Polarforschung 73 (2/3), 59 – 75, 2003 (erschienen 2006)

Geology, Magmatism and Structural Evolution of the Yelverton Bay Area, Northern Ellesmere Island, Arctic Canada

by Solveig Estrada[1], Karsten Piepjohn[1], Friedhelm Henjes-Kunst[1] and Werner von Gosen[2]

Abstract: The area around Yelverton Bay on the north coast of Ellesmere Island (Canadian Arctic Archipelago) is characterized by the Proterozoic to lower Paleozoic Pearya Terrane and Cretaceous to Cenozoic outliers. Here, the exotic Pearya Terrane comprises the Proterozoic crystalline basement (Succession 1) as well as metasediments and metavolcanics (Succession 2) with a likely Neoproterozoic to Cambrian age. In the Late Ordovician, Pearya rocks were affected by low-grade metamorphism and deformation of the M'Clintock Orogeny. Cretaceous igneous activity started with the emplacement of tholeiitic basaltic dykes (123-97 Ma). At northeastern Wootton Peninsula, west of Yelverton Bay, a 92-Ma-old hypabyssal microgranite intruded Pearya Succession 2. It represents the northeastern part of the bimodal Wootton Intrusive Complex which passes through the Wootton Peninsula within the NE-SW trending Mitchell Point Fault Zone. The microgranite is overlain by about 82-Ma-old bimodal volcanics and volcanogenic sediments of the Hansen Point Volcanic Complex. The volcanic rocks consist of rhyodacites, trachyandesites and rhyolites as well as alkali basalts and mafic dykes. The intrusion of the Wootton Intrusive Complex is probably related to initial movements along the Mitchell Point Fault Zone which separates Pearya Proterozoic basement rocks in the SE from Pearya Neoproterozoic to Cambrian metasediments and metavolcanics in the NW. Dextral strike-slip faulting along the Mitchell Point Fault Zone took place after the formation of the Hansen Point Volcanic Complex and is probably related to the evolution of the passive continental margin towards the Arctic Ocean. No evidence for Eocene Eurekan compression was found in the study area.

Zusammenfassung: Das Gebiet um die Yelverton-Bucht an der Nordküste der Ellesmere-Insel (Kanadischer Arktischer Archipel) ist durch das proterozoische bis unterpaläozoische Pearya-Terrane und isolierte kretazische bis känozoische Vorkommen gekennzeichnet. Das exotische Pearya-Terrane besteht hier aus dem proterozoischen kristallinen Grundgebirge (Serie 1) und einer Folge von Metasedimenten und Metavulkaniten (Serie 2) von möglicherweise neoproterozoischem bis kambrischem Alter. Im späten Ordovizium führte die M'Clintock-Orogenese zu einer schwachen Metamorphose und Deformation der Pearya-Gesteine. In der Kreide setzten magmatische Aktivitäten mit der Platznahme von tholeiitischen basaltischen Gängen (123-97 Ma) ein. Vor 92 Ma wurde westlich der Yelverton-Bucht (auf der nordöstlichen Wootton-Halbinsel) die Serie 2 des Pearya-Terranes von einem hypabyssischen Mikrogranit intrudiert. Dieser stellt den nordöstlichsten Teil eines bimodalen intrusiven Gesteinszuges (Wootton Intrusive Complex) dar, der sich innerhalb der NE-SW streichenden Mitchell-Point-Störungszone quer durch die Wootton-Halbinsel zieht. Der Mikrogranit wird von ca. 82 Ma alten bimodalen Vulkaniten und vulkanogenen Sedimenten überlagert (Hansen Point Volcanic Complex). Die vulkanischen Gesteine umfassen Rhyodazite, Trachyandesite und Rhyolithe sowie Alkalibasalte und basaltische Ganggesteine. Die Intrusion des Wootton-Komplexes ist möglicherweise an initiale Bewegungen entlang der Mitchell-Point-Störungszone gebunden. Diese Störungszone trennt proterozoisches Grundgebirge des Pearya-Terranes im SE von neoproterozoischen bis kambrischen Pearya-Metasedimenten und -Metavulkaniten im NW. Dextrale Lateralbewegungen entlang der Mitchell-Point-Störungszone fanden nach der Bildung des Hansen-Point-Vulkanitkomplexes statt und stehen möglicherweise mit der Entwicklung des passiven Kontinentrandes des Arktischen Ozeans im Zusammenhang. Im Untersuchungsgebiet wurden keine Hinweise auf eine kompressive Phase im Eozän gefunden.

[1] Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, 30655 Hannover, Germany, <solveig.estrada@bgr.de>
[2] Geological Institute, University of Erlangen-Nürnberg, Schloßgarten 5, 91054 Erlangen, Germany.

Manuscript received 15 June 2005, accepted 04 November 2005

INTRODUCTION

The study of structures and magmatism related to the complex opening of the Arctic Ocean is the research focus of the CASE projects (Circum-Arctic Structural Events) of the German Federal Institute for Geosciences and Natural Resources (BGR), Hannover. Bimodal volcanic and intrusive rocks of Late Cretaceous age are exposed on the northern coast of Ellesmere Island (Canadian Arctic Archipelago; TRETTIN & PARRISH 1987). These rocks are still little understood (regarding their exact age, the relationship between extrusive and intrusive rocks, and their relationship to the country rock). Therefore, several locations in the area around Yelverton Bay were visited by the authors during the CASE 6 and CASE 7 expeditions in 2000 and 2001.

This paper presents field observations as well as results of structural investigations and petrographical studies on the Cretaceous igneous rocks and their Proterozoic and Paleozoic country rocks. About 175 thin sections of the Cretaceous intrusive and extrusive igneous rocks as well as sedimentary rocks were examined, together with 60 thin sections of the metasedimentary and metavolcanic Pearya rocks. Additionally, the mineralogy of some very fine-grained varieties of the metamorphic rocks was determined by XRD using a Philips X'pert PW 3710.

Detailed geochronological, geochemical, and Sm-Nd and Rb-Sr isotope studies on the igneous rocks are in progress. Here we include some preliminary results (ESTRADA et al. 2004) which are necessary for the understanding of the geological and structural situation.

GEOLOGICAL SETTING

Northern Ellesmere Island is characterized by four major structural units (Fig. 1). These are from south to north: the Canadian Shield, the Franklinian Basin, the Sverdrup Basin, and the Pearya Terrane (TRETTIN 1991a and references therein). In the southeast, Precambrian metasedimentary and crystalline rocks of the Canadian Shield extend towards Greenland across Smith Sound and Nares Strait (e.g., SCHUCHERT 1923, THORSTEINSSON & TOZER 1960, 1970). The basement is overlain by Neoproterozoic to Devonian sediments of the Franklinian Basin (e.g., STUART SMITH & WENNEKERS 1979, DEWING et al. 2004), which build up large parts of Ellesmere Island and continue northeastwards to North Greenland. The infill of the Franklinian Basin consists of km-thick clastic and carbonate deposits and can be divided into a southeastern shelf platform and a northwestern deep water sequence (e.g.,

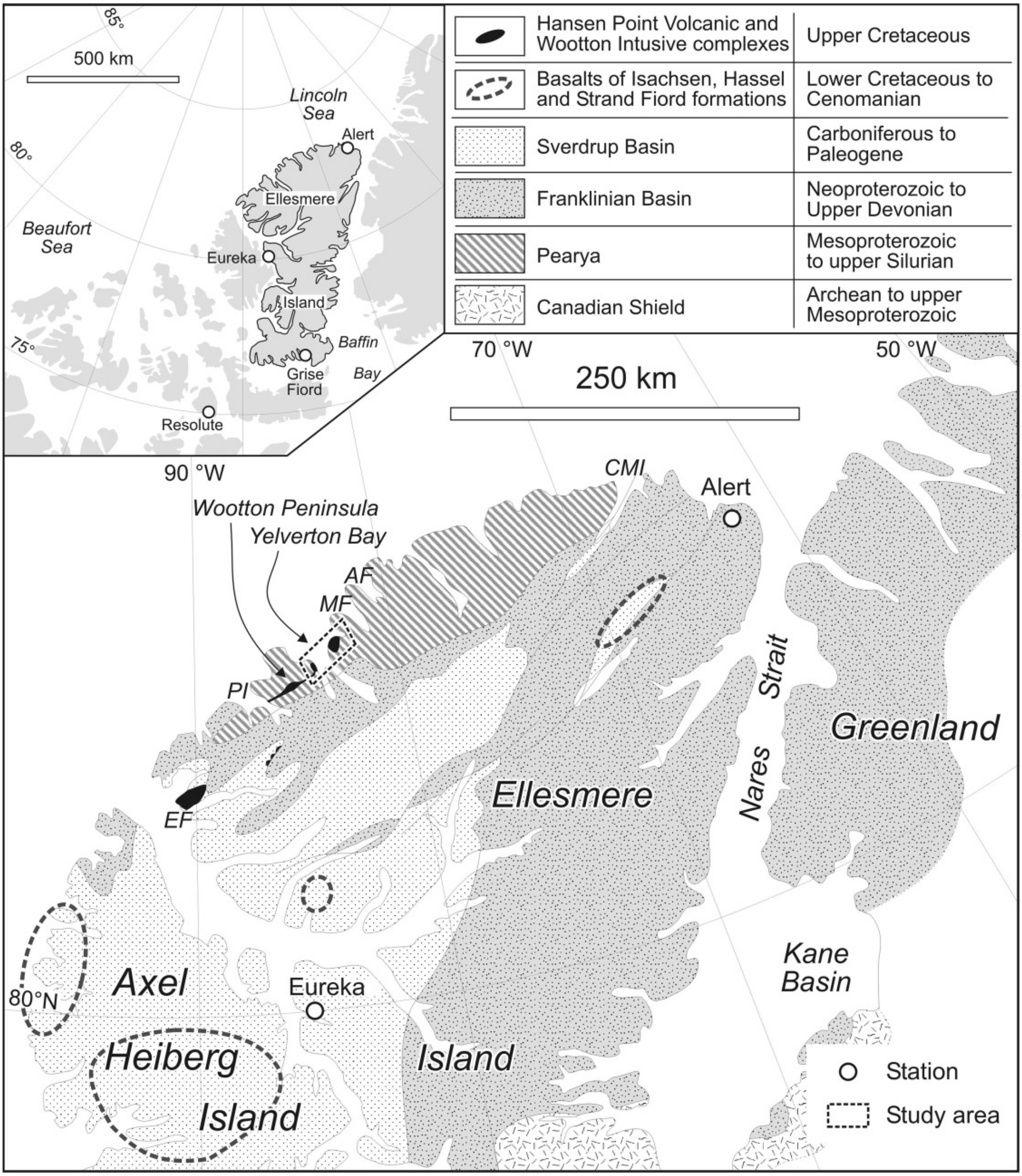


Fig. 1: Base map of the major tectonic units on northern Ellesmere Island (modified from Trettin 1991a) and location of the study area. AF = Ayles Fiord; CMI = Clements Markham Inlet; EF = Emma Fiord; MF = Milne Fiord; PI = Phillips Inlet.

Abb. 1: Übersichtskarte der wichtigsten tektonischen Einheiten auf der nördlichen Ellesmere-Insel (umgezeichnet nach Trettin 1991a) mit der Lage des Untersuchungsgebietes.

Dawes & Peel 1981, Higgins et al. 1991, Trettin 1991a). In Late Devonian/Early Carboniferous time, the Franklinian Basin was affected by intense crustal shortening of the Ellesmerian deformation (e.g., Thorsteinsson & Tozer 1957, 1960, 1970, Trettin & Balkwill 1979, Higgins et al. 1981, Trettin 1991a), which caused km-scale folding of the entire basin succession. The folded Franklinian Basin is unconformably overlain by the Sverdrup Basin (Trettin 1991a) consisting of 3-km-thick upper Paleozoic and 9-km-thick Mesozoic clastic and carbonate sediments locally followed by up to 3-km-thick predominantly clastic Upper Cretaceous and Paleogene sediments.

The northernmost part of Ellesmere Island consists of Precambrian and Paleozoic rocks of Pearya (named by Schuchert 1923) and is interpreted as an exotic terrane (Trettin 1991a,b). The Pearya Terrane can be divided into five major successions (Trettin 1998): the upper Mesoproterozoic to lower Neoproterozoic crystalline basement (Succession 1), Neoproterozoic to Lower Ordovician metasediments and metavolcanics (Succession 2), Lower-Middle Ordovician arc-type metavolcanics and metasediments including ultramafic-mafic complexes (Succession 3), and Middle Ordovician to upper Silurian sediments and volcanics (Successions 4 and 5). The successions are separated by important unconformities or by major faults (Trettin 1998). The Middle Ordovician M'Clintock Orogeny (Trettin et al. 1982) caused metamorphism of successions 1-3 ranging from lower greenschist facies to lower amphibolite facies and the emplacement of granitic plutons (Trettin 1991b). The study area is located at the southwest end of Pearya (Fig. 1) and is characterized by NE-SW trending structural units which are separated by steep fault zones (Fig. 2).

