Canadian Journal of Earth Sciences
 Revue canadienne des sciences de la Terre

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Journal:	<i>Canadian Journal of Earth Sciences</i>
Manuscript ID	cjes-2015-0142.R1
Manuscript Type:	Article
Date Submitted by the Author:	17-Oct-2015
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Two garnet growth events in polymetamorphic rocks in south-west Spitsbergen, Norway: insight in the history of Neoproterozoic and early Paleozoic metamorphism in the High Arctic

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Short title: Polymetamorphic rocks of SW Svalbard

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Abstract

Geochronological studies in northern Wedel Jarlsberg Land, southwestern Svalbard (Norway) showed that the Tonian (c. 950 Ma) igneous rocks were subjected to metamorphism during the Torellian (c. 640 Ma) and early Caledonian (470-460 Ma) events. Predominant augen gneisses, derived from a Tonian protolith, are intercalated in that area with schists comprising two distinct metamorphic mineral assemblages. The M1 (Torellian) assemblage containing garnet-I + quartz + plagioclase-I + biotite-I + muscovite-I was formed under amphibolite-facies conditions at c. 550-600°C and 5-8 kbar. The M2 (Caledonian) assemblage comprising garnet-II + quartz + plagioclase-II + biotite-II + muscovite-II + zoisite + chlorite crystallized at c. 500-550°C and 9-12 kbar corresponding to epidote-amphibolite facies conditions. The M2 mineral assemblage constitutes the pervasive Caledonian fabric of the schists that was subsequently reactivated in a left-lateral strike-slip shear regime. The subsequent c. 70° clockwise rotation of the original structure to its present position was caused by a large-scale passive rotation during the Paleogene Eurekan Orogeny. The new P-T estimates suggest that metamorphic basement in the study area was consolidated during the Torellian middle-grade event and then overprinted by Caledonian moderate- to high-pressure subduction related metamorphism. A following sinistral shear zone assembled the present structure of basement units. Our results pose a question about the possible extent of Torellian precursor to the Caledonian basement across the High Arctic and the scale of its subsequent involvement in early Caledonian subduction. In conjunction with previous studies, they suggest a possible correlation between southwestern Spitsbergen and the Pearya Terrane in Ellesmere Island.

Key words: Svalbard, P-T estimates, North Atlantic Caledonides, Pearya Terrane, polymetamorphism

51 **INTRODUCTION**

52 A classical view on the evolution of crystalline basement in Svalbard (Norway) is that early
53 Paleozoic Caledonian deformation and metamorphism overprint the effects of earlier
54 tectonothermal events dating back to the Grenvillian Orogeny and preceding Paleo- to
55 Mesoproterozoic magmatism (e.g., Gee and Page 1994; Gee and Tebenkov 2004). In addition,
56 in a number of papers published over the past few years, we provided increasing body of
57 evidence documenting a Torellian tectonothermal event (c. 640 Ma) that affected the
58 southwestern part of Svalbard (e.g., Majka et al. 2008, 2010, 2014). Originally documented in
59 the southern part of Wedel Jarlsberg Land (Majka et al. 2008), the Torellian event
60 encompassed Late Neoproterozoic (c. 640 Ma) deformation, metamorphism and magmatism,
61 the processes tentatively correlated with the Timanide orogeny (see e.g., Majka et al. 2014 for
62 more details). We also emphasized the similarities between southwestern Svalbard and the
63 Timanide Orogen of Northern Europe as well the Pearya Terrane of Canadian Ellesmere
64 Island (e.g., Mazur et al. 2009; Majka et al. 2014). In the current contribution, we document
65 two-phases of garnet growth in the Tonian igneous rocks of southwestern Svalbard during the
66 Torellian and early Caledonian metamorphic events (470-460 Ma). In consequence, we
67 provide further evidence for a significant role played by late Neoproterozoic metamorphism
68 and subsequent ductile Caledonian sinistral shear deformation in southwestern Svalbard.
69 Furthermore, we present evidence for a Caledonian middle- to high-pressure metamorphic
70 overprint, thus showing that vestiges of early Palaeozoic metamorphism in a subduction
71 setting are more widespread in Svalbard than previously thought. We show an integrated
72 approach for deciphering both tectonic and metamorphic events recorded by the highly
73 deformed basement rocks, the significance of which has not been hitherto fully understood.
74 The results of our structural and petrological investigations presented in this work have
75 immediate implications for understanding the structure and history of the North Atlantic

Caledonides, and in a broader perspective, for analysing complex tectonic patterns in highly reworked metamorphic terrains elsewhere.

GEOLOGICAL SETTING

The area where the Torellian metamorphic event has been thus far identified belongs to the Southwestern Caledonian Basement Province (Fig. 1; SBP) of Gee and Tebenkov (2004). The oldest rocks of the SBP crop out in southern part of Wedel Jarlsberg Land (Fig. 1). They are represented by late Mesoproterozoic sediments and igneous rocks belonging to the Eimfjellet Group (c. 1200 Ma gabbros and granites; e.g., Balashov et al. 1995, 1996; Larionov et al. 2010). The Eimfjellet Group is thrust over the early Neoproterozoic sediments of the Isbjørnhamna Group (Fig. 2). Both units are metamorphosed under upper greenschist- to upper amphibolite-facies conditions (e.g., Majka et al. 2010). Notably, these units yielded the Torellian (c. 640 Ma) age of metamorphism (Maneck et al. 1998; Majka et al. 2008). Amphibolite-facies rocks have been also found in a few other places within the SBP where they are tectonically juxtaposed against surrounding lower grade units. For example, in Wedel Jarlsberg Land, the amphibolite-grade Eimfjellet and Isbjørnhamna Groups, preserving record of Torellian metamorphism, are juxtaposed across the Vimsodden-Kosibapasset Zone (VKZ; Fig. 1) with the greenschist-facies sedimentary rocks of the early Neoproterozoic Deilegga and late Neoproterozoic Sofiebogen Groups (Fig. 2; e.g., Mazur et al. 2009; Kościńska et al. 2015). The VKZ is developed as a regional-scale left-lateral ductile shear zone that is c. 2 km wide. The top of the Deilegga Group is marked by an angular unconformity (Torellian unconformity; Birkenmajer, 1975; Bjørnerud, 1990; Dallmann *et al.*, 1990) the age of which is inferred to post-date 640 Ma (e.g., Mazur et al. 2009; Majka et al. 2014). The unconformity is overlain by basal conglomerate, locally intercalated with volcanic rocks (e.g., Gołuchowska et al. 2012), and succeeding finer-grained sediments of the Sofiebogen Group. Both the

Deilegga and Sofiebogen Groups were deformed and metamorphosed during the Caledonian event. These two units can be traced along the entire SBP although they are known under different local names in other parts of the SBP (see Fig. 2; Dallmann et al. 2015 and Gasser 2014 for more details). The overlying Bellsund Group (and equivalents) forms a thick succession of diamictites of possible glacio-marine origin (Fig. 2). Little is known about the age of these rocks, but it is inferred that they are the latest Neoproterozoic in age (the Gaskiers stage; Gasser and Andresen 2013). The youngest (lower Palaeozoic) and least metamorphosed Sofiekammen Group (and equivalents) overlies all other basement units along an unconformable or tectonic contact (e.g., Mazur et al. 2009).

