A reassessment of the Nils Jörgennutane suite in the Ahlmannryggen

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The Nils Jörgennutane suite, which has been recognised in the Ahlmannryggen by previous authors, is described and discussed. Two major lithologies within the suite are recognised, namely (i) A quartz monzonite to quartz monzodiorite group, which occurs at the type locality and (ii) Granite (sensu stricto) *from the Grunehogna area. The monzonitic rocks are shown to be late stage fractionation products of Borgmassivet intrusions, whereas the granites are small-scale products of anatectic melting of wet sediments adjacent to Borgmassivet intrusions. Neither of the two groups warrants status as a separate suite and it is proposed that the use of the term "Nils Jörgennutane suite" be discontinued. A revised definition of the Borgmassivet intrusions is suggested and the formal terms* ***Borgmassivet Suite*** *and* ***Grunehogna Granite*** *are proposed.*

Die Nils Jörgennutane-suite, wat in die Ahlmannryggen deur vorige outeurs herken is, word beskryf en bespreek. Twee hoof-litologieë word in die suite herken, naamlik (i) 'n kwartsmonzoniet- tot kwartsmonzodioriet-groep, wat by die tipe-lokaliteit voorkom; en (ii) graniet (sensu stricto) *van die Grunehogna-gebied. Daar word aangetoon dat die monzonitiese gesteentes laatfase-fraksioneringsprodukte van die Borgmassivet-intrusies is, waarteenoor die graniete kleinskaalse anatektiese produkte is van smeltings van nat sedimente langsaan die Borgmassivet-intrusies. Nie een van die twee groepe kan op die status van 'n suite aanspraak maak nie, en daar word voorgestel dat die gebruik van die term "Nils Jörgennutane-suite" beëindig word. 'n Gewysigde definisie vir die Borgmassivet-intrusies word gegee en die formele terme* ***Borgmassivet-suite*** *en* ***Grunehogna-graniet*** *word voorgestel.*

Introduction

The Nils Jörgennutane suite (NJS) in the Ahlmannryggen (Figs 1 and 2) was defined as consisting of "*felsic rocks, ranging in composition from syenodiorite and syenite to granodiorite, that occur as plugs, dykes, irregular bodies and veins in the Borgmassivet intrusions and the sediments of the Ahlmannryggen Group*" (Neethling, 1970; Wolmarans & Kent, 1982). The type locality is at Nils Jörgennutane and other exposures are found at Grunehogna, Ovenuten, Flårjuven, Slettfjel, Aurhö, Viddalskollen, Kjölrabbane and Snöhetta (Fig 1). The classification by Le Maitre (1989), used in this report, indicates that most of the granitic rocks and the syenite described in earlier work are granite (*sensu stricto*), quartz monzodiorite and quartz monzonite.

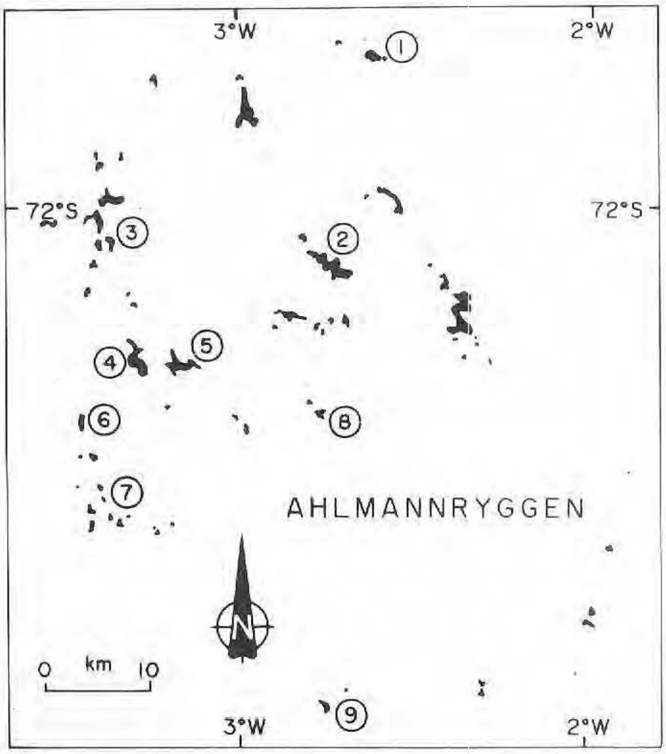


Fig 1: *Locality map. 1: Nils Jörgennutane; 2: Grunehogna; 3: Flårjuven; 4: Slettfjell; 5: Aurhö; 6: Ovenuten; 7: Kjölrabbane; 8: Snöhetta; 9: Viddalskollen*

The field characteristics, petrography and limited geochemistry of some occurrences of the NJS at Grunehogna (Krynauw, 1986; Krynauw *et al*, 1988), Nils Jörgennutane, Flarjuven, Slettfjell and Aurhö are described and discussed below. These investigations reveal that the existence of the NJS should be reevaluated.

