an early, ductile phase of nappe emplacement, while detached semi-brittle folds in the overlying nappe indicate a later reactivation of the thrust under cooler conditions (see *Macnairrabbane Window*).

The special structures in the contact zone between the Craigtoppane and Pinkie units and the correlated mega-boudinage structures at Richardlaguna are dealt with in a separate section below, where also the age of the ductile fabric of the basement rocks is discussed.

Photo 107: Ductile fabric of the basement rocks: Foliation and isoclinal folds in the Fuglehuken Formation, Mosehjellen, west of Fuglehukfjellet.

Photo 108: Ductile fabric of the basement rocks: Boudinage (chert bands) and ptygmatic folds (quartz vein) in the Baklia facies calcareous rock, east of Finneryggen (Selvågen).

Photo 109: Ductile fabric of the basement rocks: Sheared and irregularly folded in an Omondryggen facies marble, west of Conquerorfjellet.

Photo 110: Ductile fabric of the basement rocks: Sheared and irregularly folded marbles at large scale on western Conquerorfjellet (compare Photo 20).

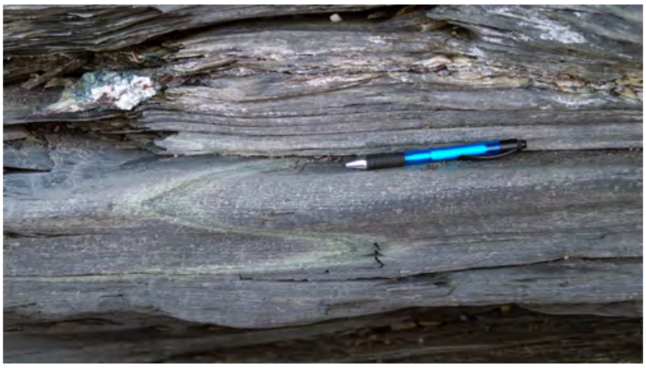


Photo 111: Ductile fabric of the basement rocks: Shear folds in sandy slate of the Kaggen Formation, showing a penetrative foliation at an angle with primary bedding.

Photo 112: Ductile fabric of the basement rocks: Lithological banding in a purple slate of the Kaggen Formation, obliquely cut by a penetrative foliation. Northern shore of Selvågen.

Photo 113: Ductile fabric of the basement rocks: Layer-parallel foliation in a slate of the Kaggen Formation, obliquely cut by a tightly spaced cleavage. (part of Photo 27). Northern shore of Selvågen.

Photo 114: Ductile fabric of the basement rocks: high-strain zone in quartz schists with conglomeratic layers, Conquerorfjellet Formation south of Sutorfjellet.

Photo 115: Ductile fabric of the basement rocks: Detail of the high-strain zone (Photo 114) in a conglomeratic layer.

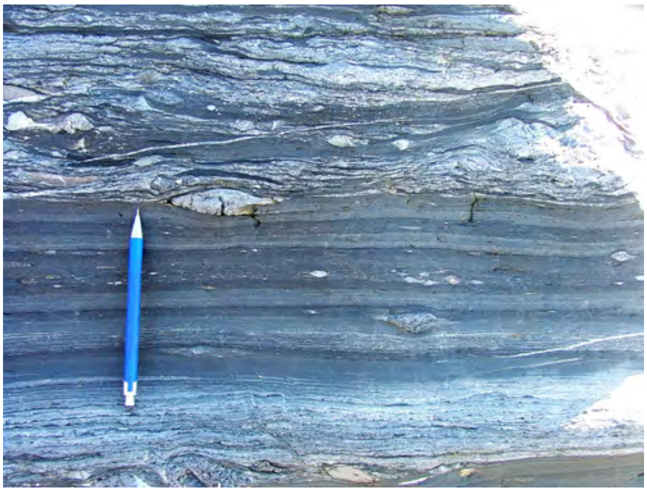


Photo 116: Ductile fabric of the basement rocks: Detail of the high-strain zone (Photo 114) showing mylonitic foliation, boudinaged quartz veins and rods.

Photo 117: Ductile fabric of the basement rocks: Detail of the high-strain zone (Photo 114) in a conglomeratic layer showing mylonitic foliation surrounding a competent pegmatitic pebble.

Photo 118: Ductile fabric of the basement rocks: High-strain zone in a greenschist at the upper thrust boundary of the Macnairrabbane Window, upper Glenmoredalen.

Photo 119: Ductile fabric of the basement rocks: High-strain zone in a greenschist at the upper thrust boundary of the Macnairrabbane Window, upper Glenbegdalen.

Photo 120: Ductile fabric of the basement rocks: High-strain zone at the upper thrust boundary of the Macnairrabbane Window, here situated in the overlying metapsammitic lithologies (Conquerorfjellet Formation) at Gjelet.

Photo 121: Ductile fabric of the basement rocks: High-strain zone at the upper thrust boundary of the Macnairrabbane Window at Gjelet (Photo 120), displaying boudinage and superimposed crenulation.

Photo 122: Ductile fabric of the basement rocks: High-strain zone at the upper thrust boundary of the Macnairrabbane Window at Gjelet (Photo 120), displaying large-scale boudinage of pegmatitic dykes.

Photo 123: Ductile fabric of the basement rocks: High-strain zone at the upper thrust boundary of the Macnairrabbane Window at Gjelet (Photo 120), displaying a mylonitic foliation and a superimposed, tightly spaced cleavage.

Photo 124: Ductile fabric of the basement rocks: High-strain zone in a greenschist at the upper thrust boundary of the Macnairrabbane Window at Gjelet (Photo 120) – mylonitic foliation, boudinage and crenulation.

Photo 125: Selvågen conglomerate, exceptionally ductile deformed with foliated matrix and stretched pebbles, on Sesshøgda.

Photo 126: Selvågen conglomerate, exceptionally ductile deformed with foliated matrix and stretched pebbles, on Sesshøgda. (Photo: Iwona Klonowska)

An important observation is that ductile deformed zones are also seen in the Palaeogene Selvågen conglomerate on Sesshøgda, which exhibits stretched dolomite and other carbonate pebbles in a local high-strain zone with a well-developed foliation (Photos 125-126).

Semi-brittle folds and thrusts

Along with Morris (1981) and Piepjohn et al. (2000) we consider the macro-scale folds and thrusts that refold and cut the ductile fabric (Photos 127, 128) as clearly distinct in style and age from the syn-metamorphic, ductile event. Piepjohn's (2000) assignment of the macro-scale folds to a late Caledonian deformational phase was based on the misconception that the Sutorfjella conglomerate was deposited in the Devonian. The new interpretation of a late Eocene age of the conglomerate means that an early Palaeogene age of the folding and thrusting as suggested by Morris (1981) is feasable. Knowing that the West Spitsbergen Fold Belt developed between chrons 24B and 21 in the early Eocene (e.g. Piepjohn et al. 2016), a correlation with the structures on PKF would undoubtfully be reasonable. The tectonic style of the macro-scale folds and thrusts is similar to Palaeogene deformation known from the West Spitsbergen Fold Belt.

North of Murraybreen, NE-verging folds and thrusts prevail, while they tip over in the northern part of Grampianfjella and verge W to WSW to the south of it (Fig. 17A-C). WSW-verging large-scale folds of 100-500 m amplitude in the mountain sides (Morris 1981) are prevalent in central PKF (Photo 127).

Due to exposure conditions in relevant areas in northern PKF, NE-verging folds of similar dimensions are less prevailent at outcrop scale (Photos 128, 129), but undoubtedly present as can be seen by the mapped structural pattern (Fig. 7). An exception is the overturned fold on the middle summit of Fuglehukfjellet in the very north of the island, which has an opposite, WSW-directed short limb (Photo 130). Minor fold structures in the Macnairrabbane Window also show WSW-verging directions (Fig. 17D, Photo 131).

The geometry of the folds is generally asymmetric to overturned, only exceptionally recumbent. They are often polyclinal with elements of box and kink folds and slip planes between competent layers have developed into minor reverse faults that cut through the limbs (Photos 127, 132-134). Steeply-dipping fracture cleavages with steep to moderate easterly dips occur. Map-scale fold axes are subhorizontal, with very gentle northwesterly or southeasterly plunge, while measured minor folds in outcrops show plunges up to 40° in similar directions (Fig. 17).

Occasionally in areas close to the eastern fault margin, gently southwest-plunging minor fold axes are observed. This corresponds to similarly directed folds in the Palaeogene sediments and may be caused by late transpressional movements along the faults (Fig. 17E, see *Structure of the Palaeogene*).

Thrust sheets and tectonostratigraphy

The basement succession is repeated by at least three thrust sheets or nappes (Fig. 10). They have not been mapped out in detail along Grampianfjella, but only traced on aerial photographs, which means that there is a high probability of future modifications (Photos 135-141; for photo locations see Fig. 16).

In the area mapped in detail in northern PKF (Fig. 7), the lower thrust sheet is represented by the Macnairrabbane Window, which seems to reoccur along the western foothills of Grampianfjella and makes up most of the basement area in central PKF (Fig. 9). Northern PKF represents part of the middle thrust sheet, which can be traced along the western front of Grampianfjella. Its basal thrust cuts across the ridge at Jessiefjellet and cannot be traced on the eastern mountain slopes. The basal thrust of the upper thrust sheet

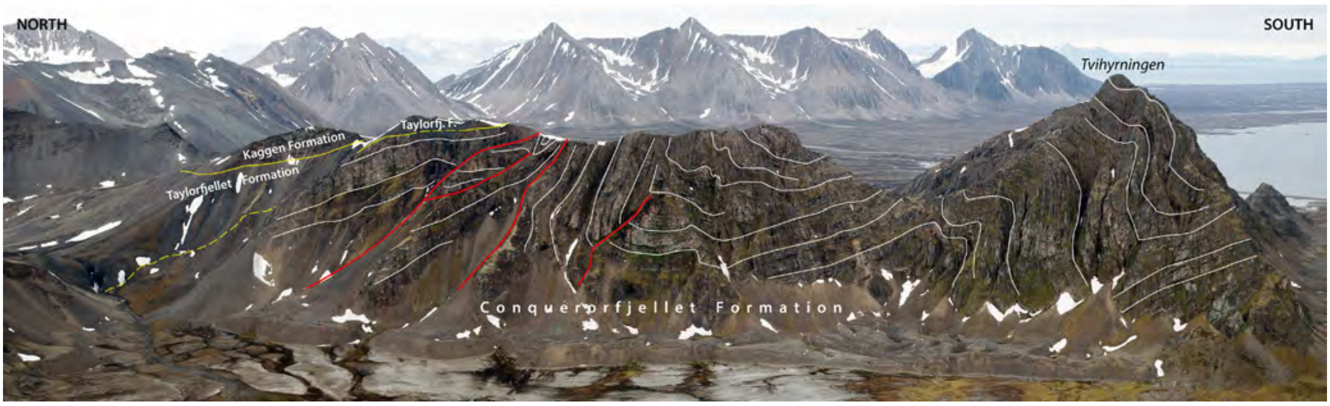


Photo 127: Semi-brittle fold-thrust structures in the Conquerorfjellet Formation at southern Omondryggen and Tvihyrningen. Outside the picture to the north (left), the structures root in the Omondryggen Syncline, with the overlying Taylorfjellet and Kaggen formations in the core. Red lines: faults, white lines: layering.


Photo 128: *Tight ENE-verging folds in the upper thrust sheet, shown here in the eastern part of Rudmosefjellet, Conquerorfjellet Formation.*


Photo 129: *ENE-verging, folded metapsammite-slate succession in the Fuglehuken Formation at Fuglehuken (compare photo 7).*


Photo 130: *WSW-verging, overfolded fold on Fuglehukfjellet, an abnormal vergence direction in northern Prins Karls Forland.*


Photo 131: *WSW-verging minor folds are common in the Macnairrabbane Window. The photograph also shows refolded isoclinal folds of the early ductile phase.*

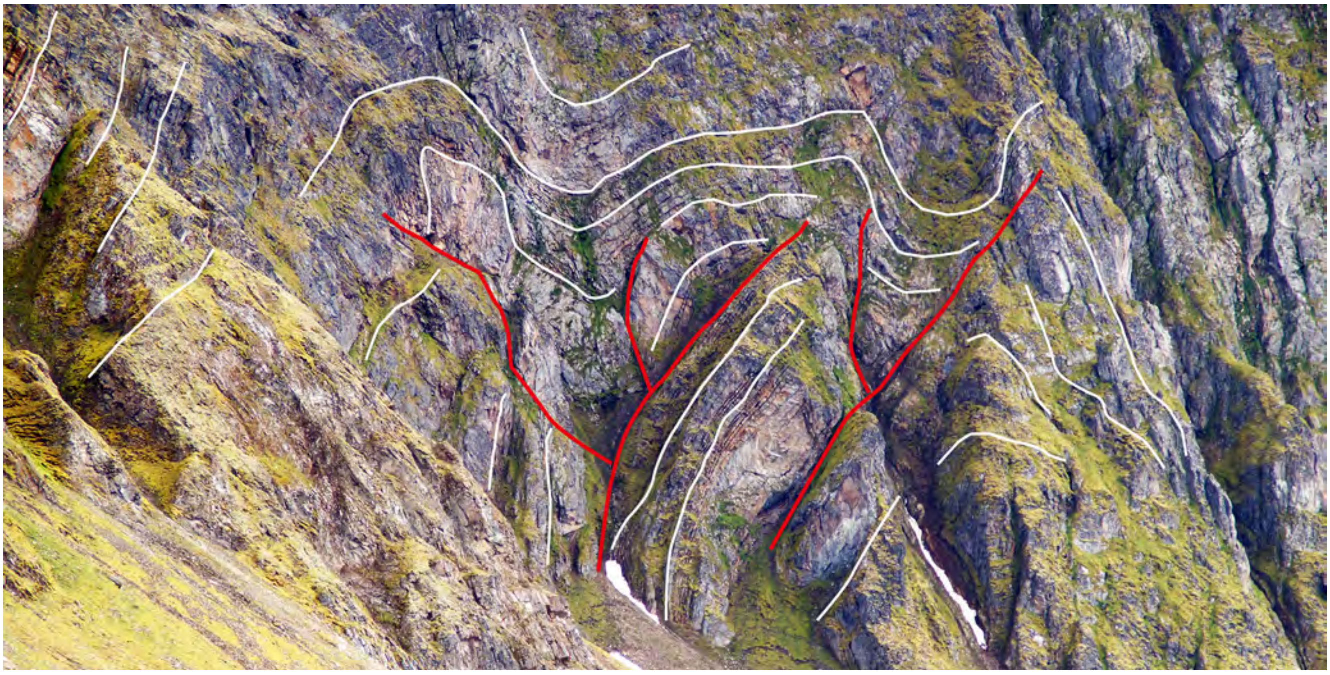


Photo 132: *Semi-brittle folds and thrusts in the Conquerorfjellet Formation in the central part of Omondryggen, reminiscent of a minor flower structure with ENE- and WSW-verging thrust splays. Area on the left side of Photo 127, but hidden behind ridges there.*

Photo 133: Semi-brittle fold-thrust deformation in the Conquerorfjellet Formation at Charlesfjellet (Grampianfjella), viewing towards the northwest from Krokodillen. The thrusts are very steep, but verge slightly to the WSW.

Photo 134: Semi-brittle fold-thrust deformation in the Conquerorfjellet Formation at Margaretfjellet (Grampianfjella), viewing towards the west from Krokodillen. The thrusts are very steep, but verge slightly to the WSW, away from the observer.

is observed in the upper, northern slopes of Laurantzonfjellet and Krungletoppen, from where it can be traced along the upper, western slopes of Grampianfjella southward to Parnasset, where it also crosses the ridge over to the eastern slopes. The base of the upper thrust sheet is thought to be located below the Pinkie unit, while the ductile shear zone above the Pinkie unit is an older structure, which has only shown Eurekan reactivation (see *Structural relations of the Pinkie unit*).

A clue concerning this can be expected to lie in Laurantzonfjellet, which is not yet mapped in detail.

There is a clear tendency that the basal thrusts dip northward (Fig. 10). This opens for two alternative options:

1) Convergence was orthogonal or near-orthogonal and the entire northern tectonic block of PKF was tilted northwards subsequent to thrusting.

2) Convergence was highly oblique and thrusting happened in a transpressional regime, which would translate the thrust sheets at an acute angle towards SSW.

The bimodal verging directions of the associated folds and minor thrust structures favour the second alternative, provided that

Photograph Nos. (DSC ...) in this and the following photo captions refer to the location map, Fig. 16.