The area located in Oscar II Land (Fig. 1) is a unique part of the SBP because of the occurrence of well preserved high-pressure (HP) rocks represented by blueschists, eclogites and glaucophane-bearing garnet-phengite schists (e.g., Hirajima et al. 1988). These HP rocks, belonging to the Vestgötabreen Complex, are dated as Early- to Mid-Ordovician (470-460 Ma, Horsfield 1972; Dallmeyer et al. 1990; Bernard-Griffiths et al. 1993) and probably represent a vestige of early Caledonian subduction within marginal basins of the Iapetus Ocean. It has been tentatively proposed that the Vestgötabreen Complex might be an equivalent of the M'Clintock Complex of the Pearya Terrane (Labrousse et al. 2008; Kośmińska et al. 2014) based on the similar age and comparable tectonostratigraphy in both regions. The extent of the HP rocks was initially thought to be limited to Oscar II Land only. However, Kośmińska et al. (2014) have recently identified another blueschist-facies occurrence in Nordenskiöld Land (Fig. 1), thus showing that the HP rocks may be more widespread in western Svalbard than previously assumed.

The basement along the west coast of Spitsbergen was affected by the Paleogene Eurekan orogeny that formed the West Spitsbergen Fold-and-Thrust Belt (WSFTB). The WSFTB structural pattern is dominated by the ENE-vergent, kilometres-scale synclinal-anticlinal fold structures (e.g., von Gosen and Piepjohn 2001) and the ENE-directed thrust faults that accommodate shortening in the basement (Piepjohn et al. 2001; Saalman et al. 2002). The WSFTB formed along the transform plate boundary between Greenland and the western Barents Sea (Eurasia) during Paleocene-Eocene breakup in the North Atlantic (e.g., Talwani and Eldholm 1977; Faleide et al. 2008; Leever et al. 2011). Approximately 10–40 km margin-perpendicular shortening (e.g., Piepjohn et al 2001; von Gosen and Piepjohn 2001) accumulated in the WSFTB is usually attributed to transpression and strain partitioning in a restraining bend (Harland 1969; Lowell 1972; Bergh et al. 1997; Leever et al. 2011) or by a succession of tectonic events with orthogonal compression during a first stage and dextral strike-slip faulting during a second stage (CASE-Team 2001). The WSFTB consist of four major zones of distinct structural style (e.g., Dallmann et al. 1993; Braathen and Bergh 1995; Bergh et al. 1997; CASE-Team 2001; Fig. 3):

- (1) The western hinterland zone that was affected solely by Oligocene right-lateral transpressional to transtensional deformation postdating the formation of the WSFTB;
- (2) The thick-skinned, basement-involved fold-thrust complex with mostly ENE-directed brittle reverse faults and thrust sheets and the large scale syncline and anticline-pair.
- (3) The eastern, thin skinned domain with sub-horizontal thrust faults with flats-and-ramps geometries affecting Carboniferous to Paleogene deposits.
- (4) The Central Tertiary Basin affected by some thrust faults and local cleavage formation and underlain by detachment horizons especially in the Jurassic and Triassic sediments between domain (3) in the west and the Billefjorden Fault Zone in the east.

THE BERZELIUSEGGENE UNIT OF NORTHERN WEDEL JARLSBERG LAND

In northeastern Wedel Jarlsberg Land, east of Recherchebreen (Fig. 4), an assemblage of generally greenschist-facies metamorphosed sedimentary and igneous rocks crop out on the ridges along the eastern and western sides of Antoniabreen. Since these rocks are best exposed on the Berzeliussegge Ridge to the east of Antoniabreen they are referred to here as the Berzeliussegge unit (BU, see also Majka et al. 2014 and Dallmann et al. 2015). Highest grade metamorphic rocks are represented by augen gneisses, with some pegmatites, occasional amphibolites and schists, probably of volcanic (felsic to intermediate) or volcano-sedimentary (tuffaceous) origin. The original contacts between different lithologies are impossible to resolve because of intense overprint by Caledonian deformation (see below). The BU tectonically overlies metasediments of the Deilegga and Sofiebogen Groups (Majka et al. 2014) and is in turn unconformably covered by lower Carboniferous and younger successions of the south Spitsbergen Basin.

A sample of the augen gneiss from the BU was dated by Majka et al. (2014) at 950 ± 5 Ma using U–Pb zircon analysis, the age interpreted as time of magmatic emplacement. Mylonitic and cataclastic varieties of the BU are ubiquitous, occasionally with visible pseudotachylites. Although extensively retrogressed, the occasional presence of garnet in the BU indicates earlier, presumably amphibolite-facies metamorphism, prior to the tectonic juxtaposition with the Deilegga and Sofiebogen Groups.

Zircon extracted from a pegmatite dyke occurring within the BU yielded a discordia upper intercept age of 665 ± 11 Ma (Majka et al. 2014). The age obtained defines the time of pegmatite emplacement within the BU lithologies under at least medium-grade metamorphic conditions. The Torellian tectonometamorphic event is additionally confirmed by the age of

metamorphic rims on zircons from the BU augen gneiss sample yielding an age of 635 ± 10 Ma (Majka et al. 2014). Since the BU augen gneisses and the rare schists intercalated contain metamorphic garnet the justifiable interpretation is that crystallisation of garnet and metamorphic rims on zircons jointly represent a single amphibolite-grade metamorphic event. A Caledonian metamorphic event was not recorded in zircons from the BU that were analysed by Majka et al. (2014). However, this does not preclude lower temperature overprint as suggested by K–Ar mica ages clustering around 460 Ma (Dallmann et al. 1990).

