Grenvillian U-Pb zircon ages of quartz porphyry and rhyolite clasts in a metaconglomerate at Vimsodden, southwestern Spitsbergen

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Proterozoic metasupracrustal rocks form a NNW–SSE trending basement zone along the western coast of Spitsbergen. The rocks show complex structures as a result of both Caledonian and Tertiary deformation, and most of the subordinate metaigneous rocks are not suitable for isotopic age determination. Some zircon-bearing rocks were found in the southwestern part of Spitsbergen and an attempt of U-Pb dating was performed.

U-Pb dating was carried out on zircon fractions from quartz porphyry and rhyolite clasts in a metaconglomerate unit of the Pyttholmen Formation northwest of Hornsund, southwestern Spitsbergen. The Pyttholmen Formation is considered to be a lateral equivalent of the upper part of the Gulliksenfjellet quartzite and in the same time as the upper part of the Skålfjellet metavolcanites. Therefore, the obtained ages are applicable to the age of the Skålfjellet igneous activities. Some of the dated samples are strongly schistose and their magmatic origin is difficult to confirm; the interpretation of the isotopic results is not well constrained; however, some explanations are possible which refer to the known geological conditions; an igneous age of siliceous volcanic rocks of ca. 1200 Ma, inherited zircon ages of ca. 2500 Ma and a regional metamorphic age of ca. 930 Ma. The last age belongs to the Grenvillian period and is conformable with the Rb/Sr whole rock age obtained from the garnet-biotite schists of the Isbjørnhamna Group underlying the Skålfjellet metavolcanites.

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Introduction

Pre-Old Red Sandstone basement occurs along the western coast of Spitsbergen. It is composed mainly of Precambrian rocks (Ohta 1994), except for limited occurrences of Cambro-Ordovician, low grade phyllites and subordinate amounts of carbonates and metabasic rocks, all of which were deformed and metamorphosed during the Caledonian orogeny. The ages of these rocks are not well constrained, except for the high-pressure metamorphic rocks of Motalafjella, middle western part of Spitsbergen (Dallmeyer et al. 1990; Bernard-Griffiths et al. 1993) and some Caledonian ages from the south of Bellsund (Hauser 1982; Dallmann et al. 1990).

Two unconformities were proposed within the Precambrian successions of northern Hornsund by Birkenmajer (1959, 1975, 1992), the Torellian and Werenskioldian. The upper, Torellian unconformity is defined by the base of the Slyngfjellet Conglomerate (Table 1, Fig. 1), and its northwestern extension was mapped in western Wedel-Jarlsberg Land by Bjornerud (1990).

A Precambrian igneous complex, the Eimfjellet Group, has been known northwest of Hornsund (Hoel 1918; Orvin 1940) below the lower, Werenskioldian unconformity (Table 1). It was studied in detail by Birkenmajer (1959), Birkenmajer & Narebski (1960), Smulikowski (1965, 1968), Krasilščikov & Kovaleva (1979), Teben'kov (1983) and summarised geologically by Birkenmajer (1981, 1992), Czerny et al. (1993) and Ohta & Dallmann (1994).

A rhyolite conglomerate was described by Smulikowski (1968) at Vimsodden, NW of Nottinghambukta (Figs. 1 and 2) and considered to be a part of the middle member of the Nottinghambukta Formation of the Vimsodden Subgroup of the Eimfjellet Group (Table 1; Birkenmajer 1992). The present paper reports some results of the U/Pb zircon dating from the clast of quartz-

Table 1. Lithostratigraphy of the Precambrian successions in southern Wedel-Jarlsberg Land by Birkenmajer (1992) and our proposal which is similar to Czerny et al. (1993). Correlation of the upper Vimsodden Subgroup is unknown since it is bounded by faults on both sides. VKF: Vimsodden-Kosibapasset fault.

Birkenmajer (1992)		Present paper		
Group	Formation	S of Werenskioldbr.	N of Werenskioldbr.	
Sofiebogen	Gåshamna phy.		Sofiebogen	Neoprot.
	Höferpynten dol.			
(Torellian event)	Slyngfjellet congl.	VKF		
Deilegga (Werenskioldian event)		(unexposed)	930 Ma Deilegga	Mesoproterozoic
Eimfjellet	Skålfjellet Subgr. / Vimsodden Subgr.	Skålfjellet volcanics / Pytth. Fm. / Gulliksen-fjellet qtz.	1.2 Ga (unexposed)	
	Steinvikskardet			
	Gulliksenfjellet qtz.	Feldspathic qtz.		
Isbjørnhamna	Revdalen Ariekammen Skoddefjellet	Isbjørnhamna ↓ 2.5 Ga		

porphyry and rhyolite and matrix from the meta-conglomerate.