In Mesozoic times, the northern margin of the Canadian Arctic Archipelago was affected by episodic igneous activity. Basaltic flows are exposed in the Barremian to Cenomanian Isachsen, Hassel, and Strand Fiord formations on Axel Heiberg and Ellesmere islands (Ricketts et al. 1985, Embry & Osadetz 1988, Osadetz & Moore 1988). Extrusive activity was accompanied by the emplacement of widespread mafic dykes and sills on Ellesmere, Axel Heiberg and other arctic islands (Balkwill 1978, Embry 1991, Buchan & Ernst 2004). Lower Upper Cretaceous bimodal intrusive and extrusive igneous rocks are known on the north coast of Ellesmere Island (Trettin & Parrish 1987) (Fig. 1). The plutonic rocks of the Wootton Intrusive Complex consist of gabbros, minor granitoids and hybrid rocks (Trettin & Parrish 1987). They are restricted to a NE-SW trending narrow zone crossing the Wootton Peninsula between the master faults of the Mitchell Point Fault Zone (Fig. 2). The Hansen Point volcanics, an Upper Cretaceous suite of bimodal volcanics and pyroclastics, as well as a minor amount of sandstone, siltstone, shale, and coal (Trettin & Parrish 1987, Embry & Osadetz 1988, Embry 1991) form isolated outcrops between Emma Fiord in the SW and south of Phillips Inlet, as well as around Yelverton Bay (Figs. 1, 2). In this study, we prefer the term Hansen Point Volcanic Complex (HPVC).

The last pulse of clastic sediments in the region ranges in age from latest Cretaceous to late Eocene or earliest Oligocene and is represented by a locally more than 3 km thick succession (Eureka Sound Group) of sandstone, mudrock, conglomerate, and coal (Trettin 1991a, Miall 1991). West of Yelverton Bay area, a Paleocene outlier is exposed (Fig. 2) which is formed by steeply to subvertical dipping beds of sandstone, conglomerate, and mudrock (Trettin & Frisch 1996). This outlier was not visited.

In the Eocene, the Eurekan compressive deformation affected northern parts of the arctic islands (e.g., Thorsteinsson & Tozer 1970, Soper et al. 1982). It is related to a northward movement of the Greenland plate during a phase of simultaneous seafloor spreading in Labrador Sea /Baffin Bay and the North Atlantic between magnetic anomalies 24 and 13 (Srivastava & Tapscott 1986, Tessensohn & Piepjohn 1998).

STRATIGRAPHY OF THE PROTEROZOIC AND LOWER PALEOZOIC ROCKS OF THE PEARYA TERRANE

Proterozoic basement of Pearya (Succession 1)

In the study area, the oldest rocks are represented by the polydeformed Proterozoic basement rocks of Pearya Succession 1 which crop out between the Mitchell Point Fault Zone and the Petersen Bay Fault (Fig. 2). They consist mainly of granitoid gneiss with subordinate mica schist, amphibolite, quartzite, and marble (Trettin & Frisch 1996, Trettin 1998). The rocks of Succession 1 were affected by plutonism and metamorphism in late Mesoproterozoic and earliest Neoproterozoic times (e.g., Frisch 1974, Trettin 1987, Trettin 1998). In the southeast, they are thrust over Ordovician deep-water sediments of the Franklinian Basin to the SE along the Petersen Bay Fault (Trettin & Frisch 1987, Klaper 1992) (Fig. 2).

At location 9 (Fig. 2), Succession 1 consists of augen gneiss and light-colored gneiss in the NW and dark mica schist in the SE which are separated by a NE-SW trending vertical fault zone (Fig. 3). The mica schist consists mainly of very fine-grained biotite (partly chloritized), muscovite, and quartz. Accessories are opaque minerals, including pyrite which partly forms idiomorphic grains up to 1.5 mm in size, tourmaline, apatite, and rarely zircon. Some lenses and irregular veinlets are formed by coarser grained quartz, mica and carbonate.

Neoproterozoic to lower Paleozoic metasediments and metavolcanics of Pearya (Succession 2)

Neoproterozoic to Lower Paleozoic metasediments and metavolcanics of Succession 2 cover large parts of Pearya with an estimated thickness of more than 2 km. They are interpreted to represent a major phase of subsidence and deposition postdating the Grenvillian Orogeny and predating the M'Clintock Orogeny (e.g. Trettin 1998). In the study area, Succession 2 is exposed northwest of the Mitchell Point Fault Zone on northeastern Wootton Peninsula (Trettin & Frisch 1996) and within a narrow slice south of Hansen Point (location 3, Fig. 2). On Wootton Peninsula, it has been preliminarily subdivided by Trettin & Frisch (1996) and Trettin (1998) from bottom to the top as follows:

- Unit W1: monotonous succession of quartzite and phyllite of probably pre-Varangian Neoproterozoic age;
- Unit W2: diamictite (conglomeratic greywacke), phyllite, thin units of marble and dolostone and minor quartzite of Varangian to Early Cambrian age;
- Unit W3: marble, variably recrystallized limestone and microcrystalline dolostone of possibly Early Cambrian age.

As a consequence of our field work and the petrographic studies, we propose to preliminarily subdivide Succession 2 into only two mappable lithological units W1 and W2/3 on NE Wootton Peninsula (Fig. 2).

Unit W1

Metasediments of Unit W1 are widely distributed on northeastern Wootton Peninsula (locations 6, 7, and 8, Fig. 2). Here, they are represented by a thick, monotonous sequence of phyllites and interbedded layers of quartzitic slates to quartzites. In parts, calcareous slates are intercalated.

The phyllites are characterized by dark-gray colours and a fine lamination of alternating dark argillaceous and light-gray silty

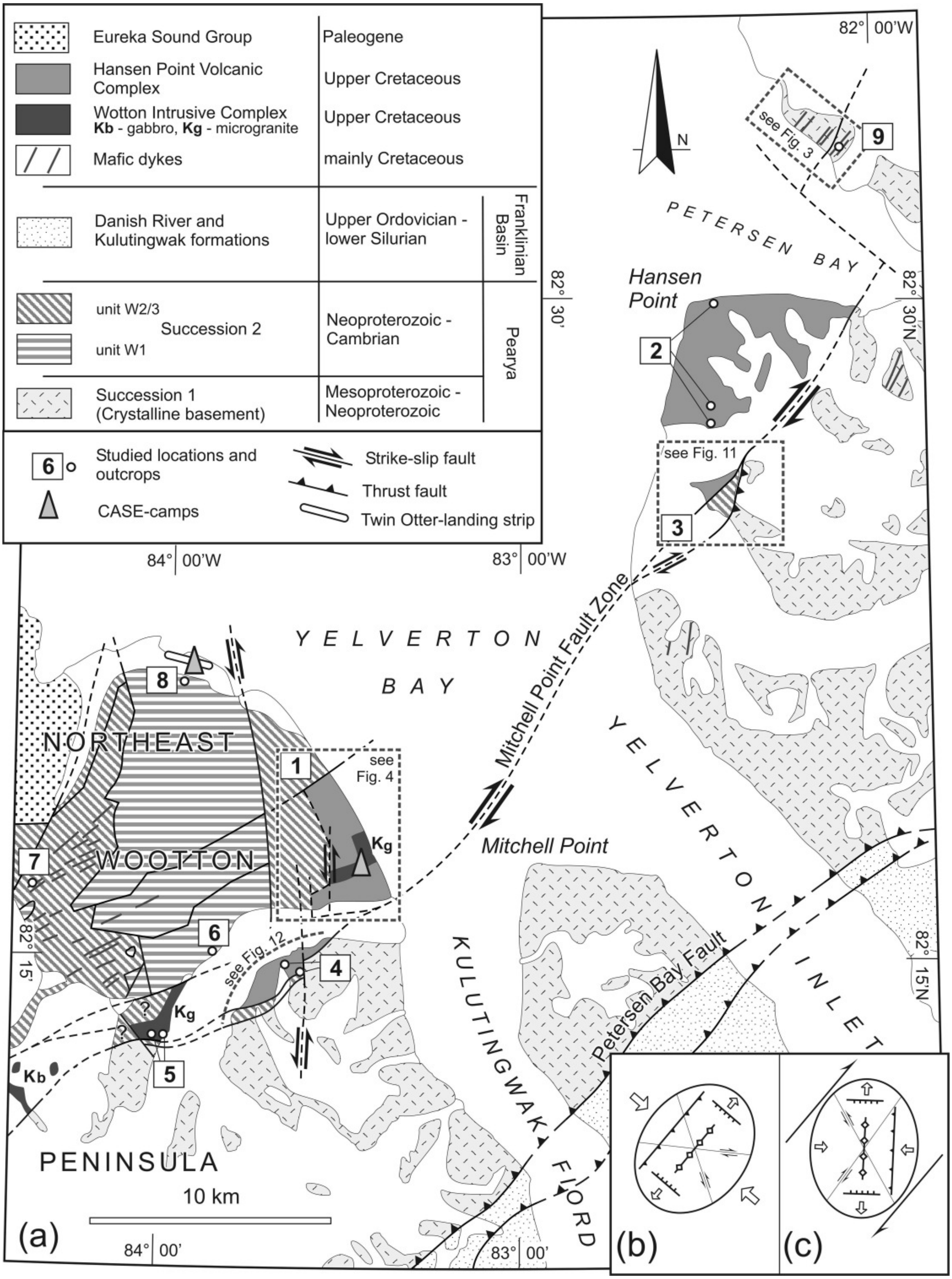


Fig. 2: (a) Geological map of the Yelverton Bay area, modified from Trettin & Frisch (1996). Dashed frames indicate locations of outcrop maps and descriptions. The dominant structure in the study area is the NE-SW trending Mitchell Point Fault Zone. The structural inventory and the orientation of the faults indicate an overall dextral strike-slip regime (c), whereas orthogonal compression related to the Mitchell Point Fault Zone can be ruled out (b).

Abb. 2: (a) Geologische Karte der Umgebung der Yelverton-Bucht, modifiziert nach Trettin & Frisch (1996). Die mit Rechtecken gekennzeichneten Gebiete sind in separaten Karten und Aufschlussbeschreibungen näher erläutert. Die dominante Struktur im Arbeitsgebiet ist die NE-SW-streichende Mitchell-Point-Störungszone, deren strukturelles Inventar ein übergeordnetes dextrales strike-slip-Regime aufweist (c). Orthogonale Kompression entlang der Störungszone kann aufgrund der tektonischen Hinweise und der Orientierung der Störungen ausgeschlossen werden (b).

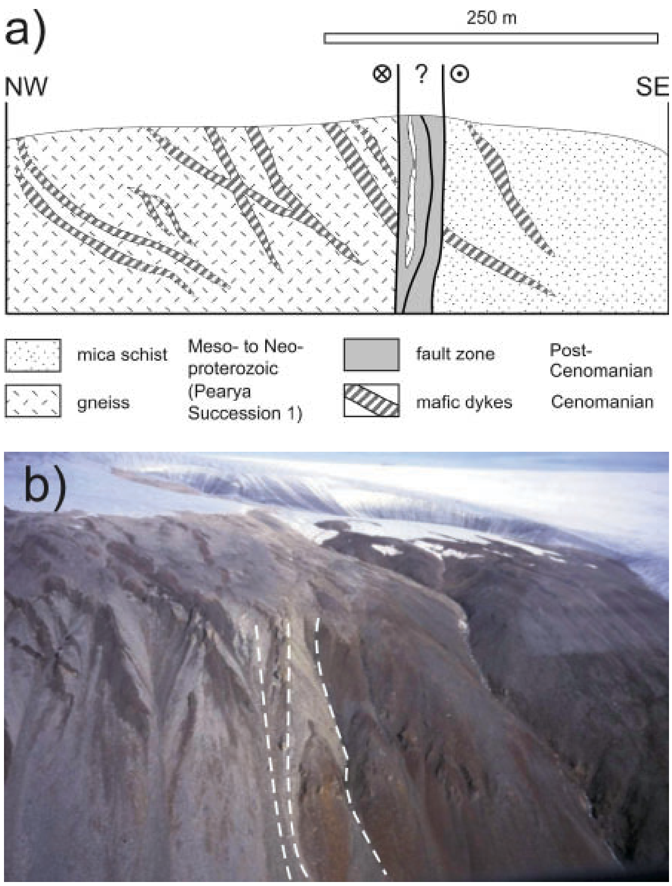


Fig. 3: Simplified profile sketch (a) and view from helicopter (b) on location 9 northeast of Petersen Bay (for location see Fig. 2). A dextral fault zone separates gneisses in the NNW (left) from dark mica schists in the SSE (right) which are both part of Pearya Succession 1. The fault zone also cuts through Cretaceous mafic dykes which intruded the metamorphic rocks. (Light coloured features on the right side of the photo (b) are reflections of the helicopter window.)

Abb. 3: Schematische Profilskizze (a) und Blick vom Hubschrauber (b) auf das Teilgebiete 9 nordöstlich der Petersen-Bucht (Lage in Abb. 2). Eine dextrale Störungszone trennt Gneise im NW (links) von dunklen Glimmerschiefern im SE (rechts) der Pearya-Serie 1. Die Störungszone versetzt kretazische mafische Gänge, die in die metamorphen Gesteine intrudiert sind. (Die helleren Bereiche ganz rechts in Bild (b) sind Reflexionen vom Hubschrauber-Fenster.)

layers. Interbedded are cm-thick gray to red-brown silty and sandy quartzitic slates. They often occur in thick beds but are internally thin-bedded or laminated. The grains of the sandy layers are mainly quartz, minor plagioclase, muscovite and chloritized biotite. They are embedded in a matrix of sericite, chlorite and quartz. Typical heavy minerals are tourmaline and zircon.

Location 7 (Fig. 2) was originally mapped as Unit W2 by Trettin & Frisch (1996). In this area, gray and dark-gray laminated calcareous slates are exposed with a matrix of very fine-grained lepidoblastic calcite, minor quartz, sericite, and chlorite and with stronger silty to sandy laminae. The grains of the latter are mainly quartz as well as some muscovite and tourmaline. The metasediments are similar to those at locations 6 and 8 in terms of metamorphic grade and mineral composition – apart from the carbonate content. They can also be related to Unit W1.

Unit W2/3

According to our field observations and petrographic studies, we suggest to summarize the units W2 and W3. The Unit W2/3 was studied in detail at location 1 (Fig. 2) on northeast Wootton Peninsula (Figs. 4, 5) and is characterized by a heterogeneous sequence of clastic, calcareous, and volcanogenic deposits.