STRUCTURAL DATA

The Antoniabreen area is located within the thick-skinned, basement-involved fold-thrust complex (domain 2 on Fig. 3) of the WSFTB that corresponds to an antiformal stack system with a steep eastern flank (Dallmann et al. 1990, 2015; Bergh et al. 1997; von Gosen and Piepjohn 2001). Since the study area occupies position on the steep, eastern flank of the fold structure (Fig. 3), all structures pre-dating the growth of the ENE-vergent anticlinal-synclinal pair must have experienced extensive synthetic rotation. This corollary concerns not only early thrusts developed in the course of initial shortening within the WSFTB but also the old Caledonian structural grain. The observation of thrust faults and an angular unconformity at the base of the Carboniferous actually confirms their steep, sub-vertical orientation (Fig. 5). Restoring the unconformity and thrusts to their initial position provides an approximate estimate for the finite rotation in the range of $65\text{--}70^\circ$.

The BU occurs in gently north-dipping slivers on the eastern and western sides of Antoniabreen where it is tectonically intercalated with younger Neoproterozoic sedimentary formations. On the ridge along the eastern side of Antoniabreen, the compositional banding and tectonic contacts with other lithologies dip at low to moderate (30°) angles northwards.

The whole succession is tectonically repeated and two different slivers, separated by strongly deformed metasediments of unknown origin, can be observed on Aldegondaberget and Berzeliuseggene. West of Antoniabreen, on Jarnfjellet, only one tectonic slice occurs.

The dominant foliation of the BU is defined by garnet, biotite and plagioclase (Fig. 6a,b) that grew under epidote-amphibolite facies conditions (see below M2 mineral assemblage). The earlier amphibolite-facies metamorphic assemblage (M1), indicative of the Torellian event, is only preserved in microlithons (Fig. 6c). Therefore, the pervasive fabric in the BU rocks is interpreted herein as a Caledonian feature obliterating earlier structures. Furthermore, the rocks demonstrate syn-kinematic transition to the greenschist-grade M3 metamorphic event. The dominant foliation was reactivated throughout the M3 event by non-coaxial shearing leading to widespread mylonitization and decomposition of earlier M2 porphyroblasts (Fig. 6d). Composite foliation S_{2+3} bears pervasive stretching lineation marked out by biotite and plagioclase belonging to the M2 assemblage. However, in the mylonitic rocks stretching lineation is mostly defined by elongate quartz aggregates and muscovite-chlorite streaks.

The measurements of foliation and lineation reveal their fairly uniform orientation across the study area (Fig. 7) with Caledonian structures being clearly oblique to Paleogene thrust planes. On a synoptic diagram (Fig. 7a), the foliation dips to the north and north-west at a moderate angle. Poles to foliation are dispersed along a girdle with an axis gently plunging towards the NNW. Stretching lineation measurements form a single cluster corresponding to a shallow plunge towards the north (Fig. 7a). Characteristically, the lineation is oblique at a low angle to the axis of the foliation girdle. Keeping in mind the structural framework of the area and evidence provided by sub-vertical orientation of thrusts and erosional unconformity (Fig. 5), the present-day attitude of the Caledonian fabric does not represent its original orientation.

We attempted antithetic rotation of foliation and lineation measurements to restore their original pre-Paleogene position. The rotation applied was 70° to restore the Carboniferous unconformity to subhorizontal position about the rotation axis defined by folded foliation, assuming folding is Eureka in age. The restored foliation is steeply dipping to the south-west whereas the lineation is sub-horizontal along the NNW-SSE direction (Fig. 7b). The trend of unrotated lineation is parallel to the axis of the foliation girdle despite a slightly shallower plunge. This suggests that the structural plan of the WSFTB was at least to some extent controlled by the pre-existing, Caledonian structural grain.

Numerous kinematic indicators such as asymmetric pressure shadows of clasts and S-C fabric point to the top-to-the S sense of shear in present-day coordinates (Fig. 8). In combination with the current fabric orientation, shear sense indicators define top-to-the S kinematics of deformation potentially related to Caledonian thrusting. However, after restoring the original structural plan through antithetic rotation of measurements kinematics changes to sinistral strike-slip on the steep SW-dipping foliation (Fig. 7b).

SAMPLE DESCRIPTION

Samples of schists were collected on the ridges and slopes of Jarnfjellet and Berzeliuseggene. They occur within metaigneous rocks of the BU. The sampled schists are dark grey to black in colour, very fine grained and strongly foliated. A total of 10 samples was collected and examined under light microscopy. The sample with the best preserved mineral assemblages was chosen for further petrological studies.

Petrography

Sample Sp122/07 was collected at Berzeliuseggene (Fig. 4). Although the schist is strongly foliated (Fig. 6a,b,c), it has microlithons (up to 1.5 mm long) that are mainly built of plagioclase-I, biotite-I, quartz and muscovite-I (Fig. 6c). Biotite-II, muscovite-II, plagioclase-II and, in minor amounts, zoisite and chlorite occur as elongated blasts within foliation planes (Fig. 6a,c). The sample contains also subhedral to euhedral garnet porphyroblasts (up to 0.5 mm in diameter). Notably, in the BSE images, garnet shows two growth zones (Fig. 6a,b). It contains scarce inclusions, mainly in the rim, which consist of plagioclase, quartz, allanite and titanite. The latter two, zircon and zoisite are common accessories also in the matrix. Late chloritization of predominantly biotite-II is abundant. Moreover, garnet porphyroblasts of both generations are occasionally crushed into pieces that are smeared along foliation (Fig. 6d).

Mineral chemistry

Mineral compositions were determined by a Cameca SX-50 and Jeol JXA-8530F Hyperprobe electron microprobes at the Centre for Experimental Mineralogy, Petrology and Geochemistry, Department of Earth Sciences, Uppsala University, Sweden. The analytical conditions were as follows: 15 kV accelerating voltage, 20 nA beam current, 10 s counting time on peak and 5 s on $\pm$ background and beam diameter 1-15 μ m. Following standards were used for calibration: Si, Ca – wollastonite, Na – albite, K – orthoclase, Fe – hematite (Cameca) and fayalite (Jeol), Mn, Ti – pyrophanite, Al – Al_2O_3 , Cr – Cr_2O_3 , Mg – MgO. Only $K\alpha$ lines were measured. Raw data was corrected using PAP routine. Elemental mapping of Mn, Ca, Fe and Mg in garnet has been performed using the aforementioned Jeol instrument. Analytical conditions were as follows: counting time per step – 100 ms, beam current 20 nA, 15 kV accelerating voltage and two accumulations. The same

mineral standards and spectral lines were used as for the single point analyses (see above).

The mineral abbreviations are according to Whitney and Evans (2010).

Garnet

Two generations of garnet can be distinguished. Garnet-I forms the inner growth zone and represents the cores of bigger grains, whereas garnet-II builds outer growth zone forming subhedral to euhedral rims on garnet-I (Figs 6a,b & 9a). Some of the smaller garnet grains (up to 0.2 mm in diameter) show only a single growth zone represented by garnet-II.