Geological outline and sample occurrences

New mapping (Ohta & Dallmann 1994; Czerny et al. 1993) indicates a major fault or fault zone from Vimsodden to Kosibapasset (VKF, Fig. 1), part of which was observed along the southern coast of Vimsodden as a wide shear zone, including several faults with associated sulphide mineralisation veins (Czerny et al. 1992). The area north of VKF shows the Torrellian unconformity between the Deilegga and the Sofiebogen Groups (Fig. 1). To the south of VKF, the Eimfjellet and Isbjørnhamna groups are distributed. The stratigraphic relation between these two areas is unknown. Birkenmajer (1975, 1981) defined the Werenskioldian event on the southeastern side of Austre Torellbreen, north of VKF, where his Eimfjellet Group is unconformably overlain by the Deilegga Group. Birkenmajer's Deilegga Group, however, has been reinterpreted as the Gåshamna phyllites of the Sofiebogen Group and the Eimfjellet Group has been shown to be a different igneous complex, the Jens Erikfjellet volcanites (Fig. 1), within the Slyngfjellet Conglomerate of the Sofiebogen Group, according to our observations and Czerny et al. (1993). The Werenskioldian unconformity is therefore a matter of debate.

The lower part of the Vimsodden Subgroup of Birkenmajer (1992), most of his Nottinghambukta Formation, occurs to the south of VKF, shown as a part of the Gulliksenfjellet quartzite in Fig. 1, and the upper part, his Elveflya Formation, to the north, shown as the Vimsodden Subgroup in Fig. 1. A part of the Nottinghambukta Formation is considered here to be a lateral equivalent of the upper part of the Gulliksenfjellet quartzite and is termed the Pyttholmen Formation (Czerny et al. 1993, Table 1). The Vimsodden Subgroup (Birkenmajer's Elveflya Formation) around Vimsodden contains three or four beds of intensely deformed metadiamictites which have been considered tilloids. Birkenmajer (1959, 1991) and Harland (1978) considered them Precambrian tillites; Harland et al. (1993) considered them to be lower Vendian tillites. We observed typical tillitic rocks in front of Werenskioldbreen on the strike direction of the metadiamictites, but the continuation with the latter is unknown due to wide glacier and Quaternary covers. Czerny et al. (1993) considered these diamictites to be Vendian tilloids. These new observations seem to support the opinion of Harland et al. (1993); however, since both sides of the Vimsodden Subgroup (Fig. 1) are bounded by faults (Fig. 1), their stratigraphic position is unknown.

The sampled meta-rhyolite conglomerate unit

Legend:
1 Glacier and Quaternary cover
2–4 Sofiebogen Group, 2: Gåshamna phyllites
3 Höferpynten carbonates
4 Slyngfjellet conglomerates
5 Vimsodden Subgroup
6 Jens Erikfjellet volcanites
7–10 Skålfjellet metavolcanites and Gulliksenfjellet quartzites
7 Metabasic rocks
8 Gulliksenfjellet quartzites
9 Metabasic rocks containing gabbro-diabase and granite blocks
10 Feldspathic quartzite at the base of the Skålfjellet volcanites
11 Isbjørnhamna Group
12 Deilegga Group
13 Faults
The metaconglomerate unit is shown in solid black (exaggerated). VKF: Vimsodden-Kosibapasset Fault.

Place names:
E: Eimfjellet
G: Gangpasset
J: Jens Erikfjellet
K: Kosibapasset
P: Pyttholmen
S: Slyngfjellet
SK: Skålfjellet
V: Vimsodden.
Square area: Fig. 2.

