Newtontoppen granitoid rocks, their geology, chemistry and Rb-Sr age

A. M. TEBEN'KOV, Y. OHTA, JU. A. BALAŠOV and A. N. SIROTKIN

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A post-tectonic Caledonian granite in southern Ny Friesland has been fully mapped and the following new names are proposed: the Chydeniusbreen granitoid suite, consisting of the Raudberget granitoid body in the north; the Newtontoppen granitoid body in the middle; and the Ekkoknausane granitoid body in the south.

The contact relationships, internal structures and distribution of various rock types infer an asymmetric lopolith or a harpolith-like body, a large sickle-shaped intrusion stretched in the direction of general tectonic transport, for the Newtontoppen granitoid body.

Seven rock types are described in the Newtontoppen granitoid and four emplacement stages are recognised. The major rock types seem to have an alkali-calcic to alkalic bulk rock chemistry and show a transition between I- and S-type granite derived from anatectic melting of various protoliths under relatively high temperature conditions. Possible later K_2O introduction modified the earlier formed rock types.

A Rb-Sr whole rock age of 432 ± 10 Ma has been obtained by a seven point isochron with MSDW = 2.59 and an initial Sr isotope ratio = 0.715. This age is approximately 30 Ma older than the previously obtained K-Ar whole rock and Rb-Sr biotite ages, ca. 400 Ma, which represents the period of cooling. The high initial Sr isotope ratio supports the interpretation of an anatectic origin.

A. M. Teben'kov and A. N. Sirotkin, Polar Marine Geological Expedition, ul. Pobedy 24, 189510 Lomonosov, St. Petersburg, Russia; Y. Ohta, Norsk Polarinstitutt, P.O. Box 5072 Majorstua, N-0301 Oslo, Norway; Ju. A. Balašov, Geological Institute, Kola Science Centre of Academy of Sciences, ul. Fersman 14, 184200 Apatity, Russia.

Introduction

Three intrusive bodies of granitoid rocks are known in southern Ny Friesland and northwestern Olav V Land, northeastern Spitsbergen (Fig. 1, inserted map, right). The granitic rocks have been known from as early as the latter half of last century (Drasche 1874; Nordenskiöld 1875; Garwood 1899; Nathorst 1910). Backlund (1908) described two rock types and found that these granitoid rocks cut the Precambrian Hecla Hoek succession. A petrographic summary was made by Tyrrell (1922). Oddel (1927) found the northern locality in the Raudberget area, where the granitic rock is unconformably overlain by Carboniferous strata, and thus concluded that the granitoids are of Caledonian age. Hjelle (1966) and Krasil'ščikov (1969) made petrographic studies and described another separate locality in the south around the Ekkoknausane area, in the upper reaches of Nordenskiöldbreen.

These granitoid rocks have been called the Chydenius granite (Oddel 1927) or the Chydenius batholith (Harland 1959). However, as the place name "Chydenius" does not exist, these names should be changed according to the suggestion of the Norwegian Stratigraphic Committee. Chydeniusfjella is actually outside the distribution area of the granitoid rocks. Small nunataks consisting of the granitoid rocks occur on both sides of Chydeniusbreen; therefore, the following new names will be introduced here: the Chydeniusbreen granitoid suite for the three bodies together, the Raudberget granitoid body for the northern occurrence, the Newtontoppen granitoid body for the middle massif, and the Ekkoknausane granitoid body for the southern locality (Fig. 1, inserted map, right).

The rock compositions range from clinopyroxene-bearing granodiorite to granosyenite (Hjelle 1966; Krasil'ščikov 1969), and the structure has been considered a batholith, the three

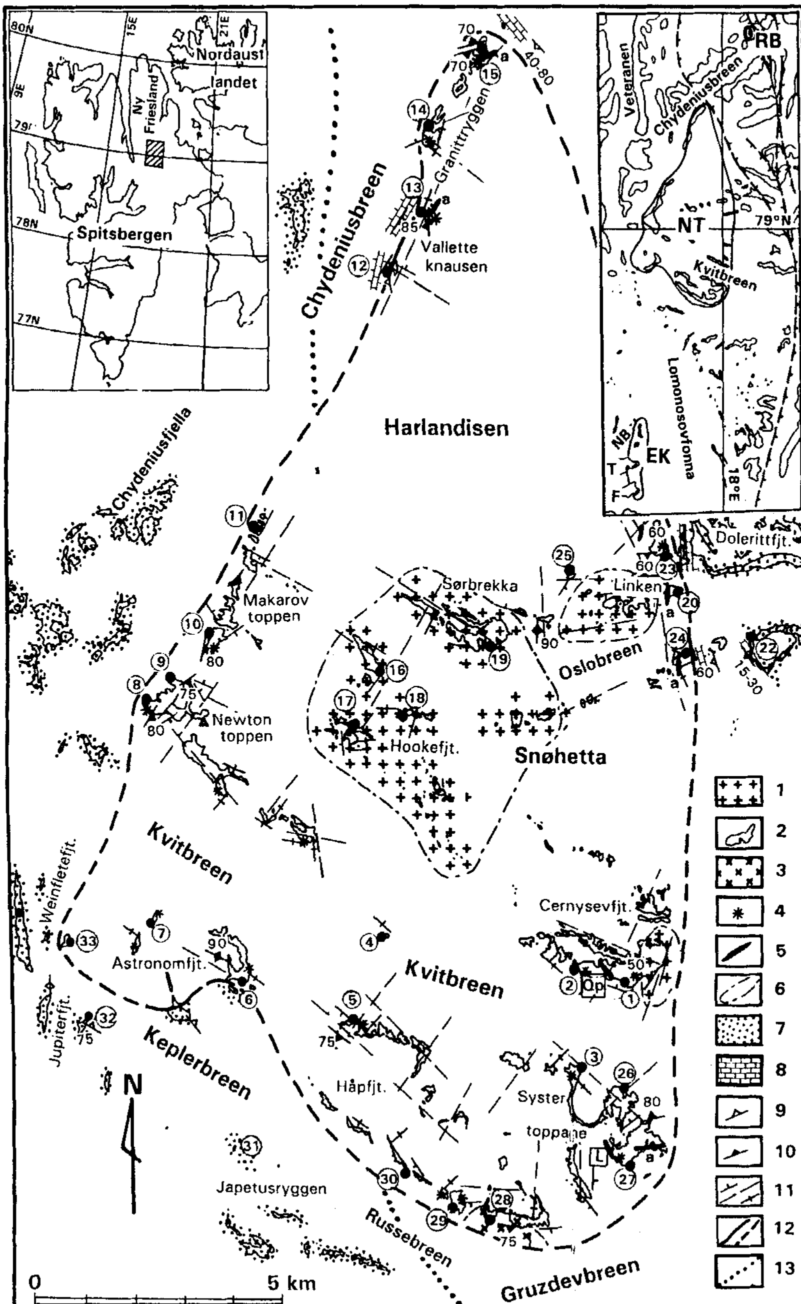

Fig. 1. Geological map of the Newtontoppen granitoid body, with inserted location maps. Inserted map in the right: RB = Raudberget granitoid, NT = Newtontoppen granitoid, EK = Ekkoknausane granitoid, NB = Nordenskiöldbreen, T = Terrierfjellet, F = Ferrierfjellet. Key: 1, grey granites; 2, (without ornament) pink-grey granosyenites; 3, granosyenite with aligned K-feldspar; 4, pegmatites; 5, aplites (a), quartz-feldspar porphyry (Qp) and lamprophyre (L); 6, estimated outlines of the rock types; 7, meta-clastic sediments of the Veteranen Group; 8, marbles of the Akademikerbreen Group; 9, cleavages of the metasediments; 10, mesoscopic structures within the granitoid rocks; 11, joints and their general trends; 12, observed and estimated boundary of the Newtontoppen granitoid body; 13, estimated boundary between the Veteranen and the Akademikerbreen Groups. Dot and Nos. with circle: observation points and sample localities (ref: all tables and Figs. 2, 3, 4, 9, 10).