Garnet-I shows almost flat compositional zonation profiles (Fig. 9b). The end-members range from $X_{\text{Alm}}=0.58-0.64$, $X_{\text{Sps}}=0.22-0.25$, $X_{\text{Grs}}=0.09-0.12$ and $X_{\text{Prp}}=0.03-0.07$.

The transition from garnet-I to garnet-II is marked by a sharp compositional change (Fig. 9a,b). Grossular increases rapidly reaching $X_{\text{Grs}}=0.27-0.30$ that remains quite constant towards the outer rim. Almandine gradually increases from $X_{\text{Alm}}=0.47$ in the inner part to $X_{\text{Alm}}=0.59$ in the outermost part. Spessartine decreases slightly from $X_{\text{Sps}}=0.22$ to $X_{\text{Sps}}=0.17$ in the outer rim. Pyrope is generally low ($X_{\text{Prp}}=0.02$) and stable throughout the grains. Representative garnet compositions are listed in Table 1.

Biotite

Biotite-I occurs as transversal blasts and within augens. It has X_{Fe} varying from 0.58 to 0.60 (Tab 2). Biotite-II forms flakes aligned in the foliation planes, with X_{Fe} ranges between 0.61 and 0.66. The Ti in both generations is similar ($\text{Ti}=0.09-0.11$ a.p.f.u.).

White mica

White mica occurs predominantly as elongated flakes in the foliation planes (muscovite-II, Fig. 6a,c), however it also forms isolated blasts within bigger plagioclase augens (muscovite-I, Fig. 6c). Both generations have similar composition with Si ranging from 3.13 to 3.16 a.p.f.u. (Table 2) for muscovite-I, and between 3.14 and 3.20 a.p.f.u. for muscovite-II. The Na content in both types is almost identical and varies between 0.04 and 0.06 a.p.f.u.

Plagioclase

Plagioclase forms composite augens with quartz and biotite, but also occurs as porphyroblasts in the matrix (Fig. 6a,c). The composition of plagioclase-I varies from Ab 75 to 82 mol % (Table 3), whereas plagioclase-II composition ranges between Ab 77 and 95 mol %.

PRESSURE-TEMPERATURE ESTIMATES

P-T conditions were estimated using both conventional geothermobarometry and phase equilibrium modelling. For both the M1 and M2 metamorphic events (i.e., garnet-I and garnet-II growths, respectively) the garnet-biotite geothermometer, in calibration of Holdaway et al. (1997), improved by Holdaway (2000), and the garnet-biotite-plagioclase-quartz geobarometer (Wu et al. 2004) have been used. Phase equilibrium models (pseudosections) have been derived using Perple_X 6.7.1 software package (Connolly 2005) with the internally consistent thermodynamic dataset of Holland and Powell (1998). The following solid-solutions models were used: Gt(GCT) for garnet (Ganguly et al. 1996), Bio(TCC) for biotite (Tajčmanová et al. 2009), Mica(CHA) for white micas (Coggon and Holland 2002), Pl(h) for plagioclase (Newton et al. 1980) and Chl(HP) for chlorite (Holland et al. 1998).

Geothermobarometry

M1 metamorphic event

Geothermobarometrical calculations for the M1 event have been performed for garnet-I, plagioclase-I and biotite-I. The lowest X_{Fe} ($Fe/(Fe+Mg)$) values in garnet have been coupled with several biotite-I flakes enclosed in augens to derive temperature. Similarly, the highest X_{Ab} ($Na/(Na+Ca+K)$) values in plagioclase-I have been used together with aforementioned garnet-I and biotite-I to calculate pressure. The calculated temperatures range between 578 and 594°C, whereas pressures are scattered from 6.31 to 6.83 kbar (Table 4).

M2 metamorphic event

For the M2 event the lowest X_{Fe} values in garnet-II (usually in the outermost rims) were coupled with neighbouring biotite-II and plagioclase-II. P-T estimates vary from 505 to 552°C and from 9.15 to 9.94 kbar (Table 5).

Phase equilibrium modelling

M1 metamorphic event

A phase equilibrium diagram was constrained on the basis of whole-rock bulk chemistry, which was obtained using XRF analysis (Fig. 10a). A pseudosection has been calculated in the Na_2O - CaO - K_2O - FeO - MgO - MnO - Al_2O_3 - SiO_2 - H_2O (NCKFMMnASH) system. H_2O and SiO_2 were considered as excess phases, because quartz as well as hydrous minerals were present in the P-T range of interest. Titanium was not included in the calculations, because the Ti-bearing phases (i.e. titanite) play a minor role. CaO was reduced according to the bulk-rock P_2O_5 content, assuming all Phosphorous was bound to apatite. Iron is predominantly present in the ferrous state, thus all iron was considered as FeO . The P-T conditions were estimated using the compositional isopleths for garnet-I and biotite-I. The isopleths of grossular ($X_{Grs}=0.09$ -0.12) and pyrope ($X_{Prp}=0.05$ -0.07) in garnet were compared with isopleths of X_{Fe} in biotite ($X_{Fe}=0.58$ -0.60). The X_{Grs} is more pressure sensitive, whereas X_{Prp} and X_{Fe} in biotite

are rather temperature sensitive. The isopleths plot in the stability fields of biotite-chlorite-plagioclase-muscovite-garnet and biotite-plagioclase-muscovite-garnet. The modelled isopleths cross cut at c. 5-8 kbar and 550-600°C.

M2 metamorphic event

The P-T pseudosection for the M2 event was calculated on the basis of modified bulk-rock composition (Fig. 10b). The effective rock composition was obtained by the extraction of garnet-I chemistry from the whole-rock bulk chemistry. The modal proportion of garnet-I was determined from garnet compositional maps using computer image processing and the average composition of garnet-I was calculated using compositional profiles through several garnet grains. The other preserved minerals of the M1 assemblage form tiny relicts and represent a minor modal portion of the rock without a real impact on the bulk chemistry, thus they were not included in calculation of the effective rock composition. The P-T pseudosection was calculated in the NCKFMnASH system. The same modelling parameters have been used as for the previous pseudosection. Compositional isopleths for garnet-II, biotite-II and muscovite-II were constructed. The grossular ($X_{\text{Grs}}=0.28-0.30$) and pyrope ($X_{\text{Prp}}=0.02-0.04$) in garnet as well as silicon number ($\text{Si}=3.17-3.20$ a.p.f.u.) in muscovite and X_{Fe} ($X_{\text{Fe}}=0.61-0.63$) in biotite crosscut in the stability fields of biotite-chlorite-plagioclase-muscovite-garnet-zoisite and biotite-chlorite-plagioclase-muscovite-garnet. Estimated P-T conditions vary between 9-12 kbar and 500-550°C, respectively.