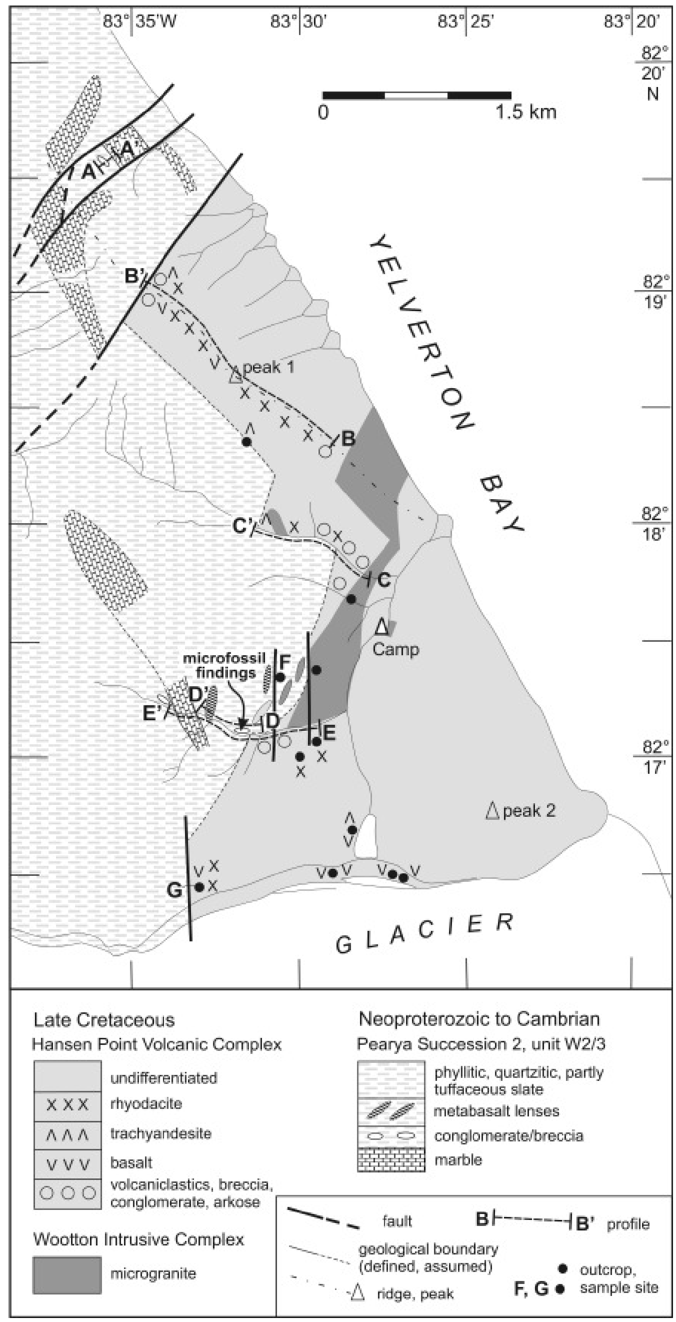


Fig. 4: Geological map of location 1, northeast Wootton Peninsula (for location see Fig. 2). The outcrop situation is generally poor. Large areas are covered by Quaternary glacial and fluvial sediments which are ignored in the map. Additionally, the rocks are tectonically and hydrothermally affected due to diverse fault zones.

Abb. 4: Geologische Karte des Teilgebietes 1 auf der nordöstlichen Wootton-Halbinsel (Lage in Abb. 2). Die Aufschluss-Situation ist generell schlecht. Große Flächen sind von quartären glazialen und fluviatilen Ablagerungen bedeckt, die in der Karte nicht berücksichtigt wurden. Außerdem sind die Gesteine durch diverse Störungszonen tektonisch und hydrothermal beansprucht.

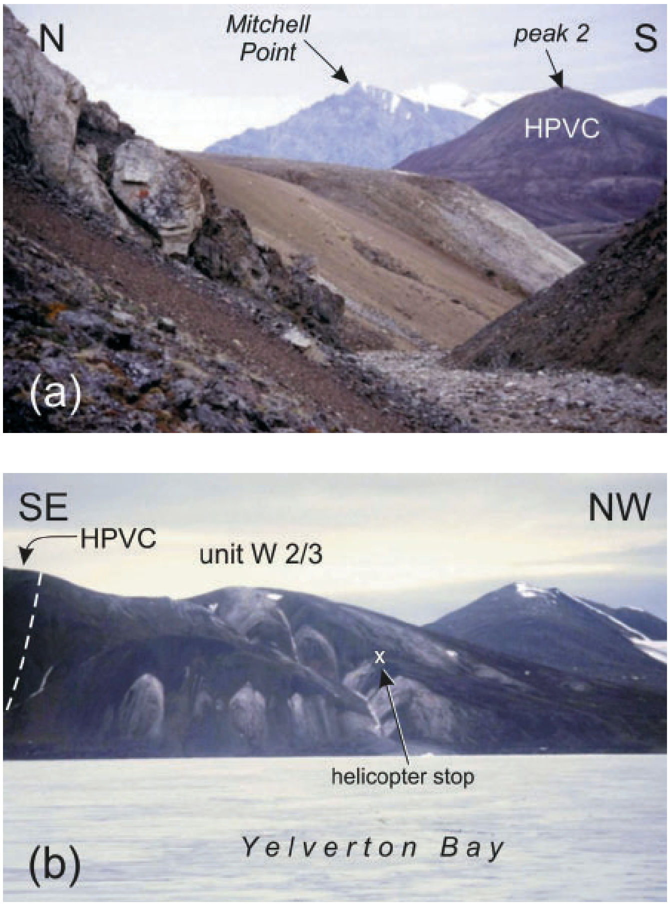


Fig. 5: Pearya Succession 2 (Unit W2/3) with marble beds at location 1, northeast Wootton Peninsula (for location see Fig. 4) west (a) and north (b) of the Cretaceous rocks (HPVC and WIC).
(a) View towards east through a creek valley (part of profile E'-E). The dark cone right in the middle ground (peak 2 in Fig. 4) consists of rocks of the Hansen Point Volcanic Complex (HPVC). In the background: Crystalline basement rocks of Succession 1 at Mitchell Point (see Fig. 2).
(b) Helicopter view from Yelverton Bay towards west (to the area of profile A-A'). Leftmost: Unit W2/3 is fault-bounded to the Hansen Point Volcanic Complex (HPVC). Marble beds (light coloured) form neither an inclusion nor a fault slice in the Hansen Point Volcanic Complex, which contradicts the proposal by Trettin & Frisch (1996).

Abb. 5: Marmorbänke in der Pearya-Serie 2 (Einheit W2/3) im Teilgebiet 1 auf der nordöstlichen Wootton-Halbinsel (Lage in Abb. 4) westlich (a) und nördlich (b) der kretazischen Gesteine (HPVC und WIC).
(a) Blick von West nach Ost durch ein Bachtal (Teilabschnitt des Profils E'-E). Der dunkle Bergkegel rechts im Mittelgrund (Peak 2 in Abb. 4) besteht aus Gesteinen des Hansen-Point-Vulkanitkomplexes (HPVC). Im Hintergrund: Kristallines Grundgebirge der Pearya-Serie 1 am Mitchell Point (s. Abb. 2).
(b) Blick vom Hubschrauber über die Yelverton-Bucht nach Westen (zum Profil A-A'). Links außen: Einheit W2/3 ist durch eine Störungszone vom kretazischen Hansen-Point-Vulkanitkomplex (HPVC) getrennt. Im Gegensatz zu Trettin & Frisch (1996) bilden die Marmorbänke (helle Farben) weder einen Einschluss noch eine Störungsschuppe im Hansen-Point-Vulkanitkomplex.

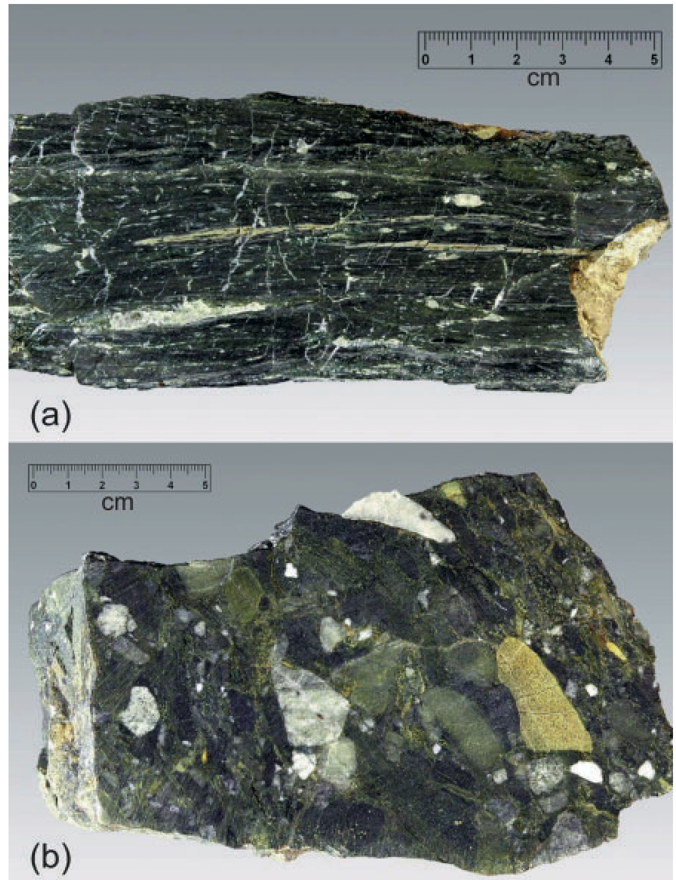


Fig. 6: Conglomerates/breccias of Succession 2 at location 1, NE Wootton Peninsula (for location see Fig. 4) north (a) and west (b) of the Hansen Point Volcanic Complex.
(a) Sheared conglomerate (profile A-A', Fig. 4) with enlongated pebbles of light colored carbonates and fine-grained arkosic sandstones. The carbonate pebbles contain small amounts of calc-silicate minerals in the form of garnet, titanite, and epidote.
(b) Breccia (profile D-D', Fig. 4) containing fragments of quartzitic sandstone, polycrystalline quartz aggregates, chessboard quartz, silicified carbonate rocks, mudstones, and mafic volcanics. The breccia is free of plagioclase and alkali feldspar, and poor in carbonate. (Photos by S. Pietrzok)

Abb. 6: Konglomerate/Brekzien in der Pearya-Serie 2 im Teilgebiet 1, NE Wootton-Halbinsel (Lage in Abb. 4), nördlich (a) und westlich (b) des vulkanischen Hansen-Point-Komplexes.
(a) Geschertes Konglomerat (Profil A-A', Abb. 4) mit ausgewalzten Geröllen von hellen Karbonaten und feinkörnigen Arkose-Sandsteinen. Die Karbonat-Gerölle enthalten Kalksilikat-Minerale wie Granat, Titanite und Epidot.
(b) Brekzie (Profil D-D', Abb. 4) mit Fragmenten von quarzitischen Sandsteinen, polykristallinen Quartz-Aggregaten, Schachbrett-Quarzen, verkieselten Karbonatgesteinen, Tonsteinen und basischen Vulkaniten. Sie ist frei von Plagioklas und Alkalifeldspat, und arm an Karbonat. (Fotos: S. Pietrzok)

Large parts of Unit W2/3 are represented by dark massive or dark-gray and greenish to brownish-gray laminated to thin-bedded silty to sandy quartzitic slates which are partly calcareous and/or tuffaceous. The microcrystalline matrix of the slates consists mainly of quartz, chlorite, sericite, and sometimes carbonate. The angular to subrounded silty and sandy grains consist dominantly of undulose quartz as well as small amounts of plagioclase, alkali feldspar, lithoclasts of carbonate rocks, and accessory zircon and apatite. Alkali-feldspar rich laminae and lenses (up to some mm long) within the slates are interpreted as tuffaceous beds and felsic volcanic lapilli. A black variety of quartzitic, ?tuffaceous slate is rich in opaque material formed mainly by magnetite (Fig. 4, profile A-A').