bodies being considered to be continuous under the surface (Harland 1959). The Ekkoknausane granitoid has been thought to be the roof of the batholith, rich in xenoliths and aplite-pegmatite dykes (Hjelle 1966). Krasil'ščikov (1969, 1979) considered the exposures in Ekkoknausane to be a group of small intrusions.

The Newtontoppen granitoid body cuts the strata of the metasediments of the Lomfjorden Supergroup (Harland 1959). The cooling age has been given by K-Ar whole rock ages of 385–406 Ma and Rb-Sr biotite ages of 401–402 Ma (Hamilton et al. 1962).

The present paper describes the field occurrences of all three bodies, the bulk rock chemistry, and the Rb-Sr whole rock isochron age from the Newtontoppen granitoid body.

Contact relationships

The contacts of the Newtontoppen granitoids to the surrounding metasediments are evidently cross-cutting and intrusive. The surrounding rocks at the contacts are meta-arenaceous sediments of the Veteranen Group on the western side, and marbles and meta-pelitic rocks of the Akademikerbreen Group to the east, both of the Lomfjorden Supergroup of Neoproterozoic age. The greenschist-subgreenschist facies metamorphic mineral assemblages in these rocks were locally superimposed by middle amphibolite facies assemblages in the thermal aureole produced by the granitoids, as much as 100 m away from the contacts. The meta-arenaceous rocks at the southwestern contact (Fig. 1, Loc. 6) were converted into andalusite-cordierite-biotite hornfelses. The carbonate rocks at the northwestern (Fig. 1, Loc. 13) and middle eastern (Fig. 1, Loc. 23) contacts recrystallised into marbles with wollastonite, tremolite and quartz, and the meta-arenaceous rocks at Loc. 23 were converted into biotite-cordierite-quartz hornfelses.

The contact surface dips 70–90° in the south and west, and 40–60° in the north and east, both beneath the granitoid body. Thin aplite veins are confined within the body, striking subparallel to the contacts, and have not been seen intruding the surrounding rocks. No exotic xenolith has been found, but preferred alignments of elongated melanozomes are distinct in the marginal part of the body.

The Raudberget granitoids form a small nunatak which is located ca. 12 km NE of the Newtontoppen granitoid body, on the northern side of Chydeniusbreen (Fig. 1, inserted map, right), and the continuation to the latter is uncertain. The granitoid rocks are unconformably covered by flat lying Carboniferous strata.

The Ekkoknausane granitoids (Fig. 1, inserted map, right) consist of five nunataks, and are probably covered unconformably by the Carboniferous Nordenskiöldbreen Formation. The granitoids show sharp intrusive contacts to the Veteranen Group quartzites and sandstones at Terrierfjellet and Ferrierfjellet, southeast of Nordenskiöldbreen. Aplitic and granitic veins increase in the surrounding rocks approaching the contacts. A 50 m by 100 m granitoid mass cuts a quartzite-sandstone succession on the southern side of Ferrierfjellet, possibly a stock or a dyke, though the boundary is covered by scree. At Terrierfjellet, the westernmost part consists of gneissic rocks of the Planetfjella Group in fault contact with the Veteranen Group which forms the eastern part. The granitoid rocks cut a quartzite-sandstone succession of the latter.

At the three nunataks of Ekkoknausane, in the uppermost reaches of Nordenskiöldbreen, the granitoid rocks are markedly heterogeneous, containing quartzo-pelitic xenoliths with cross bedding and ripple marks, dark patches and seams of melanocratic inclusions containing clinopyroxene-hornblende aggregates, and irregular blocks of gabbroic and gneissose granitic rocks with cataclastic textures. Some dark inclusions show orbicular structures.

In summary, the Ekkoknausane granitoid body is located near the boundary between the Mesoproterozoic Planetfjella and Neoproterozoic Veteranen Groups, and the Newtontoppen granitoid body is situated around the boundary between the Veteranen and Akademikerbreen Groups. The Raudberget granitoid body occurs within the Akademikerbreen Group, but near the eastern marginal fault zone of the Neoproterozoic metasediments towards the Carboniferous to the east.

Structure of the Newtontoppen granitoid body

Alignments of K-feldspar phenocrysts and elongated melanozomes are the main mesoscopic structural elements within the Newtontoppen granitoid body. These structures are confined to the peripheries of the body and are mainly oriented subparallel to the margins (Fig. 1), except for two measurements in the eastern and southeastern margins (Locs. 23 and 27 in Fig. 1).

The K-feldspar phenocrysts sometimes include granulated plagioclase, especially near their rims. No granulated plagioclase has been seen in the non-porphyritic lithologies. This means that the K-feldspar phenocrysts were formed in the granulated parts of the rocks; thus the K-feldspar porphyritic parts generally show the distribution of granulation, which in turn suggest locally granulated parts in the body during emplacement movements. The interior of the body is completely massive, and a weak planar structure represented by preferred arrangement of phenocrysts could be measured at only one locality.

Joints are regularly developed in the body on two steep dipping planes, one subparallel and the other subperpendicular to the contacts, and on one subhorizontal plane (Fig. 1). Small dip-variations of the horizontal joints infer a gentle dome-like cooling surface over the body. The simple joint pattern throughout the body suggests a single cooling unit.

Later aplitic and quartz-feldspar porphyry dykes occur along the peripheries within the body from the north to the southeastern margin. These are obliquely cut by the steep dipping joints.

A lamprophyre dyke occurs near the southeastern margin. This rock is petrogenetically unrelated to the granitoids, but often occurs near Caledonian granite intrusions in Svalbard (Lauritzen & Ohta 1984; Kovalyova & Teben'kov 1986).

Weak post-consolidation movements have been recorded as slips along joint surfaces near the western margin (Loc. 8 in Fig. 1), where the surfaces are covered by chlorite. A 3 m-wide shear zone with hematite has been observed at Valletteknausen, on the southern side of Chydeniusbreen (Loc. 13 in Fig. 1), separating the porphyritic granite from Carboniferous white-grey limestones, without any thermal effect.

