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Geology of the Kottas Terrane, Heimefrontfjella (East Antarctica)

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Abstract: The Kottas Terrane is the northernmost crustal block in the Heimefrontfjella. It is composed of juvenile Mesoproterozoic igneous rocks of calc-alkaline composition and minor sedimentary rocks, which underwent amphibolite-facies metamorphism in late Mesoproterozoic times (Grenvillian-age orogeny). Whereas central Heimefrontfjella was strongly affected by the East-African – Antarctic Orogeny in Late Neoproterzoic to Cambrian times, the Kottas Terrane shows only a weak overprint at brittle/ductile transition conditions, mostly manifested as northward-directed thrusts. The boundary between the Kottas and Sivorg terranes of central Heimefrontfjella is marked by the prominent Heimefront Shear Zone, which is exposed in two small nunataks immediately south of the main massif of Kottasberge.

Zusammenfassung: Das Kottas-Terrane bildet den nördlichsten Teil der Heimefrontfjella. Es wird aus mesoproterozoischen, juvenilen kalkalkalischen Magmatiten und untergeordnet von Sedimentgesteinen aufgebaut, die am Ende des Mesoproterozoikums eine amphibolitfazielle Metamorphose durchliefen. Während der zentrale Teil der Heimefrontfjella während der Ostafrikanisch – Antarktischen Orogenese stark überprägt wurde, findet man im Kottas-Terrane nur nordgerichtete Scherzonen mit Gefügen im spröd-duktilen Übergangsfeld. Die Grenze zwischen dem Kottas- und dem Sivorg-Terrane wird durch die Heimefront-Scherzone gebildet, die unmittelbar südlich des Hauptmassivs der Kottasberge aufgeschlossen ist.

INTRODUCTION

Sheet Vikenegga covers all known outcrops of the Kottas Terrane. This northernmost region of the Heimefrontfjella (main massif of Kottasberge / Milorgfjella) is lithologically and structurally very different from the central part of the range (Sivorgfjella, XU-Fjella, and northern Tottanfjella). Jacobs et al. (1996) defined this northernmost region, which is dominated by metamorphic rocks of mainly magmatic origin as the Kottas Terrane (Fig. 1). Geochronological data show that the terrane is made up of juvenile Mesoproterozoic protoliths, which were metamorphosed between 1090 and 1060 Ma. The rocks were only weakly affected by the latest Neoproterozoic/Cambrian orogeny (Jacobs et al. 2003). The southern boundary of the terrane is marked by the Heimefront Shear Zone (Fig. 2), which is only exposed in the sheared gneisses of two small nunataks of Lauringrabben and Hasselknippenova, but which can be clearly traced on aerogeophysical images (Golynsky & Jacobs 2001).

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METAMORPHOSED SUPRACRUSTAL ROCKS

In the Kottas Terrane, rocks of supracrustal origin are not very abundant, being exposed only in one recumbent syncline in the main massif and in the nunataks of Arntzenrustene and Hanssonhorna. The metamorphic supracrustal sequence is partly migmatitic, with thin (cm-scale) leucosomes developed parallel to the gneissic layering. This, coupled with the mineral parageneses hornblende-plagioclase ± garnet in metabasite layers, is broadly indicative of the amphibolite facies. Only calc-silicate rocks provided temperature-sensitive mineral assemblages, which could be explained by the relatively pressure-independent reaction

$1\ Tr + 11\ Dol \leftrightarrow 8\ Fo + 13\ Cc + 9\ CO_2 + 1\ H_2O$.

The reaction requires temperatures between 625 °C and 675 °C (Winkler 1979).

Paragneiss and calc-silicate rocks (KMS)

Paragneisses occur as finely layered sequences that include alternating biotite-plagioclase and garnet-biotite-plagioclase gneisses. Individual layers are up to 250 cm thick (Fig. 3) and the thickness of the whole succession in the main massif of Kottasberge is at least 200 m. At the isolated nunataks of Arntzenrustene, thickness estimation is impossible.