Field relations and petrography

Nils Jörgennutane

Nils Jörgennutane consists of four nunataks (Fig 1) of which the easternmost is considered to be the type locality for the NJS (Neethling, 1970). Wolmarans and Kent (1982) described the occurrence as a "plug of syenodiorite", based on the work of Neethling (1964). The present study of the nunatak, which rises about 75 m above the snow line, shows that the base consists of medium-grained quartz monzodiorite (terminology after Le Maitre, 1989, based on norm data), with a high content of ilmenite and hematite pseudomorphs after magnetite (3-4 volume % total oxides). This granular rock is composed of variable amounts of andesine, uralitised

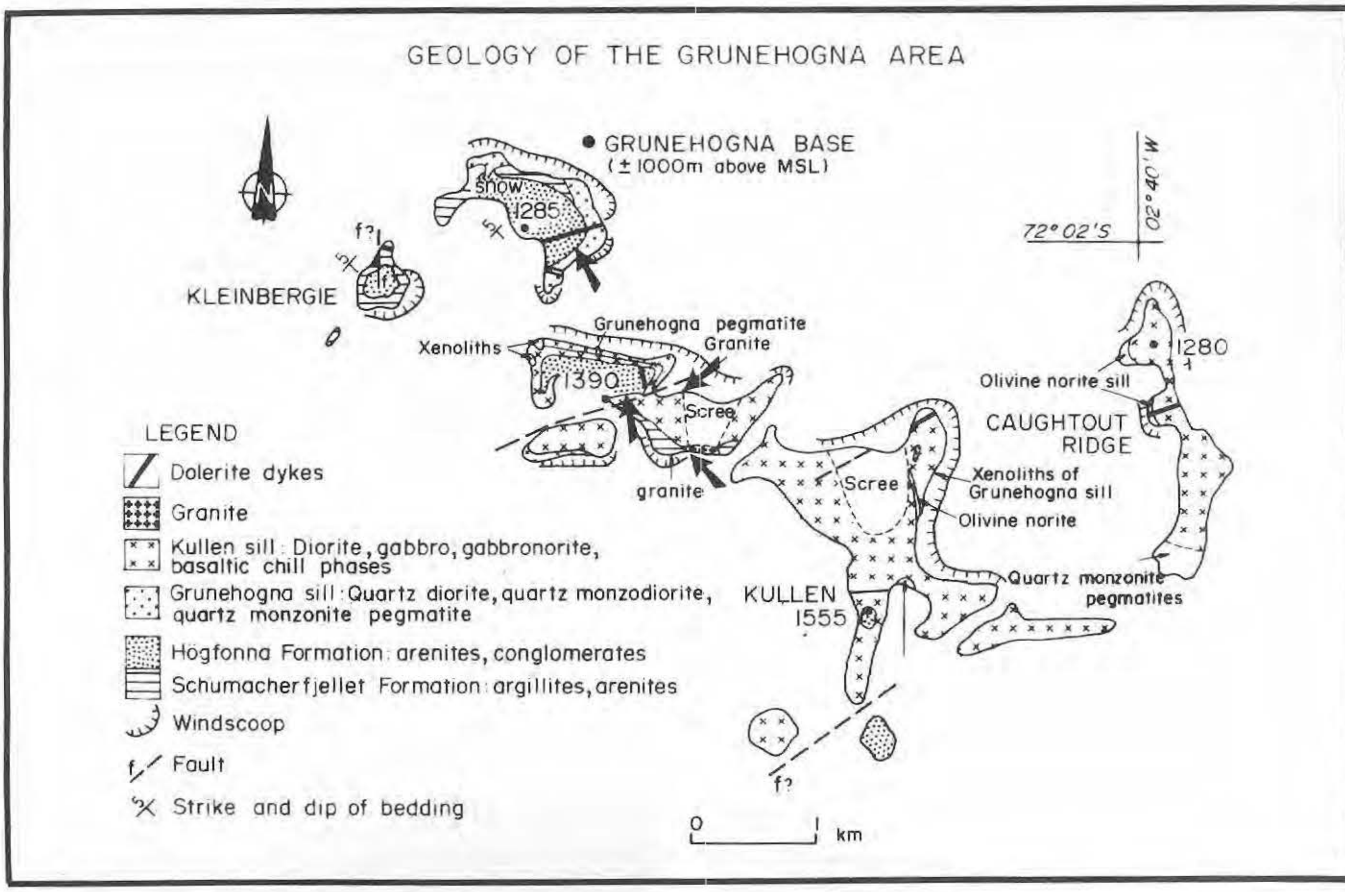


Fig 2: Geological map of the Grunehogna area, modified after Aucamp (1972), Bredell (1976) and Krynauw et al *(1988). The large arrows indicate areas where Nils Jörgennutane rocks were identified by previous authors. Similar rocks are present approximately 400 m north-east of Kullen Peak 1555 and on the southern extremity of Caughtout Ridge (thin arrows)*

clinopyroxene, hornblende, quartz and K-feldspar. Norm proportions are presented in Table 1. Some of the hornblende is euhedral and represents primary magmatic crystallisation, whereas late (deuteric or metamorphic) hornblende replaces clinopyroxene as uralitisation products. Tremolite and actinolite, associated with chlorite, are present as radiating needles. Plagioclase, which is partially to extensively sericitised and saussuritised, shows both normal and reversed zoning ranging in composition from about An_{35} to An_{50}. The ilmenite is subhedral to anhedral and locally exhibits poikilitic and symplectic textures. Discrete, anhedral hematite grains are typi-

Table 1

Norm compositions of selected samples from the "Nils Jörgennutane suite"

	G15/82	G16A/82	G16B/82	NJ1/88	NJ3/88	NJ4/88	GW6/81	GW10/81	G52/82
QTZ	11.40	12.19	19.88	9.36	9.77	12.42	23.54	34.20	22.72
OR	13.36	3.65	1.31	15.32	16.87	14.27	19.05	24.29	21.50
AB	24.51	26.21	15.77	29.32	28.99	25.61	26.94	25.99	34.55
AN	15.50	18.85	24.47	10.64	11.15	14.09	10.67	5.81	2.14
DI	9.67	19.98	29.17	8.92	8.99	9.26	2.46	1.78	1.75
HY	18.99	14.09	4.19	19.32	17.18	17.12	13.81	6.55	14.34