Thin, cm to dm-thick conglomerate/breccia beds (Fig. 6) and metabasalt lenses form characteristic intercalations in the Unit W2/3. Several dm-scale lenticular intercalations of black to green-gray, massive, fine-grained, greenschist-facies-metamorphosed basalt can be found in the metasediments west of the occurrence of the Hansen Point Volcanic Complex (Fig. 4, profile D-D' and Site F). Remnants of igneous textures and minerals are preserved (fluidal texture, phenocrysts of plagioclase, idiomorphic grains of opaque Fe oxides, apatite). The metabasalts can be confused with hydrothermally altered Cretaceous Hansen Point basalts which show the same alkaline character geochemically (Fig. 7a). A second overprint (after

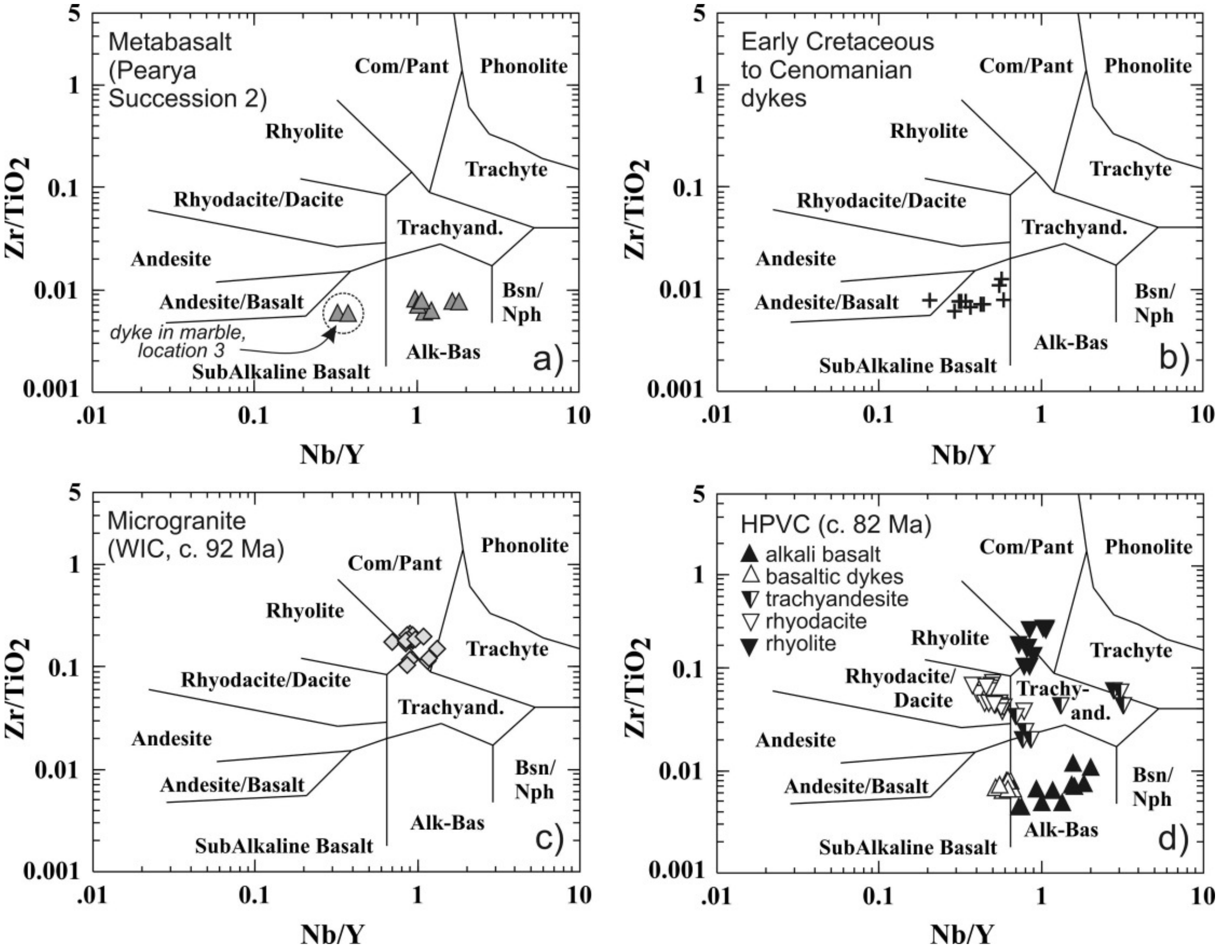


Fig. 7: Geochemical classification of the igneous rocks of the study area by Zr/TiO_2 versus Nb/Y diagrams from WINCHESTER & FLOYD (1977). See text for explanations. WIC = Wootton Intrusive Complex; HPVC = Hansen Point Volcanic Complex

Abb. 7: Geochemische Klassifikation der magmatischen Gesteine des Untersuchungsgebietes in Zr/TiO_2 versus Nb/Y-Diagrammen nach WINCHESTER & FLOYD (1977). Erläuterungen im Text.

the greenschist-facies regional metamorphism) by contact metamorphism and metasomatism (formation of fresh red-brown biotite and pale-green clinopyroxene in small lenses or veins; see Fig. 8) is caused by the Cretaceous microgranite (see below). Therefore, the metabasalts are most probably part of the metasedimentary sequence W2/3.

The Unit W2/3 contains meter-thick beds of light-coloured, very pure marble and light-gray to yellowish-gray massive fine to medium grained calc-silicate marble (Fig. 5). The marbles mainly consist of recrystallized, fine- to medium-grained calcite. They contain the calc-silicate minerals garnet, clinopyroxene, tremolite, wollastonite and/or xonotlite (a para-wollastonite, identified by X-ray diffractometry) as well as titanite in variable combinations and concentrations. The presence of clinopyroxene and wollastonite in the marbles indicates medium-grade metamorphism. It could be caused by the intrusion of the Cretaceous microgranite (see below) which probably has a larger subsurface extension at location 1 (Fig. 4).

Equivalents of Unit W2/3

Unit W2/3 is also exposed at location 5 and is inferred within small tectonic slices southwest (location 4) and east of Yelverton Bay (location 3) (Fig. 2).

At location 5 (Fig. 2), a slice of marble (without calc-silicate minerals) is exposed between Cretaceous igneous rocks in the north and the Proterozoic basement in the south. The marble is white and gray laminated with a lepidoblastic texture consisting of alternating finer and coarser grained bands of calcite. Locally, cm-thick intercalations of dark-gray and brownish-gray chert were found in the marbles at locations 1 and 5 (Fig. 2).

At locations 3 and 4 (Fig. 2), fault-bounded slices of metasediments, mainly marble and phyllite, are exposed within the Mitchell Point Fault Zone. East of Yelverton Bay (location 3), a NE-SW trending slice of reddish and whitish weathering, partly coarse-grained, partly laminated marble and subordinate phyllites is wedged in the Mitchell Point Fault Zone (Fig. 9). The low-grade metamorphism of the phyllites indicates that this slice of metasediments is more likely part of Succession 2 (Unit W2/3) than part of the high-grade metamorphosed Proterozoic Succession 1.

At least one dm-thick dyke at location 3 (Fig. 2) is distinguished petrographically from the Cretaceous dykes in the

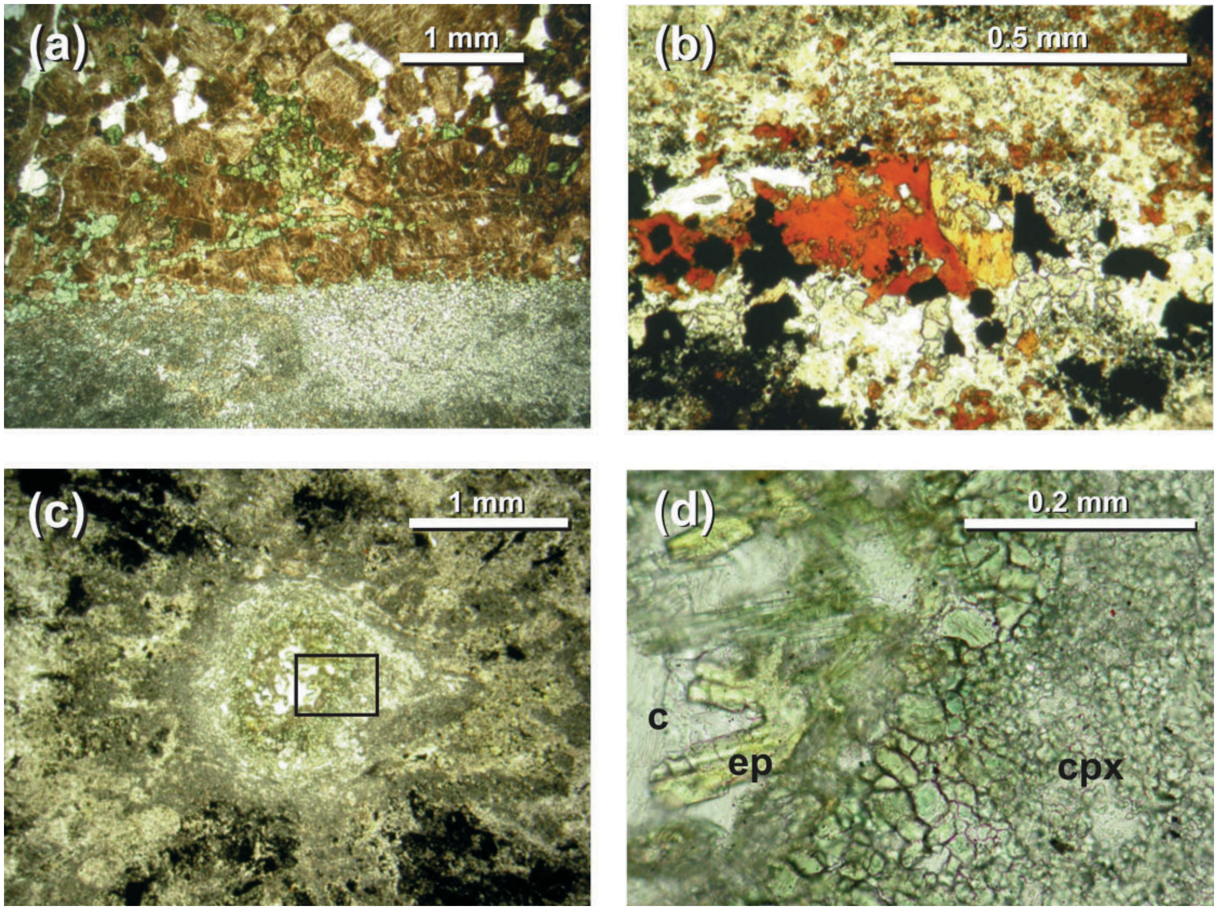


Fig. 8: Photomicrographs from thin sections (plane polarized light) showing (a) the contact between microgranite and hornfels and (b-d) metabasalts of Pearya Succession 2 which are affected by contact metamorphism caused by the intrusion of microgranite; samples from location 1 around site F (see Fig. 4).
(a) Fine-grained microgranite (top) consisting of alkali feldspar (brown, altered), quartz (white), as well as aegirinaugite (green) and very fine-grained calc-silicate hornfels (bottom) formed of clinopyroxene (light greenish) and alkali feldspar (brownish).
(b) Newly formed biotite (red-brown and yellow pleochroic, among others the aggregate in the center) and clinopyroxene (forming fine, very light-greenish grains) in porphyritic metabasalt. Black grains: Fe oxides.
(c) Metabasalt with a light colored lens formed mainly of calcite (in the center), epidote (yellow), and clinopyroxene (greenish) on margin (probably a former calcite amygdale).
(d) Zoomed section of (c) (see frame). c = calcite; ep = epidote; cpx = clinopyroxene

Abb. 8: Dünnschliff-Fotos (parallele Nicols) (a) vom Kontakt zwischen Mikrogranit und Hornfels und (b-d) von Metabasalten in der Pearya-Serie 2, die durch die Mikrogranit-Intrusion kontaktmetamorph überprägte wurden. Proben stammen vom Teilgebiet 1 (um Punkt F, Abb. 4).
(a) Oben: Feinkörniger Mikrogranit bestehend aus Alkali-Feldspat (braun, alteriert), Quarz (weiß), Ägirinaugit (grün). Unten: Sehr feinkörniger Kalksilikat-Hornfels bestehend aus Klinopyroxen (hellgrün) und Alkali-Feldspat (bräunlich).
(b) Neubildung von Biotit (rotbraun und gelb, u.a. das Aggregat im Zentrum) und feinen Klinopyroxen-Körnchen (leicht hellgrün) in einem porphyrischen Metabasalt. Die schwarzen Körner sind Fe-Oxide.
(c) Metabasalt mit einer hellen Linse, die hauptsächlich aus Kalzit (im Zentrum), Epidot (gelb) und Klinopyroxen (grünlich) am Rand besteht (möglicherweise eine ehemalige Kalzit-Mandel).
(d) Vergrößerter Ausschnitt von (c) (siehe Rahmen). c = Kalzit, ep = Epidot, cpx = Klinopyroxen

area (see below). This dyke is a fine to medium-grained dolerite which consists mainly of plagioclase, chlorite, calcite, epidote, and titanite with small amounts of amphibole, biotite, actinolite and apatite. The igneous texture is still preserved. Plagioclase is relatively fresh but shows strongly undulose extinction and twisted twin lamellae. The mafic minerals are completely replaced by secondary minerals. A hydrothermal overprint of the rock is related to sulfide impregnation as well as calcite and epidote mineralization along fissure joints. The dyke is characterized by a sub-alkaline geochemical signature (Fig. 7a). It should be noted that this dyke has been affected by greenschist-facies metamorphism which indicates an emplacement before the M'Clintock orogeny.