Brown biotite, plagioclase, and quartz are the main components of the paragneisses. Garnet, as well as K-feldspar, are minor components in individual layers. Common accessory minerals include apatite, detrital zircon, rutile, and opaque minerals such as magnetite and ilmenite. Intense ductile deformation under retrograde greenschist-facies conditions led to alteration of garnet to biotite and the formation of secondary muscovite.

A few quartzite layers are intercalated with the paragneisses. They contain apatite and various opaque minerals, which were identified as graphite, pyrrhotite, pyrite and marcasite (Bauer 1995). The mineral paragnesis of graphite and sulphides is typical for sedimentary protoliths rich in organic matter.

Within the paragneisses, a few layers of pale greenish-grey calc-silicate rocks and impure forsterite marbles occur. The main carbonate mineral is dolomite, with only ~10 % of the carbonate minerals being calcite, which mainly occurs as fine-grained crystals within the matrix. Forsterite in the impure marbles is only preserved as small serpentine pseudomorphs. Further common minerals are tremolite, diopside, quartz, biotite, and titanite. Grossular-rich garnets were only found at one locality in easternmost Arntzenrustene.

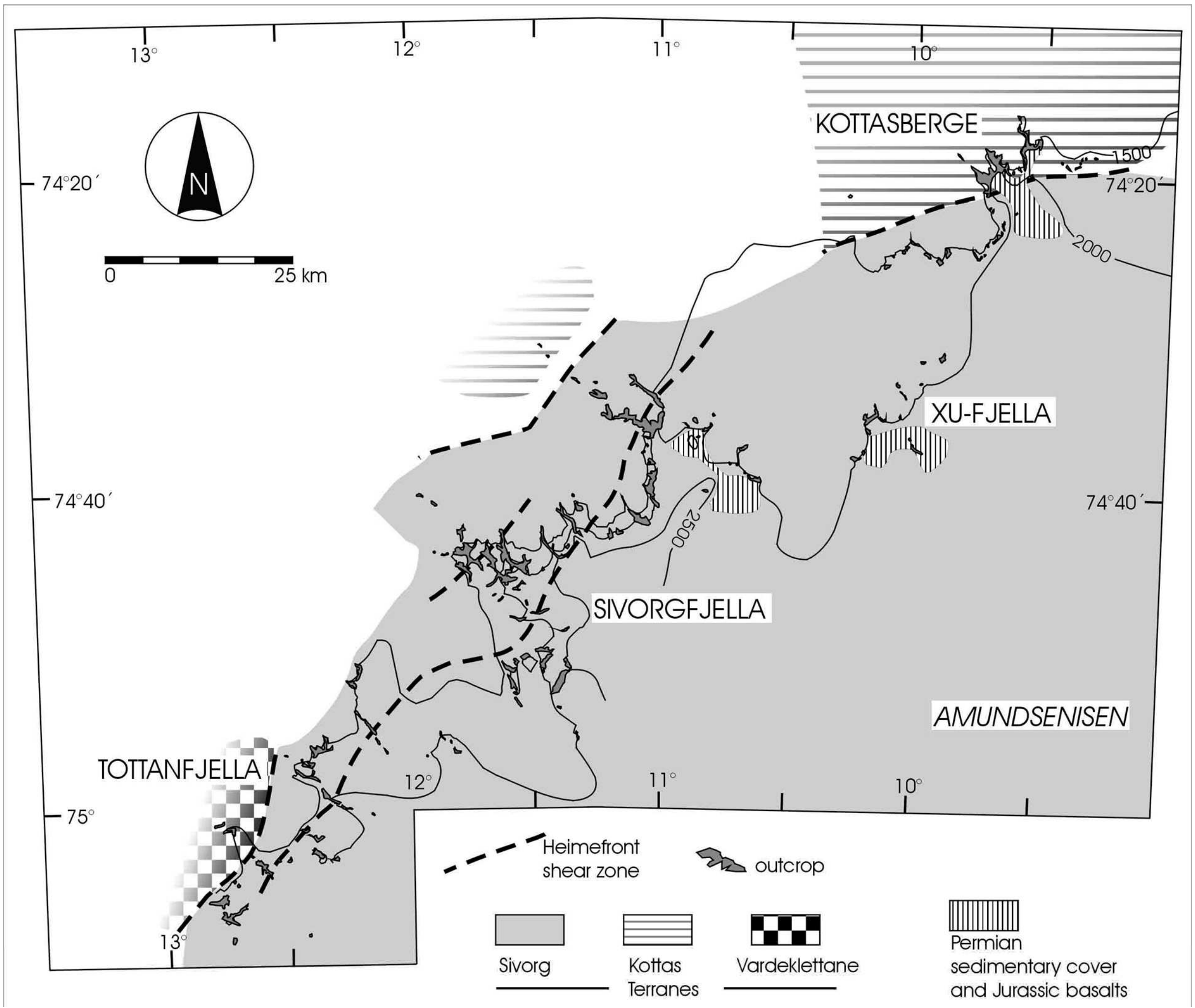

Fig. 1: Geological overview of the Heimefrontfjella.

Abb. 1: Geologische Übersichtskarte der Heimefrontfjella.