DISCUSSION

Metamorphic evolution and regional correlatives of the Berzeliusseggen unit

The P-T estimates, based on conventional geothermobarometry and phase equilibrium modelling, yielded consistent results for both the M1 and M2 metamorphic events. The M1

peak conditions were achieved under low amphibolite-facies conditions at moderate pressures (c. 550-600°C and 5-8 kbar), whereas the M2 event took place at somewhat lower temperature, but substantially higher pressure (c. 500-550°C and 9-12 kbar) under epidote-amphibolite facies conditions. Several features as (1) the M1 mineral assemblage (excluding garnet-I) enclosed in the microlithons or (2) sharp boundaries between garnet-I and garnet-II, associated with abrupt compositional changes, suggest that the M1 and M2 assemblages did not grow during a single tectonothermal event, but rather bear evidence for a polymetamorphic evolution.

The M1 assemblage grew during the Torellian tectonothermal event at c. 640 Ma (Majka et al. 2008, 2014). This corollary is based on the Torellian age of metamorphism in the BU augen gneiss (Majka et al. 2014) and the similarity of metamorphic evolution between the gneiss and associated schists. The data presented are insufficient to draw a P-T path for the M1 event. However, Majka et al. (2010) suggested a clockwise P-T path for the Isbjørnhamna Group metapelites from the southern part of Wedel Jarlsberg Land, a potential equivalent to the schist currently studied. Although the Isbjørnhamna Group rocks reached higher peak P-T conditions than the BU, both the units experienced amphibolite-facies metamorphism of similar type. Therefore, it is postulated here that the studied schist and the entire BU were subjected to the Torellian metamorphic event that is typical of the Isbjørnhamna Group.

The M2 assemblage developed during the Caledonian tectonothermal event. Although there is no direct radiometric evidence available, K-Ar biotite ages obtained from the BU yielded c. 460 Ma (Dallmann et al. 1990). Comparable Ordovician ages are known from the blueschist unit of the SBP (Vestgötabreen Complex; Fig. 1) and the eclogites of the Richarddalen Complex in the Northwestern Province (Gromet and Gee 1998; Fig. 1). Therefore, the age

data available so far suggest that the M2 event, recognized within the BU, may have been contemporaneous with HP metamorphism in other parts of Svalbard. The P-T conditions for the M2 event locate the BU near the highest pressure limit of the epidote-amphibolite facies, on the 12-14°C/km geotherms (Fig. 11) alike to the eclogites of the Richarddalen Complex (Elvevold et al. 2014). Consequently, albeit the studied BU rocks did not reach eclogite-facies conditions, they may have also been metamorphosed during subduction of continental crust.

Structural implications

The metamorphic evolution of the BU seems to combine records characteristic of the HP and middle-grade metamorphic units belonging to the SBP of Svalbard and the Richarddalen Complex of the Northwestern Province. This observation has two significant consequences: (1) the extent of the Torellian metamorphic event in Svalbard might be wider than previously thought (e.g., Majka et al. 2008, 2010, 2014) and not solely restricted to the SBP, and (2) the vestiges of HP metamorphic event are also more common than previously thought indicating a regional-scale event despite the present scarcity of blueschists and eclogites in Svalbard. The implication is that the present subdivision of Svalbard between the Southwestern and Northwestern Province may need revision in the future when more data are available.

In a wider perspective, the HP rocks exposed along the western coast of Svalbard could have been involved in the same subduction system and subsequent collision either with a continent or an island arc. There is no evidence for an Ordovician continental collisional event in the Arctic Caledonides, but there exists evidence for a possible collision with an island arc. According to Trettin (1987, 1989), the juxtaposition of different fragments of the Pearya Terrane of northern Ellesmere Island resulted from the collision of the Pearya basement with an island arc during the Early Ordovician M'Clintock Orogeny. Labrousse et al. (2008) and

422 Kościńska et al. (2014) suggested that the likely counterpart for the blueschists of the
423 Svalbard's SBP is the ophiolitic sequence and island arc lithologies of the Pearya Terrane.
424 Mazur et al. (2009) and Kościńska et al. (2014) postulated that the Pearya Terrane and
425 Svalbard's SBP could have been separated by major left-lateral strike-slip faults, well
426 pronounced in Svalbard (e.g., Harland, 1997; Mazur et al. 2009; Michalski et al. 2012) and in
427 the Pearya Terrane (Gosen et al. 2012; McClelland et al. 2012). Consequently, the Pearya
428 Terrane and the Svalbard's SBP could have been forming a single composite terrane before
429 the dismemberment during large-scale Caledonian strike-slip tectonics (Mazur et al. 2009;
430 Kościńska et al. 2014). Such a composite terrane would have to include at least the HP and
431 middle grade metamorphic units of the SBP, the Richarddalen Complex and the crystalline
432 basement of the Pearya Terrane. The composite SW Svalbard-Pearya Terrane would, in turn,
433 have to be involved in an early Caledonian subduction system directed beneath an island arc
434 (Fig. 12). This process resulted in the formation of blueschists (now exposed in the Oscar II
435 Land – Vestgötabreen Complex and Nordenskiöld Land of Svalbard) due to subduction of the
436 Iapetus oceanic crust, followed by subduction of the SW Svalbard-Pearya continental crust
437 represented by the Richarddalen Complex and BU (Fig. 12). In this view, the Richarddalen
438 Complex and BU both represent the same Torellian crust, but subducted to various depths.
439
440 If our approach to rotate the Caledonian fabric from the Antoniabreen area back to its original
441 pre-Paleogene position is correct (Fig. 7), the restored structural plan is similar to that earlier
442 described from the VKZ in southern Wedel Jarlsberg Land (Mazur et al. 2009) and the Late
443 Caledonian sinistral ductile shear zones in Ny Friesland east of Billefjorden Fault Zone
444 (Harland et al. 1974; Manby et al. 1994; Witt-Nilsson et al. 1998). The analogies between the
445 study area and the VKZ are even further reaching, bearing in mind the presence of mylonites
446 in both areas with mylonitic fabric overprinted on amphibolite-facies rocks. Since the VKZ

occurs in the western hinterland zone of the WSFTB (Fig. 3) its present-day orientation is believed to reflect the late Caledonian structural plan (Mazur et al. 2009). Consequently, we consider herein the possibility that the Antoniabreen area contains a high strain zone that was extensively re-oriented within the basement-involved fold-thrust complex of the WSFTB. Similarly to the VKZ, a high strain zone in the Antoniabreen area juxtaposes the amphibolite-grade domain (BU) against the greenschist-facies Deilegga and Sofiebogen Groups missing any evidence for the Torellian metamorphic event. However, a few outstanding questions still remain. Do the VKZ and the Antoniabreen area expose the same shear zone or we are dealing with a set of high strain zones with similar kinematics? The regional correlation is not simple because of poor exposure and complexity introduced by the WSFTB. Is the Torellian unconformity between the Deilegga and Sofiebogen Groups a shallow level expression of the late Neoproterozoic (Torellian) orogenic event? More petrological and structural work is necessary to obtain conclusive evidence whether the amphibolite- and greenschist-facies domains represent different crustal levels of the same terrane or are exotic for one another.