Discussion of the stratigraphic position of units W1 and W2/3

The age estimate of Succession 2 is mainly based on diamictite horizons found at NE Pearya (Fig. 1) (Trettin 1991b). The compositional and textural similarity of those units to upper Neoproterozoic glaciogenic diamictites in the Canadian Cordillera (Hambrey 1983, Aitken 1991), central East Greenland (Hambrey 1983, Hambrey & Spencer 1987), and Svalbard (Harland et al. 1993) indicates that they probably also represent Varangian glaciogenic sediments (Trettin 1991b, 1998). The conglomeratic greywackes on Wootton Peninsula (SW Pearya) have been interpreted as equivalents of the glaciogenic diamictites of Varangian age (Trettin 1998). On NE Wootton Peninsula, conglomerates / breccias are inter-

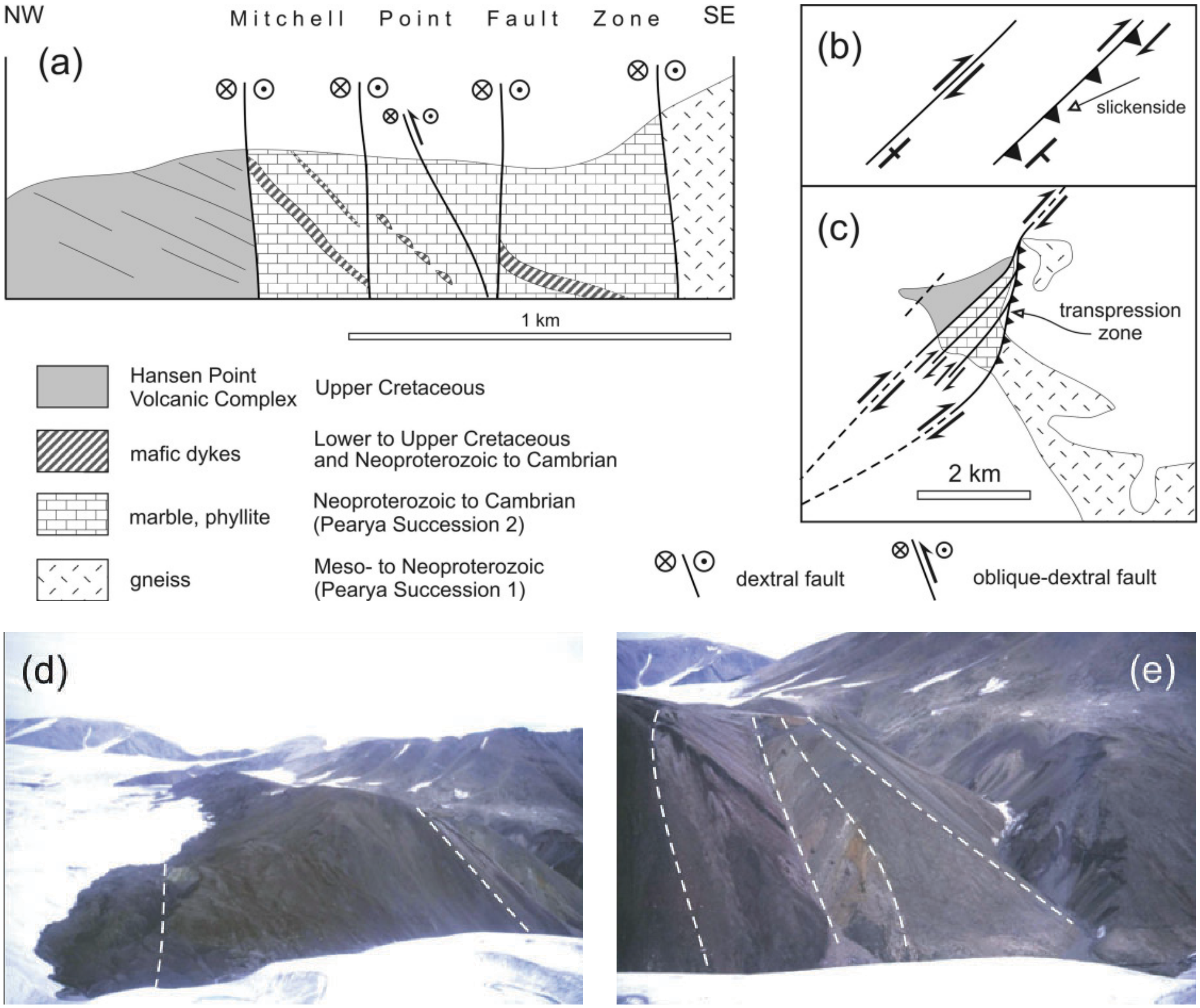


Fig. 9: The Mitchell Point Fault Zone at location 3 east of Yelverton Bay (for location see Fig. 2).
(a) Schematic cross section through fault zone with the Cretaceous Hansen Point Volcanic Complex in the NW, marbles and phyllites of Pearya Succession 2 in the center, and Proterozoic gneisses (Pearya Succession 1) in the SE.
(b) Orientations of vertical dextral (left) and steeply SE-dipping oblique dextral (right) shear planes and faults. (c) Inset map of location 3 with the possible explanation of the mapped thrust fault (see TRETTIN & FRISCH 1996) as a transpression zone of the overall dextral Mitchell Point Fault Zone.
(d) and (e) View from helicopter towards location 3: (d) View eastward over the dark colored Hansen Point Volcanic Complex in the center and the light colored marbles right. (e) Oblique view to the fault zone with the dark Hansen Point Volcanic Complex (leftmost) as well as marbles and phyllites of Pearya Succession 2 truncated by mafic dykes (center and right).

Abb. 9: Die Michell-Point-Störungszone am Teilgebiet 1 östlich der Yelver-ton-Bucht (Lage in Abb. 2).
(a) Schematischer Schnitt durch die Störungszone mit dem kretazischen Han-sen-Point-Vulkanitkomplex im NW, Marmoren und Phylliten der Pearya-Serie 2 im Zentrum und proterozoischen Gneisen (Pearya-Serie 1) im SE.
(b) Orientierung der vertikalen dextralen (links) und der steilen, nach SE ein-fallenden schrägen (rechts) dextralen Scherflächen und Störungen. (c) Eingefügte Karte des Teilgebietes 3 gibt eine mögliche Erklärung der kar-tierten Störungszone (siehe TRETTIN & FRISCH 1996) als Transpressionszone der insgesamt dextralen Mitchell-Point-Störungszone.
(d) und (e) Blick vom Hubschrauber auf Teilgebiet 3: (d) Blick nach Westen über die dunklen Gesteine des Hansen-Point-Vulkanitkomplexes im Zentrum und die hellen Marmore rechts. (e) Schräger Blick auf die Störungszone mit dem dunklen Hansen-Point-Vulkanitkomplex (links außen) sowie Marmoren und Phylliten der Pearya-Serie 2 mit mafischen Gesteinsgängen (Mitte und rechts).

bedded not only in greywacke-like sediments, as reported by TRETTIN (1998), but also in tuffaceous and quartzose sandy sediments of Unit W2/3. All these conglomerates / breccias contain clasts of carbonate rocks or silicified carbonate rocks. No indication of their possible glaciogenic origin has been found so far.

Another time marker for Succession 2 is the U/Pb zircon age of 503.2 +8/-2 Ma from a sheared rhyolitic flow or welded tuff in the upper part of Succession 2, SE of Milne Fiord (TRETTIN et al. 1987, TRETTIN 1991b, 1998) which indicates a Middle to Late Cambrian age (according to GRADSTEIN et al. 2004).

Important enclosures in a sedimentary breccia of Unit W2/3 (Fig. 6b) are represented by calcium phosphate minerals (identified by scanning electron microscopy and cathodoluminescence) which appear as dark microcrystalline to fine crystalline masses and as spicule-like shapes forming single crystals (up to 0.2 mm in length), ramified crystals, or net-like aggregates (Fig. 10). The spicule-like crystals are often characterized by brownish, optically isotropic zones in the cores and colourless anisotropic zones at the rims. In contrast to common apatite, the optical character of elongation is always positive. The spicules are present in interspaces of large fragments or inside the fragments of silicified carbonate rocks. Some of the calcium phosphate was obviously replaced and recrystallized in the breccia during diagenesis and metamorphism. Nevertheless, some of the phosphatic (or secondarily phosphatized?) spicule shapes are inferred to be microfossils. Some of them are similar in size and shape to hexactinellid-like sponge spicules which are described from a Lower Cambrian "small shelly fossils" assemblage in the Atdabanian part of the Lena River section at Aččagy Tuoidach in Yakutia (Figs. 1E and F in Dzik 1994). These spicules are calcitic, but were possibly siliceous originally. Phosphatized or calcitized sponge spicules, mostly hexactines, occur together with other phosphatized fossils in the deeper Tommotian part of the Lower Cambrian section (Dzik 1994). The phosphatic spicules show also similarity to some Ediacarian hexactinellid sponge spicules from south-western Mongolia which are preserved in iron oxide within early diagenetic chert concretions (Brasier et al. 1997). These spicules are less than 0.1 mm in length.

Thus, the redeposited phosphatic sponge spicules can be of Early Cambrian or Ediacarian age. An age younger than Proterozoic is supported by the presence of unidentifiable, calcitic, shelly microfossil fragments in a dark-gray massive and fine-grained limestone which crops out near the spicule-bearing breccia. At NE Pearya, SW of Clements Markham Inlet (Fig. 1), sponge spicules were found in a silicified limestone of inferred Early Cambrian age (Trettin 1998). This sponge-spicule-bearing unit was correlated stratigraphically with the former Unit W3 (Trettin 1998).

More investigations (e.g., fossil findings and radiometric dating) are necessary to clarify the age of Pearya Succession 2 and its units. Actually, the best estimate for the age of Unit W2/3 is Neoproterozoic (?post-Varangian) to Early Cambrian.

CRETACEOUS IGNEOUS ROCKS AND SEDIMENTS

Apart from Paleogene clastic deposits on Wootton Peninsula which were not visited, the youngest rocks in the study area are Cretaceous igneous and volcaniclastic rocks (Fig. 2): (i) mafic dykes cutting Pearya rocks, (ii) microgranite of the Wootton Intrusive Complex, (iii) volcanic and volcaniclastic rocks as well as related mafic dykes of the Hansen Point Volcanic Complex.

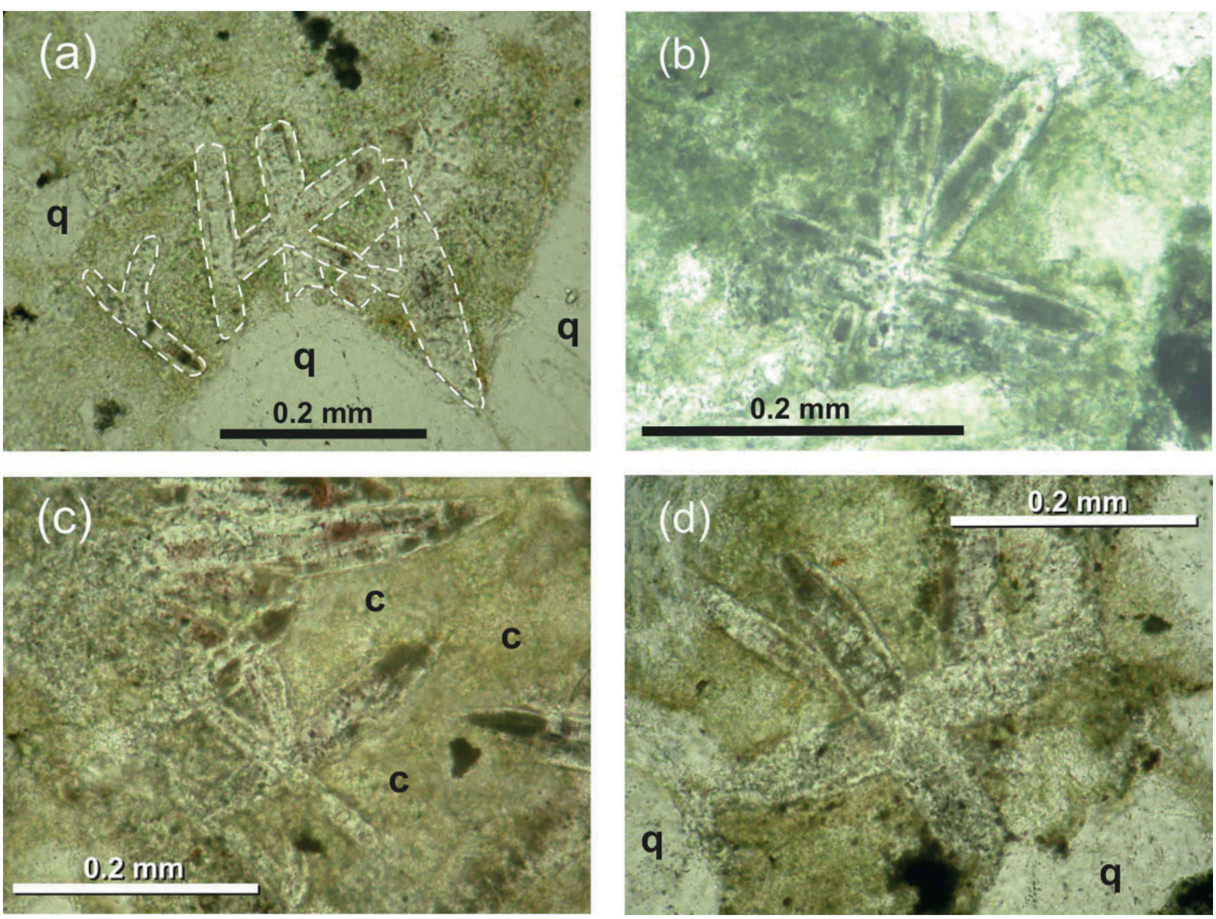


Fig. 10: Calcium-phosphatic spicules (inferred sponge spicules) in a breccia of Pearya Succession 2 (shown in Fig. 6b). The outlines of the spicules are marked by dashed lines in (a). q = quartz, c = calcite (Photomicrographs from thin sections, plane polarized light).

Abb. 10: Kalziumphosphat-Nadeln (vermutlich Schwammnadeln) in einer Brekzie der Pearya-Serie 2 (siehe Abb. 6b). In (a) sind die Umrisse der Nadeln durch gestrichelte Linien markiert. q = Quarzkörner, c = Kalzit (Dünnschliff-Fotos, parallele Nicols).

Mafic dykes cutting Pearya rocks

In the Yelverton Bay area, single mafic dykes or dyke-swarms crosscut both Pearya Succession 1 (location 9) and Succession 2 (locations 4, 6 and 7) (Fig. 2). They are not metamorphosed or deformed, indicating that their emplacement at least post-dates the M'Clintock Orogeny.

^{40}Ar-^{39}Ar whole rock dating of some of the dykes yielded 110 ±1 Ma and 123 ±1 Ma (location 6, Fig. 2) as well as 97 ±1 Ma (location 9, Fig. 2) (Estrada et al. 2004). The dykes show subalkaline (tholeiitic) geochemical composition (Fig. 7b). Thus, they are comparable geochronologically and geochemically (after data from Estrada & Henjes-Kunst 2004) to the basalts of the Isachsen and Strand Fiord formations which are exposed on Axel Heiberg Island and northwest Ellesmere Island (Fig. 1). The Early Cretaceous to Cenomanian dykes pre-date the Wootton intrusion and the Hansen Point volcanism and represent the oldest Cretaceous igneous event in the study area.