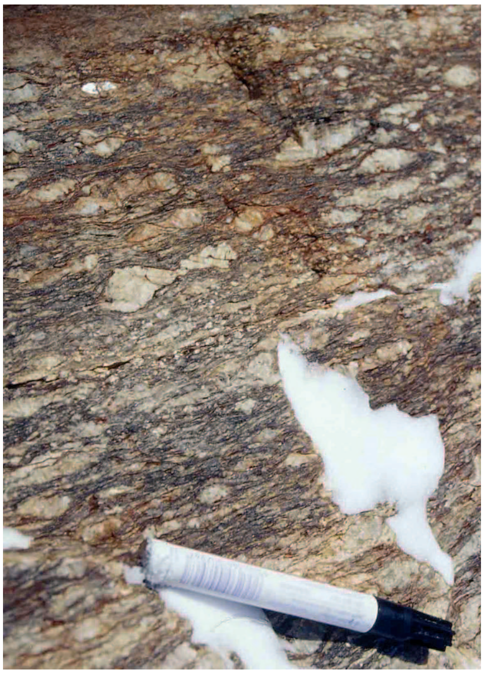

Fig. 2: Mylonitic augen gneiss (KG1), at Hasselknippenova, south of the Schivestolen massif. Aeromagnetical data by GOLYNSKY & JACOBS (2001) show that this outcrop is part of the Heimefront Shear Zone which separates the Kottas from the Sivorg Terrane.

Abb. 2: Mylonitischer Augengneiss (KG1) von Hasselknippenova, unmittelbar südlich des Schivestolenmassivs. Aeromagnetische Daten GOLYNSKY & JACOBS (2001) zeigen, dass dieser Aufschluss bereits zur Heimefront-Scherzone gehört, die Kottas- und Sivorg-Terrane gegeneinander abgrenzt.

Metarhyolite (KMR)

Pink, finely-layered "leptinitic" rocks of rhyolitic to rhyodacitic composition are interpreted as metamorphosed acid volcanics. A modal analysis of a typical metarhyolite is given in Table 1. The main components microcline, oligoclase, and quartz form an equigranular, granoblastic texture. BÜCKSTEEG et al. (1995) investigated zircons of three acid metavolcanite samples. They are relatively small (100 ±20 μm), with mean elongation (length/width ratio) between 1.99 and 2.50, which is characteristic for zircons in volcanic rocks. As a result of relatively high crystallization rates during a short cooling phase, they contain many elongate fluid inclusions and show only weak zonation. Crystal habits of zircons show a preferential development of (101) pyramids. Both prism faces (100)