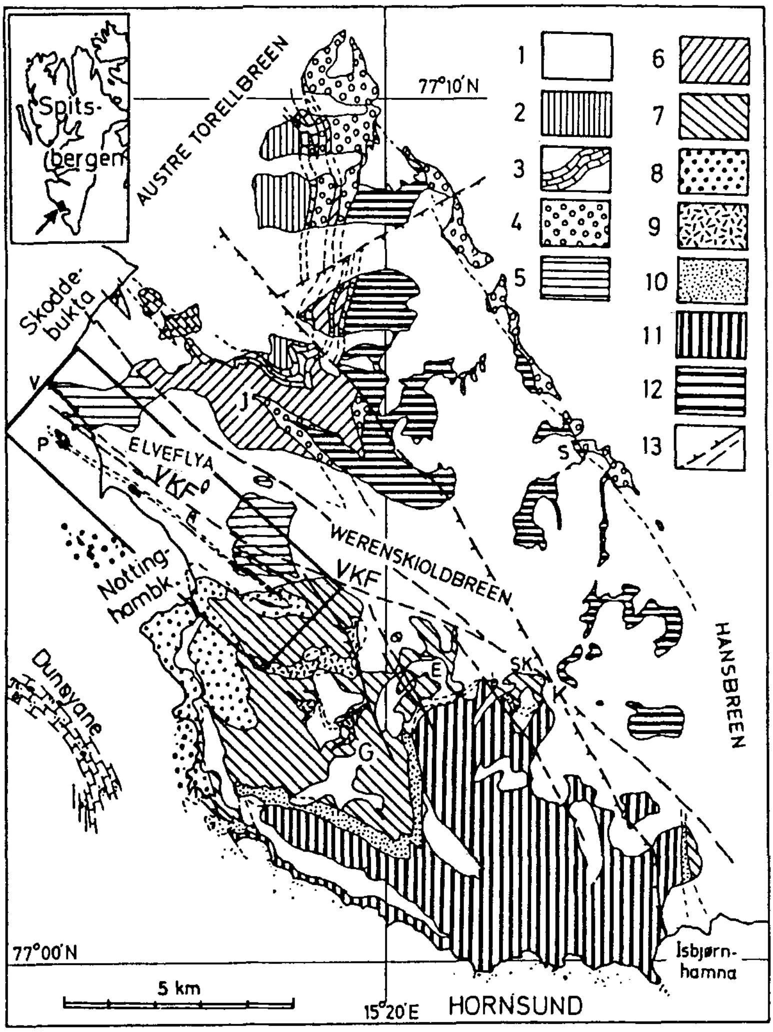

Fig. 1. Geological map of southwestern Wedel Jarlsberg Land, based on recent mapping (Ohta & Dallmann 1994; Czerny et al. 1993).

occurs at Pyttholmen, north of Kvislodden, and in the frontal flat of Werenskioldbreen (Fig. 2). The conglomerate is a member of the Pyttholmen Formation of Czerny et al. (1993) and has a total thickness of more than 150 m.

One of the faults of VKF is inferred to occur along the southernmost coast of Vimsodden. To the south of the fault there is a 30 m thick layer of biotite-bearing, green-grey phyllites which contains large blocks of aphanitic basic rocks, gabbro-diabases and diorite. Each block is up to 5 m across and all are weakly metamorphosed. Dark green phyllites (55 m) occur on the bottom of the shallow water between the Pyttholmen island and the mainland. White-green quartzite (35 m) and a chlorite-sericite quartz schist (13 m) occur in the northern and middle parts of Pyttholmen island, respectively. The southernmost part of the island consists of the sampled metaconglomerate unit (20 m). The clasts consist entirely of rhyolic rocks in the northern part of the unit. Southwards, the content of quartz porphyry clasts increases, and some granite clasts can be observed in the southern part. The size and frequency of the clasts

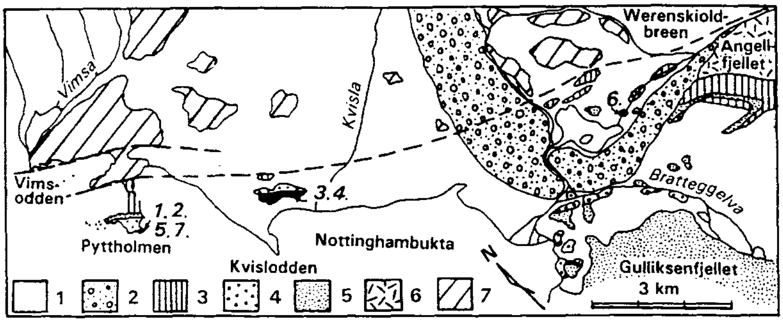

Fig. 2. Distribution of the Pyttholmen Formation.