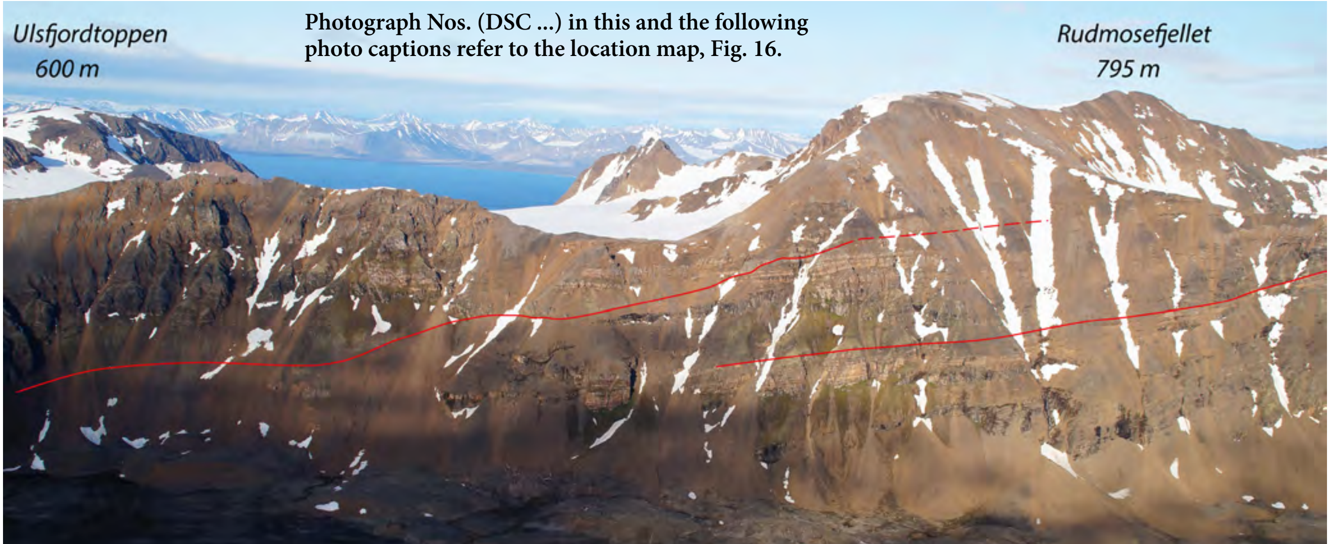


Photo 135: Photograph No. DSC06154 taken from a helicopter, location and angle shown in Fig. 16. This and similar photographs have been used to tentatively trace thrust faults (red lines) within the Conquerorfjellet Formation in the central ridge from Millerbreen to Grampianfjella to establish the tectonostratigraphy.

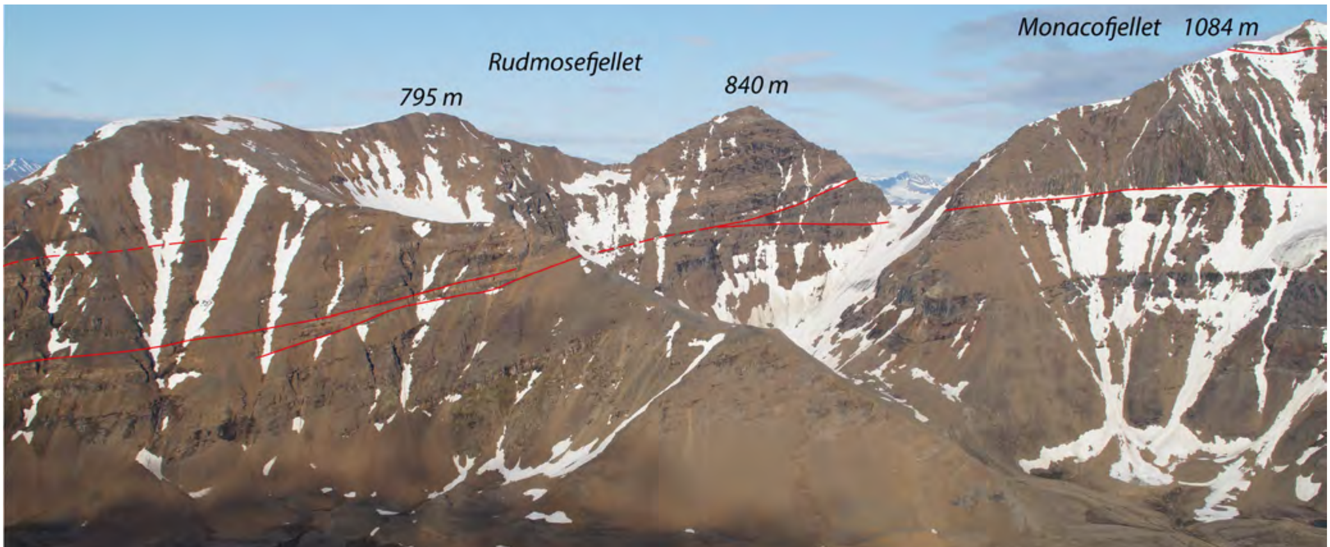


Photo 136: Photograph No. DSC06155 taken from a helicopter, location and angle shown in Fig. 16. This and similar photographs have been used to tentatively trace thrust faults (red lines) within the Conquerorfjellet Formation in the central ridge from Millerbreen to Grampianfjella to establish the tectonostratigraphy.

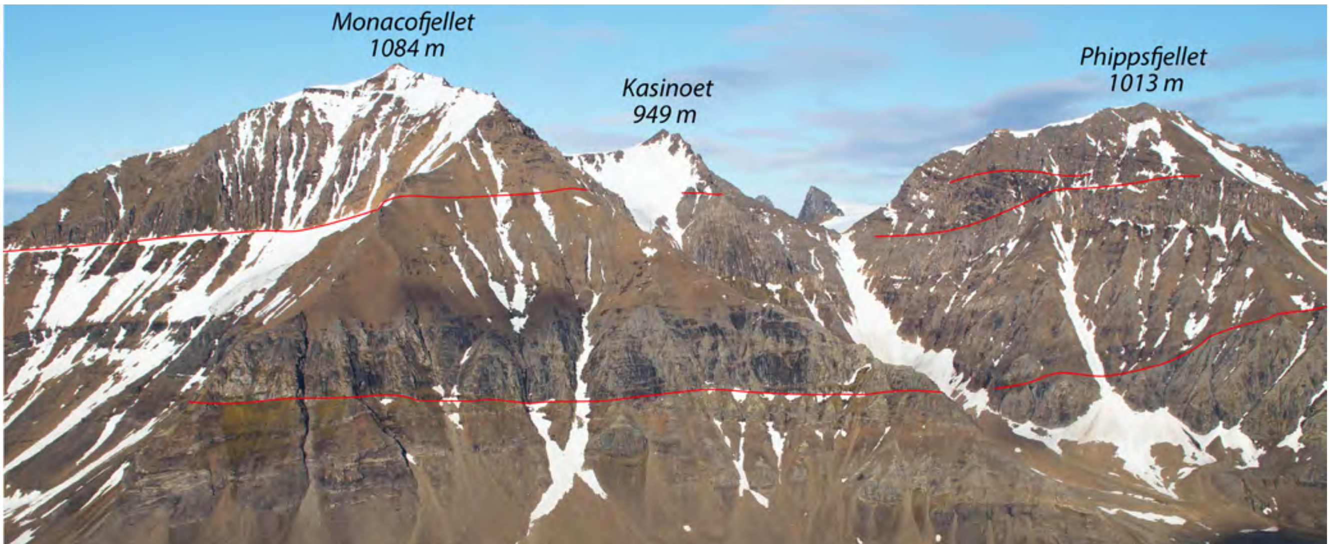


Photo 137: Photograph No. DSC06157 taken from a helicopter, location and angle shown in Fig. 16. This and similar photographs have been used to tentatively trace thrust faults (red lines) within the Conquerorfjellet Formation in the central ridge from Millerbreen to Grampianfjella to establish the tectonostratigraphy.

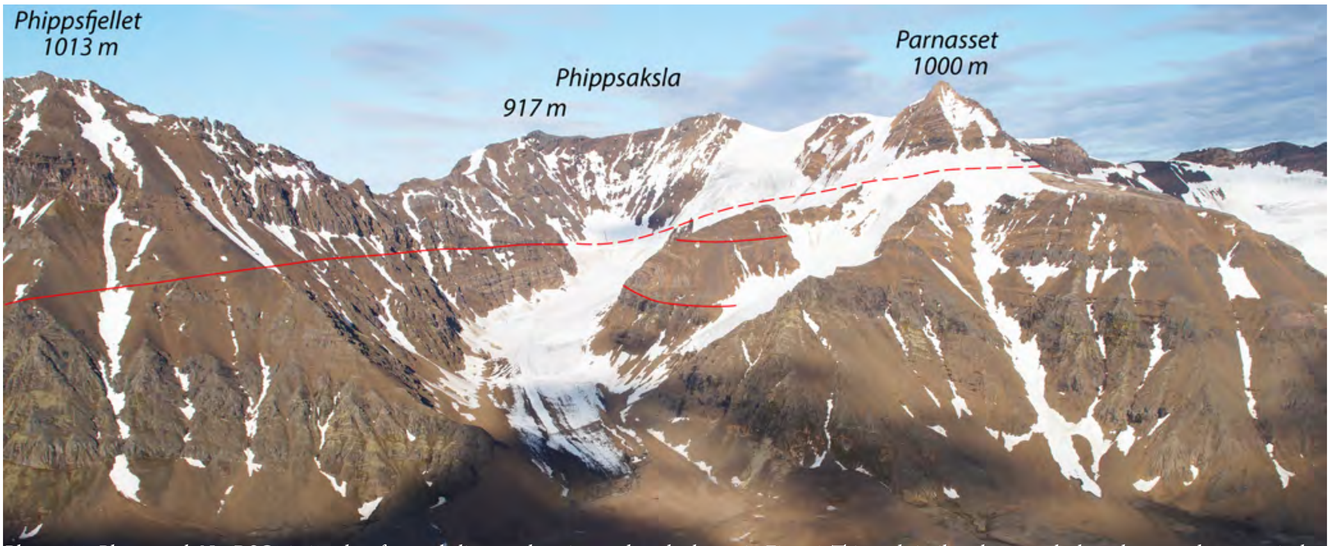


Photo 138: Photograph No. DSC06160 taken from a helicopter, location and angle shown in Fig. 16. This and similar photographs have been used to tentatively trace thrust faults (red lines) within the Conquerorfjellet Formation in the central ridge from Millerbreen to Grampianfjella to establish the tectonostratigraphy.

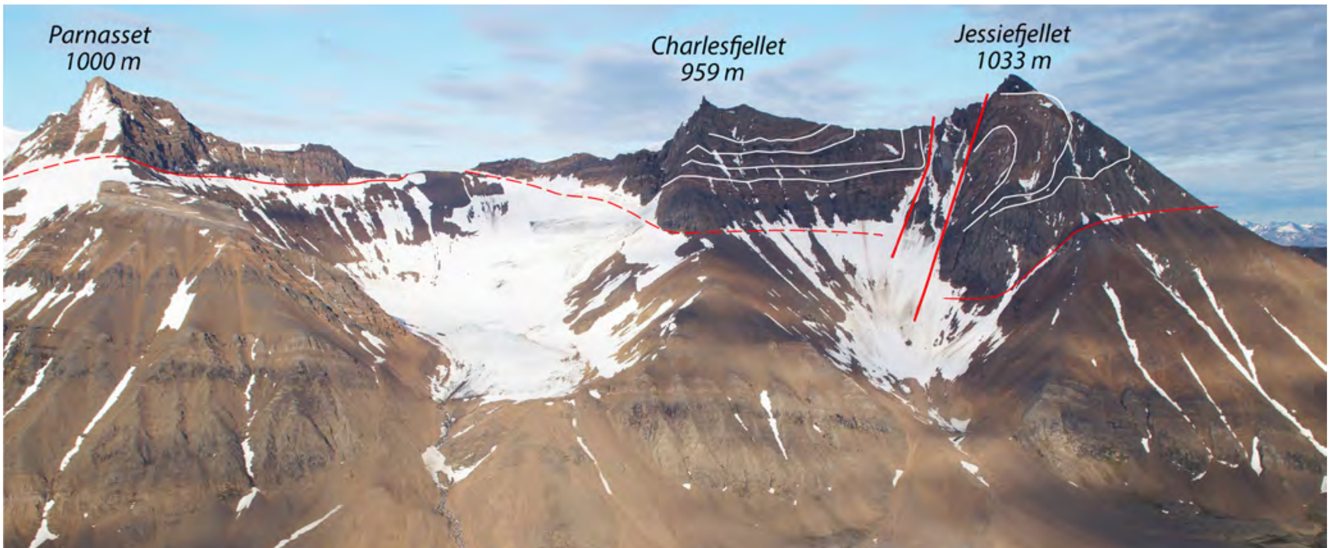


Photo 139: Photograph No. DSC06162 taken from a helicopter, location and angle shown in Fig. 16. This and similar photographs have been used to tentatively trace thrust faults (red lines) within the Conquerorfjellet Formation in the central ridge from Millerbreen to Grampianfjella to establish the tectonostratigraphy.

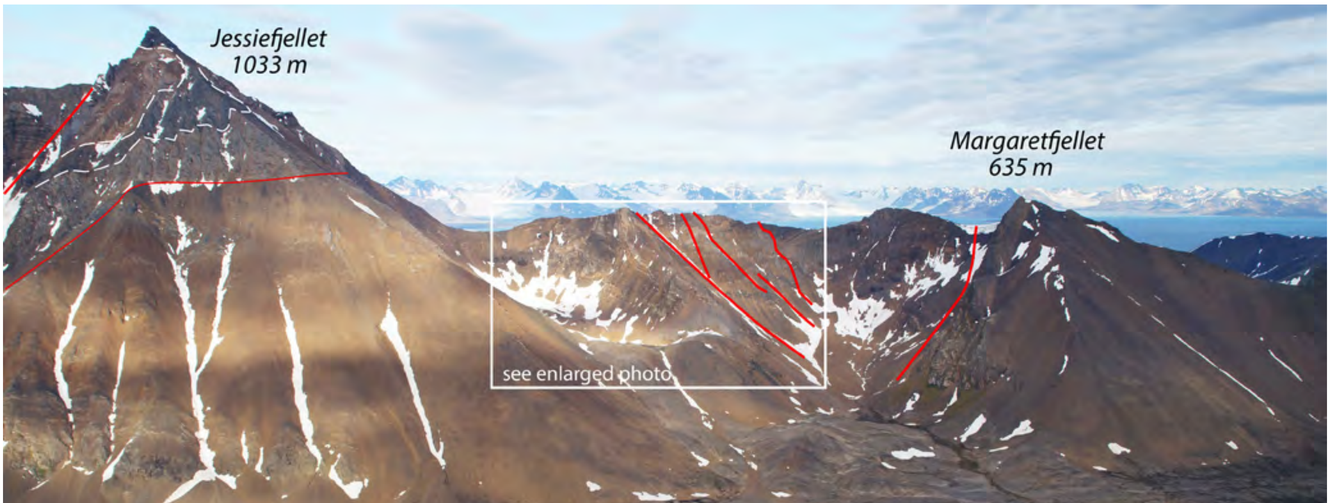


Photo 140: Photograph No. DSC06165 taken from a helicopter, location and angle shown in Fig. 16. See Photo 141 for enlarged section. This and similar photographs have been used to tentatively trace thrust faults (thin red lines) within the Conquerorfjellet Formation in the central ridge from Millerbreen to Grampianfjella to establish the tectonostratigraphy. The lowermost thrust strikes into the air at Jessiefjellet (left). The underlying tectonic unit is supposed to correspond to that in the Macnairrabbane Window (Fig. 10). At Margaretfjellet (right) structures are dominated by steep reverse faults (compare Photo 134).

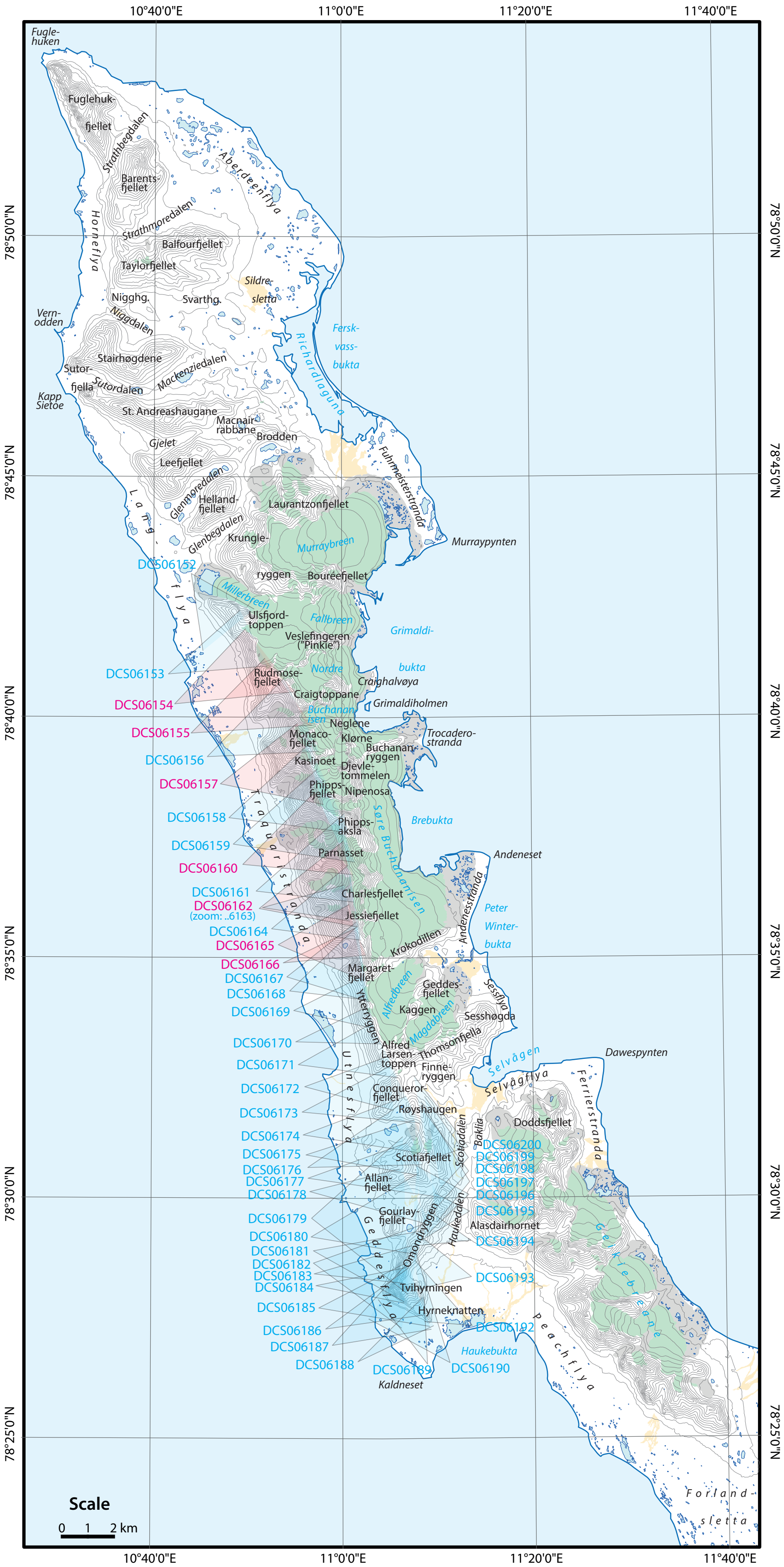


Fig. 16: Map showing place names in central and northern Prins Karls Forland. Positions and angles of oblique aerial photographs are indicated (original photo numbers from archives). Red numbers refer to photos 135-141 in this report.