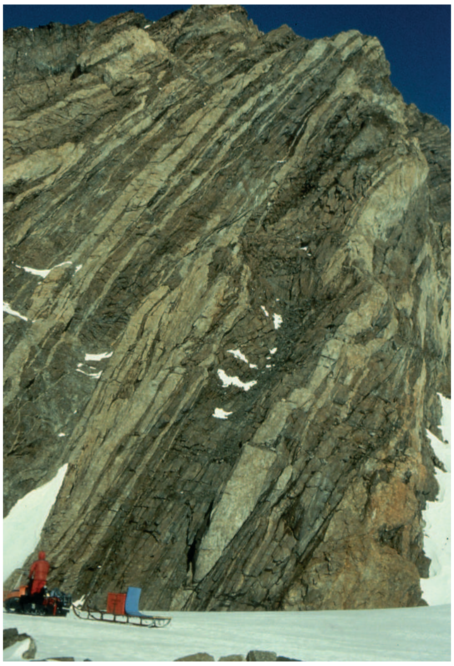

Fig. 3: Typical metatuffite sequence, exposed at Lütkennupen, view towards SW.

Abb. 3: Typische Metatuffit-Abfolge, aufgeschlossen am Lütkennupen, Blick nach SW.

and (110) occur, but most of the crystals have larger (100) prisms. According to Pupin (1980) such habits depict crystallization from calc-alkaline melts at temperatures between 850 °C and 700 °C. Zircon fractions from a fine-grained pink gneiss, which was interpreted as an acid metavolcanic rock, gave a conventional U-Pb zircon age of 1093^{+35}_{-39} Ma (ARNDT et al. 1991).

Metatuffite (KMT)

The supracrustal sequence is dominated by medium-grained layered grey gneisses of broadly tonalitic composition, which crop out at Buråsbotnen, southern Vikenegga, Haukelandnuten, and Arntzenrustene. They are intercalated on a centimetre to decimetre scale with leucocratic quartz-plagioclase gneissses and subordinate amphibolites. The most common grey tonalitic gneisses contain plagioclase phenocrysts up to 1 cm in size, set in a medium- or fine-grained matrix of quartz, plagioclase, biotite, and hornblende (Tab. 1). Retrograde reactions include saussuritization of plagioclase phenocrysts. This alteration, including the localized growth of calcite, clinozoisite, and epidote, is concentrated in the core of crystals thus traces the original normal zoning of magmatic plagioclase, and marks. BÜCKSTEEG et al. (1995) analyzed the zircon population of a metatuffite sample. This zircon population was composed of well-rounded detrital zircons and small euhedral zircons with similar habits to those in the acid metavolcanic rocks.

Melanocratic metavolcanic rocks, amphibolites (KMV)

Melanocratic metavolcanic rocks are medium-grained amphibolites with plagioclase, euhedral green hornblende, accessory titanite, clinozoisite, epidote, ilmenite and magnetite ± garnet. They are under-represented on the mapface of sheet Vikenegga, because they typically form only dm-thick layers in other supracrustal rocks and could not be shown as individual units at the mapping scale.

Geochemical analyses of melanocratic metavolcanic rocks from Arntzenrustene yielded trace element distributions, which are typical for N-type MOR basalts (BAUER 1995). At Arntzenrustene, they are interlayered with rocks of marine sedimentary origin (paragneisses, quartzites, calc-silicate rocks), fine-grained intermediate metatuffites and acid metavolcanics, which makes them similar to a metamorphosed