The Newtontoppen granitoid body is assumed to be an asymmetric lopolith or a harpolith-like shape; a large sickle-shaped intrusion elongated in general tectonic transport direction, based on the following evidence: (1) steep dips of the contact surfaces beneath the body in the southwest and moderate dips from north to southeast, (2) relatively rich melanozomes in the south and southwest, and (3) the distribution of aplite dykes from the southeast to the northern margin. This suggests that the body has a steep root in the southwest and an extended thinner tongue to the east and north. The exposed thickness of the body is about 900 to 1000 m in the southern to southwestern parts. The roof of the harpolith-like body has been removed by erosion. The contact hornfelses having andalusite-cordierite assemblages infer low pressure conditions at a relatively shallow depth.

Petrography

Backlund (1908) described porphyritic and non-porphyritic varieties from the granitoid rocks, while Oddel (1927) wrote that these varieties are caused by various degrees of surface weathering. Hjelle (1966) reported that the modal compositions of the rocks range from granodiorite to granosyenite. The following rock types have been recognised in the Newtontoppen granitoid body in the field, with their field names, referring to Streckeisen (1976):

1. melanozomes and dark grey granosyenites,
2. pink-grey granosyenites and pink quartz monzonites,
3. grey granites,
4. granosyenite with aligned K-feldspar phenocrysts,
5. aplitic veins,
6. pegmatites,
7. quartz-feldspar porphyry.

Melanozomes and dark grey granosyenites

These rocks are represented by melanozomes and dark varieties of the more common pink-grey granosyenites. The melanozomes (sample nos. 1, 2 in Tables 1, 2 and Figs. 2–4) occur as inclusions in various types of granosyenites near the margin of the body, as round and/or elongated patches and seams of several cm to 4–5 m in length, with partly diffused margins. They contain more mafic minerals and less quartz than the host rocks, with modal compositions of melanocratic granosyenite. Their constituent minerals are the same as other granosyenites and they are considered to be cognate inclusions. Some gabbroic inclusions found in the Ekkoknausane body could be similar in origin. The melanozomes contain as much as 10 modal % clinopyroxene which is always sur-

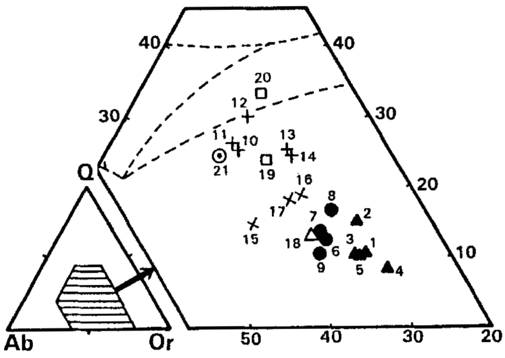

Fig. 2. CIPW normative ratios, Q-Or-Ab diagram. Key: solid triangles = melanozomes and dark grey granosyenites; solid circles = pink-grey granosyenites; crosses = grey granites; oblique crosses = pink quartz monzonites; open triangles = granosyenite with aligned K-feldspar; open squares = aplites; circle with dot = quartz-feldspar porphyry. These symbols are the same in all figures, except for Figs. 9 and 10. Broken curves: eutectic minimums at various vapour pressures. Nos. refer to the first column of Table 1.

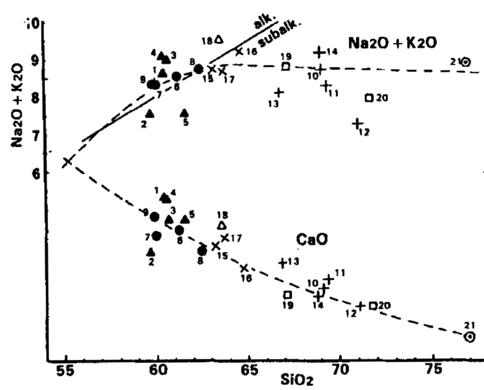

Fig. 4. $Na_2O + K_2O$ and CaO vs. SiO_2 diagram, in weight percent. Alkali-subalkali division: Irvine & Baragar (1971). The alkali-lime index is roughly estimated between 56 and 47. Same nos. and symbols as Fig. 2.

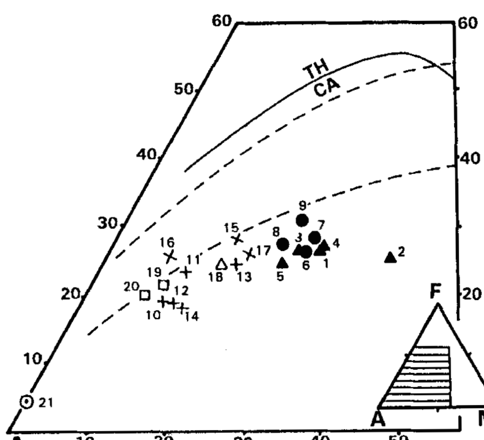

Fig. 3. AFM diagram. TH-CA dividing curve: Irvine & Baragar (1971); between the two broken curves: common CA field (Ringwood 1974). Same nos. and symbols as Fig. 2.

rounded by green prismatic hornblende (ca 15 modal %). Brown biotite occupies ca. 10 to 15 modal % of the rock. K-feldspar occurs interstitially in most rocks, but it is locally phenocrystic and includes many grains of prismatic plagioclase and mafic minerals.

The dark grey granosyenites (sample nos. 3, 4, 5 in Tables 1, 2 and Figs. 2–4) are more coarse-grained than the melanozomes, having similar modal compositions, locally with K-feldspar porphyritic texture. They show a gradational transition contact with the pink-grey granosyenites.

Syenites, monzonites and granites

The differences in modal compositions of quartz and mafic minerals and the colour of K-feldspar discriminate these rock types; pink-grey granosyenites (sample nos. 6 to 9 in Tables 1, 2 and Figs. 2–4), pink quartz monzonites (sample nos. 15 to 17 in Tables 1, 2 and Figs. 2–4) and grey granites (sample nos. 10 to 14 in Tables 1, 2 and Figs. 2–4).

These rocks occupy ca. 90% of the Newtontoppen granitoid body. The grey granite occupies the center of the body, while the other two rock types are irregularly mixed and occur around the grey granite. No cross-cutting relationship has been observed between them and the borders are gradational.

All of these rocks are K-feldspar porphyritic; phenocrysts are 4–5 cm in size and occupy ca. 40–50 modal % of the rocks. K-feldspar always exceeds plagioclase, and microcline twins are distinct in the K-feldspars of the granosyenites and quartz monzonites, while not distinct in the grey granites. The matrices of all three rock types show a coarse-grained, hypidiomorphic texture and consist of K-feldspar, quartz and plagioclase in similar amounts (5–20 modal % each), biotite and hornblende (5–20 modal % each) and clinopyroxene. Clinopyroxene is absent in the grey

Table 1. Major element compositions of granitoid rocks from the Newtontoppen granitoid body. The first numbers in the second column correspond to the locality numbers in Fig. 1. Melanozomes and dark grey granosyenites: 1–5; pink-grey granosyenites: 6–9; grey granites: 10–14; pink quartz monzonites: 15–17; granosyenite with aligned K-feldspar: 18; aplites: 19 and 20; quartz porphyry: 21. No. 17 is a quartz monzonite from the Raudberget granitoid body. The sample numbers are common in all tables and figures. I = average I-type granite, S = average S-type granite from Taylor & McLennan (1985).