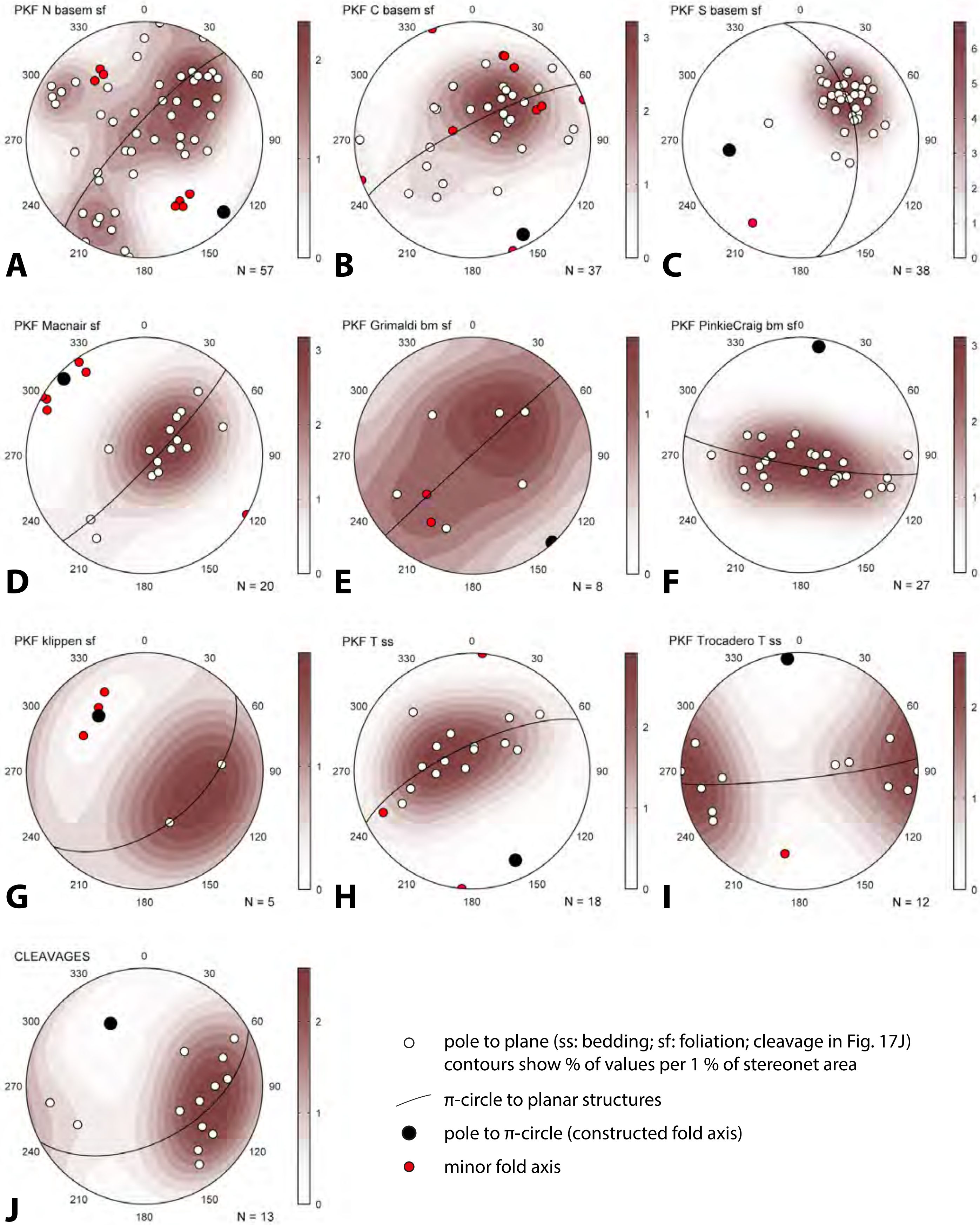


Fig. 17: Stereo plots of semi-brittle planar structues refolding the ductile planar fabric in Prins Karls Forland. A: Basement of northern PKF; B: Basement of central PKF; C: Basement of southern PKF; D: Macnairrabbane Window; E: Basement in the Grimaldibukta area; F: Pinkie and Craigtoppane units in the Bouréefjellet area; G: Klippen on Thomsonfjella; H: Palaeogene strata (bedding); I: Folded section at Trocaderostranda (Palaeogene, bedding); J: Cleavages (occasional readings only).

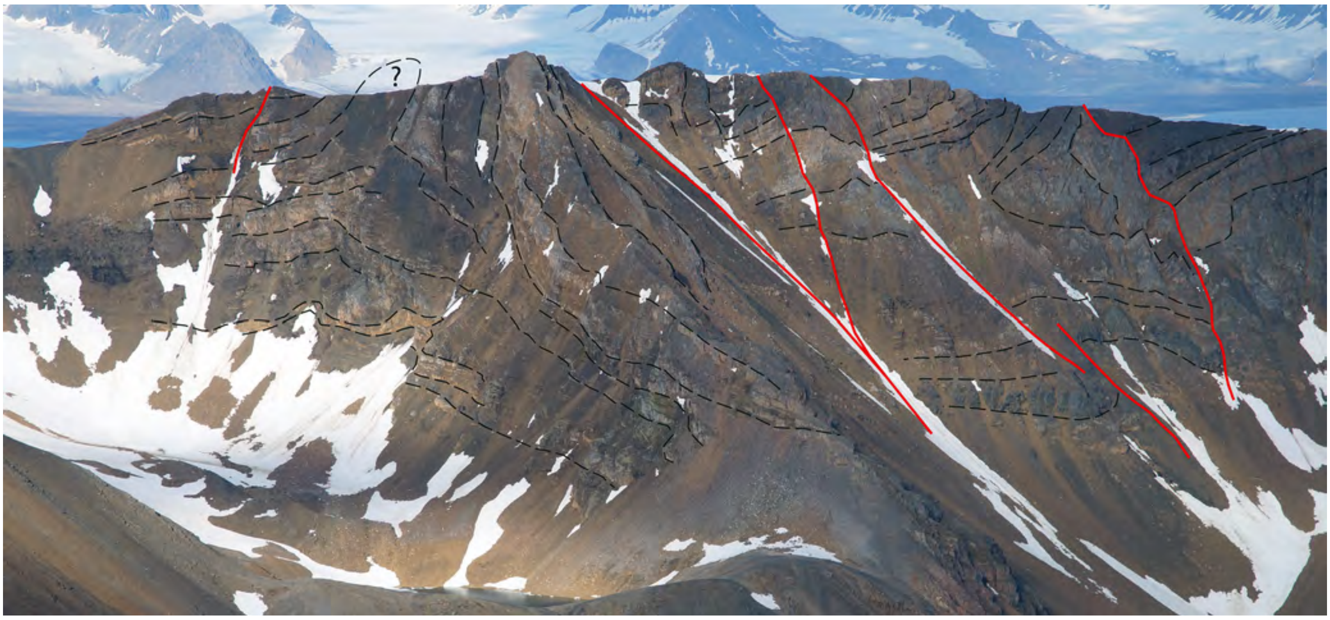


Photo 141: Photograph No. DSC06166 taken from a helicopter, location and angle shown in Fig. 16 and Phot 140. Area between Margaretfjellet (right) and Jessiefjellet (left). Here are no thrust sheets like further north, tectonics are dominated by steep reverse faults (red lines; compare Photos 133 and 134).

Photo 142: Macnairrabbane area at Brodden, showing the approximate location of the thrust (red line) and the Brodden Fault (black line). The orange-weathering rocks are lenses of conglomerate (compare photos 33-36, 143).

transpression occurred between two oblique-slip fault strands, which would be situated on either side of the extremely elongate island in the De Geer Transform fault zone.

It appears to be premature to introduce names to the thrust sheets, as they have not been mapped continuously in the field. The name "Northern Grampian Thrust" used by Manby (1978, 1986) is not recommended, because it is based on a completely different tectonic interpretation of the basement. It does not coincide with any of the structures mapped by us (even the Western Forlandsundet Fault, a major normal fault, has been considered to be part of it by Manby, 1986).

Macnairrabbane Window

The Macnairrabbane Window (Piepjohn et al. 2000) provides a view through the basal thrust of the middle thrust sheet and exposes lithologies of the Grampianfjella Group belonging to the lower thrust sheet. The window's area was extended during the present study (see *Stratigraphic relations in the lower part of the Grampianfjella Group*).

Rocks deformed by the boundary thrust are exposed in the valleys Gjelet, Glenmoredalen and Glenbegdalen on the western margin of the window. These show ductile deformation in a several metres (>10 m?) thick shear zone, which is developed in the lithologies above and below the lithological boundary (Photos 118-124). Strong ductile shearing has occurred in greenschists, phyllites and slates, and thick quartzites are intensively fractured and brecciated within a wide zone above and below the lithological contact. Quartzite layers of up to more than a metre's thickness are boudinaged. Conglomerate pebbles are elongate in the direction of fold axis (NNW-SSE). The latter may suggest that thrusting occurred during metamorphic peak conditions (lower greenschist facies), which prevailed during the Palaeozoic orogenies, but certainly not during the semi-brittle Tertiary foldbelt formation.

Outcrop-scale, semi-brittle folds in the rocks above the shear zone do not continue into the window, which suggests the presence of a young, semi-brittle thrust situated above or within the ductile shear zone. From mapping experience, it is thought to be situated within the lithologies of the overlying thrust sheet, at least at Gjelet and Glenmoredalen (Fig. 7). It is – like most brittle faults – throughout covered with talus. Large parts of the terrain surface of the window are not far from the eroded thrust in vertical distance (Photos 32, 142).

The thrust itself forms a gentle fold with a NW-SE trending axis, culminating at 200-250 m a.s.l. close to the mountain passes at Gjelet, Glenmoredalen and Glenbegdalen. The southwestern limb dips at ca. 10° SW, while the northeastern limb dips 2-4° NE (estimated from map data).

Photo 143: Stretching lineations in the orange-coloured dolomite conglomerates of Macnairrabbane.

One thrust fault within the window, cross-cutting the internal stratigraphy in its northwestern corner, has been mapped. It has a low angle with the Macnairrabbane Thrust and separates the chlorite-phyllite from the other lithologies. Farther south, this thrust seems to fade out and the contact is conformable, although not exposed.

The Macnairrabbane Window is structurally well defined at map scale, where the lithological units are cut by its ductile thrust. Also lithologies of the overlying thrust sheet are cut in the eastern, recently mapped reaches of the window, close to Richardlaguna (Fig. 7).

Internal structures of the Window are similar to structures elsewhere in the basement of northern PKF. Map-scale, gentle folds with <25° SW and NE plunge dominate (Fig. 17D). Good exposures are rare due to intense fracturing of the rocks in many places. Tight small-scale folds and stretching lineations (Photos 131, 143) have been observed locally in the orange conglomerates. They all verge to the SW and have moderately NE-dipping axial surfaces, and fold axes plunging gently NW. An anomally oriented fold of some tens of metres wavelength and a WSW-trending axis was observed just east of the easternmost of the two lakes in Macnairrabbane.

The klippen

On Thomsonfjella, central PKF, two rock units occur in unnormal stratigraphic positions and must have been emplaced tectonically (Fig. 9; photos 144, 145). Both rest on slates of the Kaggen Formation. The western one (forming the peak Alfred Larsentoppen) consists of Grampianfjella metapsammites and slates, while the eastern one represents diamictitic quartz-carbonate-mica schists reminiscent of the Neukpiggen Formation (Ferrier Group; Photos 146-149) and a other, not determined lithologies.

Although the exposed contact (265/55°) between the western unit and the underlying Kaggen slate on the pass east of Alfred Larsentoppen does not look tectonised, it would not be possible to explain the juxtaposition of these units without thrusting. The same applies for the western contact of the eastern unit, where the contact on the ridge is a younger normal fault and the original contact is not exposed. Both are thought to be klippen (Manby 1978), residual pieces of thrust sheets. At least the western klippe must be refolded by southwestward directed convergence after thrust emplacement to explain the present outcrop shape. As the thrust cannot be observed, it is not known whether it is ductile or brittle.

The easternmost part of the eastern klippe needs more field investigation. It is probably more complicated than shown on the present version of the field map. East of the Neukpiggen diamictites,

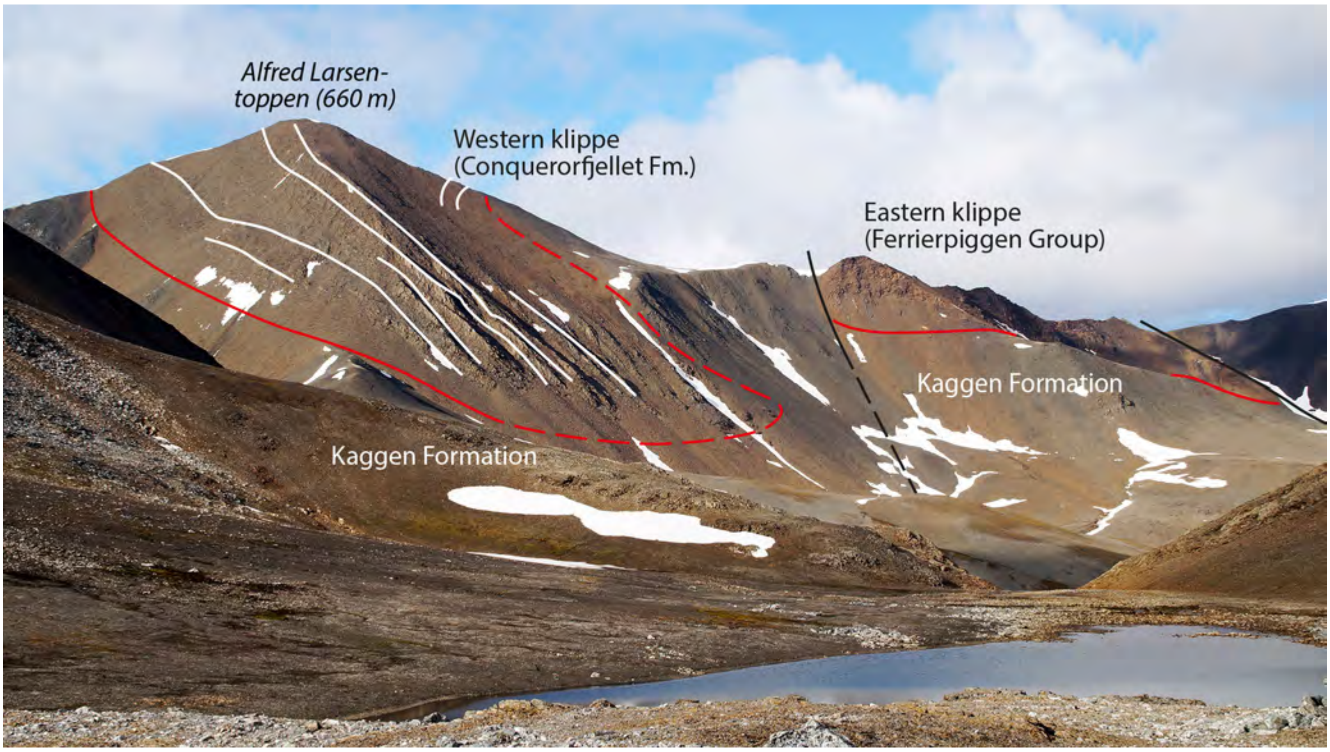


Photo 144: The tectonic klippen on Thomsonryggen viewing towards the north-east. Red lines denote the basal thrusts, white lines indicate bedding traces, while black lines show normal faults.