MT	2.19	2.02	1.75	2.24	2.03	2.04	1.45	0.75	1.60
IL	3.67	2.96	2.65	3.45	3.58	3.73	1.59	0.53	1.11
AP	0.73	0.05	0.79	1.45	1.47	1.50	0.50	0.10	0.26

G15-G16B/82: Grunehogna pegmatite, peak 1390
NJ1-NJ4/88: "Nils Jörgennutane suite" from the type locality
GW6-GW10/81: Grunehogna granite from southern outcrops at Grunehogna
G52/82: Granite from peripheral zone, western outcrops of peak 1390

cally associated with ilmenite.

Higher in the succession the rocks become increasingly heterogeneous in grain size, which varies from fine to coarse-grained to pegmatitic, and in composition (Table 1). There is a gradual increase in K-feldspar content of the quartz monzodiorite, which grades into a quartz monzonite in the upper 25 m of the nunatak. The K-feldspar occurs in orange-red granophyric concentrations (< 1 cm diameter) intergrown with quartz. This increase in K-felldspar content imparts a brick-red colour to the hand specimen, which is characteristic of all the rocks in the Ahlmannryggen that previously have been included in the NJS. Whereas K-feldspar in the quartz monzonite is present mainly in granophyric intergrowths, locally it is also found as discrete grains (Fig 3). The K-feldspar is microperthitic to perthitic and has a reddish-brown, cloudy appearance in thin section owing to the presence of finely disseminated, exsolved hematite. Quartz occurs in three forms, viz (i) granophyric intergrowths with K-feldspar and plagioclase; (ii) discrete, partially corroded grains which have undulose extinction and Boehm lamellae; and (iii) rarely, euhedral, unstrained grains. The mafic mineral content ranges from approximately 20 to 35 per cent. Interstitial minerals consist of chlorite, intergrown with tremolite/actinolate needles, sphene, carbonate and epidote/zoisite. Concentrations of epidote are present in elliptical patches, up to 10 cm in diameter, that have diffuse contacts. Apatite is an important minor constituent (in places $> 1\%$) and forms needles greater than 2 mm in length. In one sample, a hopper-type apatite grain, about 2 mm in length, was identified (Fig 4). Unless otherwise indicated, the petrography of the NJS elsewhere is identical to that of the quartz monzonite in the type area.