Rock type Sample	meta-rhyolite (KMR) KF28	meta-tuffite (KMT) KS37	melanocr. metavolc. (KMV) KS2	augen-gneiss (KG1) KS36	augen-gneiss (KG2) KF1	meta-tonalite (KTT) KB18	granite (KG3) KF24	diorite (KD4) KF22
Quartz	38	27	9	23	13	25	36	14
K-feldspar	23	3	-	57	16	1	23	-
Plagioclase	28	36	35	15	53	52	30	44
Biotite	3	24	4	5	8	7	< 1	4
Muscovite	2	-	-	-	1	-	-	-
Chlorite	2	< 1	-	< 1	< 1	< 1	4	1
Hornblende	-	2	41	< 1	2	14	-	32
Epidot/Zoisite	-	6	-	< 1	3	-	6	2
Titanite	-	< 1	-	< 1	2	< 1	< 1	2
Zircon	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Apatite	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1
Opaque	1	< 1	9	< 1	< 1	< 1	< 1	< 1

Tab. 1: Selected modal analyses (vol.%, ~1800 measured points per sample) of main rock types from the Kottas Terrane (BAUER 1995 and unpublished data).

Tab. 1: Ausgewählte Modalanalysen der Hauptgesteinsarten (Vol. %, ~1800 Messpunkte pro Probe) des Kottas-Terranes (BAUER 1995 und unveröffentliche Daten).

complex of a coloured melange origin.

ORTHOGNEISSES

Metatonalite-trondhjemite-diorite: Vikenegga Suite (KTT)

The oldest igneous suite consists of sheet-like intrusive bodies of a metamorphosed quartz diorite-tonalite-rondhjemite association, termed the Vikenegga Suite by JACOBS et al. (1996). The most mafic and probably oldest members of this suite include foliated ocellar quartz diorite, composed of green hornblende, plagioclase (recrystallized oligoclase), and biotite with accessory titanite, apatite, and zircon. Rocks of similar composition are intercalated as thin layers within the supracrustal gneisses, which are interpreted as possible volcanic equivalents.

The suite also includes grey, coarse-grained tonalitic gneisses. The most felsic members of the Vikenegga Suite, with up to 25 % quartz, comprise thin sheets of leucocratic metatrondhjemite. These leucocratic members show an equigranular granoblastic texture. With increasing amounts of mafic minerals the metamorphic foliation becomes stronger, mainly defined by lepidoblastic biotite.

Individual layers of each composition do not exceed ~5 m in thickness. The total thickness of the Vikenegga suite is unknown, but at the northern tip of Vikenegga at least 500 m are exposed, although the amount of structural repetition is also unknown.

Zircons from a metatonalite sample yielded a U-Pb SHRIMP age of 1130 ±17 Ma, which is interpreted as the crystallization age (Jacobs et al. 1999). Although this date is statistically within error of the date obtained on metarhyolites from the supracrustal rocks the tonalite intrudes (1095^{+35}_{-39} Ma, ARNDT et al. 1991), it puts a minimum age on the metarhyolite sequence.

Granitic augen gneiss (KG1)

Large sheet-like bodies of this augen gneiss type crop out at the southeastern part of the Kottasberge. Individual sheets measure up to 400 m in thickness and can be traced through the steep walls of the main massif. They intruded subparallel to the layering of the supracrustal gneisses and the Vikenegga Suite.

The gneisses are typically composed of large, pink K-feldspar augen (constituting up to 40 % of the total rock), between 2 and 4 cm in length, set in a fine-grained, greyish-green matrix of quartz, K-feldspar, oligoclase, green biotite with sagenitic exsolution textures, and green hornblende, with accessory titanite and zircon. In some samples biotite is partially altered to chlorite. The plagioclase is commonly replaced by a very fine-grained mixture of zoisite group minerals and white micas (saussuritization), which are not considered in the modal analyses of Table 1. The K-feldspar augen are often porphyroclasts rather than porphyroblasts, showing antithetic microfaults in sheared samples. An augen gneiss yielded a conventional U-Pb zircon age of 1110^{+23}_{-17} Ma, interpreted as the crystallization age (JACOBS et al. 1999).