Wootton Intrusive Complex (WIC)

A narrow, NE-SW trending zone of intrusive rocks (gabbro, minor granitoids and hybrid rocks), the Wootton Intrusive Complex (Trettin & Parrish 1987), crosses the Wootton Peninsula between the master faults of the Mitchell Point Fault Zone (Figs. 1, 2). In the study area, a hypabyssal microgranite is exposed at locations 1 and 5 in the northeast continuation of the early Late Cretaceous Wootton Intrusive Complex (Figs. 2, 7c, 11b, c). Intrusive contacts to Pearya Succession 2 (see Fig. 8) and cm to dm-sized mafic inclusions (interpreted as the result of magma mingling or mixing, see Fig. 11c) at location 1 (Fig. 2) clearly characterize the microgranite as an intrusive rock. U/Pb zircon dating of microgranite samples from locations 1 and 5 yielded ages of 92 Ma and 93 Ma (Estrada et al. 2004). Thus, the microgranite is of the same age as the Wootton Intrusive Complex which was dated as 92 ±1 Ma (U/Pb zircon age, Trettin & Parrish 1987).

The microgranite is a pale-reddish (salmon-like) to dark brown, fine to medium-grained, phaneritic or porphyritic rock. The main components are alkali feldspar and quartz often forming granophyric texture. The phenocrysts are perthitic feldspar. An aegirinaugite-bearing variety appears at location 1 near the boundary to the country rock (Fig. 8a). This variety was probably formed by metasomatic interaction of the granitic magma with the metasedimentary country rock.

Hansen Point Volcanic Complex (HPVC)

The volcano-sedimentary HPVC is exposed at locations 1, 2, 3, and 4, as well as in minor parts at location 5 (Fig. 2). Its boundaries against the Pearya Succession 2 and the WIC microgranite (as far as they are exposed) are formed by faults (Figs. 2, 4).

The volcanic rocks are characterized by a bimodal chemical composition (Fig. 7d). Chemically evolved volcanic rocks (rhyodacites, trachyandesites and rhyolites) and related pyroclastic rocks predominate. They are intercalated with mostly volcaniclastic sediments. Lavas of primitive, mainly alkali-basaltic composition form smaller parts of the suite. East of Yelverton Bay, the volcano-sedimentary suite is truncated by mafic dykes representing the youngest igneous rocks of the HPVC.

Volcanic rocks

Rhyodacitic volcanics and pyroclastic rocks of the HPVC predominate at locations 1 and 2 but become less important at location 3 (Figs. 2, 11a, b). Trachyandesites are exposed at location 1 and in subordinate amounts also at locations 4 and 5 (Fig. 2). Both rhyodacites and trachyandesites are dark, mostly porphyritic rocks partly with fluidal texture. Phenocrysts are plagioclase and alkali feldspar, and rarely also clinopyroxene, quartz, and magnetite. The matrix is very fine-grained or shows spherulitic devitrification.

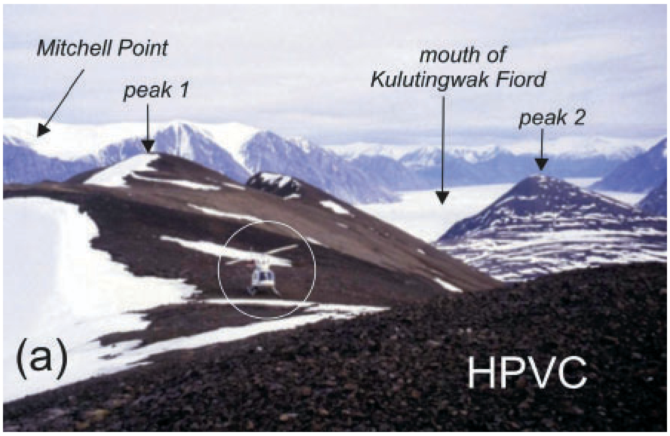
Rhyolites are only exposed at location 4 (Figs. 2, 12). Here, some tens-of-meters-thick layers of mainly rhyolitic lava flows and/or pyroclastic rocks form high, steep cliffs. The dark red-brown and brown colored rhyolites are intensely hematitized and show holohyaline textures often with perlitic cracks and spherulitic devitrification.

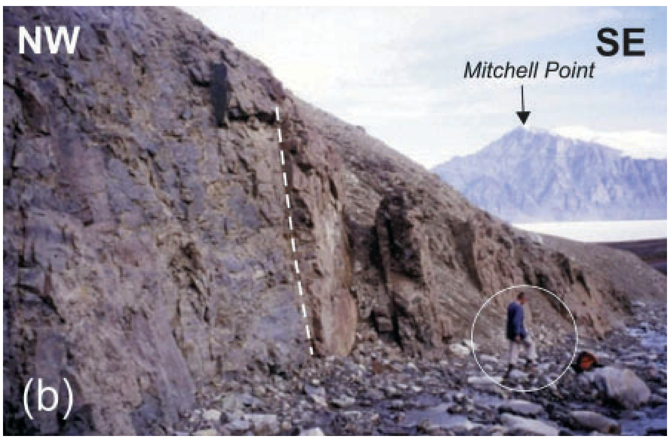
Lava flows of fine-grained, mostly porphyritic, sometimes also fluidal alkali basalts are exposed at the southern part of the HPVC at location 1 (Figs. 4, 11e) and at location 3 (Figs. 2, 9d). Their matrix is mainly formed by plagioclase, clinopyroxene, and minor olivine, which also appear as phenocrysts. At location 1, a lava flow contains olivine-rich mantle and granite xenoliths.

Volcaniclastics and other sediments

The volcaniclastic rocks of the HPVC form alternating cm to dm-thick beds of variable colour, composition and grain size (Fig. 11b). They comprise pyroclastic rocks as well as redeposited volcanics and pyroclastic rocks forming tuffaceous siltstones, sandstones and conglomerates/breccias. Locally, thin beds of gray and light brown to reddish brown arkosic siltstones to sandstones and conglomerate beds with pebble to cobble-grade clasts of microgranite and minor volcanic rocks are intercalated in the volcaniclastic sequence at location 1 (Fig. 11d).

Sedimentary and tectonic breccias are exposed as debris at location 1 within the fault zones at the border between the HPVC and Pearya rocks (Fig. 4). The polymictic, matrix-poor breccias mostly consist of angular fragments in the 0.1 mm to about 1 cm range. On the one hand, the spectrum of clasts is characterized by material of the HPVC and microgranites of the Wootton Intrusive Complex. On the other hand, the fragments comprise low-grade metasediments of Pearya Succession 2 (phyllites, quartzitic phyllites, marbles, siltstones and sandstones) as well as quartz grains and polycrystalline quartz aggregates, both with undulose extinction, probably coming from Pearya Succession 1. A vent breccia (found in the northern fault zone near site B', Fig. 4) exclusively contains clasts of metasediments (silty quartzitic phyllites). The interstices between the fragments are mineralized by calcite, quartz, chlo-





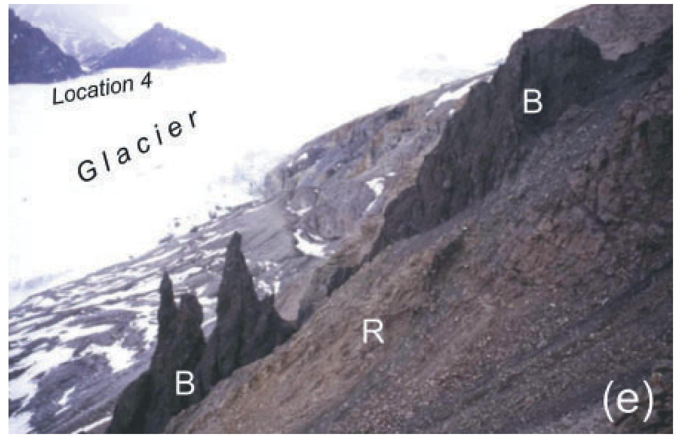


Fig. 11: Microgranite and Hansen Point Volcanic Complex at location 1, NE Wootton Peninsula (Figs. 2, 4).
(a) The hills in the foreground (with peak 1, see Fig. 4) and the cone right in the center (peak 2, see Fig. 4) consist of dark volcanic rocks of the Hansen Point Volcanic Complex (HPVC). Background: Crystalline rocks of Pearya Succession 1. Photo was taken near point B' (Fig. 4) looking towards SSE (helicopter for scale).
(b) Profile along a creek valley (southeastern part of profile C-C', Fig. 4): Reddish-brown microgranite (right) is fault-contact with volcaniclastic beds of the Hansen Point Volcanic Complex (left) (geologist for scale).
(c) Dark, mafic inclusions in the microgranite (below the hammer).
(d) Fragments of microgranite, minor volcanic rocks in a volcaniclastic bed (profile C-C').
(e) Alkali basalt flow (B) surrounded by reddish-brown altered rhyodacitic rocks (R) in the southwest of location 1 (point G in Fig. 4). Volcanic rocks of location 4 (Fig. 2) are seen on the other side of the glacier (upper left).

Abb. 11: Mikrogranit und Hansen-Point-Vulkanitkomplex im Teilgebiet 1 auf der nordöstlichen Wootton-Halbinsel (Abb. 2, 4).
(a) Die Bergkette im Vordergrund (mit Peak 1, siehe Abb. 4) und der Bergkegel rechts der Mitte (Peak 2, siehe Abb. 4) werden von dunklen vulkanischen Gesteinen des Hansen-Point-Vulkanitkomplexes (HPVC) gebildet. Im Hintergrund: Das kristalline Grundgebirge der Pearya-Serie 1. Das Foto wurde in der Nähe des Profilpunktes B' (Abb. 4) mit Blick nach SSE aufgenommen (Hubschrauber als Maßstab).
(b) Profil entlang eines Bachtales (südöstlicher Teil von Profil C-C', Abb. 4): Rötlichbrauner Mikrogranit (rechts) wird durch eine Störung von vulkaniklastischen Schichten des Hansen-Point-Vulkanitkomplexes (links) getrennt (Geologe als Maßstab).
(c) Dunkle mafische Einschlüsse im Mikrogranit (unterhalb des Hammers).
(d) Fragmente von Mikrogranit und untergeordnet von Vulkaniten in einer vulkaniklastischen Lage (Profil C-C').
(e) Alkalibasaltischer Lavastrom (B), von rötlichbraunen, alterierten rhyodazitischen Gesteinen (R) umgeben, im Südwesten des Teilgebietes 1 (Punkt G in Abb. 4). Vulkanische Gesteine des Teilgebietes 4 (Abb. 2) sind jenseits des Gletschers zu sehen (oben links).

rite, alkali feldspar, sometimes also fluorite and garnet. These hydrothermally altered breccias also indicate the explosive character of the Hansen Point volcanism.

Basaltic dykes

At locations 2 and 3 east of Yelverton Bay (Fig. 2), the volcanics and sediments of the Hansen Point Volcanic Complex are truncated by dm to m-thick, fine-grained basaltic dykes. Geochemically, they show a weak subalkaline tendency (Fig. 7d). The marbles in the tectonic slice of location 3 (Fig. 2) are also intruded by these undeformed basaltic dykes (Fig. 9e).

Age of the Hansen Point Volcanic Complex

The presence of microgranite fragments in volcaniclastic sediments indicates that the Hansen Point Volcanic Complex is younger than the Wootton Intrusive Complex. This is supported by radiometric age determinations on Hansen Point volcanics. TRETTIN & PARRISH (1987) reported a U/Pb zircon age of 88 +20/-21 Ma obtained on a porphyritic rhyodacite from a brecciated flow at the NE end of location 3 east of Yelverton Bay. We obtained a well-defined Rb/Sr isochron age of 80 ±2 Ma on Hansen Point volcanics from the western-most outcrops on Ellesmere Island (ESTRADA & HENJES-KUNST 2004) and ^{40}Ar-^{39}Ar whole rock ages between 84 and 82 Ma on volcanics of the study area (ESTRADA et al. 2004). Thus, it is most likely that the HPCV is about 10 Ma younger than the Wootton Intrusive Complex.

Fig. 12: View from helicopter towards location 4 along the glacier from NE (a) to SW (b) (for location see Fig. 2).
(a) Foreground: Rhyolitic lava flows and pyroclastic rocks of the Hansen Point Volcanic Complex. Background: Crystalline basement rocks, Pearya Succession 1.
(b) A slice of marbles and phyllites of Pearya Succession 2 between hydrothermally altered rocks of the Hansen Point Volcanic Complex (HPVC, left) and the crystalline basement of Pearya Succession 1 (upper right).

Abb. 12:. Blick vom Hubschrauber auf das Teilgebiet 4 entlang des Gletschers von NE (a) nach SW (b) (Lage in Abb. 2).
(a) Im Vordergrund: Rhyolithische Lavaströme und Pyroklastite des Hansen-Point-Vulkanitkomplexes. Im Hintergrund: Gesteine des kristallinen Grundgebirges, Pearya-Serie 1.
(b) Eine tektonische Schuppe aus Marmor und Phylliten der Pearya-Serie 2 ist zwischen hydrothermal alterierten Gesteinen des Hansen-Point-Vulkanitkomplexes (HPVC, links) und dem kristallinen Grundgebirge (Pearya-Serie 1, rechts oben) eingeschaltet.

SYNTHESIS OF STRUCTURAL EVOLUTION AND MAGMATIC EVENTS

M´Clintock Orogeny (D1)

The volcanics and sediments of Pearya Succession 2 have been affected by deformation and metamorphism of the Early to Middle Ordovician M´Clintock Orogeny (TRETTIN et al. 1982).