Porphyritic bodies of felsic quartz monzonite, present at the summit of the nunatak, vary in shape from near spherical (10-70 cm in diameter) to ovoids about 30 x 700 x 100 cm. Contacts with the enclosing quartz monzonite are sharply defined. The felsic quartz monzonite typically has a fine-grained groundmass, in which occur randomly arranged needles of amphibole up to 15 mm in length. The origin of these bodies has not been investigated, but they are considered to be autoliths derived from intrusion of the magma into its own upper chilled margin.

A 10 m thick tabular quartz monzonite body is present approximately 1 km west of the outcrops described above within a sill that is correlated with the Kullen sill of the Grunehogna area (Krynauw *et al*, 1988). The shape of the quartz monzonite is not clear owing to weathering of the exposed area, but it occurs within the granophyric, upper part of the Kullen-type sill, which also contains numerous quartz monzonite and quartz monzodiorite pegmatites.

Grunehogna area

The field relations at Grunehogna have been studied in more detail than at any other locality in the Ahlmannryggen area (Aucamp, 1972; Ferreira, 1986; Krynauw, 1986; Krynauw *et al*, 1988, in press). Wolmarans and Kent (1982), following Bredell (1976), identified four localities in the Grunehogna area where the NJS is present

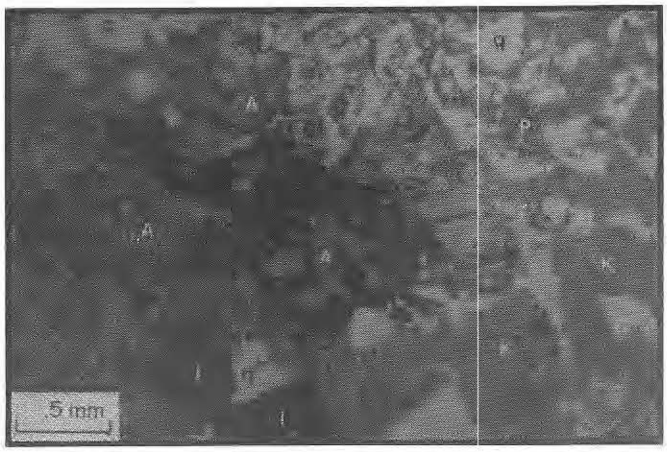


Fig 3: *Photomicrograph of typical quartz monzonite microstructure of the "Nils Jörgennutane suite", plane polarised light; q: quartz; K: K-feldspar; P: plagioclase; A: amphibole; I: ilmenite and/or hematite after magnetite. Euhedral amphibole at centre contains exsolved ilmenite*

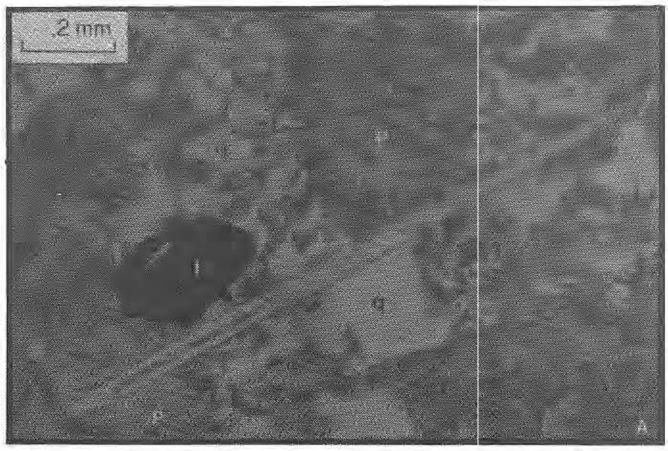


Fig 4: *Apatite needle in quartz monzonite showing hopper-type crystallisation. Symbols as for Fig 3*

(Fig 2), i e (i) on the SE side of Peak 1285; (ii) at Grunehogna Peak 1390; (iii) east of Peak 1390; and (iv) in the central part of Grunehogna, SE of Peak 1390.

(i) The occurrence at the SE side of Peak 1285 was described as a 3 m thick granodiorite sheet, which had intruded along the contact between a mafic sill (named the Grunehogna sill by Krynauw, 1986; and Krynauw *et al*, 1988) and sedimentary rocks of the Högfonna Formation. However, Krynauw *et al* (1988) have shown that these rocks are described better as a 3-m-thick peripheral zone consisting of reconstituted sedimentary rocks. They concluded that unconsolidated, water-saturated sediments in the zone were fluidised, recrystallised and partially fused following intrusion of the Grunehogna sill. The red colour of the peripheral zone is a result of crystallisation of K-feldspar, which subsequently exsolved fine-grained hematite.