CONCLUSIONS

The Berzeliuseggene unit of Wedel Jarlsberg Land (SW Svalbard) experienced a polymetamorphic evolution punctuated by the M1 Torellian and M2 Caledonian events that took place under amphibolite (550-600°C; 5-8 kbar) and epidote-amphibolite (c. 500-550°C; 9-12 kbar) facies conditions, respectively. The combination of records characteristic of the high-pressure and middle-grade metamorphic units belonging to the Southwestern Province of Svalbard implies that both Torellian amphibolite-facies metamorphism and Caledonian high-pressure event were more widespread than previously thought. Furthermore, the affinity of the Berzeliuseggene rocks to the Richarddalen Complex of the Northwestern Province suggests

the continuation of basement units across the traditional boundaries of Svalbard's provinces,
the subdivision that may require reconsideration in the light of our data.

The high-pressure rocks of western Svalbard may constitute a counterpart to the ophiolitic and
island arc sequences of the Pearya Terrane (Ellesmere Island) jointly representing a vestige of
an early Ordovician subduction complex exhumed due to the collision between the Pearya-
SW Svalbard terrane and an island arc. However, the exact location and orientation of the
presumed subduction system remains uncertain. The interpretation is hampered owing to the
additional complexity introduced by later dismembering of the original terrane in the course
of the North Atlantic break-up and the Paleogene Eurekan orogeny.

If the idea of Eurekan rotation experienced by Caledonian structural grain is correct new
prospects of trans-regional correlations immediately open up. Caledonian sinistral ductile
shear zones do exist in Ny Friesland east of Billefjorden Fault Zone, in Wedel Jarlsberg Land
and within the Pearya Terrane on the other side of the present-day North Atlantic.

Consequently, the basement of western Svalbard may consist of units that were juxtaposed by
sinistral shearing in a late stage of the Caledonian Orogeny.

ACKNOWLEDGEMENTS

Marcia Bjørnerud and Nikolay Kuznetsov are greatly acknowledged for their help and
discussions in the field. Piotr Zagórski is thanked for his warm hospitality at the Calypsobyen
Station in Bellsund. This work was supported by the NCN (National Science Centre, Poland)
research project no. UMO-2013/11/N/ST10/00357 and the AGH-UST statutory funds no.
11.11.140.319.

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Figures' captions

Figure 1. Schematic geological map of the Svalbard Archipelago showing the position of the Caledonian basement provinces (modified after Gee and Tebenkov 2004). Green dashed line shows position of cross section Figure 3. Outlined box shows location of Figure 4.

Figure 2. Tectonostratigraphic scheme showing the tectonic position of individual lithostratigraphic units in Wedel Jarlsberg Land. Colours correspond to those used on the Figure 4. Modified from Dallmann et al. (2015).

Figure 3. WSW-ENE cross section through the West Spitsbergen Fold-and-Thrust Belt (WSFTB) from Nathorst Land across Van Keulenfjorden towards the west coast of Wedel Jarlsberg Land (modified from Dallmann et al. 1990, 2015; von Gosen and Piepjohn 2001). From WSW towards ENE, the major domains of the Eureka deformation are exposed: (1) The western hinterland zone; (2) two large fold-structures of the thick-skinned, basement-involved fold-thrust complex; (3) thin skinned domain with sub-horizontal thrust faults with flats-and-ramps geometries and (4) the Central Tertiary Basin. The steep faults between and within domains (1) and (2) have possibly strike-slip kinematics. See Figure 1 for location. The approximate position of the study area is indicated by blue boxes and arrows.

Figure 4. Geological map of the Antoniabreen area showing the Berzeliuseggene unit and its structural setting as well as the location of observation points (modified from Dallmann et al. 1990).

Figure 5. View on the Aldegondaberget Ridge towards the south. The Berzeliuseggene unit (BU) is separated from the Carboniferous – Permian and younger Mesozoic strata by an angular unconformity shown as a white line with dots. The unconformity is presently nearly vertical, dipping towards the east at an angle of 70-80°, due to a passive rotation on the eastern flank of the basement-involved fold-thrust complex (compare Fig. 3).

Figure 6. Photomicrographs and BSE images of the Berzeliuseggene unit rocks: (a) garnet porphyroblasts embedded in the foliation formed during the M2 event; (b) enlarged view of composite garnet porphyroblast visible in (a) – see also chemical map of the same garnet presented in Fig. 9; (c) microlithon composed of muscovite-I, biotite-I and plagioclase-I embedded in foliation formed by muscovite-II, biotite-II and plagioclase-II; (d) garnet crushed during late stage shearing, plane polarized light.

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Berzeliusseggen unit garnet-schist (this study), Nordenskiöld Land blueschist (Kośmińska et al. 2014), Richarddalen Complex eclogite (Elvevold et al. 2014), Vestgötabreen Complex blueschist (Kośmińska et al. 2015), Vestgötabreen Complex carpholite-schist (Agard et al. 2005), Vestgötabreen Complex eclogite (Hirajima et al. 1988). Metamorphic facies fields are after Okamoto & Maruyama (1999). AM – amphibolite-facies, BS – blueschist-facies, EA - epidote-amphibolite facies, EC – eclogite-facies, GR – granulite-facies. GS – greenschist-facies, HG - high-pressure granulite-facies, PP - prehnite-pumpellyite facies, Z – zeolite-facies.

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Tables

- Table 1. Representative microprobe analyses of garnet.
- Table 2. Representative microprobe analyses of micas.
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- Table 4. Atom per formula unit values for Fe, Mg, Ca, Mn in garnet, Fe, Mg, Al^(VI) in biotite and Ca, Na, K in plagioclase used for geothermobarometry and obtained temperatures and pressures for the M1 event.
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Table 1. Representative microprobe analyses of garnet.