Granodioritic augen gneiss (KG2)

A second group of augen gneisses has a different modal composition with plagioclase predominant over K-feldspar and low quartz content as compared to the granitic augen gneiss. Table 1 shows the modal analysis of a representative sample from this rock type. Furthermore, a high concentration of titanite in some layers is noteworthy. In the field the granodioritic augen gneiss is easy to distinguish from the granitic variety by its higher content of mafic minerals, which imparts a more greenish colour. These rocks also originally intruded as sheet-like bodies parallel to the layering of the supracrustal gneisses and underwent the same metamorphic and deformational history as the granitic augen gneisses (BAUER 1995).

The granodioritic augen gneisses yielded a conventional U-Pb zircon age of 1088 ±10 Ma, interpreted to represent the age of their intrusion (ARNDT et al. 1991).

Amphibolite (A)

Numerous mafic dykes, which underwent amphibolite-facies metamorphism are exposed in the Kottas Terrane. The thickness of the dykes varies between 10 cm and 20 m, with most falling in the 0.4 to 10 m width range. The amphibolite dykes are composed of green hornblende, plagioclase, biotite, ilmenite, and magnetite. Depending on the degree of a later retrograde overprint, additional epidote, chlorite and seladonite locally occur.

Most dykes intruded parallel to the pre-existing foliation of their host rocks, but were subsequently deformed and boudinaged. Such structural observations as well as a conventional U-Pb zircon age of 1031 ±25 Ma (ARNDT et al. 1991), suggests that they were intruded syntectonically with regard to the Grenville-age Mesoproterozoic orogeny.

LATE TECTONIC MAGMATIC ROCKS

A suite of calc-alkaline intrusive rocks was named the “Laudalkammen Suite” by BAUER (1995) and JACOBS et al. (1996). Characteristically, they have a very weak penetrative foliation or are unfoliated. They contain original magmatic mineral assemblages, underwent no higher than greenschist-facies metamorphism and their contacts are discordant to the host rocks.

Laudalkammen Granite (KG3)

The Laudalkammen Granite is pink and mainly coarse-grained, with rare finer-grained facies. It crops out at Laudalkammen, the top of Waglenabben and at one of the nunataks of Arntzenrustene.

The granite is composed of euhedral pink K-feldspar crystals up to 2 cm in diameter, set in a finer-grained matrix of microcline, plagioclase (oligoclase), and quartz (Tab. 1). Minor components are apatite, epidote, euhedral titanite, and biotite, which is partially altered to Fe-Mg chlorite. In the northern Laudalkammen area, weak deformation can be identified by undulatory extinction of quartz grains. The deformation increases to the southern margin of the intrusion in southern Laudalkammen, where elongated, dynamically recrystallized quartz grains define a foliation roughly parallel to the intrusive contact.

Laudalkammen Diorite (KD4)

At Laudalkammen, the granite is intruded by a c. 20 m thick diorite sill. The diorite is grey to greenish-grey with an equigranular, medium-grained texture. The main components are plagioclase (oligoclase-andesine) and bluish-green hornblende (barroisite). Quartz content reaches up to 15 % in some rocks, which classifies them as quartz-diorite in the Streckeisen nomenclature. Accessory components are biotite, titanite, zircon, and opaque minerals with secondary chlorite and epidote. A penetrative foliation is absent, but undulatory extinction of quartz indicates that both granitic host rock and the diorite sill underwent the same weak deformation.