(ii) The rocks at Grunehogna Peak 1390 are meta-arenites of the Högfonna Formation. They have not been fluidised to the same extent as those at Peak 1285 but have a light red colour, indicative of partial melting along grain boundaries, followed by crystallisation of K-feldspar (e g Krynauw *et al*, 1988, Fig 12f).

(iii) and (iv) The granite intrusions east and SE of Peak

1390 were first reported by Aucamp (1972) and Bredell (1976), both of whom described the occurrence as a 300-m-wide granodioritic intrusion. Krynauw *et al* (1988) named the intrusion the Grunehogna granite and pointed out that the width appears exaggerated owing to the development of large scree fields which obscure much of the contact with the country rocks. The granite locally forms cuspate bodies that downwarp the bedding of the sedimentary rocks, with the result that both conformable (i e sill-like) and cross-cutting (i e dyke-like) contacts are present.

The Grunehogna granite consists of granodiorite and granite (*sensu stricto*), but the latter rock type predominates. The granitic rocks, including those from the peripheral zones are medium-grained rocks with textures ranging from granular to granophyric. In the latter rocks, quartz, albite and K-feldspar in the granophyre occur in radial intergrowths which define white spheres up to 5 mm in diameter. Secondary epidote and chlorite are present in subordinate amounts.

Outcrops of the Grunehogna sill on the lower part of the north face of Peak 1390 are virtually identical in field, mineralogical and petrological characteristics to the outcrops on the eastern nunatak of Nils Jörgennutane, described above. However previous authors have not included this occurrence in the NJS. The uppermost 50 m of the sill consists of heterogeneous quartz monzonite to quartz monzodiorite pegmatite, named the Grunehogna pegmatite (Krynauw, 1986; Krynauw *et al*, 1988). The pegmatite has a sharply-defined lower contact with the underlying, medium-grained quartz monzodiorite, but the latter rock contains increasing amounts of orange-red granophyric quartz, K-feldspar and plagioclase intergrowths as its upper contact is approached.

Peripheral zone rocks, similar to those at nunatak 1285, occur at Kullen Peak 1555, about 400 m northeast of the peak, and on the southern extremity of Caughtout Ridge (Fig 2).

Table 2

Whole rock major and trace element geochemistry of samples from the eastern and east-north-eastern nunataks at Nils Jörgennutane

Sample	NJ1/89	NJ3/88	NJ4/88	NJ5/88
SiO_2*	57.57	58.20	58.23	54.82
$A_{12}O_3$	12.35	12.79	12.73	16.23
Fe_2O_3	1.54	1.40	1.40	1.06
FeO	12.48	11.35	11.34	8.62
MnO	0.23	0.22	0.20	0.16
MgO	1.90	1.92	2.02	4.58
CaO	5.01	5.16	5.83	9.65
Na_2O	3.45	3.42	3.02	2.75
K_2O	2.58	2.85	2.41	1.30
TiO_2	1.81	1.88	1.96	1.02
P_2O_5	0.61	0.62	0.63	0.13
Total	99.53	99.81	99.77	100.40
LOI	1.04	0.97	1.41	1.58
Nb**	15.7	12.0	13.6	6.7
Zr	226	219	227	110
Y	48.6	41.2	39.7	15.2
Sr	190	261	146	198
Rb	80	97	84	55
Zn	103	103	108	79
Cu	117	15	80	119
Ni	LDL***	LDL	LDL	33
Sc	31.0	30.6	32.0	32.4
Cr	1	LDL	1	32
Ba	759	849	638	337
V	30	42	36	227

* Oxides in per cent by weight
** Trace elements in parts per million
*** LDL: Below detection limit

Samples NJ1/88, NJ3/88, NJ4/88 from the eastern nunatak; NJ5/88 from the east-north-eastern nunatak at Nils Jörgennutane