Legend:
1 Glaciers and Quaternary cover
2 Moraines
3 Green-grey phyllites, locally containing gabbro-diorite blocks
4 Mica-chlorite-quartz schists
5 Gulliksenfjellet quartzites
6 Skålfjellet metabasic rocks
7 Vimsodden Subgroup north of VKF.
Black: metaconglomerate unit and its correlatable rhyolite.
Italic nos: localities of the dated samples.

decrease to the south; therefore, a southward younging structure is tentatively deduced.

At ca. 700 m north of Kvislodden, an outcrop of green-grey phyllite occurs south of VKF. A white-grey, micaceous quartzitic schist (20 m), locally gritty, and a sandy phyllite with chlorite clots occur ca. 100 m south of the green-grey phyllite. To the south of these is a grey siliceous phyllite (ca. 50 m) containing a thin dark rhyolite layer, possibly a lava, and angular clasts of dark reddish rhyolite. A grey quartz schist (15 m), containing large feldspar fragments, occurs in the southern part of this locality and has scattered clasts of rhyolite up to 35 cm in size. This rock is well stratified and seven graded units were counted, all showing southward-fining. These siliceous phyllites and schists are located roughly in the strike direction of the metaconglomerate unit of Pyttholmen and are correlated with the latter. Some of the present authors consider that these phyllites and schists were originally siliceous lavas and pyloclastics, and not conglomerates.

A phyllitic rhyolite (ca. 10 m thick), exposed isolately along a stream on the southern frontal flat of Werenskioldbreen, is considered to be correlatable with the metaconglomerate unit of Pyttholmen. Neighbouring scattered exposures are micaceous quartz schists. A white quartzite, showing brecciated structures, occurs ca. 150 m northwest of the phyllitic rhyolite. This quartzite is traceable discontinuously to the southeast onto the western ridge of Angellfjellet, where it turns back to the northwest along the lower part of Bratteggelva, and joins with the major part of the Gulliksenfjellet quartzite (Fig. 2). A thin metarhyolite lens occurs in the Gulliksenfjellet quartzite ca. 700 m southeast from the mouth of Bratteggelva. The quartzite contains sandy schist layers in its upper part on the eastern coast of Nottinghambukta (the Nottinghambukta Formation of Birkenmajer, 1992).

These observations from Vimsodden to Nottinghambukta show that the Pyttholmen Formation consists of quartzite, locally with greenish tint, and quartz schists similar to the Gulliksenfjellet quartzite and green-grey phyllites which locally contain blocks of coarse-grained igneous rocks, similar to those commonly seen (Czerny et al. 1993) in the Skålfjellet Subgroup of Birkenmajer (1992).

The Skålfjellet and the Vimsodden subgroups were thought to be lateral equivalents by Birkenmajer (1959, 1992) and the Gulliksenfjellet quartzite and the Skålfjellet Subgroup of Birkenmajer are laterally transitional (Czerny et al. 1993). We consider that the Pyttholmen Formation is a lateral facies variation of the upper Gulliksenfjellet quartzite, and at the same time, it is the western facies variety of the upper Skålfjellet Subgroup (Fig. 3). Accordingly, the rhyolite and quartz porphyry clasts in the metaconglomerate unit of the Pyttholmen Formation are considered to be derived from the Skålfjellet Subgroup, forming the westernmost distribution of the felsic pyroclastic-eruptive rocks of the subgroup. It is difficult to judge whether the clast-bearing, strongly schistose rocks of the unit consist totally of volcanic materials or contain certain amount of sedimentary components. Solid clasts were chosen for the dating, but some schistose