No. in Figs. 2–5	Loc. No. in Fig. 1	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	ig. loss	Total
1	1-3	60.40	1.00	13.66	0.97	4.08	0.13	5.02	4.30	2.17	6.47	0.37	1.35	99.92
2	5-2	59.68	1.20	13.26	1.00	4.11	0.10	7.12	2.86	1.94	5.62	0.60	2.41	99.90
3	8-1	60.64	0.93	13.52	0.65	4.29	0.10	4.41	3.72	2.37	6.64	0.47	2.35	100.09
4	23-2	60.39	1.06	12.76	1.37	4.07	0.13	5.39	4.27	2.04	7.06	0.32	1.26	100.12
5	5-1	61.55	0.95	12.40	1.02	3.60	0.08	4.21	3.72	2.45	7.11	0.45	1.71	99.25
6	9-1	61.20	0.88	14.67	0.89	3.90	0.10	4.41	3.44	2.57	6.01	0.45	1.54	100.06
7	11-1	60.03	0.95	15.30	0.95	4.11	0.10	4.51	3.29	2.13	6.22	0.46	1.77	99.82
8	8-2	62.42	0.68	13.74	1.90	3.06	0.07	3.78	2.83	2.56	6.30	0.37	2.09	99.86
9	8-3	59.85	0.84	14.91	0.65	5.11	0.11	4.04	3.81	2.56	5.81	0.38	1.45	99.61
10	1-1	69.13	0.40	14.12	0.32	2.14	0.05	1.30	1.86	3.57	5.17	0.22	1.67	99.95
11	18-1	69.33	0.50	13.74	0.08	3.03	0.05	1.41	2.15	3.47	4.88	0.26	1.03	99.93
12	19-1	71.01	0.40	13.68	0.22	2.10	0.04	1.41	1.43	3.29	5.02	0.22	1.23	100.05
13	20-1	66.83	0.60	14.14	0.85	2.70	0.07	2.41	2.58	2.71	5.46	0.35	1.28	99.98
14	1-2	68.94	0.50	12.83	0.72	1.93	0.05	1.90	1.72	3.13	6.06	0.29	1.65	99.72
15	13-8	63.16	0.83	14.73	0.06	3.54	0.06	3.21	3.01	3.45	5.34	0.41	2.14	99.94
16	15-1	64.62	0.65	15.64	0.70	3.06	0.07	1.10	2.44	3.01	6.20	0.37	1.91	99.77
17	34-1	63.66	0.68	14.90	1.33	2.81	0.08	2.80	3.23	2.96	5.72	0.28	1.14	99.59
18	28-2	63.49	0.68	14.84	1.12	2.88	0.08	2.45	3.54	2.96	6.60	0.12	1.06	99.86
19	1-4	71.74	0.33	14.11	0.35	1.89	0.03	0.80	1.43	2.97	5.00	0.16	1.15	99.96
20	23-3	76.96	0.11	13.07	0.10	0.29	–	–	0.62	3.22	5.72	0.22	0.42	100.53
21	1-5	67.15	0.50	16.16	0.55	2.16	0.04	1.20	1.72	3.23	5.60	0.22	1.48	100.01
I		69.17	0.43	14.33	–	3.23	0.07	1.40	3.20	3.13	3.40	0.11	–	98.47
S		70.27	0.48	14.10	–	3.37	0.06	1.42	2.03	2.41	3.96	0.15	–	98.25

Table 2. Trace element analyses. I and S: same as in Table 1.

No. in Figs. 2–5	No. in Fig. 1	Li	Rb	Cs	Sr	Ba	Sc	Y	Zr	V	Cr	Co	Ni	Cu	Ga
1	1-3	–	–	–	100	470	13	21	560	74	580	18	280	9	19
2	5-2	33	373	7	520	1800	13	22	1100	100	360	26	250	31	15
3	8-1	40	289	15	500	1600	10	20	430	82	230	18	66	27	16
4	23-2	–	–	–	200	800	9	22	720	56	530	19	100	19	15
5	5-1	23	329	7	560	1300	9	22	560	74	250	19	100	20	24
6	9-1	33	278	11	560	2000	14	18	300	94	200	20	74	22	17
7	11-1	41	286	11	660	2200	13	22	350	82	200	20	80	18	16
10	1-1	62	335	15	350	700	5	14	190	27	72	5	13	<5	14
11	18-1	–	–	–	560	580	5	14	300	32	400	12	34	5	9
12	19-1	31	251	11	440	900	6	13	190	26	63	12	38	23	12
13	20-1	48	324	11	640	900	8	19	300	54	100	12	40	10	10
14	1-2	47	317	13	390	800	5	13	190	36	96	8	22	<5	14
15	13-8	18	262	12	520	1200	10	18	390	64	210	14	68	<5	20
16	15-1	–	–	–	470	1400	8	19	300	60	170	14	70	12	22
17	34-1	–	–	–	500	1500	10	12	400	70	95	14	34	18	15
18	28-2	23	278	11	780	1800	8	16	400	54	100	14	60	19	14
19	1-4	–	–	–	100	320	14	10	160	25	600	5	24	18	9
20	23-3	–	–	–	<100	<100	<5	<5	82	<5	160	<5	120	8	11
21	1-5	–	–	–	200	300	<5	13	290	26	120	8	50	14	19
I		–	132	–	253	520	15	27	143	74	27	12	9	11	16
S		–	–	–	139	480	14	32	170	72	46	13	17	12	17

granites, while it occurs as much as 2 modal % in the granosyenites. The phenocrystic K-feldspar contains inclusions of prismatic plagioclase grains, often showing granulated texture with overgrowth of sericite, biotite and hornblende. This suggests that a large part of the K-feldspar was formed after the inclusion minerals and the granulation of plagioclase. Albite usually rims the K-feldspar phenocrysts.

Green hornblende shows prismatic and idiomorphic shapes, 0.5–2.5 mm in length, and rarely includes small grains of prismatic clinopyroxene. The clinopyroxene has optical parameters of the diopside-hedenbergite series. Brown biotite flakes, 0.5–1.5 mm in length, contain zircon and orthite. Conversion of the biotite into chlorite is not common. Accessories are idiomorphic sphene, often up to 1.5 mm in length, bipyramidal orthite with zonal structures and twins, zircon, monazite, apatite and opaques. Orthopyroxene, anatase and fluorite have been identified by the X-ray powder diffraction method in the heavy mineral fractions separated from twelve samples. Opaques are magnetite, hematite, ilmenite, sphalerite and molybdenite.