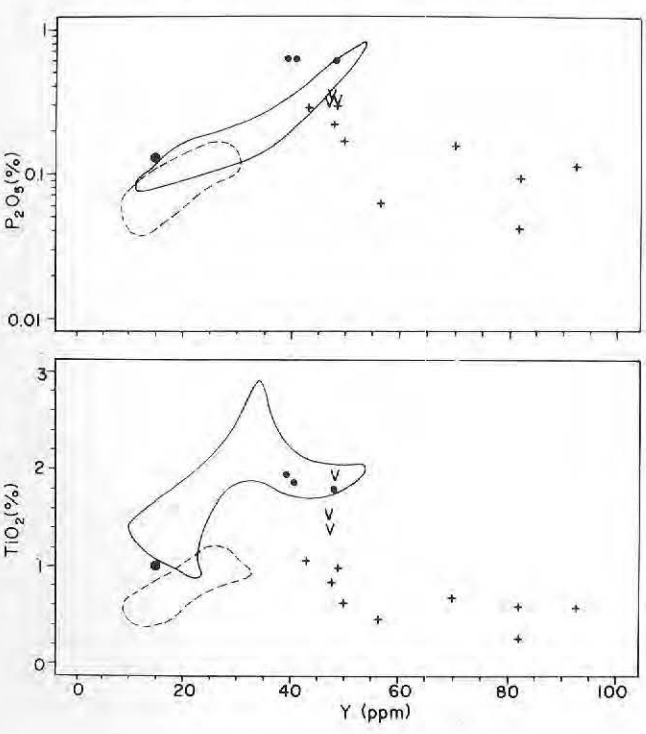
Flårjuven area

A nearly complete section of the Kullen sill is exposed in the Flårjuven area. The field and petrographic characteristics of the sill at Kullen and Preikestolen have been described by Krynauw (1986), Snow (1986) and Krynauw *et al* (1988). The sill typically consists of a basal zone, which may be up to 3 m in thickness, a cumulate zone (45-50 m), a central zone (120-130 m) and an upper zone (200-230 m). A 1-m-thick chilled margin is present at the top of the sill.

The central zone at Flårjuven main peak varies from a medium-grained porphyritic to granular and, locally, granophyric quartz gabbro to quartz monzogabbro. Orange-red granophyric intergrowths, as described for the Grunehogna sill, increase in amount upwards in the central zone. The gabbroic rocks grade into brick-red quartz monzonite and quartz monzodiorite of the NJS over a vertical distance of about 10 m, approximately 30 to 35 m below the contact with the upper zone. The medium to coarse-grained monzonitic zone is about 30 m thick. In places there are horizontal layers, 50 cm to 1 m thick, which are fine- to medium-grained, but all the petrographic features are similar to those described for the NJS monzonitic rocks. Quartz, carbonate, amphibole and epidote-filled vugs, all < 1 cm in diameter, occur throughout the monzonitic zone. The zone grades over a vertical distance of 2-3 m into a medium-grained, granophyric quartz monzogabbro, typical of the upper zone of the Kullen sill. However, at Flårjuven it is only about 10 m thick and is overlain by 10-20 m of coarse-grained, porphyritic gabbro. The overlying rocks of the upper zone at Flårjuven have been removed by erosion.

Geochemistry

Three quartz monzonite NJS samples from the easternmost nunatak of Nils Jörgennutane and one quartz gabbro, correlated with the Kullen sill, from the east-northeastern nunatak, were analysed for major and trace elements (Table 2). These samples were supplied by B Corner (Pers comm, 1988). The analyses were performed on a Philips PW 1404 X-ray fluorescence spectrometer in the Department of Geology, University of Natal, Pietermaritzburg. Three analyses of the Grunehogna pegmatite and nine from the Grunehogna granite have been