Mineral	Grt-I	Grt-I	Grt-I	Grt-I	Grt-I	Grt-I	Grt-II	Grt-II	Grt-II	Grt-II	Grt-II	Grt-II
SiO ₂	36.54	36.95	36.74	36.59	36.69	36.80	37.23	37.37	37.17	36.81	37.23	36.79
TiO ₂	0.00	0.00	0.00	0.00	0.02	0.01	0.05	0.11	0.15	0.08	0.09	0.16
Al ₂ O ₃	20.62	20.79	20.93	20.96	20.94	20.52	20.88	20.68	20.78	20.27	20.46	20.90
Cr ₂ O ₃	0.01	0.05	0.10	0.00	0.02	0.08	0.00	0.00	0.04	0.89	0.00	0.04
FeO	27.93	28.56	28.08	29.93	29.62	28.36	26.17	23.59	23.83	23.27	22.41	23.95
MnO	9.70	9.19	9.41	6.71	8.35	9.14	5.12	7.72	7.44	7.75	8.75	8.02
MgO	1.44	1.50	1.35	1.89	1.19	1.52	0.78	0.57	0.56	0.72	0.56	0.54
CaO	2.94	2.91	3.05	2.98	3.25	3.05	9.07	9.82	9.94	9.15	9.74	9.66
Total	99.17	99.95	99.67	99.06	100.09	99.48	99.30	99.86	99.90	98.94	99.23	100.06
Si	3.00	3.00	2.99	2.99	2.98	3.00	3.01	3.01	2.99	2.99	3.01	2.97
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01
Al	1.99	1.99	2.01	2.02	2.01	1.98	1.99	1.96	1.97	1.94	1.95	1.99
Cr	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.06	0.00	0.00
Fe	1.91	1.94	1.91	2.04	2.01	1.94	1.77	1.59	1.60	1.58	1.52	1.62
Mn	0.67	0.63	0.65	0.46	0.58	0.63	0.35	0.53	0.51	0.53	0.60	0.55
Mg	0.18	0.18	0.16	0.23	0.14	0.18	0.09	0.07	0.07	0.09	0.07	0.07
Ca	0.26	0.25	0.27	0.26	0.28	0.27	0.78	0.85	0.86	0.80	0.84	0.83
Total	8.01	8.00	8.00	8.00	8.01	8.01	8.00	8.00	8.01	8.00	8.00	8.03
X _{Alm}	0.63	0.65	0.64	0.68	0.67	0.64	0.59	0.52	0.53	0.53	0.50	0.53
X _{Sps}	0.22	0.21	0.22	0.15	0.19	0.21	0.12	0.17	0.17	0.18	0.20	0.18
X _{Prp}	0.06	0.06	0.05	0.08	0.05	0.06	0.03	0.02	0.02	0.03	0.02	0.02
X _{Grs}	0.09	0.08	0.09	0.09	0.09	0.09	0.26	0.28	0.28	0.27	0.28	0.27

Structural formulae calculated on the basis of 12 oxygens.

Table 2. Representative microprobe analyses of micas.

Mineral	Bt-I	Bt-I	Bt-I	Bt-II	Bt-II	Bt-II	Ms-I	Ms-I	Ms-I	Ms-II	Ms-II	Ms-II
SiO ₂	36.80	36.12	36.35	34.65	35.41	34.24	47.06	47.64	47.80	46.71	47.10	46.54
TiO ₂	2.05	1.70	1.92	1.92	1.91	1.60	1.39	0.23	0.54	0.50	0.24	1.50
Al ₂ O ₃	17.78	17.91	17.36	17.79	16.99	17.17	32.32	32.51	33.68	32.60	31.24	31.86
FeO	20.97	21.08	20.89	23.99	23.27	23.27	1.75	2.66	2.16	2.23	2.33	1.95
MnO	0.28	0.21	0.16	0.26	0.16	0.27	0.09	0.04	0.00	0.00	0.01	0.03
MgO	7.98	8.10	8.00	7.07	7.78	8.04	1.21	1.52	1.34	1.27	1.45	1.14
CaO	0.01	0.07	0.02	0.00	0.02	0.01	0.04	0.00	0.05	0.00	0.00	0.00
Na ₂ O	0.01	0.07	0.07	0.03	0.04	0.05	0.37	0.33	0.35	0.37	0.33	0.33
K ₂ O	8.94	8.77	8.87	9.28	9.78	9.11	10.39	10.25	10.29	11.09	11.21	11.00
Total	94.82	94.01	93.65	94.98	95.35	93.76	94.60	95.19	96.20	94.78	93.92	94.34
Si	2.82	2.80	2.82	2.71	2.76	2.71	3.15	3.15	3.13	3.14	3.20	3.15
Ti	0.12	0.10	0.11	0.11	0.11	0.10	0.07	0.01	0.03	0.03	0.01	0.08
Al	1.61	1.63	1.59	1.64	1.56	1.60	2.55	2.54	2.60	2.58	2.50	2.54
Fe	1.34	1.36	1.36	1.57	1.52	1.54	0.10	0.15	0.12	0.13	0.13	0.11
Mn	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Mg	0.91	0.93	0.93	0.82	0.90	0.95	0.12	0.15	0.13	0.13	0.15	0.11
Ca	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na	0.00	0.01	0.01	0.00	0.01	0.01	0.05	0.04	0.04	0.05	0.04	0.04
K	0.87	0.87	0.88	0.93	0.97	0.92	0.89	0.87	0.86	0.95	0.97	0.95
Total	7.70	7.73	7.71	7.82	7.84	7.85	6.94	6.91	6.91	7.00	7.02	6.99
X _{Fe}	0.60	0.59	0.59	0.66	0.63	0.62						

Structural formulae calculated on the basis of 11 oxygens.

Table 3. Representative microprobe analyses of plagioclase.

Mineral	Pl-I	Pl-I	Pl-I	Pl-I	Pl-II	Pl-II	Pl-II	Pl-II
SiO ₂	62.51	62.90	62.17	62.64	62.22	64.28	64.16	66.84
TiO ₂	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Al ₂ O ₃	22.60	23.57	23.72	23.72	22.86	22.20	21.97	20.21
CaO	4.35	4.71	5.24	5.00	4.50	3.54	3.32	1.08
Na ₂ O	8.57	8.80	8.56	8.60	8.42	9.13	9.46	10.74
K ₂ O	0.12	0.13	0.06	0.12	0.08	0.10	0.10	0.26
Total	98.16	100.11	99.77	100.08	98.07	99.26	99.00	99.12
Si	2.81	2.78	2.76	2.77	2.80	2.85	2.85	2.95
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al	1.20	1.23	1.24	1.24	1.21	1.16	1.15	1.05
Ca	0.21	0.22	0.25	0.24	0.22	0.17	0.16	0.05
Na	0.75	0.75	0.74	0.74	0.73	0.78	0.82	0.92
K	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
Total	4.96	4.99	4.99	4.98	4.96	4.97	4.98	4.99
X _{An}	0.22	0.23	0.25	0.24	0.23	0.18	0.16	0.05
X _{Ab}	0.78	0.77	0.74	0.75	0.77	0.82	0.83	0.93
X _{Or}	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01

Structural formulae calculated on the basis of 8 oxygens.