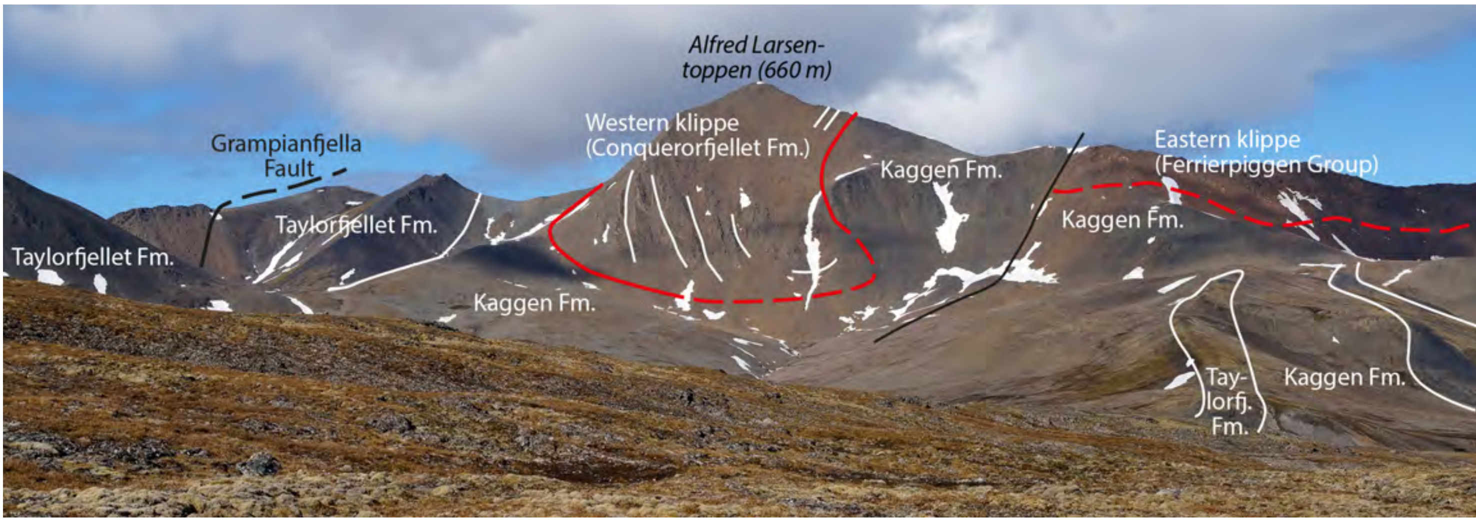


Photo 145: The tectonic klippen on Thomsonryggen, viewing towards the northwest to the northeast. Red lines: basal thrusts of the klippen; black lines: normal faults; white lines: formation boundaries and bedding traces.

Photo 146: Small-scale kink folds in the quartz-carbonate-mica schist of the estern klippe assigned to the Neukpiggen Formation (Ferrierfjellet Group).

Photo 147: Elongated conglomerate pebbles in the diamictite of the Neukpiggen Formation in the eastern klippe.

Photo 148: Large dolomite boulders in the diamictite of the Neukpiggen Formation in the eastern klippe.

Photo 149: Layered diamictite of the Neukpiggen Formation in the eastern klippe.

massive, grey limestone with a light weathering colour occurs on the ridge. It can be traced northward on the western face of the minor ridge or spur protruding into Magdabreen. The lithology does not occur elsewhere in the Scotiafjellet Group, so it should be part of the klippe. It might correlate to the carbonate rocks of the Geikie Group. A fault contact with abundant secondary dolomite and siderite separates the lithology from the Kaggen slates to the east (Photo 150). Light and grey carbonate rocks, subvertically standing on the eastern side of the protruding ridge may be the top of the Taylorfjellet Formation, but this is not documented. The locality may be cut by additional faults and has to be revisited (see *Promontory north of Thomsonfjella*).

Most probably, foliation and pebble elongation in the lithologies of the eastern klippe reflect early, syn-metamorphic deformation (Photo 147), while the superimposed kink folds (Photo 146) may belong the young, semi-brittle event. Measured small-scale fold axes in the klippen have moderate, northwesterly plunges in similarity with the basement rocks of northern PKF, but different from the underlying basement in central PKF (Fig. 17G). The age of thrusting is not known as the thrusts are not exposed. In any case, thrusting

Photo 150: Siderite precipitation at the normal fault contact between the Kaggen Formation and the eastern klippe. Compare Fig. 18.

and folding must have taken place prior to the formation of the Forlandsundet Graben, during which the tectonic block with the klippen was down-faulted along the Western Forlandsundet Fault. Also the N–S trending faults bounding the eastern klippe on the ridge of Thomsonfjella may belong to the graben faulting event. The klippen of Thomsonfjellet consequently represent one of the highest structural levels of the basement north of the Baklia Fault Zone.

Structural relations of the Pinkie unit and its emplacement

The high-grade metamorphic Pinkie unit structurally underlies the low-grade Craigtoppane carbonate unit and Grampianfjella Group within the upper thrust sheet, separated by a thick, ductile shear zone (Maraszewska et al. 2016) (Fig. 8; Photos 151, 152). From Kośmińska's et al. (2015, 2016, 2020) age determination it can be concluded that juxtaposition most likely occurred through ductile thrusting at peak-metamorphic conditions during the Ellesmerian Orogeny.

The Pinkie unit is regionally folded around a NNE-trending, subhorizontal fold axes. Verging directions are not documented. Similar folds occur in the overlying Craigtoppane Formation. They are partly tight and recumbent and verge to different directions (Photos 153-156). The fold orientations in this area deviate from the remaining areas of the island (Fig. 17F) and the more ductile, recumbent style may indicate that they are inherited from Ellesmerian deformation (and then refolded?).

The shear zone above the Pinkie unit is subhorizontal at the eastern end of Bouréefjellet (Photos 151, 152), dips locally eastward farther west in the same mountain massif, but must dip westward at a regional scale because it does not reoccur on the western side of Grampianfjella (Fig. 8). As shown from 40Ar/39Ar geochronology by Schneider et al. (2018), it was reactivated during the Eurekan deformation (55-44 Ma), where highly fractured zones and cataclasites were formed (Bouréefjellet Fault Zone)

Consequently, brittle Eurekan folding and fault reactivation has overprinted an Ellesmerian, ductile fold-and-thrust system, in which the high- and low-grade rocks had been juxtaposed.

Photo 151: Panorama of Bouréefjellet seen from the south; Veslefingeren ("Pinkie") in the left foreground.

Photo 152: Bouréefjellet seen from the southwest. The line indicates the position of the thrust between the underlying high-grade metamorphic Pinkie unit and the ductile shear zone at the base of the Craigtoppane Formation.

Photo 153: Veslefingeren seen from the north. Apparent disconformities of bedding directions indicate the presence of faults, which are not mapped or classified yet. (Photo: Maciek Manecki)

Photo 154: East-verging, asymmetric anticline in Craigtoppane, view towards the west from Craighalvøya.

Photo 155: Eastern part of Klørne, seen from the southeast, showing west-verging, recumbent folds in the Craigtoppane Formation just above the ice field.

Photo 156: Western end of Veslefingeren, view from the north, showing west-verging folds and cross-cutting normal faults, Craigtoppane Formation.

Late brittle faults and related structures

In this section, we describe faults that cut through all ductile and semi-brittle structures in the basement. They are generally considered younger than the convergent deformation that occurred during the Eurekan event. Although, as we expect from the tectonic transform margin setting of PKF during the Eocene, there is room for overlap of alternating transpressional and transtensional settings which could make some of the age relations between post-depositional, Paleogene folds and later faults more intricate.

Western Forlandsundet Fault Zone

The western boundary fault zone of the Forlandsundet Graben has been mapped by us in more detail and continuation than in earlier work (Figs. 7-10). It affects mainly the eastern half of PKF, but widens south of Grimaldibukta, where its main trend turns from NNW-SSE to almost N-S. South of Søre Buchananisen, the westernmost fault strand is offset to the west and lies in the summit area of Grampianfjella, close to the island's western coast. In the Selvågen-Haukebukta area, the fault zone is abruptly cut by the Baklia Fault Zone at an acute angle and is displaced sinistrally. It may be argued that it widens due to the presence of the Baklia Fault Zone and the structural/lithological discontinuity expressed by the southern basement block on its opposite side.

South of Selvågen, the boundary fault zone is reduced to one known onshore fault strand crossing the small coastal promontory between Selvågen and Ferrierstranda at Dawespynten. Otherwise it is situated offshore to the east.

The fault zone consists of a varying number of subparallel faults. The most continuous one, and the one with the largest normal offset, is the Western Forlandsundet Fault proper. For descriptive purposes, it is subdivided into several segments, from north to south: the Richarlaguna fault segment, the Buchananryggen fault segment and the Petuniaskaret fault segment. To the southeast of the Baklia Fault Zone, the Ferrierstranda fault segment occurs in a much more eastern position.

On the western side of the island, the fault at Kapp Sietoe (see *Kapp Sietoe area*), which limits the Sutorfjella congomerate occurrence to the west, may also be part of this graben system.

The Western Forlandsundet Fault Zone is cut and offset by a number of almost perpendicular transverse faults. These are in general not exposed, but are needed to explain the outcrop pattern. One of them may be the Strathmoredalen Fault (see separate section below). One fault may be situated below Murraybreen, two on each side of Grimaldiholmen in Grimaldibukta, and two on each side of Krokodillen (the southern one is compulsory). Others may occur below the glaciers.

Richardlaguna fault segment (Aberdeenflya–Fuhrmeisterstranda/Murraybreen) (Figs. 7, 10)

The Richardlaguna fault segment is not exposed, but its position can in several places be approximated by adjacent outcrops of either basement or Palaeogene strata. It seems to separate outcrops of basement and Palaeogene strata along a strait line, but the lack of continuous outcrops on the coastal plains does not permit to state this for sure. For the same reason it cannot be said if there are several parallel fault strands or just one.

Minor faults subparallel to the Western Forlandsundet Fault proper occur occasionally and seem to pinch out after few kilometres. A number of such faults occur in Fuglehukfjellet (Figs. 7, 10; Photos 157, 158).

The Brodden Fault (Photo 142), which cuts through the Macnairrabbane Window at a 2 km distance from the Richgardlaguna fault segment, probably belongs to this set of faults. It is a normal fault with a down-to-east offset of between < 50 m (S) and 80 m (N). The fault parallels the main Forlandsundet Graben faults, but bends into a west-northwesterly trend when tracing it northward. It is possible, though not documented, that the straight SE-NW striking contact between the Grampianfjella and Scotiafjellet groups north of the window across Mackenziedalen defines the northward continuation of this fault.

Photo 157: Brittle fault close to Fuglehuken with a coherent fault breccia at outcrop scale.

Photo 158: Brittle faults in Fuglehukfjellet, seen from the north (part of panorama, Photo 5).

Buchananryggen fault segment (Grimaldibukta–Buchananisen) *(Figs. 8, 10)*

In Grimaldibukta, the fault separates high-grade rocks of the Pinkie unit in the west from low-grade rocks of the Scotiafjellet Group to the east. Both the Taylorfjellet and Kaggen formations are present, but have not been mapped in detail. Most of the coastal lowland consists of these lithologies. Selvågen conglomerate overlies the basement very close to the shore. The boundary is roughly primary, though submitted to some shear along the discontinuity. It is displaced by several (at least three) E-W striking minor faults with offsets at a 10 m-scale.

Farther south, at Craighalvøya, the situation is similar, but much more of the Selvågen conglomerate is preserved on land. Distinct offsets of the angular unconformity between Craighalvøya and Grimaldiholmen suggest an E-W-striking transverse fault in between, and a similar offset between Grimaldiholmen and Buchananryggen suggests another one. Minor extensional faults on Craighalvøya show slickenside lineations plunging moderately southwest (48° towards 230° and 35° towards 212°) indicating oblique dextral transtension.

Buchananryggen provides the northernmost, continuously exposed section across the main graben fault and the fault blocks to the east of it (Photo 159). The Buchananryggen fault segment dips here at 50-60° E. The footwall consists of banded carbonate rocks of the Craigtoppane Formation, which dip parallel with the fault in this location. The hangingwall consists of likewise east-dipping marbles of the Taylorfjellet Formation.

The footwall of the fault is fractured along certain fault-parallel zones with increasing intensity towards the core zone. Also the hangingwall contains brittle folded and fractured zones to a distance of tens of metres from the fault. The Taylorfjellet marbles are increasingly sheared, folded and foliated when approaching the fault. A few measured fold axes plunge gently south or moderately SE, which, if representative, would indicate sinistral oblique-slip movement (Fig. 17; Photos 160-166).

The section along Buchananryggen (Fig. 10; Photo 159) exhibits at least three fault blocks with a horst in the middle. The westernmost fault block consists of eastward-dipping Scotiafjellet Group rocks (Taylorfjellet marbles and overlying Kaggen slates). The rocks show an unknown order of lithologies, with a bed of Taylorfjellet marbles just adjacent to the distinctive green/purple slates of the Kaggen Formation, upward followed by carbonatic slates reminiscent of the Baklia facies of the Taylorfjellet Formation. It is thus possible that the rocks display different levels of the stratigraphy juxtaposed by Eurekan or earlier thrusting, or even another, unidentified normal fault. In the east, the Scotiafjellet lithologies are unconformably (?) overlain by Selvågen conglomerate, which has been tilted together with the entire fault block to a 50-60° easterly dip. This conglomerate occurrence is possibly continuous with the one on the small island just to the north, or, alternatively, it may be displaced by a minor transverse fault.

The conglomerate is cut by a down-to-west normal fault (not seen, but compulsory), which separates it from a minor horst consisting again of Scotiafjellet lithologies: Taylorfjellet marbles and Kaggen slates in correct stratigraphic order). These dip approximately 40° E. The horst is bounded to the east by an east-dipping normal fault, which contains blocks of brecciated basement lithologies (quartzite, marble) and seems thus to have a major offset. This major offset is also manifested in that the stratigraphy of the hanging wall is high up in the Palaeogene stratigraphy, most probably the Reinhardpynten Formation. It forms the eastern part of the ridge of Buchananryggen.

The transition between between the ridge and the coastal outcrops at Trocaderostranda is not exposed. The eastern block with monotonous Reinhardpynten rocks lies subhorizontally, however, while

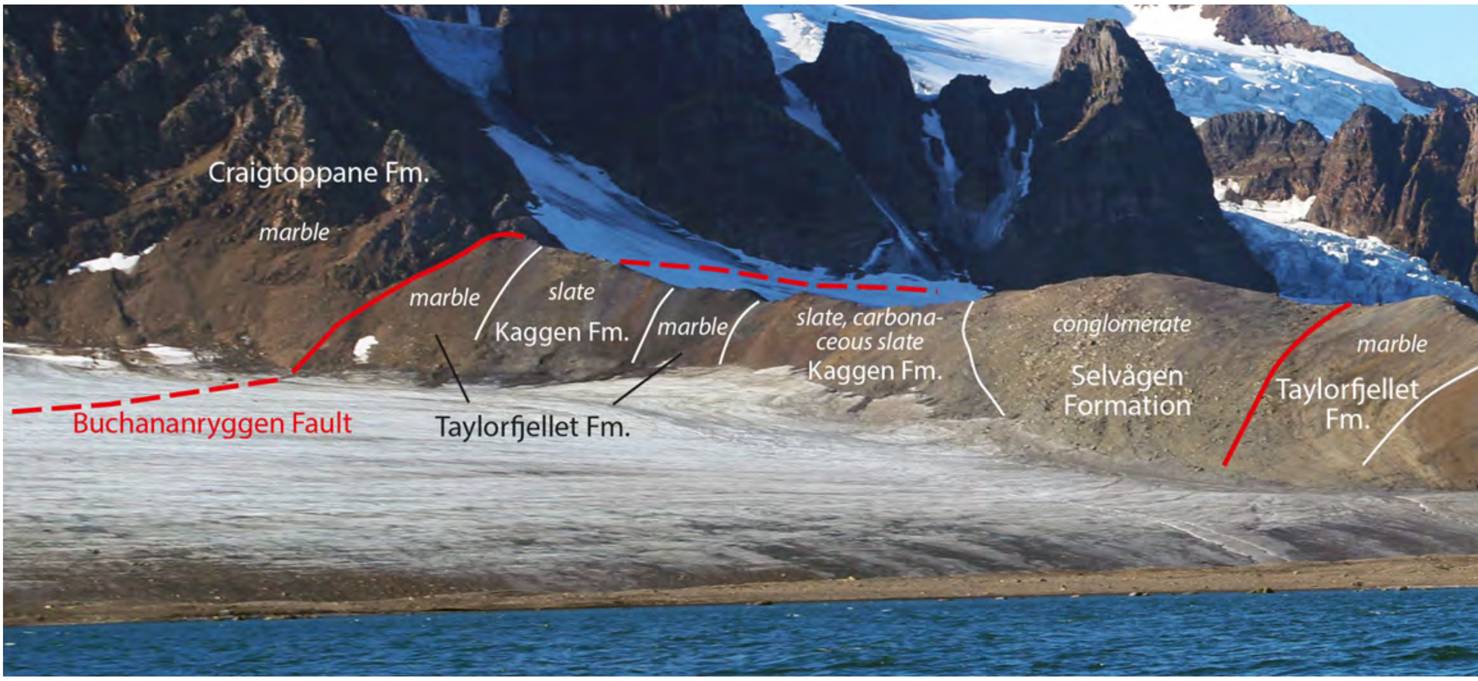


Photo 159: Panorama of Buchananryggen, seen from the southeast, with indicated geology (compare map, Fig. 8). The mountains in the background consist of the mainly calcareous Craigtoppane Formation, faulted against the younger rocks of the ridge at the Buchananryggen fault segment. Red lines: faults; white lines: formation boundaries and bedding traces.

the heterogenous Trocaderostranda exposure contains intensively folded strata of the even younger Marchaislaguna Formation. This discrepancy both in tectonic style and stratigraphy suggests another down-to-east fault in between. Folds in the Trocaderostranda coastal cliff are tight to isoclinal with subvertical axial planes oriented subparellel with the fault system and N-S to slightly NNE-SSW

Photo 160: The Buchananryggen fault segment on Buchananryggen. The people are standing at the fault contact. Foreground: hanging wall of deformed dark marble (Taylorfjellet Formation); background: footwall of patchy marble (Craigtoppane Formation).