Pegmatite and aplite

Acidic dykes are very abundant in the Kottas Terrane, but only a few of the larger dykes could be schematically drawn on the maps at the given scale. Fine-grained pale grey aplites are abundant at Vikenegga and Waglenabben. Their thickness ranges between 10 cm and 1 m. A sample from a microgranite vein gave an upper intercept conventional U-Pb zircon age of 1059 ±4 Ma (Bauer 1995). The same age (1060 ±8 Ma) was obtained from a very coarse-grained pegmatite from Vikenegga (Arndt et al. 1991). The pegmatites are composed of very large crystals of K-feldspar, up to 10 cm in length, intergrown with quartz, biotite, and minor muscovite, garnet, and accessory zircon. Further, rarely occurring minerals of the pegmatitic phase are fluorite and hematite, which were found in two pegmatites. Northern Vikenegga (Fig. 4) is soaked by anastomosing pegmatite veins and sheets, which form a complex, ramifying network in which individual sheets reach up to 10 m thickness.

STRUCTURE

Three deformation events are recognized in the Kottas Terrane (Bauer 1995, Jacobs et al. 1996). The older two fold phases (F_1 and F_2), well preserved in the supracrustal gneissses, are probably of Late Mesoproterozoic age, whereas the third (F_3) is possibly of Neoproterozoic to Cambrian age. Earliest F_1 isoclinal folds, identified at the eastern end of Laudalkammen, are refolded by F_2 folds. The latter are typically tight to closed, with axes gently plunging to the SE, and have a well developed axial planar foliation, which is the main foliation indicated in the stereograms on the maps. A SE- to south-plunging stretching lineation is locally developed. The main foliation is refolded by NE-SW trending, moderately SW-plunging F_3 fold axes. Both fold generations are exposed together at Waglenabben and Arntzenrustene, where their overprinting relations can be observed. Within the crystalline basement of the main massif of Kottasberge, a moderately SE-dipping metamorphic foliation can be found which, in places, is overprinted by a secondary, steeply south to SW dipping foliation (S_2).

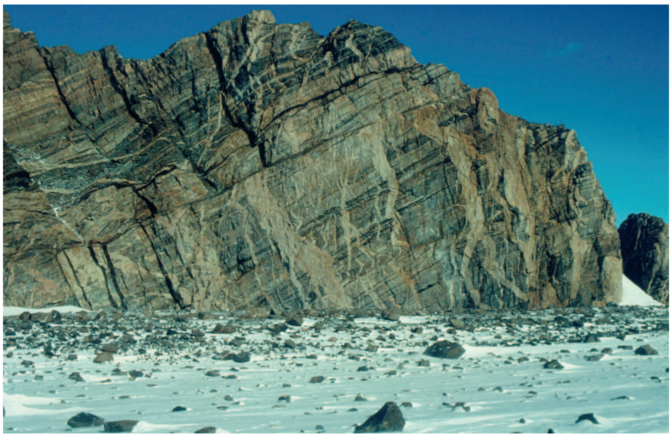

Fig. 4: Northern part of Vikenegga nunatak, metatonalite-trondhjemite-diorite suite (KTT), intruded by anastomosing coarse-grained pegmatites, which gave a U-Pb zircon age of 1060 ±8 Ma (Arndt et al. 1991). Note the subvertical mafic dykes, postdating the pegmatites on the left hand side. The thrust in the centre cuts all rock units and contains biotite that gave a Lower Palaeozoic K-Ar age of 473 ±11 Ma (Jacobs et al. 1995). Height of the wall approx. 200 m, view to SW.

Abb. 4: Nördlicher Teil von Vikenegga, eine Metatonalit-Trondhjemit-Diorit-Suite (KTT), getränkt von Pegmatiten, die ein konventionelles U-Pb-Zirkonalter von 1060 ±8 Ma (Arndt et al. 1991) aufweisen. Man beachte die subvertikalen mafischen Gänge am linken Bildrand, die die Pegmatite durchschlagen. Hellglimmer aus der Scherbahn in der Bildmitte weisen K-Ar Alter von 473 ±11 Ma (Jacobs et al. 1995) auf. Wandhöhe ca. 200 m, Blick nach SW.