Table 4. Atom per formula unit values for Fe, Mg, Ca, Mn in garnet, Fe, Mg, Al(VI) in biotite and Ca, Na, K in plagioclase used for geothermobarometry and obtained temperatures and pressures for the M1 event.

Fe Grt	Mg Grt	Ca Grt	Mn Grt	Fe Bt	Mg Bt	Al ^(VI) Bt	Ti Bt	Ca Pl	Na Pl	K Pl	GB T (°C)	GBPQ P (kbars)
1.902	0.167	0.263	0.701	1.404	0.873	0.804	0.112	0.209	0.746	0.007	594	6.83
1.902	0.167	0.263	0.701	1.365	0.973	0.980	0.110	0.209	0.746	0.007	578	6.31
1.902	0.167	0.263	0.701	1.355	0.933	1.085	0.120	0.209	0.746	0.007	583	6.33
1.902	0.167	0.263	0.701	1.338	0.918	0.869	0.095	0.209	0.746	0.007	582	6.49
1.902	0.167	0.263	0.701	1.377	0.933	0.857	0.115	0.209	0.746	0.007	583	6.56
1.902	0.167	0.263	0.701	1.400	0.943	0.845	0.000	0.209	0.746	0.007	585	6.55
1.902	0.167	0.263	0.701	1.365	0.934	0.863	0.001	0.209	0.746	0.007	583	6.47
1.902	0.167	0.263	0.701	1.383	0.926	0.826	0.118	0.209	0.746	0.007	584	6.62
1.902	0.167	0.263	0.701	1.390	0.955	0.995	0.116	0.209	0.746	0.007	582	6.42
1.902	0.167	0.263	0.701	1.426	0.940	0.992	0.001	0.209	0.746	0.007	589	6.50
1.902	0.167	0.263	0.701	1.357	0.926	0.829	0.000	0.209	0.746	0.007	584	6.51
1.902	0.167	0.263	0.701	1.375	0.949	1.016	0.111	0.209	0.746	0.007	582	6.38
1.902	0.167	0.263	0.701	1.353	0.900	1.105	0.113	0.209	0.746	0.007	587	6.40
1.902	0.167	0.263	0.701	1.345	0.911	0.854	0.116	0.209	0.746	0.007	583	6.55

GB: garnet-biotite; GBPQ: garnet-biotite-plagioclase-quartz

Table 5. Atom per formula unit values for Fe, Mg, Ca, Mn in garnet, Fe, Mg, Al^(VI) in biotite and Ca, Na, K in plagioclase used for geothermobarometry and obtained temperatures and pressures for the M2 event.

Fe Grt	Mg Grt	Ca Grt	Mn Grt	Fe Bt	Mg Bt	Al ^(VI) Bt	Ti Bt	Ca Pl	Na Pl	K Pl	GB T (°C)	GBPQ P (kbars)
1.768	0.094	0.785	0.350	1.572	0.825	0.715	0.113	0.217	0.734	0.004	552	9.47
1.768	0.094	0.785	0.350	1.597	0.870	0.601	0.116	0.217	0.734	0.004	543	9.47
1.768	0.094	0.785	0.350	1.516	0.903	0.637	0.112	0.217	0.734	0.004	533	9.15
1.587	0.068	0.847	0.526	1.428	0.921	0.739	0.110	0.168	0.784	0.006	509	9.28
1.587	0.068	0.847	0.526	1.456	0.861	0.749	0.120	0.168	0.784	0.006	520	9.55
1.604	0.067	0.857	0.507	1.543	0.949	0.637	0.095	0.158	0.816	0.006	505	9.94
1.604	0.067	0.857	0.507	1.468	0.909	0.675	0.115	0.158	0.816	0.006	508	9.81

GB: garnet-biotite; GBPQ: garnet-biotite-plagioclase-quartz

Figure 1. Schematic geological map of the Svalbard Archipelago showing the position of the Caledonian basement provinces (modified after Gee and Tebenkov 2004). Green dashed line shows position of cross section Figure 3. Outlined box shows location of Figure 4.
160x227mm (300 x 300 DPI)

Figure 2. Tectonostratigraphic scheme showing the tectonic position of individual lithostratigraphic units in Wedel Jarlsberg Land. Colours correspond to those used on the Figure 4. Modified from Dallmann et al. (2015).

186x300mm (300 x 300 DPI)

Figure 3. WSW-ENE cross section through the West Spitsbergen Fold-and-Thrust Belt (WSFTB) from Nathorst Land across Van Keulenfjorden towards the west coast of Wedel Jarlsberg Land (modified from Dallmann et al. 1990, 2015; von Gosen and Piepjohn 2001). From WSW towards ENE, the major domains of the Eurekan deformation are exposed: (1) The western hinterland zone; (2) two large fold-structures of the thick-skinned, basement-involved fold-thrust complex; (3) thin skinned domain with sub-horizontal thrust faults with flats-and-ramps geometries and (4) the Central Tertiary Basin. The steep faults between and within domains (1) and (2) have possibly strike-slip kinematics. See Figure 1 for location. The approximate position of the study area is indicated by blue boxes and arrows.

129x64mm (300 x 300 DPI)

Figure 4. Geological map of the Antoniabreen area showing the Berzeliuseggene unit and its structural setting as well as the location of observation points (modified from Dallmann et al. 1990). 185x194mm (300 x 300 DPI)

Figure 5. View on the Aldegondaberget Ridge towards the south. The Berzeliuseggene unit (BU) is separated from the Carboniferous – Permian and younger Mesozoic strata by an angular unconformity shown as a white line with dots. The unconformity is presently nearly vertical, dipping towards the east at an angle of 70-80°, due to a passive rotation on the eastern flank of the basement-involved fold-thrust complex (compare Fig. 3).

88x60mm (300 x 300 DPI)

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114x92mm (300 x 300 DPI)

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113x77mm (300 x 300 DPI)

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86x50mm (300 x 300 DPI)

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78x42mm (300 x 300 DPI)

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178x213mm (300 x 300 DPI)

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122x120mm (300 x 300 DPI)