Photo 161: Fractured shear zone in the footwall of the Buchanryggen fault segment on Buchananryggen, close to the fault.

Photo 162: Brittle shear zone in the footwall of the Buchanryggen fault segment on Buchananryggen, close to the fault.

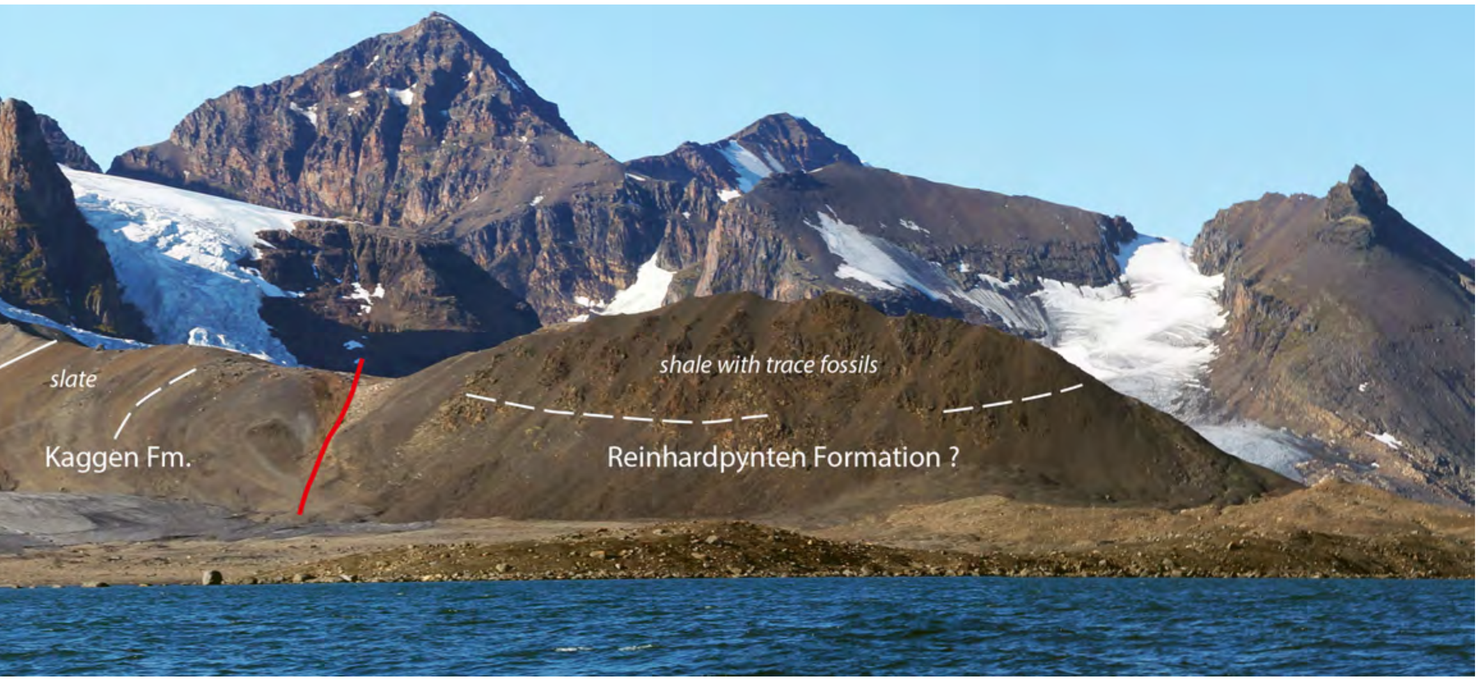


Photo 163: Weakly deformed marble of the Craigtoppane Formation, close to the Buchananryggen fault segment.

Photo 164: Sheared and shear-folded carbonate slate in the Taylorfjellet Formation in the hanging wall of the Buchananryggen fault segment.

Photo 165: Sheared calcareous slate of the Taylorfjellet Formation close to the Buchananryggen fault segment.

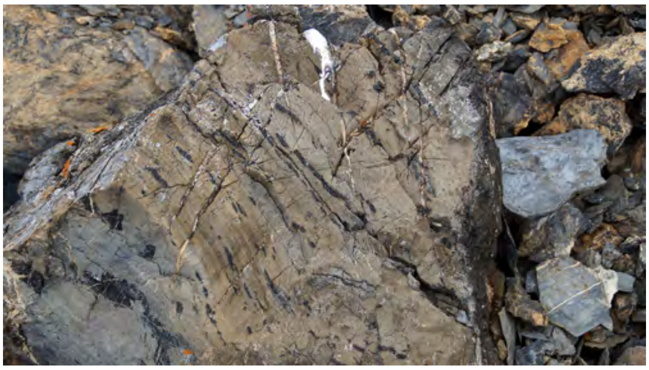


Photo 166: Marble of the Taylorfjellet Formation with its diagnostic chert nodules, weakly deformed section in the vicinity of the Buchananryggen fault segment.

Photo 167: Tight fold in the Palaeogene sediments at Trocaderostranda close to one of the graben-boundary faults, with an acute angle between the axial plane and the fault. Compare Photo 86.

Photo 168: A minor parasitic fold on the flank of the large fold (Fig. 167). The axis plunges 190/30º.

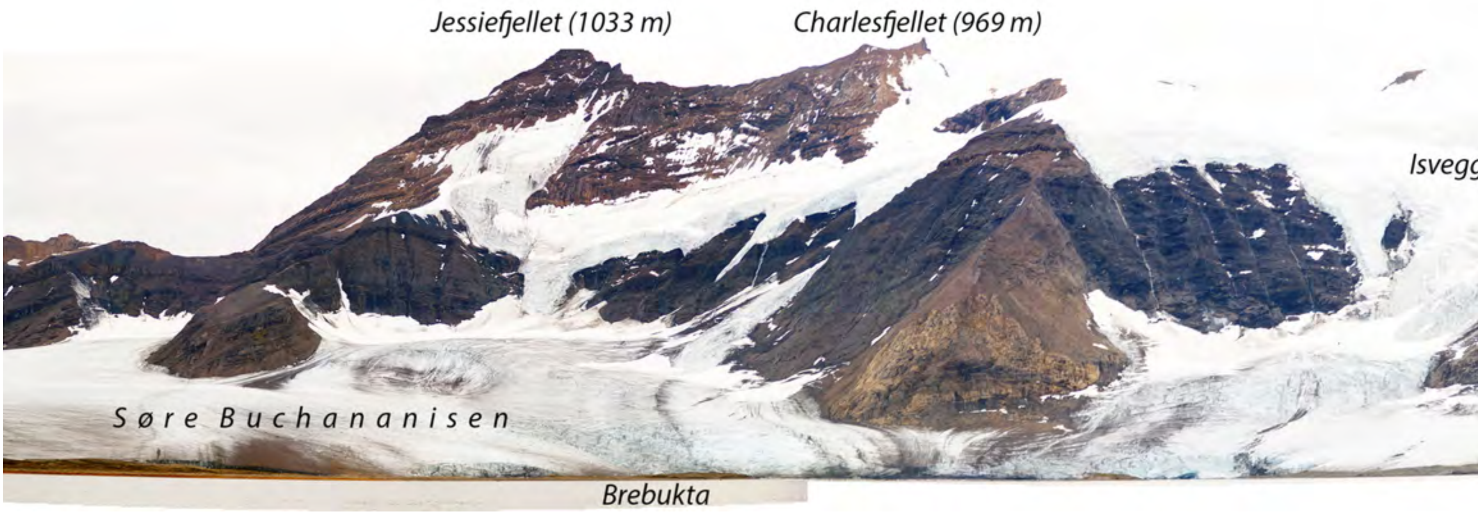


Photo 169: A distinct spaced cleavege related to the tight folds (photos 167, 168), dipping 35º towards 260º.

trending fold axes (Fig. 17; Photos 86, 167-169). They seem to have formed during E-W convergence or slightly oblique, sinistral transvergence, against the easternmost fault, probably at the time when a more competent basement stratigraphy, which acted as a buttress, was present to west of the fault. At the same time the older Reinhardpynten Formation on the adjacent block to the west was not deformed at all. These observations are important to notice in order to reconstruct the order of events during Palaeogene deformation.

Also along the Buchanaryggen fault segment, parallel minor faults occur in the basement rocks to the west, like it has been observed in the western end of Veslefingeren (Photo 156).

Between Buchananryggen and Krokodillen, along the glacier Søre Buchananbreen, there are no outcrops of either faults or Palaeogene strata. However, the morphological continuity of the eastern mountain front from Djevletommelen (west of the main fault at Buchananryggen) southward past Nipenosa, Phippsaksla, Charlesfjellet to Jessiefjellet (Photo 170) suggests that the Buchananryggen fault segment continues uninterruptedly under the glacier just in front of these mountains.

Petuniaskaret fault segment (Krokodillen–Haukedalen) (Figs. 9, 10)

The main fault strand crosses the ridge between Krokodillen and Margaretfjellet, where exposures are not good. From a distance, lithologic breaks can be observed, suggesting the presence of at least two fault strands at a close distance (Photo 171). In the west, Grampianfjella metapsammites building up Margaretfjellet occur all the way to the westernmost fault strand, which has brought down Taylorfjellet Formation (Baklia facies) to the east. After the second fault strand, slates and intercalated sandstones of the Kaggen Formation occur. These lithologies make up the ridge all the way to Krokodillen, where Palaeogene strata unconformibly overlie the basement with the Selvågen conglomerate at the base. On Krokodillen, two minor E–W striking faults occur with a minor graben in between, which could be mapped based on sudden lateral changes in stratigraphy. The majority of Palaeogene beds to the east, probably consisting of the entire stratigraphic section up to the Marchaislaguna Formation, dip at ca. 40-45° E towards Forlandsundet (Photo 81). We visited only the basal part of the succession at the western end of the ridge.

A transverse fault occurs south of Krokodillen, where the main fault strand suddenly jumps westward to the mountain foot of Ytterryggen, from where it can be traced continuously across Petuniaskaret and Normanndalen (Photos 14, 172, 173) to Haukedalen (Photo 174). A minor transverse offset may exist in the pass between Conquerorfjellet and Røyshaugen. In Normanndalen, though not exposed, it can be localised with reasonable accuracy and shows a very steep dip to the ENE. The distance between the main fault segment and the eastern fault strands increases rapidly from 1 km at Krokodillen to >2 km at Geddesfjellet and 3.5 km at Sesshøgda.

A major feature of the Petuniaskaret fault segment is the fact that basement lithologies crop out also to the east of the fault, unconformably overlain by Selvågen conglomerate on the ridges. Fault-parallel, minor WNW-ESE striking fault strands dissect the ridges farther east. From there eastwards, the ENE tilt of the Palaeogene suddenly increases and overlying formations are exposed. Both on Krokodillen and Geddesfjellet, the Palaeogene forms a monocline, possibly overlying a fault in the underlying basement and thus producing a fault-bend fold. At Thomsonfjella/Sesshøgda, two tightly-spaced, parallel faults cut through the Selvågen conglomerate and throw the Palaeogen down to the east. East of the faults, the Palaeogen is tilted 20-30°E (Photos 77, 175).

Several other faults have been mapped crossing Thomsonfjella in varying northwesterly-southeasterly directions. Most of these are older and do not cut through the Selvågen conglomerate, apart from two small faults that form a minor horst affecting the base of the Palaeogene. The offset may be a few metres.

Photo 170: Panorama of the mountain front south of Buchananryggen, opposite ridge face compared to photos 138-140. The thrust faults mapped on those photos have not been identified on this mountain side, so the tectonostratigraphic map (Fig. 10) is quite tentative here. The mountains consist mostly of rocks of the Grampianfjella Group, but both over- or underlying groups may be involved.

Photo 171: Two strands of the Western Forlandsundet Fault Zone cutting across the ridge west of Krokodillen, displaying a slice of calcareous slates (Taylorfjellet Formation) in between.

Photo 172: Petuniaskaret seen from the southwest: the Petuniaskaret fault segment of the Western Forlandsundet Fault Zone runs between the dark (Taylorfjellet Formation) and light (Conquerorfjellet Formation) rocks.

Photo 173: The Petuniaskaret fault segment exposed on Scotiafjellet at Normanndalen, northward view. Left: Conquerorfjellet Formation; right: Taylorfjellet Formation.

Photo 174: The Petuniaskaret fault segment exposed in Haukedalen at north-eastern Omondryggen and Scotiafjellet. Left: Conquerorfjellet Formation; right: Taylorfjellet Formation. (Compare Photo 187)

Ferrierstranda fault segment (south of Selvågen)

The Petuniaskaret fault segment is situated far off to the west, while the Ferrierstranda fault segment is displaced sinistrally by 1.5 km to the north–northeast by the Baklia Fault Zone. Only two small outcrops of Palaeogene were found on the shoreflat south of Selvågen close to Dawespynten, which is sufficient to approximately locate the fault (Ferrierstranda fault strand) between the basement (Ferrierpiggen Group) and the Palaeogene. The small size of the outcrops does not permit us to determine the stratigraphic position of the rocks properly, although the variety of clastic sediments

Photo 176: *Isoclinally folded Palaeogene sandstones west of Dawespynten at Selvågen, vicinity of Ferrierstranda fault segment.*

(shales, siltstone, sandstones and gritstones) might suggest that they belong to the Sesshøgda Formation.

The Palaeoegene beds in the northern coastal exposure dip generally ca. 50° ENE, but are tightly folded at outcrop scale (Photo 176). Fold axes dip gently S to SW. This is surprising considering the young age of the rocks, because a high amount of shortening at a considerable burial depth is needed to produce these structures, unless they represent unrecognised soft-sediment deformation.

South of Dawespynten, no Palaeogene rocks have ever been found on land. The fault is suggested to continue offshore along the eastern coast of southern PKF.

Baklia Fault and related structures

The northern and southern halves of Prins Karls Forland show different geological structure and stratigraphy, which led Hjelle et al. (1979) to indicate a curved fault through Haukedalen and Scotiadalen. They did not, however, provide any description or documentation of the fault. The name "Baklia Fault" was inferred by Dallmann (2015) on the basis of recent observations and documentation (first published here), not realising at that time that both Atkinson (1960) and Morris (1989) had recognised a fault in this place under the name "Scotiadalen Fault". No documentation was provided by these authors either.

On the southern coastal cliff of Selvågen (the innermost exposures in the bay), a more than 150 metres wide deformed zone shows a chaotically deformed mixture of various lithologies of the Peachflya Group (which also makes up the coastal cliffs to the east) and limestones, which resemble the ones of the Scotiafjellet Group (Photos 177-182). This chaotic zone continues southward along Baklia (Photos 183-185) towards the western slope of Alasdairhornet, where it is between 100 and 300 m wide. The deformation is brittle. Foliations are rotated dextrally into the direction of the fault zone, while faults in the adjacent succession of Peachflya Group to the east are right-stepping en-echelon faults, which may be Riedel shears from the incipient stages of strike-slip movement. Unfortunately, exposures to the west of the fault zone are very poor. Lithologies there are solely those of the Scotiafjellet Group. At least two faults run parallel to the deformed zone to either side of it (Fig. 9).

The juxtaposition of lithologies from different stratigraphic levels indicates a significant lateral displacement, this means in the order of many kilometres, possibly tens of kilometres.

The fault zone bends from N-S trend in Haukedalen and southern Baklia to a NNE-SSW trend at Selvågen. The large-scale fault pattern on the eastern side can be interpreted as tensional structures that indicate dextral movement. However, at Selvågen, the boundary faults of the Forlandsundet Graben are cut by the Baklia Fault Zone and displaced sinistrally by approximately 1.5 km. Associated faults to the west of the main strand of the Baklia Fault are arranged sub-

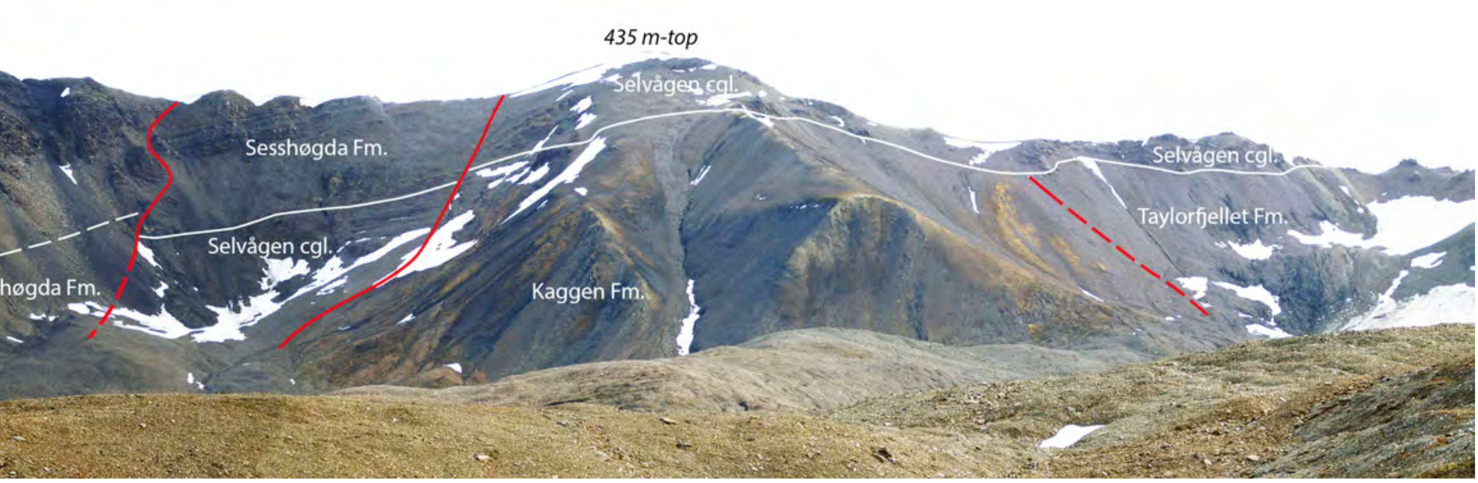


Photo 175: Panorama of Thomsonfjella-Sesshøgda seen from the north, showing the two eastern faults of the Western Forlandsundet Fault Zone displacing basement and Palaeogene succession. For opposite mountain face see Photo 77.