Granosyenite with aligned K-feldspar phenocrysts

This granosyenite (sample no. 18 in Tables 1, 2 and Figs. 2–4) exposes in the southeastern corner of the Newtontoppen granitoid body and cuts the pink-grey granosyenite at Loc. 28 (Fig. 1). The cross-cutting rock is characterised by subparallel alignment of long prismatic feldspars, 3–5 cm long. Total feldspars comprise ca. 80–90% of the rock. Phenocrystic K-feldspar is microperthitic, occupying ca. 50% of the rock. K-feldspar grains in the matrix are usually prismatic, 2–5 mm in length. Plagioclase grains are also prismatic, 0.5–1.0 mm long in the matrix, with compositions ranging from oligoclase to andesine, showing normal zoning. Quartz and biotite occupy 5–10 and 1–5 modal %, respectively, of the rock in the matrix.

Aplitic veins

Aplitic veins (sample nos. 19 and 20, in Tables 1, 2 and Figs. 2–4), 40–50 cm wide and as much as 100 m long cutting all previously described rocks, occur near the margins of the body. Most of them strike subparallel to the margins with various dips.

The aplites are fine-grained, biotite-bearing rocks, having K-feldspar, plagioclase and quartz in roughly equal amounts in a hypidiomorphic texture. Biotite flakes comprise ca. 1–2 modal % and have a dark green colour.

Pegmatites

Pegmatite veins are rare, they are less than 50 cm in width and cut all previously described rocks. The pegmatites have muscovite-K-feldspar-bearing assemblages and some veins show zonal structures constituting one or more of the following zones; muscovite-quartz-K-feldspar, muscovite-K-feldspar, quartz-K-feldspar and quartz monomineralic zones, from the margin to the core.

Quartz-feldspar porphyry

A dyke of this rock (sample no. 21 in Tables 1, 2 and Figs. 2–4), 1–1.5 m thick and ca. 50 m long, occurs along a joint in the pink-grey granosyenite, with a NW–SE strike and a subvertical dip in the southeastern part of the body (Loc. 1, Fig. 1). The dyke is considered to be the latest intrusion. The rock is massive and has a fine-grained microfelsic matrix of quartz and feldspars. Large flakes of biotite and phenocrysts of feldspars and quartz are characteristic. The biotite shows a dark green to almost black pleochroism. Quartz phenocrysts show corroded outlines and rarely have an idiomorphic shape. K-feldspar is short prismatic in shape and albite forms small prismatic phenocrysts aligned in a subparallel texture.

Lamprophyre

A lamprophyre dyke cuts the pink-grey granosyenite at Loc. 27 (Fig. 1) in the southeastern part of the body. The rock has dark green to black colour and a fine-grained texture with ca. 20 modal % of large flaky biotite. The matrix consists of talc and carbonate aggregates (some are probably after olivine), zeolitized glass and small flakes of biotite. The mafic minerals occupy ca. 30–40 modal % of the rock and the rest is mainly dusty feldspars. Accessories are apatite and quartz. The modal and chemical compositions of the rock are that of a felsic monchiquite. This rock is similar to the Late Paleozoic lamprophyres from other parts of Svalbard, such as the monchiquite and comptonite from Krosspynten, on the western side of Austfjorden, a comptonite from inner

Wahlenbergfjorden, central Nordaustlandet (Lauritzen & Ohta 1984; Kovalyova & Teben'kov 1986), and a lamprophyre on the southern side of Ragnarbreen, NE Petuniabukta, recently found by the present authors. These rocks do not seem to be genetically related to the late Caledonian granitoid rocks, but are the members of the Late Paleozoic platform magmatic activity.

Sequence of emplacement

The following successive emplacement stages have been deduced from the occurrence of the melanozomes and intrusive relationships among various types of rocks in the Newtontoppen granitoid body:

1. Incorporation of the melanozomes at depth, as inclusions in the dark grey granosyenites,
2. Emplacement of the dark grey granosyenites,
3. Emplacement of the pink-grey granosyenites, pink quartz monzonites and grey granites to form main part of the body,
4. A small intrusion of the granosyenite with aligned K-feldspar phenocrysts in the southeastern part of the body,
5. Intrusion of aplites, pegmatites and quartz feldspar porphyry.

Petrochemistry

Major and trace element compositions of the Newtontoppen granitoid rocks are given in Tables 1 and 2.

Porphyritic and hypidiomorphic textures of the constituent minerals in all rocks indicate a magmatic crystallisation process. The normative Q-Ab-Or diagram (Fig. 2) shows that the aplites, the grey granites and the quartz-feldspar porphyry plot near the eutectic valley of relatively high H_2O pressure, while the melanozomes and dark-grey granosyenites have the highest Or ratios, but with larger amounts of mafic minerals than of common granites. All other rocks plot between these two groups of rock types.

The ACF ratios (not shown in this article) show that two aplites and a quartz-feldspar porphyry plot in the muscovite-biotite plagioclase field, while all other rocks are in the biotite-hornblende-plagioclase field, conformable with the observed assemblages.

The present rocks are projected in a field of slightly lower total iron than common calc-alkaline rocks (Ringwood 1974) on the AFM diagram (Fig. 3). The alkali-lime index is difficult to estimate, due to a flat trend of the total alkalis, but it is estimated to be between 56 and 47, which is in the alkali-calcic to alkalic rock series (Fig. 4). The roughly constant amount of total alkalis in the whole range of SiO_2 is remarkable, unlike a positive trend normal for magmatic rocks. Four grey granosyenites, three melanozome-dark grey granosyenites and the granosyenite with aligned K-feldspar are just in the alkalic rock field (Irvine & Baragar 1971), while the rest are in the subalkalic field (Fig. 4).

On the cation oxides vs. SiO_2 diagrams, FeO* (= total FeO), MgO and Na_2O (Fig. 5) and CaO (Fig. 4) show smooth curves in the range of SiO_2 more than 63 wt % and these indicate a series of magmatic crystallisation. The same oxides show consistent trend, but have some deviations in the rocks with SiO_2 less than 63 wt %; these rocks are melanozomes, dark-grey granosyenites and grey granosyenites. These deviations are due to mafic components and seem to reflect initial differences of protolith compositions or different temperatures of anatectic melting at depth. These rocks plot away from the eutectic valley in Fig. 2. Very large deviations of Al_2O_3 and K_2O in the low SiO_2 range reflect modal differences of K-feldspar and biotite. The K_2O contents are anomalously high in the rocks with SiO_2 less than 65% and this can be explained by later K-feldspar addition to the rocks formed in an earlier stage, as mentioned in the petrography. Conversion of the mafic minerals into chlorite is rare, indicating a less hydrous condition during the later stages of the consolidation. According to Hjelle (1966), the K-feldspar phenocrysts from these granitoids have 20–26 mole % of Ab contents, including exsolved perthites, but excluding inclusions. This indicates that the K-feldspar crystallisation occurred at not as low a temperature as the hydrothermal stage.