The first visible deformation D1 in the phyllites of Unit W1 is represented by very small-scale isoclinal F1-folding of mm-thin light-gray siltstone layers which still may represent bedding S0. The cleavage S1 cuts through F1 fold hinges and is parallel to S0 outside the folds. The F1 folding was accompanied by weak metamorphism and formation of the metamorphic layering. The phyllites contain quartz-mobilizates which are formed parallel to S1. The growth of sericite on S1 planes parallel to S0 planes suggests maximum lowermost greenschist facies metamorphism.

The quartz mobilizates and the S1 metamorphic layering are affected by cm-scale, isoclinal F2 folding (Fig. 13). This D2 deformation is responsible for the formation of the Caledonian penetrative S2 cleavage parallel to the S1 metamorphic layering. In addition to the cleavage, beds of conglomerates / breccias at location 1 (Figs. 4, 6a) are intensely sheared. The ductile shear planes with lenticular sheared and elongated pebbles are oriented parallel to the penetrative foliation (?S2). The phyllites at location 8 (Fig. 2) are sometimes characterized by idiomorphic, up to 2 mm-scale pyrite crystals, which overgrow the S1 cleavage planes but are partly elongated parallel to the ?S2 cleavage. It should be noted that the limestones and marbles display only one foliation that can be assigned to the penetrative S2 foliation in the phyllites.

The S1 metamorphic layering, S2 foliation, and the folded quartz mobilizates have been affected by D3 brittle compressional deformation. It is characterized by the formation of a narrow-spaced S3 slatey cleavage in fine-grained phyllites, which is often replaced by a widely spaced fracture cleavage in the interbedded siltstone layers (Fig. 13). Refraction of S3 cleavage planes between beds of mudstone and siltstone occurs. Sometimes, S3 is not developed in the siltstones. The S3 cleavage is related to open, monoclinal, cm to dm-scale F3 folding, which is accompanied by flexural gliding on S2. The trend of the F3 folds and $\delta 3$ lineations is approximately WNW-ESE. In addition, gently SW-dipping C3 shear planes are developed. Slickenside lineations indicate top-to-northwest sense of shear.

Ellesmerian Orogeny

After the development of the Paleozoic Franklinian Basin, the Ellesmerian Orogeny affected large areas of the Canadian Arctic and North Greenland in Late Devonian/Early Carboniferous times (e.g., TRETTIN 1991a, SOPER & HIGGINS 1990). In the study area, the Ellesmerian deformation seems to be restricted to the area SE of the Petersen Bay Fault (Fig. 2) (KLAPER 1990). Until now, no evidence for Ellesmerian structures have been detected in the Yelverton Bay area NW of this fault.

Early Cretaceous to Cenomanian basaltic volcanism

The oldest rocks postdating the M'Clintock Orogeny in the Yelverton Bay area are tholeiitic dykes which are probably equivalents of the Early Cretaceous to Cenomanian basalts of the Isachsen and Strand Fiord formations (Fig. 1). They represent evidence of the oldest igneous event of Cretaceous age in the study area.

Late Cretaceous emplacement of intrusive rocks (Wootton Intrusive Complex)

The about 92-93 Ma old Wootton Intrusive Complex is exposed in a narrow strip between Phillips Inlet in the SW and the mouth of Kulutingwak Fiord in the NW (Figs. 1, 2). Today, it is bounded by two branches of the Mitchell Point Fault Zone and is partly intensely brecciated due to young brittle movements along the fault zone. The microgranite was probably emplaced at a high subvolcanic level. It must already have been lifted up to the surface 10 Ma later because the volcaniclastic deposits of the Hansen Point Volcanic Complex contain fragments of microgranite.

Late Cretaceous extrusion of volcanic rocks (Hansen Point Volcanic Complex)

The youngest magmatic event in the study area is represented by the Late Cretaceous Hansen Point volcanism with an age of about 82 Ma. The HPVC is restricted to several locations immediately NW of the Mitchell Point Fault Zone (Fig. 2). The geological situation suggests that the Hansen Point Volcanic Complex overlies both the Wootton Intrusive Complex and the metasediments of Pearya Succession 2.

Post Early-Cretaceous brittle strike-slip tectonics

Mitchell Point Fault Zone

The NE-SW trending Mitchell Point Fault Zone separates the Proterozoic basement of Succession 1 in the SE from the ?Neoproterozoic to Paleozoic Succession 2 and the Cretaceous Wootton Intrusive and Hansen Point Volcanic complexes in the NW (Fig. 2). It is exposed at two localities, west of the mouth of Kulutingwak Fiord and east of Yelverton Bay (Fig. 2), and consists of a several-hundred-meter-wide zone of numerous vertical and subvertical faults.

On fault planes and shear planes parallel to the Mitchell Point Fault Zone, we have found numerous slickenside lineations to determine the senses of displacements along the fault zone. Unfortunately, the neighbouring volcanic rocks of the Hansen Point Volcanic Complex are highly magnetic so that a measurement of bedding planes, faults, shear planes and slickenside lineations was impossible.

On the geological map (Trettin & Frisch 1996), the Mitchell Point Fault Zone is shown as a steep reverse fault which carried the crystalline basement rocks of Pearya Succession 1 NW-wards over the Late Cretaceous Hansen Point volcanics. This would imply a similarity to the Kap Cannon Thrust Zone in northern Greenland, where Ellesmerian marbles und phyllites have been carried northwards along a S-dipping mylonite zone over the Late Cretaceous/Paleocene volcano-sedimentary Kap Washington Group (e.g., Soper & Dawes 1970, Soper & Higgins 1985, 1987, von Gosen & Piepjohn 1999).

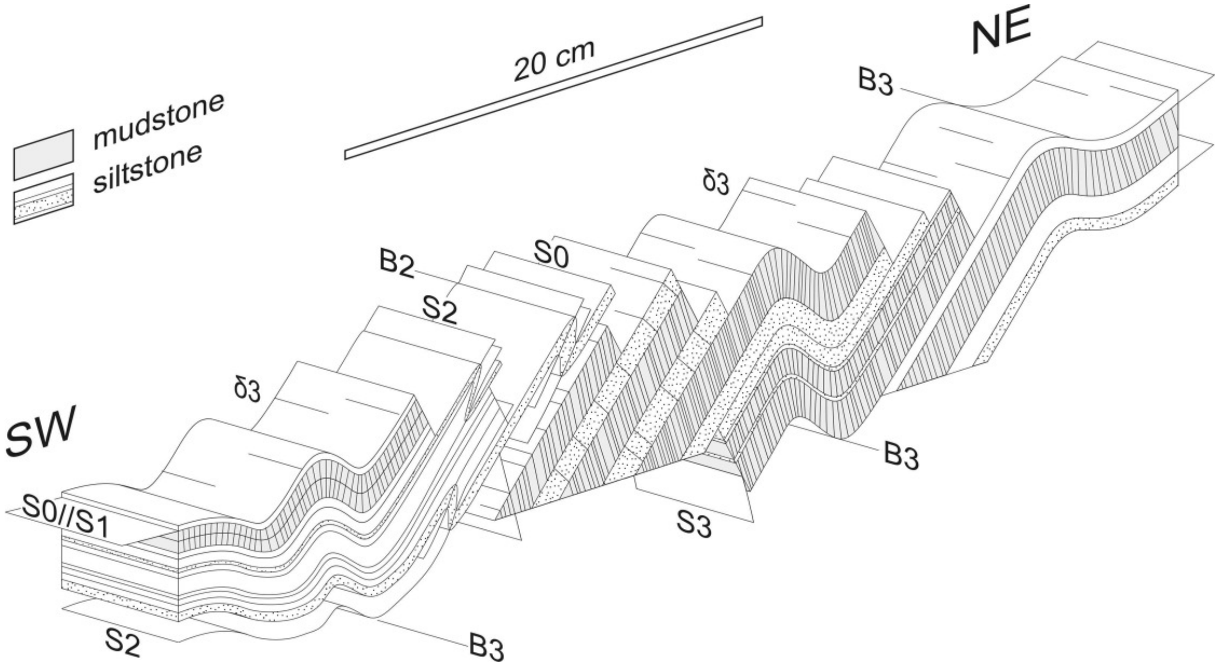


Fig. 13: Schematic sketch of the M'Clintock tectonic inventory of phyllites of Pearya Succession 2 (Unit W1) at location 8, northeasternmost Wootton Peninsula (for location see Fig. 2).

Abb. 13: Schematische Skizze des tektonischen Inventars der M'Clintock-Orogenese von Phylliten der Pearya-Serie 2 (Einheit W1) im Teilgebiet 8 im nordöstlichsten Teil der Wootton-Halbinsel (Lage in Abb. 2).

However, the Mitchell Point Fault Zone at location 3 consists of two vertical NE-SW trending master faults between the HPVC in the NW and Proterozoic gneisses (Succession 1) in the SE. The slice of marbles/phyllites (Succession 2) between the master faults is truncated by numerous vertical faults which cut through the SE-dipping dykes (Fig. 9a).

Although there are very few ENE-plunging slickensides which indicate a minor oblique component of compression (Fig. 9b), the motions along the NE-SW shear planes and faults are dominated by an overall dextral strike-slip regime. There is no indication of any NW-SE compression along the fault planes of the Mitchell Point Fault Zone. There seems to be only one exception: the southern branch of the Mitchell Point Fault Zone turns into a NNE-SSW trend east of location 3 (Figs. 2, 9c). At this location it was mapped as a west-directed thrust by Trettin & Frisch (1996) which carried Proterozoic gneisses on top of Hansen Point volcanics. Instead of volcanics, we found a slice of marbles and phyllites probably of Succession 2. Although it is possible that the rocks of Succession 1 are thrust westwards over marbles/phyllites (Figs. 2, 9c), it seems more likely on the basis of the kinematic observations and orientations of the NE-SW trending strike-slip faults, that the NNE-SSW thrust represents a transpressive element of the strike-slip zone (restraining bend) which also supports the interpretation of a dextral sense of movement along the Mitchell Point Fault Zone (Fig. 9c). According to our observations, this fault zone might represent a major NE-SW striking dextral strike-slip zone.

To the west of the mouth of Kulutingwak Fiord, the Mitchell Point Fault Zone continues to the WSW towards Phillips Inlet. At location 4 (Fig. 2), it separates the Hansen Point Volcanic Complex in the north from a narrow slice of metasediments (probably of Succession 2) in the central part and gneisses of Succession 1 in the south. As in location 3 (Fig. 2), the Mitchell Point Fault Zone is vertical without any evidence of a compressional deformation. Although no indicators of shear sense were found on fault planes parallel to the major fault zone, there is one observation which supports the dextral sense of movement along the Mitchell Point Fault Zone: at location 4 (Fig. 2), the fault zone is sinistrally displaced by an approximately N-S fault which crosses the E-W glacier north of the outcrop. The sinistral displacement along that fault is supported by sinistral slickenside lineations on N-S trending shear planes. Probably, the sinistral N-S faults represent antithetic shear planes within a general NE-SW trending dextral strike-slip regime (Fig. 2c).

N-S fault zone west of the mouth of Kulutingwak Fiord (location 1)

At location 1, a several hundred-meter-wide, more or less N-S trending fault zone separates Paleozoic metasediments of Succession 2 in the west from Cretaceous igneous rocks in the east (Figs. 2, 4). Within the fault zone, schists and marbles of Succession 2 are fragmented into small pieces by a narrow network of joints and brittle shear planes. In places, occurrences of siliceous schists are seen to be cut across by approximately N-S trending small faults with oblique-slip slicken-side lineations on the faults indicating sinistral displacements. This observation is consistent with steeply E-dipping shear planes in marbles with SE-plunging slickenside lineations. These indicate a relative sense of shear of the hanging wall obliquely towards the NW with an important sinistral component.

The igneous rocks of the Cretaceous Wootton Intrusive Complex and Hansen Point Volcanic Complex east of the N-S fault zone at location 1 are intensely affected and truncated by a narrow-spaced, complex network of different sets of brittle shear planes and faults (Fig. 4). The orientation of most of the subvertical shear planes, shear zones and cataclastic faults is approximately N-S. Although dextral displacements occur along the shear zones, dominating left-lateral slickenside lineations suggest that the major component involved sinistral movement.

The observations across the N-S fault zone at location 1 suggest that Pearya metasediments are not carried over Cretaceous rocks along a more or less W-dipping thrust fault zone as assumed by Trettin & Frisch (1996). In contrast, the subvertical orientation of the faults as well as slickenside lineations indicate that the boundary between Pearya and Cretaceous igneous rocks in this area is formed by an approximately N-S trending, sinistral fault zone. This is supported by the situation at location 4, in which the ENE-WSW trending Mitchell Point Fault Zone is sinistrally displaced by a N-S fault which is possibly a continuation of the N-S fault zone at location 1 (Fig. 2). It is most likely that the N-S fault zone at location 1 is related to the regional dextral regime along the Mitchell Point Fault Zone with dextral synthetic NE-SW faults and sinistral antithetic NNE-SSW faults (compare Fig. 2c).

CONCLUSIONS

In northeastern Wootton Peninsula, metabasalts and tuffitic slates are revealed in the Neoproterozoic to lower Paleozoic Succession 2 of the Pearya Terrane (Fig. 4). They are part of a low-grade metamorphic sequence of marbles, phyllites, and quartzitic slates with beds of conglomerates / breccias which comprises the former units W2 and W3 (now summarized to Unit W2/3) of Succession 2. Metavolcanic rocks have not yet been described in the northern Wootton Peninsula although the Pearya Succession 2 is generally defined as a metasedimentary and metavolcanic unit (Trettin 1991b, 1998).