Photo 177: Baklia Fault Zone, coastal cliff at Selvågen. Lithologies of the Taylorfjellet Formation (Baklia facies, black) are mingled with unspecified rocks of the southern tectonic block.

Photo 178: See Photo 177.

Photo 179: Baklia Fault Zone, coastal cliff at Selvågen. Close-up of shear zone on Photo 178.

Photo 180: Baklia Fault Zone, coastal cliff at Selvågen. Intensely folded, rusty phyllites, probably of the Knivodden Formation within the fault zone.

Photo 181: Baklia Fault Zone, coastal cliff at Selvågen. Intensely tectonised part of the fault zone. Deformation is brittle to semi-brittle.

Photo 182: Baklia Fault Zone, coastal cliff at Selvågen. Lithologies of the Taylorfjellet Formation, typically characterised by the grey marbles with the quartz vein network, are distiguished despite of the intense deformation.

Photo 183: Baklia Fault Zone crossing the main river canyon in the northern reaches of Scotiadalen. Light-coloured slates (Kaggen Formation) to the left (west), dark-coloured calcareous mudstones (Taylorfjellet Formation) to the right (east). The fault parallels the canyon and cuts throught its wall where the river bends.

Photo 184: Folds in Taylorfjellet Formation calcareous rocks in the Baklia Fault Zone at the minor river canyon in the northern part of Baklia. Fold axes are subhorizontal and trend north.

Photo 185: A strand of the Baklia Fault Zone crossing a side canyon close to Photo 184. Strongly folded black calcareous mudstones of the Taylorfjellet Formation (right) are butressed against metapsammites and phyllites of the Knivodden Formation (left).

parallel, though slightly fan-shaped. The lack of similar tensional structures on the western side of the fault may be only apparent, as outcrops are poor and there are no marker beds in the Taylorfjellet Formation which could be used to recognise such faults.

Slickensides as indicators of fault directions, although nont many have been found, confirm that preferentially dextral, but also sinistral strike-slip has occurred, mainly with normal components, as well as normal faulting.

Strathmoredalen Fault

Mapping revealed the existence of a fault at Vindholet that continues through Strathmoredalen into the northern reaches of Aberdeenflya, where it is covered by unconsolidated coastal plain sediments.

The stratigraphic gap between the rocks on either side of the fault indicates a down-to-SE movement of at least 200 m. A steep dip to the SE or NW can be assumed from the topography and outcrop pattern, although the fault strand is not exposed. It is assumed to cut through the coastal exposures west of Taylorfjellet, but could not be pinpointed there (compare Photo 9).

The map-scale outcrop pattern in northern PKF suggests that the Strathmoredalen Fault also dissects the Eastern Forlandsundet Fault Zone on the coastal plain Aberdeenflya to the east. A possible fault offsets was indicated by Hjelle et al. (1999) approximately in this place.

Individual areas with unsolved structural problems

A few areas within the mapped region are problematic with respect to their structural – and in part stratigraphic – context:

Omondryggen Syncline

A complex structure, preliminarily called the "Omondryggen Syncline" is situated in the southwestern part of the northern tectonic block (Figs. 9, 10). It follows the regional structural NNW-SSE trend. Its internal geometry is not yet understood due to poor exposure and limited time spent in the field there.

The Omondryggen Syncline is a nearly isoclinal, upright, regional fold structure with competent limbs consisting of metapsammites and quartzites of the Grampianfjella Group, and a core of less

Photo 186: Primary stratigraphic boundary between the Conquerorfjellet Formation (light) and Taylorfjellet Formation (dark) between Gourlayfjellet and Omondryggen, western limb of the Omondryggen Syncline.

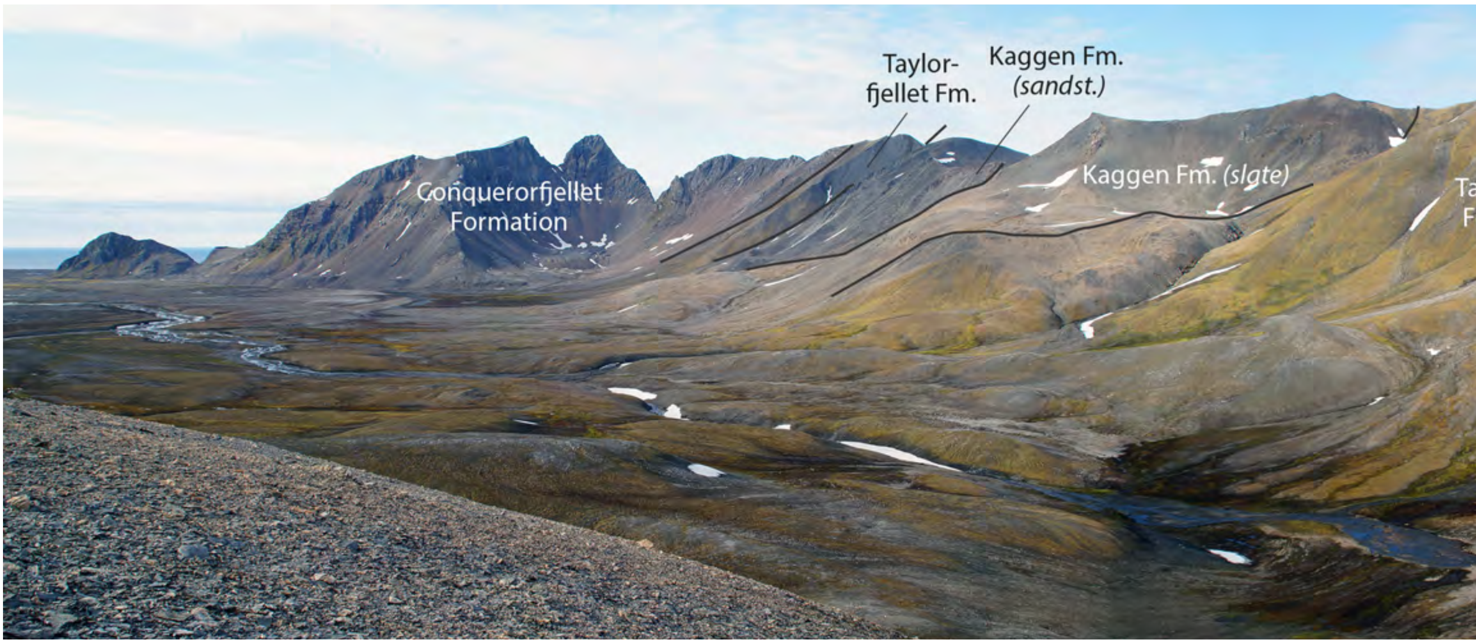


Photo 187: Panorama across the Omondryggen Syncline at Haukedalen, looking southwest (left) to northeast (right). Formation boundaries are mapped by lithologies, but internal structures cannot easily be worked out due to poor exposure of the bedrock.

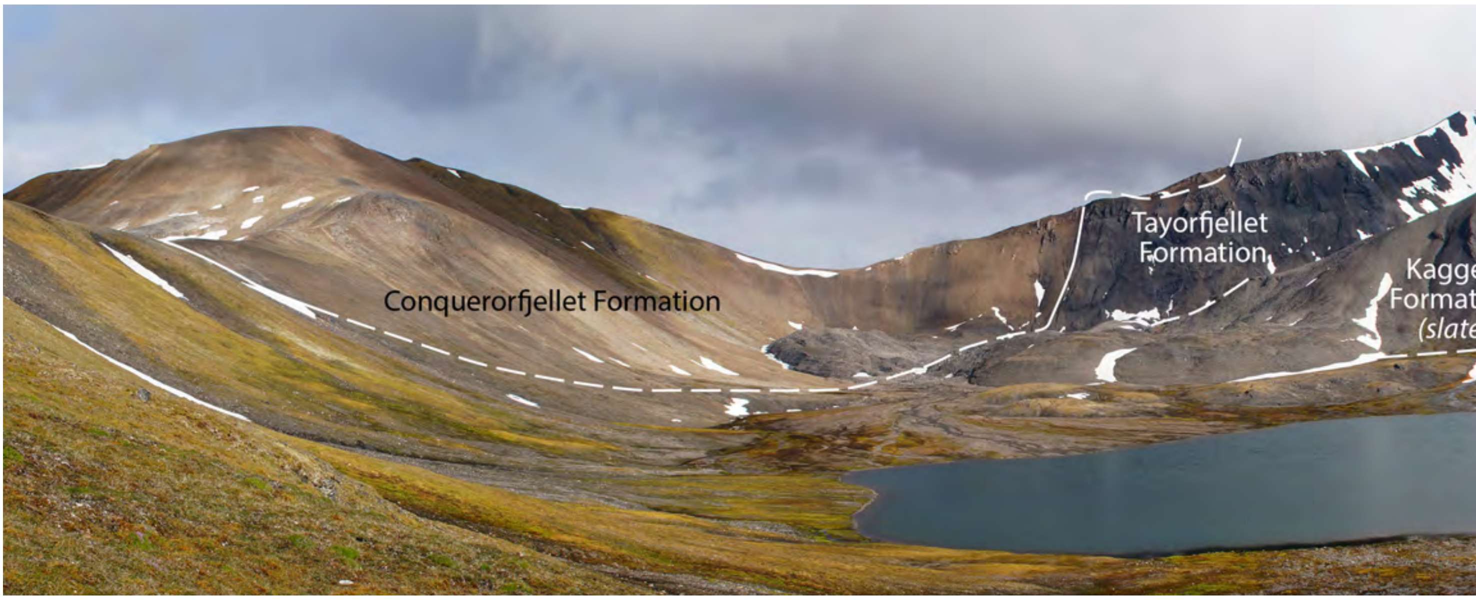


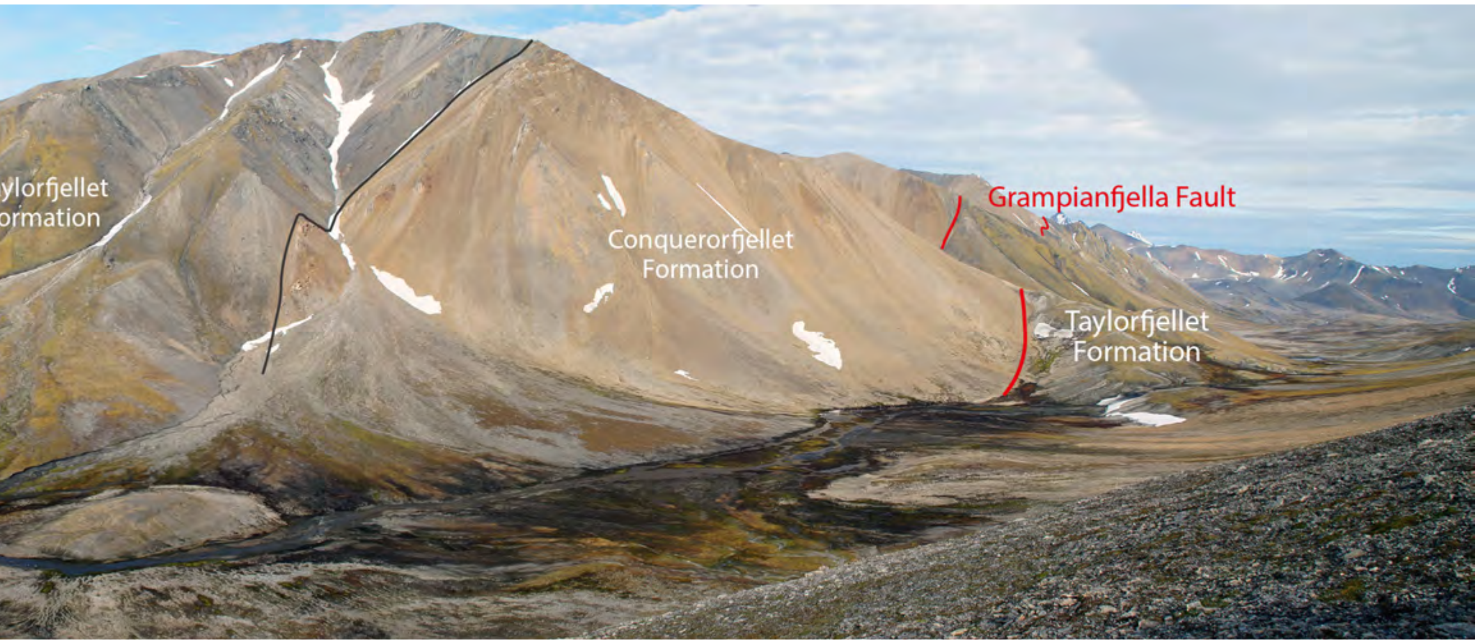
Photo 188: View of the eastern limb of the Omondryggen Syncline at Ossianvatna, view towards the east. The slate and sandstone lithologies of the Kaggen Formation cross over the ridge of Scotiafjellet, but do not reoccur north of Ossianvatna.

competent lithologies (impure marbles, slates and sandstones of the Scotiafjellet Group) (Fig. 186-189). The fold closes to the north. Although the plunge of the fold axis cannot be seen, it is interpreted to be a syncline, because the younger rocks are in the core and there is no indiaction for stratigraphic inversion (Photos 187-189).

At map scale, the syncline is thought to plunge gently towards ca. 160° (SSE). The limbs dip moderately to steeply, locally overturned up to 80° on the eastern, and up to 60° on the western limb. The core of the syncline is folded and sheared, but no preferred zones of movement could be mapped. The two lithologies both probably representing the Kaggen Formation do not show a symmetric pattern, which may indicate significant internal shear in the core of this large and tight fold structure.

The eastern limb is cut by the Petuniaskaret Fault segment of the Western Forlandsundet Fault, with a large down-to east displacement with an unknown offset. The fault cuts up and down through Grampianfjella metapsammites so that the thickness of this formation in the fold limb varies considerably. The western limb bends back to lower dip angles at Tvihyrningen where the metapsammites form a set of WSW-verging, asymmetric, tight folds with accommodating thrust faults (Fig. 9, Photo 127).

While the structure certainly was modified during the Eurekan brittle events, there is not sufficient data to decide, whether it initially was a ductile structure inherited from one of the Palaeozoic events, or was entirely formed during the Eurekan.



Promontory north of Thomsonfjella

In the middle part of Thomsonfjella, between Alfred Larsentoppen and the 435 m summit farther east, a klippe consisting maily of diamictites belonging to the Neukpiggen Formation (Ferrierstranda Group) occurs (see above, Section *The klippen*). At the eastern end of this structure, massive, whitish-weathering carbonate rocks occur that might represent the overlying Geikie Group (see above). This lithology is separated by a tectonic contact from the Kaggen slates, which represent the stratigraphic unit underlying the klippe. The fault contact is not exposed, but seems to be subvertical, with abundant brown-coloured, secondary dolomite and siderite occurring on the ridge (Photo 150). This fault probably cuts through the basal thrust of the klippe.

From the location of the suggested Geikie Group's carbonates on the ridge, a promontory descends northward into the glacier Magdabreen (Fig. 18). We did not have time to walk along it, but we photographed it from a distance, both from Thomsonfjella (Photos 190, 191) and from the coastal plain to the northeast (Photos 192, 193). The lithologies that make up the western and eastern side of the promontory are distinctly different and dip in opposite directions; both sides contain different metapelites and carbonate rocks. Orange to purple carbonate bands and lenses occur in several places on the crest of the promontory and indicate the presence of a fault. Tentatively, Geike Group rocks are expected to form the western side, while Scotiafjellet Group rocks may form the eastern side of the promontary, based on the appearance of the rocks from a distance. They are separated by the same fault that also crosses the main ridge (Photo 150). To verify or contradict this assumption (Fig. 18), the area needs to be mapped in detail.