The Newtontoppen granitoid rocks are not the M-type on the K_2O-Na_2O-CaO diagram (not shown in this article, White 1979; Pitcher 1979, 1983a, 1983b; Whalen 1985), and not the A-type on the CaO + MgO/total FeO vs. SiO_2 and the Ga vs. Al_2O_3 diagrams (not shown, Whalen et al. 1982; Collins et al. 1982). Then, the rocks were examined on the Na_2O vs. K_2O diagram (Fig. 6) which shows that all melanozomes, dark-grey

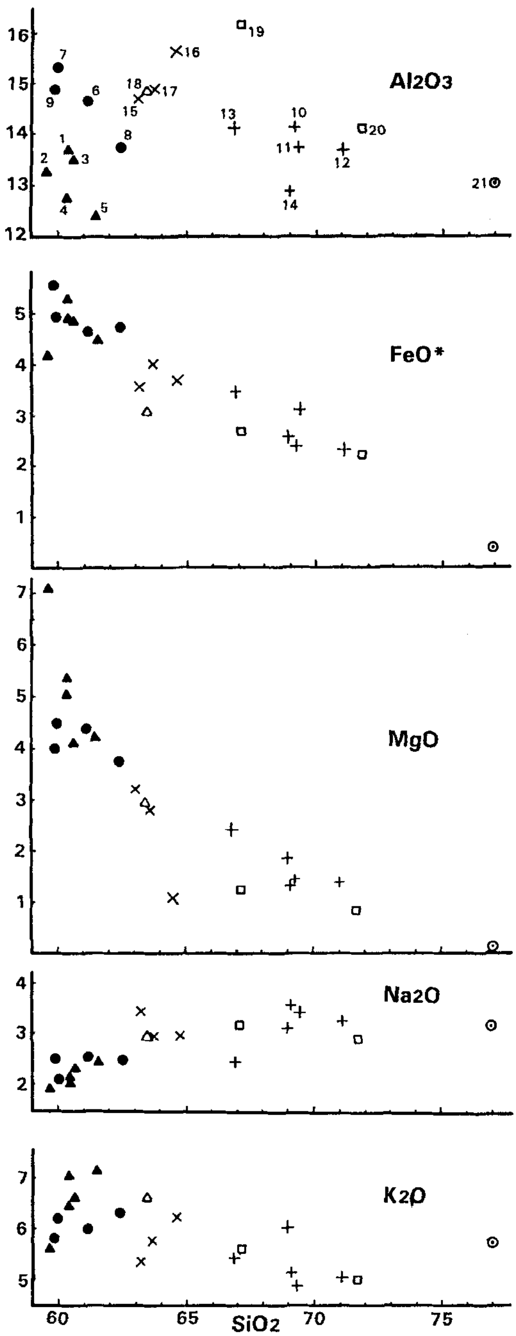

Fig. 5. Cation oxides vs. SiO_2 diagrams, in weight percent.

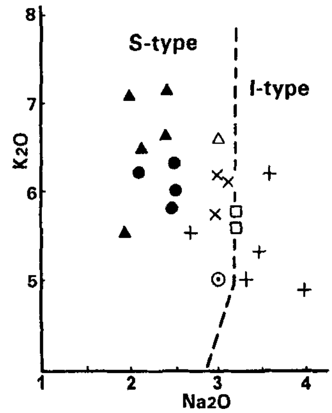

Fig. 6. K_2O-Na_2O diagram, in weight percent. The S- and I-type division: White & Chappel (1977).

granosyenites and grey granosyenites are of the S-type, while the other rocks plot around the boundary between the S- and I-type (Chappel & White 1974; White & Chappel 1977, 1983). The majority of the grey granites plot in the I-type field. Normative corundum values are higher than 1 in the aplites and the quartz-feldspar porphyry, while four granites and pink granosyenites have normative corundum less than 1 and fourteen others have 0. This also shows that the majority of the rocks are around the boundary composition between the two granite types (White & Chappel 1983). The S-type nature of the melanozomes, dark grey granosyenites and grey granosyenites suggests an anatectic origin. Their higher modal mafic constituents and occurrence of clinopyroxene in these rocks infer contamination from residual materials of the partial melting. The other rocks are the products of fractional crystallisation of the anatectic magma, the process of which was terminated around the eutectic valley to form the granites, aplites, and quartz-feldspar porphyry, thus they show I-type chemical natures. The existence of hornblende and the lack of muscovite, except for secondary sericite and those in the aplites and pegmatites, suggest that most of the rocks belong to the magnetite series of Ishihara (1977).

The analysed trace elements (Table 2) are normalised to the average I-type granite (Taylor & McLennan 1985) in spider diagrams (Figs. 7A, 7B and 7C). These diagrams show that the present granitoid rocks are evidently different from I-type granites and have similar patterns to the average S-type granite (Taylor & McLennan 1985), with more pronounced characteristics of high Zr, Cr and Ni, and low Y, Ti and V. Large deviations of alkali and alkali-earth trace elements reflect the modal difference of feldspars. High concen-

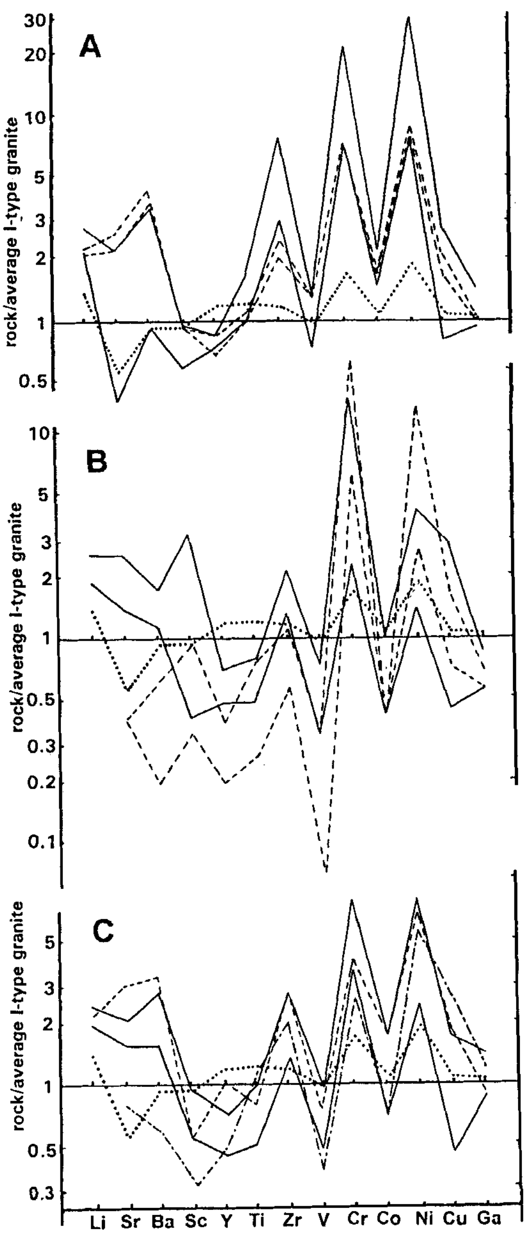

Fig. 7. Spider diagrams of the trace elements, normalised to the average I-type granite (Taylor & McLennan 1985). Average S-type granite (Taylor & McLennan 1985) is shown by the dotted line in all three diagrams.
A. Between solid lines: melanozomes and dark grey granosyenites (5 samples); broken lines: pink-grey granosyenites (2 samples).
B. Between solid lines: grey granites (4 samples); broken lines: aplites (2 samples).
C. Between solid lines: pink quartz monzonites (4 samples); broken line: granosyenite with aligned K-feldspar; chained line: quartz-feldspar porphyry.

trations of Cr and Ni infer that their protoliths may have some basic components and that the supposed anatectic melting occurred at a relatively high temperature. This is conformable with relatively high MgO contents in the melanozomes and dark grey granosyenites (Fig. 5), which may contain some residuals of inferred partial melting, e.g. clinopyroxene. Blank tests of the Cr and Ni analyses to check the contamination during preparation of samples have not been performed; however, the same laboratory procedures have been applied for many samples from various localities without any recognisable contamination.