Three geological cross-sections, which were drawn by reference to the vertical to overhanging, NE to E walls of the Schivestolen ridge, Vikenegga, and Laudalkammen nunataks, are shown on the Vikenegga map sheet. The main foliation is parallel to the compositional layering in the gneisses. At the northern tip, the metatonalite-trondhjemite-diorite suite (KTT) is soaked by coarse-grained pegmatites and some mafic dykes (MD), which could only be reproduced schematically on the profile. The complex situation of intrusive pegmatite north of the Wallnerspitze is shown in the field view of Figure 4.

At Brandstorpnabben, northern Vikenegga, Waglenabben and northern Laudalkammen, and in the southern walls of Buråsbotnen and Leabotnen, southeast-dipping ductile shear zones are exposed. Their thickness ranges between 1 and 4 m. The northern Vikenegga Thrust probably can be traced into the northern tip of Laudalkammen. Although the tectonic transport distance on individual thrusts is unknown, some thrusts are marked by very prominent, intensely deformed mylonites (Fig. 5a, b), comparable to those associated with major Alpine thrust nappes. The inclination of individual thrust planes is very gentle and in the central part of Vikenegga, the sole thrust of a klippe is sub-horizontal (see cross-section on sheet Vikenegga).

Microstructures such as SC fabrics, asymmetrical porphyroclasts, oblique grain shape fabrics, and oblique quartz-c-axes fabrics indicate a general top-to-NW or NNW thrusting direction (Bauer 1995). The various microtextures indicate that deformation occurred over a wide temperature range. Large (2-4 cm) K-feldspar porphyroclasts are deformed in a brittle manner, whereas smaller K-feldspars and plagioclase show ductile deformation. Undulatory extinction, deformation lamellae and kinking of twins are relics of mylonitization at

Fig. 5: a) NW-directed cataclastic shear zone, at the northern tip of Vikenegga. View to the SW; b) detail of Fig. 4a; sigmoidal shear bodies, indicating NW-directed sense of shear.

Abb. 5: a) Kataklastische Scherzone an der Nordspitze Vikeneggas, Blick nach SW. b) Detail von Abb. 4a; sigmoidale Scherkörper zeigen einen NW-gerichteten Schersinn.

higher temperatures at upper greenschist-facies conditions. The latest shear zones of this group are cataclastic and mark the change from ductile to brittle deformation. Sigmoidal shear bodies in these zones (Fig. 5b) indicate a consistent thrust transport vector towards the NW and NNW.

At northern Laudalkammen, the NNW-directed thrusts are cut by an E-W trending normal fault. Two parallel faults occur 400-500 m farther to the south, where they displace a large diorite body (Fig. 6). These steep faults are the youngest tectonic features observed in the Kottas Terrane.

The assumed boundary zone between the Kottas Terrane and the Sivorg Terrane is poorly exposed in two small nunataks, Hasselknippenova and Lauringrabben (sheet Vikenegga). The southern parts of both nunataks are made up of steeply S- to SSW-dipping mylonites, with a strongly developed stretching lineation plunging at 45-60° southwards. There, s-clasts clearly indicate that the Sivorg Terrane was thrust northwards over the Kottas Terrane with a significant subhorizontal strike-slip component. At this locality, the terrane boundary has a maximum width of 2 km. Farther south, at the nunataks of Haneborg-Hansenveggen (sheet Hanssonhorna), highly deformed rocks are absent; the bimodal metavolcanic rocks

Fig. 6: Laudalkammen, seen from the East. The grey mass is the diorite (KD4), which intruded the pink Laudalkammen granite (KG3); both are dissected by subvertical faults.

Abb. 6: Laudalkammen von Osten gesehen. Das dunkle Gesteinsband ist der Diorit (KD4), der den rosa Laudalkammen-Granit (KG3) intrudierte; beide Gesteine sind durch Störungen versetzt.

exposed there are typical of the Sivorg Terrane, showing that the terrane boundary has been crossed.

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