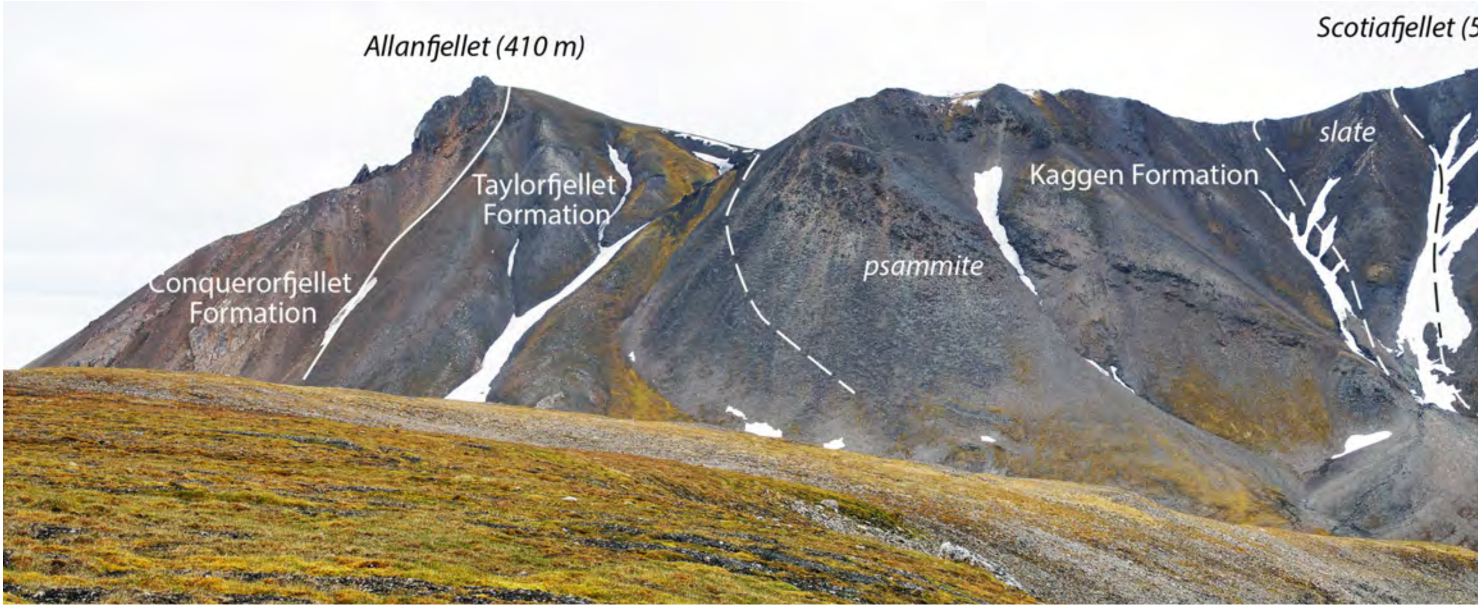


Photo 189: The Omondryggen Syncline in Normanndalen (view towards north). Formation boundaries in the synclinal core are mapped by lithology, but the internal structure and nature of the contact between slates and sandstones are still unknown.

Photo 190: North-eastward view along the eastern klippe on Thomsonfjella; the small promontory (Fig. 18) is seen in the background.

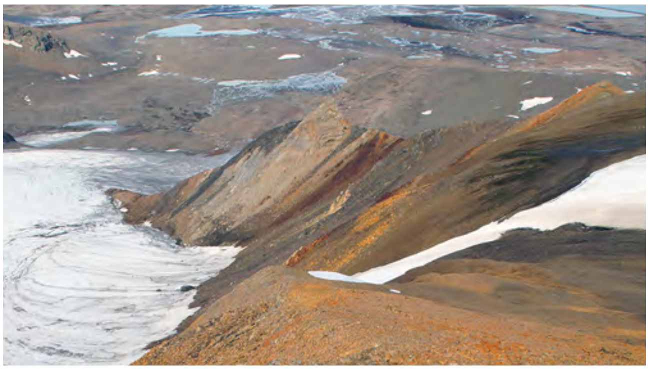


Photo 191: North-eastward view along the eastern klippe on Thomsonfjella, with the small promontory (Fig. 18) seen in the centre of the photograph.

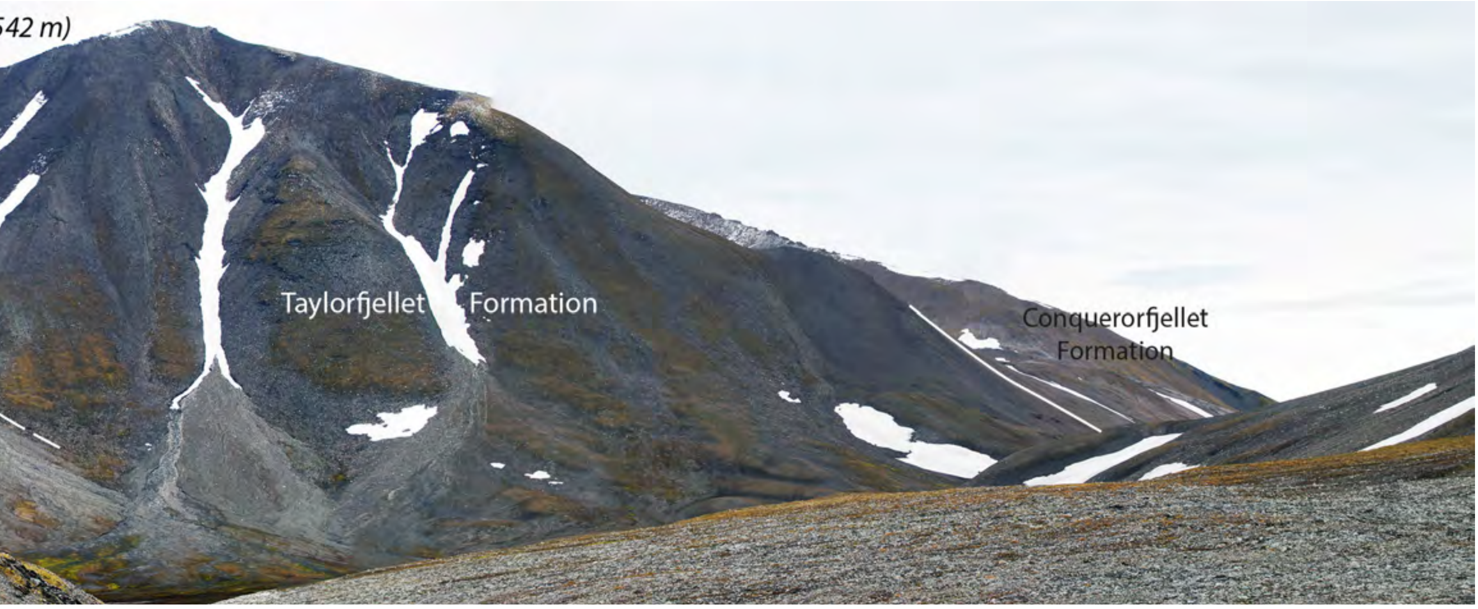
Photo 192: The promontory's (Fig. 18) eastern face probably exposing lithologies of the uppermost part of the Taylorfjellet Formation corresponding to those mapped at Finneryggen south of Thomsonfjella (Fig. 9).

Photo 193: A different view of the eastern face of the promontory (compare Fig. 18, Photo 192).

Deformed zone east of Røyshaugen

In the lower sections of two tributary streams running from the west into Scotiadalen, a zone of chaotic deformation is exposed within the Taylorfjellet Formation, stratigraphically situated below (west of) the light marble member. The streams are the one coming out of the ravine between Conquerorfjellet and Røyshaugen (A), and the one coming down from Scotiabreen (B).

The deformed lithologies are calcareous slates, sometimes with a phyllitic luster, and with dark and light-coloured (dolomitised?) marble bands. Deformation is characterised by irregular folds with bent fold axes and intensive, irregular fracturing and faulting (Photos 194, 195). Due to the poor degree of exposure, this zone cannot be traced between the two outcrops, but we suggest it to be continuous.



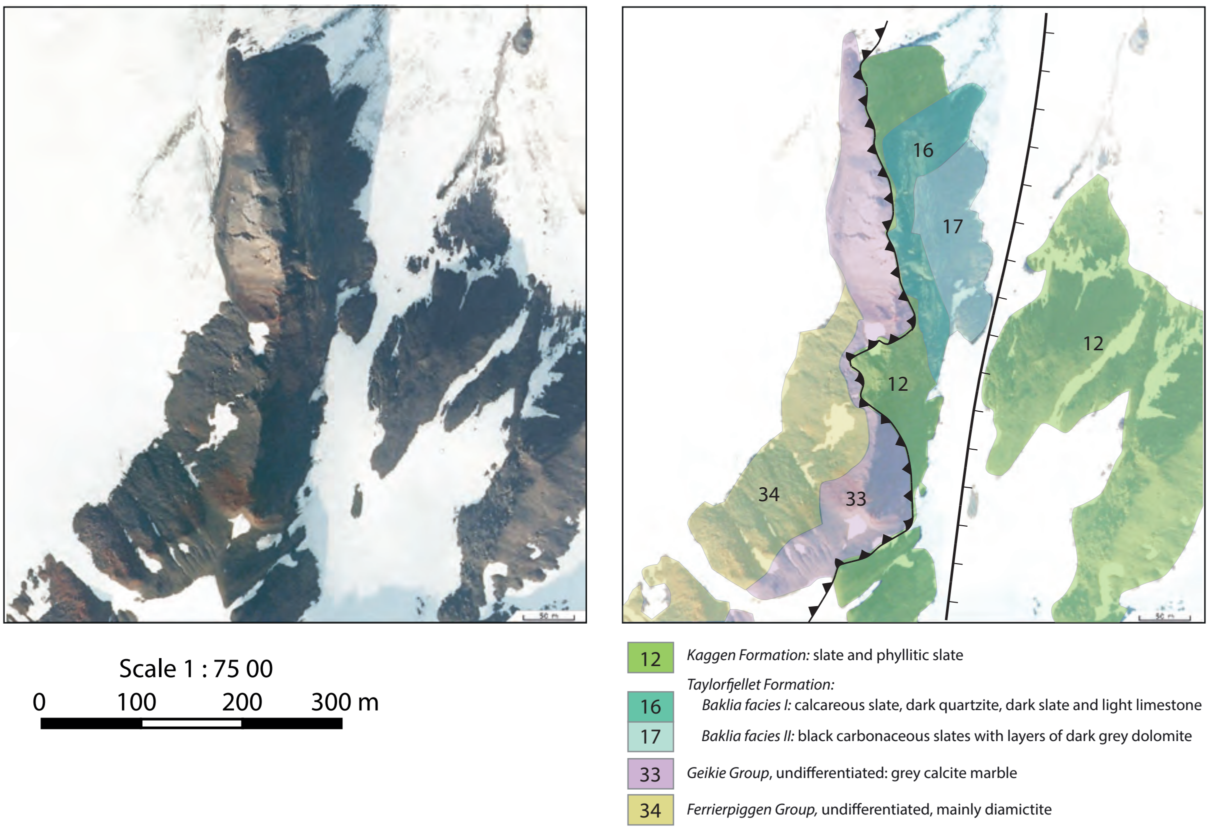


Fig. 18: Aearial photograph and geological interpretation of the promontory north of Thomsonfjella. The ridge has only been observed from a distance so far (compare photos 190-193) and rock units are assigned to formations based on their visual appearance. The thrust fault is the base of the eastern klippe.

The calcareous lithologies of the Taylorfjellet Formation gradually change northwestwards along the eastern slope of Røyshaugen to a more phyllitic composition. The overlying dark slates and quartzites, however, are unchanged. Northwest of stream A the phyllitic lithology's occurrence stops against slates of the Kaggen Formation. The contact is covered and its nature is unknown, although suggested to be a fault.

Deformation of the zone is semi-brittle to brittle, convergent and supposedly relatively young. It is tempting to compare it with the phase of post-depositional folding of parts of the Buchananisen Group's rocks against the graben faults – here expressed by folding and faulting against the competent Grampianfjella metapsammites across Petuniaskaret fault segment.

The irregular folds in the slopes of Scotiafjellet (Photo 110), as well as the minor folds in the eastern section of Normanndalen, are reminiscent of this deformation; a possible correlation of these structures should be investigated.

Photo 194: The deformed zone east of Røyshaugen with irregular folds with bent fold axes and intensive, irregular fracturing and faulting.

Photo 195: Detail from the deformed zone east of Røyshaugen (Photo 194). The zone strikes parallel to the Western Forlandsundet Fault Zone.

Kapp Sietoe area

Kapp Sietoe and the adjacent cape 800 m farther north define a strip of lowland seawards from Sutorfjella. The Palaeogene conglomerates that make up Sutorfjella are separated from the Kapp Sietoe area by a NNW-SSE striking fault with a down-to-ENE sense of movement, thus bringing basement rocks to the surface all along this coastal strip (Fig. 7). Part of the deformed zone of the fault with cataclasites is exposed in Niggbukta, where the fault strikes into the sea (Photo 49). The contact with the Sutorfjella rocks is not exposed; the most proximal outcrop in the latter is the open fold in associated red and grey sandstone (Photo 71).

The Kapp Sietoe basement block may terminate southward against the same E-W running fault, which also cuts off the Sutorfjella conglomerate to the south.

As described above (Section *Possible correlatives of the Craigtoppane Formation*), the area shows the transition from normal metapsammitic and metapelitic lithologies of the Grampianfjella Group to carbonate lithologies reminiscent of the Craigtoppane Formation. When visiting Kapp Sietoe in 2012, we had no knowledge of the latter and did not know how to relate the rocks to the stratigraphic scheme. The area should be revisited and possible evidence for its correlation with the Craigtoppane Formation should be collected. At the same time, the layers and irregular bodies of a yellowish-weathering psammite within the calcareous rock (Photos 51, 52) would need a closer look. The Kapp Sietoe area is stratigraphically complex and deformed by ductile and brittle processes. Detailed mapping (scale 1:2500 or larger) of the area (ca. 400 x 800 m) could be a promising project.

Area southwest of Richardlaguna and Laurantzonfjellet

The area between the Macnairrabbane Window and Richardlaguna shows unique lithologies (Photos 53-56), which may be continuous with the succession above the Pinkie unit in the Grimaldibukta area (see *Possible correlatives of the Craigtoppane Formation*, and *Stratigraphic trends*). This has so far not been established due to two circumstances: 1) The two areas were mainly mapped and investigated by two different groups of geologists, and 2) the intermediate area around Laurantzonfjellet has yet not been mapped at all, although it is situated in a key position with respect to a possible correlation. If structural continuity and continuous, lateral retrogradation of the rocks in the shear zone running northward from Bouréefjellet could be confirmed, then the shear zone could be traced along the chloritic lithologies all the way to the margin of the Macnairrabbane Window. Laurantzonfjellet may also hide the key for the interpretation of how the three major thrust sheets connect (see Section *Thrust sheets and tectonostratigraphy*). The validity of these correlations is assumed on the interpretative map (Fig. 10).

Tentative interpretation of Palaeogene tectonic development

Uplift history

For conclusions on the tectonic development of PKF during the Palaeogene earth movements, a short summary of available data on overburden and uplift/exhumation of the Palaeogene sediments is needed:

Rye Larsen (1982) reported relatively high vitrinite reflectance values, especially from the Selvågen area of up to Ro=4.01, corresponding to an overburden of 5-10 km, depending on the geothermal gradient. Assuming that the geothermal gradient in northwestern Svalbard was relatively high due to the vicinity of the Yermak hot spot (Amundsen et al. 1987), he suggested an overburden in the shallower range of this depth interval, or even less with an exceptional high geothermal gradient.

For comparison, vitrinite reflectance was measured to be Ro=0.9 at Aberdeenflya (2-3 km of overburden) and only Ro=0.43-0.46 at Sarsøyra on the Spitsbergen side of Forlandsundet (few hundred metres of overburden) (Rye Larsen 1982).

Manum & Throndsen (1986) gained even lower vitrinite reflectance data of Ro=0.3 from the Palaeogene at Sarsbukta on the Spitsbergen side of Forlandsundet Graben, while values from PKF were considerably higher, around Ro=4. Their evaluation of the overburden thickness was amounted to 6-8 km and also denotes a very high post-depositional uplift during the late Palaeogene compared to Spitsbergen.

Variation in the geothermal gradient may let the difference in uplift appear larger, but part of it is certainly caused by overburden, which may reflect the different age of the rocks. The palaeontologically dated rocks at Sarsøyra (late Eocene-early Oligocen) may be the youngest, while the PKF side of the Forlandsundet Graben shows older (Eocene) sediments, of which the Aberdeenflya Formation is youngest and the formations exposed at Selvågen are oldest. This implies a distinctly higher post-sedimentary uplift of PKF and especially the Selvågen area, compared to the Spitsbergen side.

Barnes & Schneider (2018), based on (U-Th)/He low-temperature thermochronology, also argued for a deeper burial of PKF during the Eurekan fold and thrust movements than the western areas of Spitsbergen. After the late-Cretaceous uplift Western Spitsbergen shows renewed subsidence during Eurekan folding and thrusting (53-47 Ma) and subsequent uplift during dextral transform motion (47-34 Ma). PKF on the other hand remained at a large burial depth at temperatures above 200°C. Exhumation started 34 Ma ago. Unroofing exceeded 4 km of overlying sediment, while it was only 2.5 to 3.5 km in western Spitsbergen. These data are roughly compatible with the older vitrinite reflectance data.

A problem arises with the age of the lower formations in the Forlandsundet Graben with respect to these data. The underlying basement rocks must necessarily have been exposed at the surface, when the Selvågen conglomerate was deposited. These were deposited unconformably above the Eurekan fold-and-thrust structures and thus are not older than early Eocene. The comparatively high overburden estimates, notably in the Selvågen area, suggest that they are distinctly older than the sediments at Sarsøyra (Eocene-Oligocene transition, see above). This stands in contrast to Barnes & Schneider's (2018) data that do not show any basement exhumation earlier than Oligocene.

To solve the problem, sample localities for Barnes & Schneider's (2018) thermochronology (not provided in the article) should be compared in detail with the geological map to find out whether or not some of them were taken in tectonic blocks that contain overlying Palaeogene. If not so, large normal fault offsets during the time of deposition along the western margin of the Forlandsundet Graben could explain the discrepancy. Thermochronology should then be repeated with samples from basement directly underlying the Selvågen conglomerate. As a working hypothesis, these large fault movements are assumed.