Two groups are recognisable on the Y-MgO

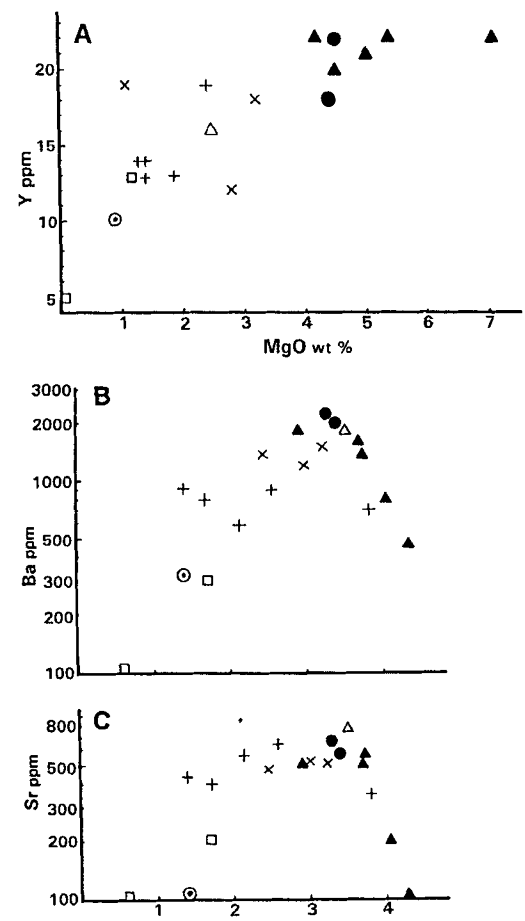

Fig. 8. Some trace and major element ratios. Symbols are the same as Fig. 2. A. Y-MgO diagram. B. Ba-CaO diagram. C. Sr-CaO diagram.

diagram (Fig. 8A). One is a very weak positive relation of Y with MgO in the high MgO range, which corresponds to the low SiO_2 range of Fig. 5. The other group is in the low MgO range and shows large deviations without any recognisable trend. As these elements are mostly in the mafic constituents, this reflects the difference of modal mafic minerals which, in turn, depends on the amount of K-feldspar. In the present samples, rocks with large amounts of feldspar have small amounts of mafic. Y-TiO_2, Cr and Ni vs MgO (not shown) show similar groups as the Y-MgO diagram.

Two similar trends can be seen in the Ba and Sr vs. CaO diagrams (Figs. 8B and 8C). Negative relations in the high CaO range are shown by the melanozomes, dark-grey granosyenites, while the pink-grey granosyenites in these diagrams and the other rocks show positive trends. The positive trends are caused by a decrease of plagioclase during crystallisation fractionation, while the negative trends in the high CaO range show no relation with the magmatic process.

On the Zr-MgO and Sc-TiO_2 diagrams (not shown in this article), the two groups are also recognised; the melanozomes, dark-grey granosyenites and the pink-grey granosyenites in the high MgO and high TiO_2 fields, and the rest of the rocks in the low fields. Both groups have positive relations in these diagrams, but with different ratios.

These two groups roughly coincide with those showing different degrees of deviation in the Al_2O_3 and K_2O variation diagrams (Fig. 5) and represent the different formation processes; an anatectic partial melting containing some protolith residuals in the early stage, e.g. with less than 63% SiO_2, and an eutectic crystallisation in the later stage.

Isotopic age determination

Previous dating

All three granitoid bodies of the Chydeniusbreen granitoid suite intrude within the Lomfjorden Supergroup producing thermal aureoles, and the Raudberget granitoid is covered unconformably by Carboniferous strata. The rocks have not suffered any orogenic deformation; they are therefore later than the major Caledonian orogenic events which probably ended in the late Silurian (Gee & Page 1994). The K-Ar whole rock and Rb-Sr biotite ages, ca. 400 Ma, (Hamilton et al. 1962) suggest cooling in Early Devonian time.

A new Rb-Sr whole rock-apatite isochron dating, using 15 samples and an U-Pb zircon dating with four samples has been attempted.

Rb-Sr dating

Analytical procedure. – Thirteen whole rocks and two apatites were analysed for their Rb and Sr contents and Sr isotope compositions. The samples were dissolved in HF and $HClO_4$ and the residue was dissolved in HCl and put in a column with resin Dowex 50 × 3 (200–400 mesh). Rb and Sr contents were determined by isotope dilution and mass-spectrometry. All isotope compositions were measured with the MI 1201-T mass-spectrometer at the Geochemical Laboratory of the Kola Science Centre at Apatity, Russia. The Rb and Sr blanks are 2 ng and 8 ng, respectively. The uncertainty of the $^{87}Rb/^{86}Sr$ ratio is assumed to be 1.5% and that of the $^{87}Sr/^{86}Sr$ to be 0.04%. The age calculation has been carried out after the program of Ludwig (1991).

Results and interpretation. – The results of Rb and Sr isotope analyses are given in Table 3 and shown in Fig. 9. The best-fit line includes seven samples: one apatite (28-2-ap, which has a smaller $^{87}Rb/^{86}Sr$ ratio than 13-8-ap), two aplites, two granosyenites with aligned K-feldspar phenocrysts, one quartz monzonite and one melanozome. These make a seven-point isochron (MSDW = 2.59) which yields 432 ± 10 Ma, with a high $^{87}Sr/^{86}Sr$ initial ratio, 0.715 ± 3, indicating a crustal origin of the rocks. Seven other samples (two quartz monzonites, a melanozome, a pink-grey granosyenite, a granosyenite with aligned K-feldspar, a quartz porphyry and an apatite; 13-8-ap) are scattered above and one quartz monzonite below the isochron. No special reason for the deviation has been found, but it may be due to the heterogeneity of these rocks. The obtained age is considered as the crystallisation age of the granitoid rocks. This age is ca. 30 Ma older than the previously reported K-Ar whole rock and Rb-Sr biotite ages (Hamilton et al. 1962) which show the cooling time.