During the Cretaceous, three major phases of magmatic activity took place in the study area:
(i) emplacement of late Early Cretaceous to Cenomanian mafic dykes cutting through successions 1 and 2 of Pearya: these dykes are equivalent to basalts of the Isachsen and Strand Fiord formations which are interpreted as continental flood-basalt volcanism (Estrada & Henjes-Kunst 2004).
(ii) Late Cretaceous (about 92 Ma) intrusion of the bimodal plutonic rocks and of a hypabyssal microgranite of the Wootton Intrusive Complex.
(iii) Late Cretaceous (about 82 Ma) extrusion of the bimodal Hansen Point Volcanic Complex immediately NW of the Mitchell Point Fault Zone.

The Mitchell Point Fault Zone represents a prominent structure in the study area which separates the Pearya Succession 1 in the SE from the Pearya Succession 2 in the NW. It should be noted that the Wootton Intrusive Complex is restricted to a narrow, NE-SW trending belt between the two master faults of the fault zone (Fig. 2).

Important vertical movements along the Mitchell Point Fault Zone must have taken place after the emplacement of the plutonic rocks and the hypabyssal microgranite of the Wootton Intrusive Complex 92 Ma ago to uplift these igneous rocks to their present level in the central area between the master faults with respect to the Pearya basement SE and NW of the Mitchell Point Fault Zone.

The volcanics and sediments of the Hansen Point Volcanic Complex are restricted to the area NW of the Mitchell Point Fault Zone (Fig. 2). Their involvement in the brittle strike-slip tectonics indicates that dextral displacements along this fault zone took place after the extrusion and deposition of the Hansen Point Volcanic Complex 82 Ma ago.

The observations along the Mitchell Point Fault Zone result in an important conclusion: there is no indication that it represents a major NW-directed reverse fault zone along which Proterozoic basement was carried over Cretaceous Hansen Point volcanics similar to the Kap Cannon Thrust Zone in North Greenland. There are also no mylonites developed along the contact between the volcanics in the NW and marbles in the SE. Compared with the tectonic fabric elements detected in the field, the theoretical configuration of tectonic fabric elements in a strain ellipsoid argues against NW-SE compression (Fig. 2b) but for a NE-SW dextral strike-slip regime (Fig. 2c). Apart from the deformation of the Tertiary deposits in northeast Wootton Peninsula (Fig. 2) reported by TRETTIN & FRISCH (1996) no evidence for Eurekan compression was found in the study area.

The Mitchell Point Fault Zone truncates Cretaceous dykes and also affects the Wootton Intrusive and Hansen Point Volcanic complexes which represent the youngest observed rock units in the area. The geology indicates that the intrusion of the Wootton microgranite and the extrusion of the Hansen Point volcanics may already have occurred during early motions along the Mitchell Point Fault Zone. It should be noted that the Hansen Point Volcanic Complex has been affected by shear planes and faults. Slickenside lineations clearly demonstrate that a part of the dextral activity along the Mitchell Point Fault Zone took place after the formation of the Hansen Point Volcanic Complex some 82 Ma ago.

ACKNOWLEDGMENTS

The project was financially supported by the German Federal Ministry of Education and Research (BMBF) as a Canadian-German science and technology cooperation project (WTZ). We thank Benoit Beauchamps, Jürgen Kothe, and the staff of the Polar Continental Shelf Project for logistical support during the field work, Peter Rendschmidt and Tadeusz Malarski for the thin-section preparation, Detlev Klosa for REM analyses, Ulrich Schwarz-Schampera for cathodoluminescence analyses, Hans-Dieter Weck for XRD analyses in the BGR laboratories, as well as Dieter Möller and Siegfried Pietrzok for technical assistance. S. Estrada thanks Klaus-Peter Burgath, Manfred Mohr, Manfred Krautter, Harald Dill, and Wolfgang Weiß for valuable advice and fruitful discussions. We thank also Anthony Buglass for improving the English text. We are grateful to Christopher Harrison and Hans-Jürgen Paech, whose very constructive reviews improved the quality of the manuscript.

References

Aitken, J.D. (1991): The Ice Brook Formation and post-Rapitan, Late Proterozoic glaciation, Mackenzie Mountains, Northwest Territories.- Geol. Surv. Canada Bull. 404: 1-43.

Balkwill, H.R. (1978): Evolution of Sverdrup Basin, Arctic Canada.- Amer. Assoc. Petrol. Geol. Bull. 62: 1004-1028.

Brasier, M., Green, O. & Shields, G. (1997): Ediacarian sponge spicule clusters from southwestern Mongolia and the origins of the Cambrian fauna.- Geology 25: 303-306.

Buchan, K.L. & Ernst, R.E. (2004): Diabase dyke swarws and related units in Canada and adjacent regions.- Geol. Surv. Canada Map 2022A, scale 1:5,000 000.

Dawes, P.R. & Peel, J.S. (1981): The northern margin of Greenland from Baffin Bay to Greenland Sea.- In: A.E.M. NAIRN, M. CHURKIN, & F.G. STEHLI (eds.), The Ocean Basins and Margins. The Arctic Ocean 5, Plenum Press, New York, London, pp. 201-264.

Dewing, K., Harrison, J.C., Pratt, B.C. & Mayr, U. (2004): A probable late Neoproterozoic age for the Kennedy Channel and Ella Bay formations, northeastern Ellesmere Island and its implications for passive margin history of the Canadian Arctic.- Can. J. Earth Sci. 41: 1013-1025.

Dzik, J. (1994): Evolution of 'small shelly fossils' assemblages of the Early Paleozoic.- Acta Palaeontologica Polonica 39: 247-313.

Embry, A.F. (1991): Mesozoic history of the Arctic Islands.- In: H.P. TRETTIN (ed.), Geology of the Innuitian orogen and Arctic Platform of Canada and Greenland. Geology of Canada 3 (also The Geology of North America E): 371-433.

Embry, A.F. & Osadetz, K.G. (1988): Stratigraphy and tectonic significance of Cretaceous volcanism in the Queen Elizabeth Islands, Canadian Arctic Archipelago.- Can. J. Earth Sci. 25: 1209-1219.

Estrada, S. & Henjes-Kunst, F. (2004): Volcanism in the Canadian High Arctic related to the opening of the Arctic Ocean.- Z. dt. geol. Ges. 154: 579-603.

Estrada, S., Henjes-Kunst, F. & Piepjohn, K. (2004): Oberkreide-Vulkanismus an der Nordküste von Ellesmere Island, Kanadische Arktis.- Arbeitskr. Geol. Polargeb. DGP, 26. Arbeitstreffen Hannover, 16./17. April 2004, 2-4.

Frisch, T. (1974): Metamorphic and plutonic rocks of northernmost Ellesmere Island, Canadian Arctic Archipelago.- Geol. Surv. Can. Bull. 229: 1-87.

Gosen, W., von & Piepjohn, K. (1999): Evolution of the Kap Cannon Thrust Zone (north Greenland).- Tectonics 18 (6): 1004-1026.

Gradstein, F.M., Ogg, J.G. & Smith A.G. (2004): A Geologic Time Scale 2004.- Cambridge Univ. Press, Cambridge: pp. 589.

Hambrey, M.J. (1983): Correlation of Late Proterozoic diamictites of northeastern Svalbard.- Geol. Mag. 119: 209-232.

Hambrey, M.J. & Spencer, A.M. (1987): Late Precambrian glaciation of central East Greenland.- Meddel. om Grønland Geosci. 19: 1-525.

Harland, W.B., Hambrey, M.J. & Waddams, P. (1993): The Vendian geology of Svalbard.- Norsk Polarinst. Skrifter 193: 1-130.

Higgins, A.K., Friderichsen, J.D. & Soper, N.J. (1981): The North Greenland fold belt between central Johannes V. Jensen Land and eastern Nansen Land.- Rapp. Grønlands Geol. Unders. 106: 35-45.

Higgins, A.K., Ineson, J.R., Peel, J.S., Surlyk, F. & Sønderholm, M. (1991): Cambrian to Silurian basin development and sedimentation, North Greenland.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada 3 (also The Geology of North America E): 109-161.

Klaper, E.M. (1990): The mid-Paleozoic deformation in the Hazen Fold Belt, Ellesmere Island, Arctic Canada.- Can. J. Earth Sci. 27: 1359-1370.

Klaper, E.M. (1992): The Paleozoic tectonic evolution of the northern edge of North America: A structural study of northern Ellesmere Island, Canadian Arctic Archipelago.- Tectonics 11: 854-870.

Miall, A.D. (1991): Late Cretaceous and Tertiary basin development and sedimentation, Arctic Islands.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada 3 (also The Geology of North America E): 437-458.

Osadetz, K.G. & Moore, P.R. (1988): Basic volcanics in the Hassel Formation (mid-Cretaceous) and associated intrusives, Ellesmere Island, district of Franklin, Northwest Territories.- Geol. Surv. Can. Paper 87-21: 1-19.

Ricketts, B., Osadetz, K.G. & Embry, A.F. (1985): Volcanic style in the Strand Fiord Formation (Upper Cretaceous), Axel Heiberg Island, Canadian Arctic Archipelago.- Polar Res. 3: 107-122.

Schuchert, C. (1923): Sites and nature of North American geosynclines.- Bull.

Geol. Soc. Amer. 34: 151-229.

Soper, N.J. & Dawes, P.R. (1970): A section through the north Peary Land fold belt.- Proc. Geol. Soc. London 1662: 60-61.

Soper, N.J. & Higgins, A.K. (1985): Thin-skinned structures at the trough-platform transition in North Greenland.- Grønlands Geol. Unders. Rep. 126: 87-94.

Soper, N.J. & Higgins, A.K. (1987): A shallow detachment beneath the North Greenland fold belt: implications for sedimentation and tectonics.- Geol. Mag. 124: 441-450.

Soper, N.J. & Higgins, A.K (1990): Models for the Ellesmerian mountain front in North Greenland: a basin margin inverted by basement uplift.- J. Struct. Geol. 12: 83-97.

Soper, N.J., Dawes, P.R. & Higgins, A.K. (1982): Cretaceous-Tertiary magmatic and tectonic events in North Greenland and the history of adjacent ocean basins.- In: P.R. DAWES & J.W. KERR (eds.), Nares Strait and the drift of Greenland: a conflict in plate tectonics. Meddr. Grønland Geosci. 8: 205-220.

Srivastava, S.P. & Tapscott, C.R. (1986): Plate kinematics of the North Atlantic.- In: P.R. VOGT & B.E. TUCHOLKE (eds.), The Geology of North America M, Geol. Soc. Amer., 379-404.

Stuart Smith, J.H. & Wennekers, J.H.N. (1979): Geology and hydrocarbon discoveries of Canadian Arctic Island.- Amer. Assoc. Petrol. Geol. Bull. 61: 1-27.

Tessensohn, F. & Piepjohn, K. (2000): Eocene compressive deformation in Arctic Canada, North Greenland and Svalbard and its plate tectonic causes.- Polarforschung 68: 121-124.

Thorsteinsson, R. & Tozer, E.T. (1957): Geological investigation in Ellesmere and Axel Heiberg islands, 1956.- Arctic 10: 2-31.

Thorsteinsson, R. & Tozer, E.T. (1960): Summary account of structural history of the Canadian Arctic Archipelago since Precambrian time.- Geol. Surv. Can. Paper 60-7: 1-23.

Thorsteinsson, R. & Tozer, E.T. (1970): Geology of the Arctic Archipelago.- In: R.J.W. DOUGLASS (ed.), Geology and economic minerals of Canada. Geol. Surv. Can., Econ. Geol. Rep. 1, 547-590.

Trettin, H.P. (1987): Pearya: a composite terrane with Caledonian affinities in northern Ellesmere Island.- Can. J. Earth Sci. 24: 224-245.

Trettin, H.P. (1991 a): Tectonic Framework.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada 3 (also The Geology of North America E): 59-66.

Trettin, H.P. (1991b): The Proterozoic to Late Silurian record of Pearya.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland. Geology of Canada 3 (also The Geology of North America E): 241-259.

Trettin, H.P. (1998): Pre-Carboniferous geology of the northern part of the Arctic islands. Chapter 4: Geology of Pearya.- Geol. Surv. Can. Bull. 425: 108-192.

Trettin, H.P. & Balkwill, H.R. (1979): Contributions to the tectonic history of the Innuitian Province, Arctic Canada.- Can. J. Earth Sci. 16: 748-769.

Trettin, H.P. & Frisch, T. (1987): Bedrock geology, Yelverton Inlet map-area, northern Ellesmere Island. Interim report and map (340F, 560D).- Geol. Surv. Can. Open File 1651, pp. 98.

Trettin, H.P. & Frisch, T. (1996): Geology, Yelverton Inlet, District of Franklin, Northwest Territories.- Geol. Surv. Canada Map 1881A, scale 1:250 000.

Trettin, H.P. & Parrish, R. (1987): Late Cretaceous bimodal magmatism, northern Ellesmere Island: isotopic age and origin.- Can. J. Earth Sci. 24: 257-265.

Trettin, H.P., Mayr, U., Embry, A.F. & Christie, R.L. (1982): Preliminary geological map and notes, part of Lady Franklin Bay map-area, District of Franklin.- Geol. Surv. Canada, Open File 834: 1-31.

Trettin, H.P., Parrish, R. & Loveridge, W.D. (1987): U-Pb age determinations on Proterozoic to Devonian rocks from northern Ellesmere Island, District of Franklin.- Geol. Surv. Canada, Current Res. B, Paper 79-1B: 269-279.

Winchester, J.A. & Floyd, P.A. (1977): Geochemical discrimination of different magma series and their differentiation products using immobile elements.- Chem. Geol. 20: 325-343.