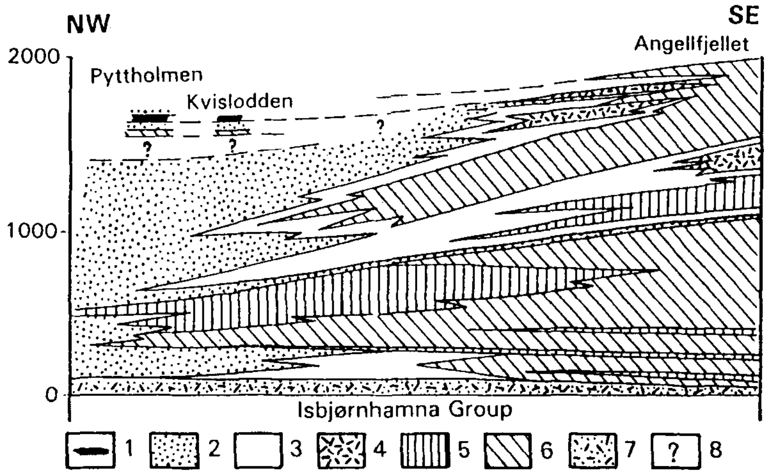

Fig. 3. Lateral changes of litho-facies between the Pyttholmen Formation, the Gulliksenfjellet quartzites and the Skålfjellet metavolcanic rocks, modified from Czerny et al. (1993).

Table 2. Modal composition of the dated rocks. Symbols of minerals are after Kretz (1983), except for feld (feldspars) and Op. (opaque minerals). The remaining content of samples 3, 5, 6 and 7 are secondary and accessory minerals which are difficult to count due to fine grain size; +: recognised, −: not recognised.

no	Major Minerals		Secondary Minerals					Accessories
	Qz	Feld	Mus	Bi	Chl	Calc	Ht	
1	60	10	10	+	10	10	-	Zr. Orth. Grt. Zo. Op.
2	50	40-50	+	+	+	+	-	Tour. Zr. Sph. Op.
3	25-35	25-40	+	+	+	+	-	Zr. Sph. Ap. Grt. Op.
4	50	40-50	+	+	+	+	-	Zr. Tour. Sph. Op.
5	25-35	25-40	+	+	+	+	-	Zr. Sph. Ap. Grt. Op
6	25-30	25-40	+	+	-	+	-	Zr. Sph. Grt. Ap. Op.
7	45	45	-	-	-	+	+	Zr. Tour. Op.

matrices were also included. The sedimentary materials, which may be mixed in the schistose samples, are considered to be derived from the same source as those in the upper Gulliksenfjellet quartzite.

Samples

Seven samples for zircon dating, each 15–20 kg, were collected from the metaconglomerate unit; the localities are given in Fig. 2, and their modal compositions are shown in Table 2.

Samples 2 (Fig. 4, left, clast) and 4 (Fig. 4, right, clast) are brownish grey and reddish quartz porphyry clasts, respectively, ca. 50 cm in length, showing relict-porphyritic and -glomeroporphyritic textures with 0.5–1.0 cm phenocrysts of quartz and K-feldspar. Round outlines of clasts

Fig. 4. Metaconglomerates. Left: schistose rhyolite conglomerate, white rhyolite clasts in a grey schistose matrix (Pyttholmen). Middle: micaceous quartz schist, either the matrix of conglomerate or strongly schistose rhyolite (north of Kvislodden). Right: schistose rhyolite conglomerate; the clasts are dark in colour (north of Kvislodden).

are well preserved, but cataclastic textures are developed within the clasts.

Samples 3 (Fig. 4, middle) and 5 (Fig. 4, left, matrix) are schistose parts of the metaconglomerate and have lepido- and granoblastic textures. Relict-porphyritic and – glomeroporphyritic textures, consisting of up to 1.0 cm size quartz and K-feldspar grains, are locally preserved, suggesting that these samples are strongly sheared rhyolite in rhyolitic pyroclastic. Some amounts of the matrix of conglomerate may be incorporated in the samples, but they are impossible to evaluate petrographically. A significant amount of muscovite and a small amount of chlorite occur along the cleavages. The layers around these rocks contain dark reddish, elongated rhyolite clasts strongly penetrated by cleavages.

Sample 6 is a light grey-brown, phyllitic rhyolite in hand-specimen and is petrographically a micaceous quartz schist, similar to sample 3 and 5, except that no chlorite has been observed.

Sample 1 has a greenish colour and is a finer grained siliceous rock compared to the others, lacking clasts of phenocrysts. Sericite-chlorite aggregates are localised along cleavages in the granoblastic texture of quartz and feldspars. This seems to be an aphanitic part of the rhyolite or sedimentary matrix.