The $T_{(DM)}$ calculated after the model-1 of Balašov et al. (1992), with the parameters of present day $^{87}Rb/^{86}Sr = 0.062576$ and $^{87}Sr/^{86}Sr = 0.7032$ of the E(enriched)-type, using the average of the

Table 3. Rb and Sr isotope analyses. The first numbers in the first column are the locality nos. in Fig. 1. Rb and Sr of the apatites were not measured.

Loc. No.	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
1-1	141.3	405.5	1.154	0.7309
1-2	318.4	449.4	1.850	0.7278
1-5	299.8	312.6	2.482	0.7320
5-1	342.8	678.8	1.232	0.7256
8-1	310.9	532.9	1.590	0.7255
9-1	276.3	752.0	1.060	0.7232
13-8	249.7	546.1	1.386	0.7238
15-1	312.0	476.1	1.977	0.7278
19-1	261.6	346.6	2.236	0.7277
20-1	323.4	520.8	1.839	0.7266
23-3	306.0	76.4	11.590	0.7867
28-2	257.3	696.5	1.067	0.7216
34-1	253.9	637.9	1.042	0.7223
13-8-ap			0.015	0.7165
28-2-ap			0.005	0.7155

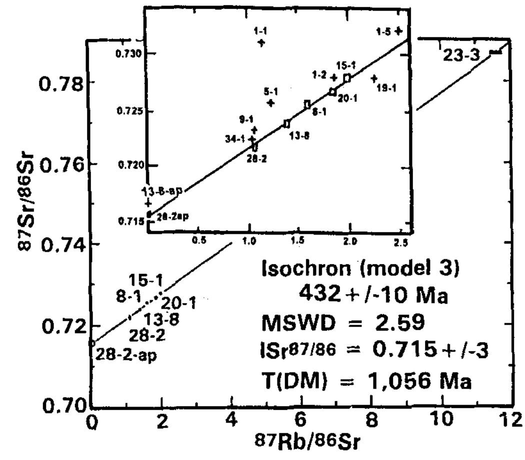

Fig. 9. Rb-Sr isotope ratios. The first numbers: locality numbers shown in Fig. 1. -ap = apatite; open square = included in the best-fit line; cross = excluded.

seven data points of the isochron, yielded a late Mesoproterozoic source age of ca. 1050 Ma. $T_{(UR)}$ calculation after McCulloch & Chappell (1982), using the parameters of present day $^{87}Rb/^{86}Sr = 0.0827$ and $^{87}Sr/^{86}Sr = 0.7045$, gave an age of ca. 730 Ma. These may suggest a Grenvillian protolith, derived from a mantle source, which would be the first indication of the Grenvillian event in Ny Friesland. However, these model ages could also be the results of mixing of older crustal rocks and juvenile mantle materials.

U-Pb Zircon dating

U-Pb isotopic data of zircon were obtained from four samples by conventional dissolution method (Table 4). The analytical method is the same as that described in Barashov et al. (1993). The isotopic results are strongly scattered and do not fit any single discordia. However, sample 13-8 plots near the concordia at around 420 Ma (Fig. 10 and Table 4), which is conformable with the Rb-Sr age.

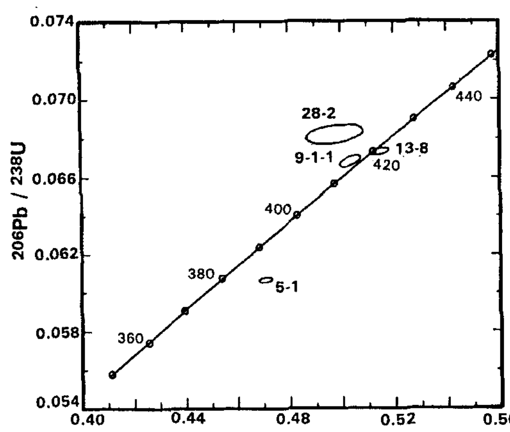

Fig. 10. U-Pb isotope ratios. The first numbers are locality numbers shown in Fig. 1.

Conclusions

New names for the Chydeniusbreen granitoid suite and its three separate bodies are introduced, based on recent mapping. The granitoid rocks intruded into the metasediments of the Lomfjorden Supergroup, causing thermal effects, and are covered unconformably by Carboniferous sediments. The shape of the Newtontoppen granitoid body is suggested to be an asymmetric lopolith or a harpolith-like body. The three bodies are located near the boundaries of different lithologies in the surrounding metasediment successions, suggesting some structural control on their emplacement positions.

The rocks of the Newtontoppen granitoids are mainly granite and granosyenite in composition and have the chemical characteristics of the alkali-calcic to alkalic series. They have transitional chemical characteristics between S- and I-type. Magmatic crystallisation is clear from their

Table 4. Pb and U isotope analyses. The first numbers in the first column are the locality nos. in Fig. 1.

Loc. No.	Weight mg	Pb radio. ppm	Pb comm. ppm	U ppm	Measured ratios 206Pb/204Pb	error %	206Pb/207Pb	error %	206Pb/208Pb	error %	Radiogenetic ratios 207Pb/206Pb	error %	207Pb/235U	error %	206Pb/238U	error %	RHO	Age (Ma) 207Pb/206Pb	207Pb/235U	206Pb/238U
5-1	20.2	84.44	3.87	1320	1296	0.97	14.835	0.33	5.097	0.26	0.056264	0.45	0.47055	0.50	0.060655	0.20	0.430	463 ± 10	392	380
9-1-1	19.1	80.16	3.80	1208	1330	1.9	15.260	0.30	7.838	0.10	0.054644	0.53	0.50334	0.67	0.066807	0.38	0.605	398 ± 12	414	417
13-8	4.9	72.59	4.66	1134	1000	1.6	14.306	0.18	11.527	0.10	0.055431	0.49	0.51465	0.56	0.067337	0.22	0.494	430 ± 11	422	420
28-2	5.3	26.51	5.88	379	284	0.8	9.60	0.70	3.796	0.40	0.05289	1.70	0.4972	1.8	0.06818	0.60	0.369	324 ± 39	410	425

textures, and the granites and aplitic dyke rocks have near eutectic compositions. The variation of SiO_2-rich lithologies resulted from the magmatic differentiation of anatectic melts. Later K-feldspar introduction modified the rocks formed in earlier stages. The rocks with SiO_2 less than 63 wt %; the melanozomes, dark-grey granosyenites and grey granosyenites, have relatively large variations in major cation oxides and trace element contents and are considered to be anatectic products from various protoliths under relatively high temperature conditions.

A new age determination by the Rb-Sr whole rock-apatite isochron method gives an Early Silurian (Tucker & McKerrow 1995) age of 432 ± 10 Ma, ca. 30 Ma older than the previous K-Ar whole rock and Rb-Sr biotite ages. The difference of these two ages may be considered as the cooling period of the body. This age is within the error range of that of the Hornemantoppen granite, the largest Caledonian granite body in northwestern Spitsbergen, 414 ± 10 Ma Rb-Sr whole rock (Hjelle 1979). The high $^{87}Sr/^{86}Sr$ initial ratio, 0.715, supports a crustal anatectic origin of the granitoid rocks. One of the U-Pb analyses suggest a similar age to the Rb-Sr age.

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