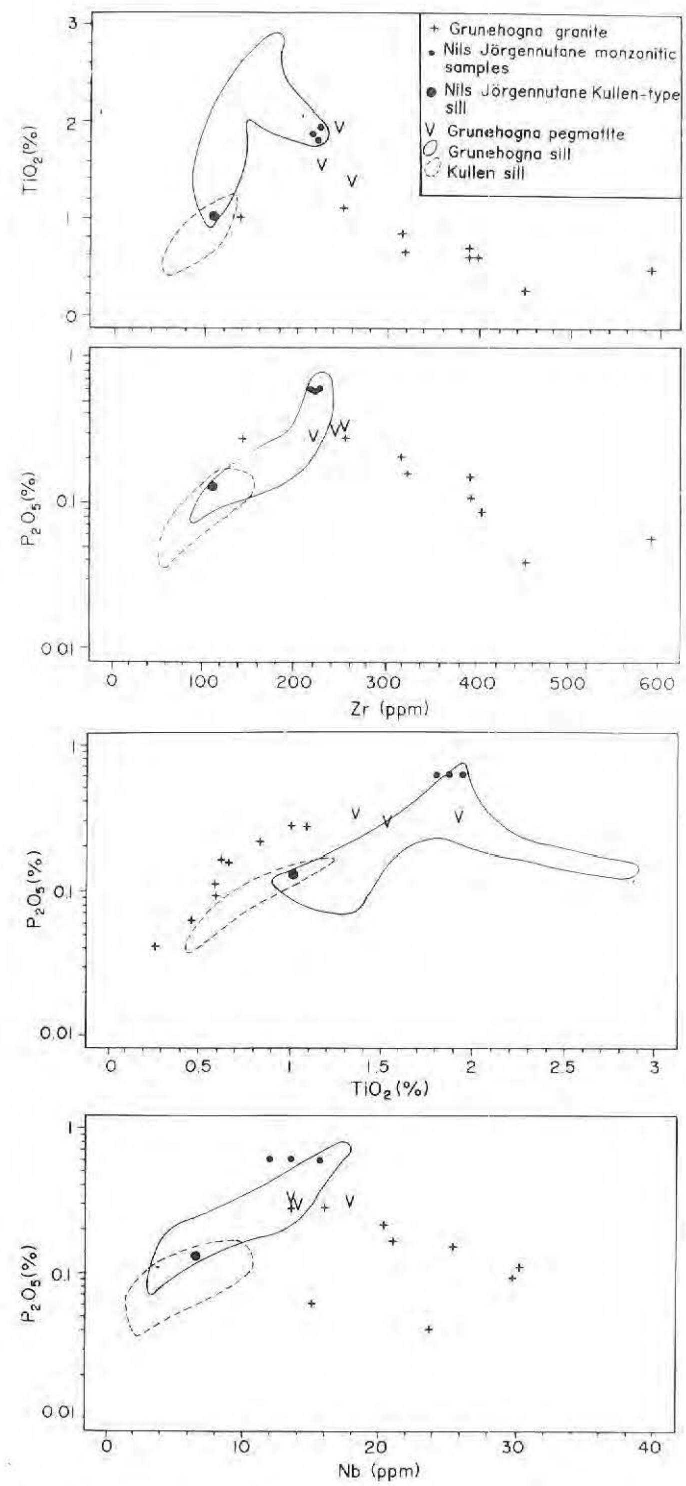


***Fig 5** Geochemical discrimination diagrams for incompatible, immobile elements. The three quartz monzonite samples from Nils Jörgennutane have high incompatible element contents compared with the sample (NJ5/88) from the Kullen-type sill, which plots within or close to the field defined by the samples from the Kullen sill in the Grunehogna-Preikestolen area. See discussion in text. Data for the Kullen and Grunehogna sills, Grunehogna pegmatite and Grunehogna granite are from Krynauw* et al *(in press) and Krynauw (1986)*

reported previously in Krynauw *et al* (in press) and Krynauw (1986). The heterogeneity of the NJS and evidence for extensive hydrothermal and/or deuteric alteration militate against a comprehensive treatment of the geochemistry of these rocks and only a brief summary, comparing them with some of the data from Grunehogna, is warranted. The geochemistry of the Borgmassivet intrusions in the Ahlmannryggen and Borgmassivet has been described by Krynauw *et al* (in press). Further data on the geochemistry of the Kullen and Grunehogna sills have been given by Krynauw *et al* (1988).

Sample NJ5/88 (Table 2) is a quartz gabbro, thought to be similar to the gabbros of the Kullen sill. The geochemical data from this sample plot consistently in the fields defined by the data from the Kullen sill in the Grunehogna and Preikestolen areas (Fig 5) and have lower incompatible element contents than the quartz monzonite. The monzonitic rocks from Nils Jörgennutane and Grunehogna show considerable scatter on diagrams employing elements, such as K, Rb and Sr, which are commonly considered to be mobile under deuteric, hydrothermal or low-grade metamorphic conditions. However, on discrimination diagrams involving the incompatible, immobile elements, Ti, P, Nb, Zr, and Y, the data from these samples plot within or very close to the geochemical fields defined by the Grunehogna sill.

On the present data set the relation of the monzonite to the Grunehogna granite is less clear. The latter define internally consistent fractionation trends (except for two anomalous samples on the P_2O_5_Nb diagram), which are not comparable with data from the Kullen and Grunehogna sills. For example, in the P_2O_5_TiO_2 discrimination diagram (Fig 5) the granite data define a trend parallel to those from the Kullen sill, whereas data from the Grunehogna sill and granite define intersecting trends on the discrimination diagrams.