Prins Karls Forland and the De Geer Transform Zone

It is clear from the above that PKF was tectonically separated from Spitsbergen during the entire Palaeogene development. This means that the plate boundary fault system was at least in part situated between PKF and Spitsbergen and already an active fault zone during the formation of the West Spitsbergen Fold-Thrust Belt (early Eocene). Being part of the De Geer Transform, these faults may accommodate major strike-slip movement during the Eocene. The overall transform movement can be roughly estimated from plate-tectonic reconstructions (e.g., Eide 2002; Piepjohn et al. 2016) to an order of size around 200 km, before the rift at an angle of ca. 25° across the De Geer Transform was initiated.

A very rough controlling calculation reveals ca. 15 mm/year on average (200 km in 13 million years), which is a realistic value. For comparsion, the spreading distance during the same period (47-34 Ma, chron 21-13) just west of the Senja Fault in the North Atlantic was ca. 300 km at an average spreading rate of 20 mm/year, based on the chron compilation map presented in Dallmann (2015, page 135).

The transition from transform motion to rifting occurred progressively around the Eocene-Oligocene boundary (Eide 2002), but happened to the west of PKF.

It is not known how much of the transform displacement was accommodated along fault strands either to the east or to the west of PKF. The island may thus be displaced in relation to Spitsbergen by an unknown net distance of up to 200 km to the north. A displacement in the upper range of this interval would explain the resemblance of the Neoproterozoic stratigraphy of the southern basement block with the coeval stratigraphy of southern Spitsbergen.

The relative movement between the southern and northern basement blocks of PKF along the Baklia Fault Zone is unknown. The fact that a klippe containing southern stratigraphy is thrust onto the basement northwest of the Baklia Fault Zone suggests that there was no significant displacement after thrusting, which must be suggested to have happened during the Eurekan fold-thrust event (53-47 Ma). The Baklia Fault Zone may therefore have had a large vertical component during Palaeocene deformation. This would again indicate that the two Neoproterozoic basement blocks of PKF reflect a vertical tectonostratigraphic succession, probably with a Palaeozoic thrust contact in between.

Conceptual model

On the basis of the above data and assumptions, a preliminary, conceptual model is proposed (Fig. 19):

During the Eurekan thrusting and folding event (53-47 Ma), PKF was most probably situated in the root zone of the orogen, because the island provides both east- and west-verging structures. The divide with both overlapping verging directions follows Grampianfjella and the central range of the northern part of the island. The basement is assumed to have risen initiating inclined and overlapping thrusts towards both sides, indicating a structure comparable to flower structures, although details will have to be revealed by further mapping. Consequently, transpression and thus transform motion may have been present already at that time, which indicates tectonic strain partitioning between the transpressional De Geer Transform and the near orthogonal convergence in the fold belt as proposed by Maher & Craddock (1988).

Several mechanisms can be responsible for the comparatively high post-Eurekan uplift rate:

(a) transpressional events during the Eocene to early Oligocene transform margin setting (ca. 47-34 Ma) of the island (De Geer Transform);

(b) shoulder uplift during initial rifting across the Fram Strait in the Oligocene (for timing, see e.g. Eide 2002);

(c) a metamorphic core complex uplift during transtensional episodes – the latter is less probable due to the fact that no major listric normal faults or detachments between the sedimentary cover and the metamorphic basement have been found. All Palaeogene normal faults are brittle and rather steep (60° or more).

Transpressional and transtensional settings could be expected to occur during the post-Eurekan transform movement phase in the Eocene after 47 Ma. PKF was situated in a continental transform fault setting. In the early part of this interval, sedimentation started

Early Eocene
(52 million years, Chron 24)

Greenland moves east along Wegener Fault, formation of West Spitsbergen Fold Belt
Transcurrent motion along Wandel Hav Mobile Strike-Slip Belt,
Incipient motion along De Geer Fault and Wandel Hav Mobile Strike-Slip Belt to tie up incipient continental rift zones in Amundsen Basin and North Atlantic
Prins Karls Forland's northern and southern tectonic blocks are becoming juxtaposed in a transpressional setting at the Baklia Fault

Eocene-Oligocene boundary
(33 million years, Chron 13)

Continuous strike-slip motion along De Geer Fault system
Sea-floor spreading in Eurasian Basin and North Atlantic
Prins Karls Forland has been assembled
Forlandsundet Graben is being formed in a shifting transtensional and transpressional setting

continental crust (now land area)
contineal crust (now shelf area)
oceanic crust
fault
fault, active at shown time
sea-floor spreading zone
Eastern boundary of West Spitsbergen Fold Belt
H Hovgård Ridge
N Northern Prins Karls Forland
S Southern Prins Karls Forland
FG Forlandsundet Graben
LR Lomonosov Ridge
YP Yermak Plateau
MJP Morris Jessup Plateau
HFFZ Harder Fjord Fault Zone
WSFB West Spitsbergen Fold Belt

Recent situation

Sea-floor spreading across the former transform boundary
Hornsund Fault Complex comprises the now inactive De Geer Fault, Forlandsundet Graben and related faults on the shelf west of Svalbard

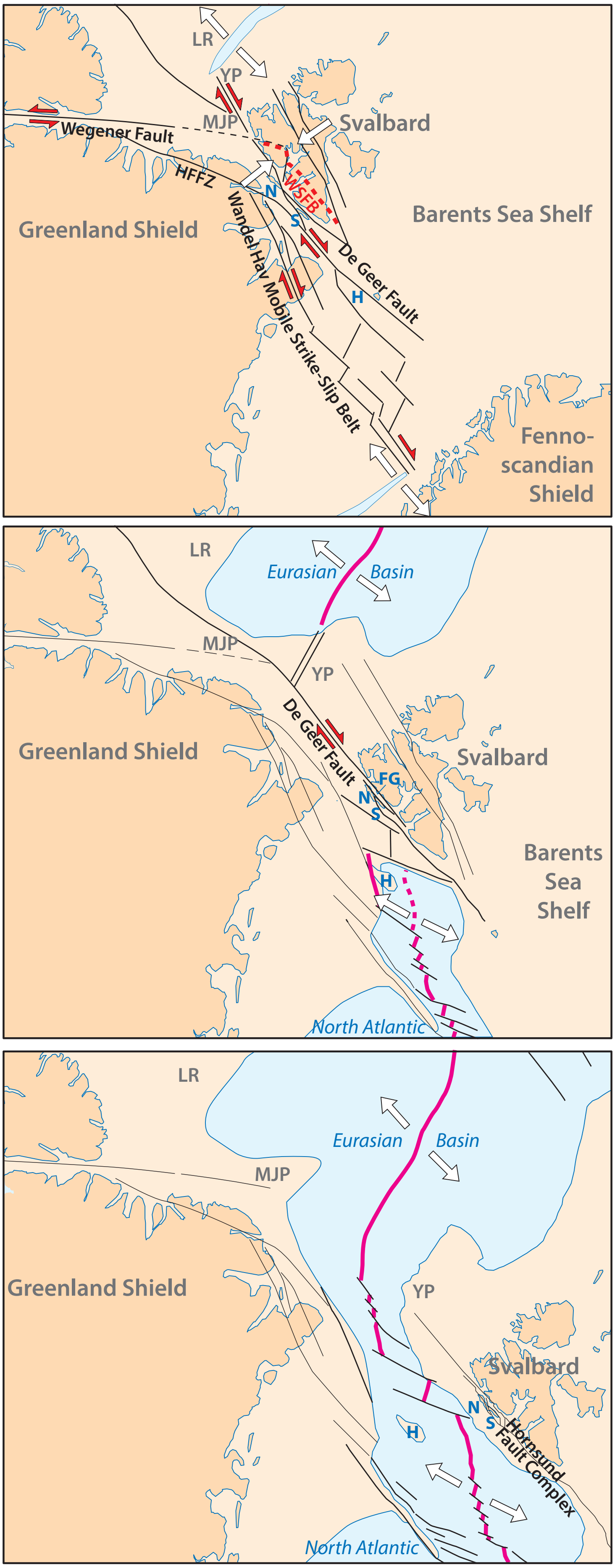


Fig. 19: A possible scenario for the movement and the assembly of Prins Karls Forland during the initial rifting between the North Atlantic and Arctic oceans in the Eocen-Oligocene. Map structures based on Eide (2002), with modifications.

with the coarse conglomerates of the Sutorfjella and Selvågen conglomerates. Synsedimentary, tectonic movements may have caused considerable thickness variations. During transtensional stages, parts of the basin accumulated the overlying clastic formations, while they were locally folded by buttressing against basement units (e.g., Trocaderostranda) during transpressive stages. Assuming a relatively narrow basin and possibly several active fault strands, considerable facies and thickness differences can be expected in such a setting.

The onset of rifting at a ca. 25° angle with the tansform from 34 Ma onward changed the regional stress field completely. An early rift phase may have widened the Forlandsundet Basin. During this event the youngest sediments, the conglomerate-prone Sarsbukta and Sarstangen formations, were deposited. They are preserved on the Spitsbergen side of the graben, where very limited uplift has occurred since. Rifting was later abandoned in the Forlandsundet Graben and changed its location to the west of PKF, where it finally turned into ocean-floor spreading during the Oligocene. PKF was left as a high structural block between the abandoned and the new rift system. Additional shoulder uplift and ridge push from the developing spreading ridge (the Knipovich Ridge) are then thought to have lifted up and tilted central parts of the island, while marginal parts – the fault blocks containing ovelying Palaeogene sediments – suffered considerably slower uplift rates. Ultra-slow spreading ridges like the Knipovich Ridge are likely to be accompanied by high shoulder uplift along high-angle faults, as it is especially well known from the Gakkel Ridge in the Eurasian Basin (Dick et al. 2003).

Major faults, particularly the Western Forlandsundet Fault Zone, developed during that time. Its western counterpart is expected to form the rift structures between the western coast of PKF and the Knipovich Ridge. The Baklia Fault may represent an oblique-slip transverse structure linking the two rift systems and compensating for differential uplift of northern and southern PKF.

This conceptual model satifies the structural observations from recent field work, the various vitrinite reflectance data and the recent low-temperature thermochronology data. Detailed future mapping of the remaining parts of the island is expected to modify the model.

APPENDIX

Other geological observations

This appendix comments shortly on geological observations made during field work, which have not been worked with in detail.

Ore occurrences

Iron ore has been decribed in the metamorphic rocks at Bouréefjellet. The geological map by Hjelle et al. (1999) shows an occurrence on top of the mountain. Large blocks were observed in the moraines of Murraybreen and Fallbreen (unpubl. reports A. Hoel 1909, 1910, 1924; Norwegian Polar Institute archives). One analysis revealed 40 % magnetite and 47 % hematite. The Scottish Spitsbergen Syndicate Expedition observed quartz-magnetite schists in situ at Bouréefjellet with up to 40 % magnetite and 20 % hematite (Tyrrell 1924).

These ores were observed in connection with the mafic rock bodies (metagabbroic and altered products) in the shear zone on top of the Pinkie unit by our cooperation partners. They occur at least in two places, one on top of Bouréefjellet and the other on the southwestern slopes of the mountain. Outcrops are poor and their relations to the country rocks are unclear.

We found boulders of iron ore in the moraine between Kaggen and Krokodillen (Photo 196), much farther south, where the possible source area (Grampianfjella) has not yet been mapped in detail.

Photo 196: Boulder of iron oxide found in the moraine at Krokodillen, probably derived from the ore bodies in the Craigtoppane Formation at Bouréefjellet or similar, undiscovered localities.

Hydrothermal carbonate veins and lenses

Ochre-coloured carbonate lenses and veins occur throughout the area in all stratigraphic basement units, but not in the Palaeogene sediments. They are especially abundant in northern PKF, but they also occur farther south. Their size varies from minor veins of mm-cm size to huge ones (Photos 197-200), the largest being Okerhaugen (northern PKF) in the Taylorfjellet Formation, with an almost circular outcrop ca. 240 m in diameter. In it occur ironstone concretions; some are of assumingly pure pyrite. Some particularly large carbonate occurrences (including the one at Okerhaugen) are lined up along a possible curved fault from Sildresletta towards Niggdalen. This may indicate the presence the southwestern of the two assumed faults on the A7G map sheet (Hjelle et al. 1999), which otherwise could not be shown to exist (Photo 197).

Photo 197: Okerhaugen south of Taylorfjellet, an orange-coloured hill made up of a large hydrothermal carbonate lens, the largest seen on Prins Karls Forland.

Photo 198: Minor hydrothermal carbonate precipitation in a metapsammite of the Fuglehuken Formation.

Photo 199: A hydrothermal carbonate lens with pyrite nodules, situated in the southeastern foothills of Taylorfjellet, northeast of Okerhaugen.

Another of these occurrences, one km NE of Okerhaugen, contains pyrite nodules of dm size, with Fe-oxyde crusts, as well as siderite. An old claim mark (now fallen down) was found there.

The highest density of ochre-coloured carbonate (dolomite) in fissures and cracks occurs in the Macnairrabbane Window. Most of the area is very closely underlying the assumed thrust above the window, which was reactivated under brittle conditions during the Eurekan Orogeny.

Two siderite lenses occur in the vicinity of Selvågen, distinguished by their purple colours. One occurs in the metapelitic Kaggen Formation, the other in the carbonate-prone Taylorfjellet Formation (Photo 201). They are only 800 m apart from each other, each a few metres in diameter, and thus probably derived from the same iron mineral source.

Photo 200: Hydrothermal carbonate lenses are being carved out of calcareous mudstones (Taylorfjellet Formation, Baklia facies) in the main river canyon in Scotiadalen, close to Selvågen.

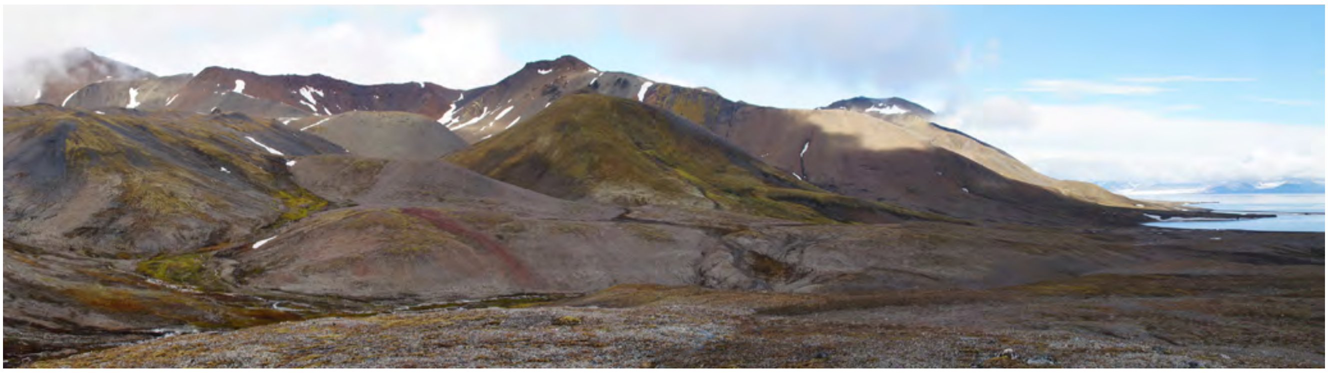


Photo 201: One out of two hydrothermal siderite lenses (marked by purple scree scattered downhill), situated between Selvågen and Finneryggen.

Rock glaciers

Abundant rock glaciers are reported from northern PKF, where they typically occur at the foothills of mountains made up of meta-sandstones and quartzites of the Grampianfjella Group (Hjelle et al. 1999). They are especially well developed on the western foothills of Fuglehukfjellet (Photos 202, 203). This situation continues southward at the foothills of the Grampianfjella mountain chain into the area mapped in 2014. Where the carbonate rocks of the Taylorfjellet Formation form the foothills, no rock glaciers occur at all. On the eastern foothills of the island, rock glaciers are developed along slopes made up of the relatively fine-grained clastic rocks of the Reinhardpynten and Krokodillen formations (Photo 204).

Photo 202: Rock glaciers at the western foothills of Fuglehukfjellet.

Photo 203: Rock glaciers at the western foothills of Fuglehukfjellet, same as Photo 202 from another angle.

Photo 204: Rock glaciers forming the southern foothills of Krokodillen.

Patterned ground

Patterned ground with a variety of stone polygons and stone circles is well developed within zones on the western foreflats and in many areas on the large coastal plains in the east of the island (Photos 205, 206). Areas with patterned ground coincide generally with the occurrence of raised beaches (Dallmann 2015: map on p. 55).

Photo 205: Patterened ground; stone circles at Carmichaelpynten.

Photo 206: Patterened ground; stone circles formed by material from the large, ochre-coloured, hydrothermal carbonate lense at Okerhaugen (Photo 197).

Peat deposits

Peat deposits are developed under bird cliffs, where bird droppings facilitate the growth of vegetation. Just south of Kapp Sietoe, in front of the cliff of the southern of the two Sutorfjella, such a peat deposit is reworked and exhuminated by wave action so that it can be observed without digging up the soil (Photos 207, 208). The deposit seems to have a quite good peat quality and is approximately 2 m thick. Similar deposits with an even larger extension may occur under the green moss carpets at the bird cliff of Fuglehuken.

Photo 207: Close-up of a peat lump at Kapp Sietoe (Photo 208).

Photo 208: Peat deposits exhuminated by wave action at Kapp Sietoe, below the bird colony of the southern peak of Sutorfjella.

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