Rb-Sr isotope geochemistry

Two "granodiorite" samples from Nils Jörgennutane and four from Grunehogna (i e from the Grunehogna granite) produced a Rb-Sr isotope whole rock errorchron of 1030 $\pm$ 70 Ma (Allsopp & Neethling, 1970). These data have been recalculated to 1020 $\pm$ 63 Ma (AB Moyes, pers comm, 1990). Barton *et al* (1983) determined an isochron age of 1008 $\pm$ 11 Ma for the Grunehogna granite on 10 samples, which have been recalculated by Moyes (pers comm, 1990) to 1005 $\pm$ 16 Ma. Sample GG5/81 of Barton *et al* (1983) was excluded from the data set for the recalculation. Moyes (pers comm, 1990) combined the data from Allsopp and Neethling (1970) and Barton *et al* (1983) and determined an isochron of 1001 $\pm$ 13 Ma on 14 of the 16 samples (excluding samples N326-a from Allsopp and Neethling, 1970; and GG5/83 from Barton *et al* 1983). In comparison, the Borgmassivet intrusions are considered to be between 1400 and 1800 Ma (Moyes & Barton, 1990).

Discussion

Neethling (1969) suggested that the "syenodiorites" (his terminology) of the NJS may be late-stage fractionation products of the Borgmassivet intrusions. However, he also considered that the NJS rocks could be related to, and contemporaneous with, the alkaline intrusions at Straumsvola and in the Sistefjell area. The field, petrographic and limited geochemical data discussed above are in agreement with Neethling's (1969) suggestion that all the monzonitic rocks which previously have been described as the "Nils Jörgennutane suite" are late stage fractionation products of the magmas of the Borgmassivet intrusions. Similar monzonitic products have crystallised in both Kullen-type and Grunehogna-type sills.

Granites from the Grunehogna area, previously ascribed to the suite, have been shown to occur as small-scale bodies derived from in situ anatectic melting of water-saturated sediments adjacent to intruding Borgmassivet magmas (Krynauw *et al*, 1988). Although both the monzonitic and granitic rock types are associated with the intrusions of the Borgmassivet intrusions, they are clearly not consanguineous.

The Rb-Sr isotope data discussed above appear to contradict the conclusion that the monzonitic rocks are fractionation products of the Borgmassivet intrusions, and suggest that the Grunehogna granite and Nils Jörgennutane monzonites are contemporaneous. It is not in the scope of this paper to discuss interpretations of the existing isotope data, but the following comments will suffice:

(i) Only two of the samples on which isotopic analyses have been performed are monzonitic rocks from Nils Jörgennutane and the rest are from the Grunehogna granite. Comparison between the Nils Jörgennutane and Grunehogna rocks on the basis of isotope data is therefore not valid.

(ii) Moyes and Barton (1990) have interpreted all the isotope data on the Borgmassivet intrusions indicating 1100-1000 Ma as reset ages. The isotopic age difference between the Borgmassivet intrusions and the Grunehogna granite may therefore be the result of a metamorphic or metasomatic event, or an artefact of the initial Rb-Sr system, as discussed by Zheng (1989).

Neither of the monzonitic or the granitic rocks previously identified in the NJS therefore warrants separate status as a suite and it is proposed that the use of the term "Nils Jörgennutane suite" be discontinued.

The Borgmassivet intrusions have been defined as "*all the relatively flat-lying sills of Precambrian age which intrude into the sedimentary volcanogenic rocks of the Ritscherflya Supergroup. The subordinate terms* ***Robertskollen suite*** *and* ***Nils Jörgennutane suite*** *are used for their ultramafic and felsic phases respectively*" (Wolmarans & Kent, 1982). Krynauw (1986) and Krynauw *et al* (in press) have shown that the Borgmassivet intrusions and Straumsnutane basalts are consanguineous, and the interpretation that the "Robertskollen suite" represents an ultramafic phase of the Borgmassivet intrusions is probably correct.

It is therefore suggested that

(i) the Borgmassivet intrusions be redefined to describe all the mid-Proterozoic intrusions into the Ritscherflya Supergroup, which can be shown on the basis of field relations and geochemical and mineralogical grounds to be consanguineous with the Kullen sill and Straumsnutane basalts;

(ii) the formal term **Borgmassivet Suite** be introduced for the Borgmassivet intrusions and the Straumsnutane basalts; and

(iii) the anatectic granites associated with the Borgmassivet intrusions be formally termed the **Grunehogna Granites.**

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