Sample 7 is a dyke, 30 cm wide and 1.5 m long, that cuts the metaconglomerate. The dyke is restricted to the inside of the metaconglomerate unit and is considered to have formed soon after deposition by segregation in a hot pyroclastic flow or segregated during a later metamorphism. The rock has a coarse-grained pegmatitic texture of quartz and feldspars and shows cataclastic fractures.

Table 3. Chemical composition of the dated rocks. Two analyses of Smulikowski (1968), 338M and 338C, are included as samples 8 and 9, respectively. The analyses were made at the SEVZAP-GEOLOGIJA Laboratory, St. Petersburg, Russia, by the X-ray fluorescence method on the KRF-18 device.

	1	2	3	4	5	6	7	8	9
SiO2	63.67	69.52	72.59	71.59	75.96	75.76	72.02	57.90	68.61
TiO2	0.50	0.50	0.40	0.10	0.50	0.30	0.20	0.17	0.22
Al2O3	14.72	12.32	13.51	13.40	10.57	12.81	8.92	13.65	12.48
Fe2O3	5.27	4.26	3.24	2.44	1.86	1.16	3.92	2.53	4.11
FeO	1.44	1.15	0.72	0.72	0.86	0.72	1.08	1.46	0.64
MnO	0.08	0.09	0.05	0.06	0.08	0.07	0.13	0.38	0.02
MgO	2.63	0.84	0.89	0.57	1.16	1.31	1.59	1.22	0.59
CaO	1.80	1.29	0.39	0.64	1.66	0.48	3.30	5.09	1.56
Na2O	0.43	0.37	0.32	0.30	0.40	1.32	0.55	0.28	0.23
K2O	6.58	8.99	7.77	9.63	6.03	3.96	4.94	10.21	9.40
P2O5	0.14	0.01	0.01	0.01	0.01	0.07	0.05	0.16	0.11
CO2								3.45	0.96
H2O	2.97	1.57	1.10	0.90	2.06	2.39	2.97	3.23	1.26
Total	100.23	100.91	100.99	100.36	101.15	100.35	99.67	99.73	100.19

Chemical analyses of the dated rocks, together with two from Smulikowski (1968) are shown in Table 3. Due to intense development of cleavages accompanied by distinctive amount of sericite, and locally chlorite, primary chemical compositions were strongly modified, especially the K_2O contents. Strict considerations of an igneous rock group can not be made for the present rocks, since some of them may contain certain amount of sedimentary materials.

Apparently the rocks have very high K_2O (average of 9 samples = 7.5%) and very low Na_2O (average of 9 samples = 0.47) contents (Table 3). Most of these rocks plotted in the rhyolite composition field on the total alkalis vs SiO_2 diagram (Fig. 5a), except for sample 1, a subalkaline dacite and samples 8 and 9, trachytes. Sample 8 has normative An_{52} and is considered to be a glassy andesitic rock modified by later addition of K_2O, although Smulikowski (1968) described it as a rhyolitic clast. Sample 9 lacks specific petrographic description in Smulikowski (1968). The samples are scattered across the alkaline and subalkaline field (Fig. 5a, Irvine & Baragar 1971), and all subalkaline rocks have a calcalkaline nature (Fig. 6, Miyashiro 1974). TiO_2 vs FeO^*/MgO ratios (figure not shown) show a typical calcalkalic trend (Miyashiro & Shido 1975). Samples 2 and 4 are clasts relatively free from penetrative cleavages, and a variation trend of total alkalis passing these two gives an alkali-lime index of ca. 52 ± −3 (Figs. 5a and 5b). Since a large addition of K_2O during later metamorphism is expected, the index will be higher in the primary rocks, i.e., alkali-calc and calc-alkali rock series.

High K_2O and low Na_2O contents apparently show that the rocks are of the S-type (Chappel & White 1974). The boundary between the S- and I-type on the K_2O-Na_2O diagram is more than 2 wt % Na_2O at 2 wt % K_2O (Chappel & White 1974). The maximum Na_2O content of the present samples is 1.32 wt %, therefore, even if some amounts of K_2O were considered to be secondary additions, the present samples remain within the S-type field in the diagram. Although some samples may contain the matrix of conglomerate, some, at least samples 2 and 4, are solid igneous rock clasts and they are in the S-type field.

This is supported by the trace element variations (Table 4 and Fig. 7). Since only four elements for standard spider diagram are available, Fig. 7 is an unusual spider diagram and the analyses were normalised to the average I-type

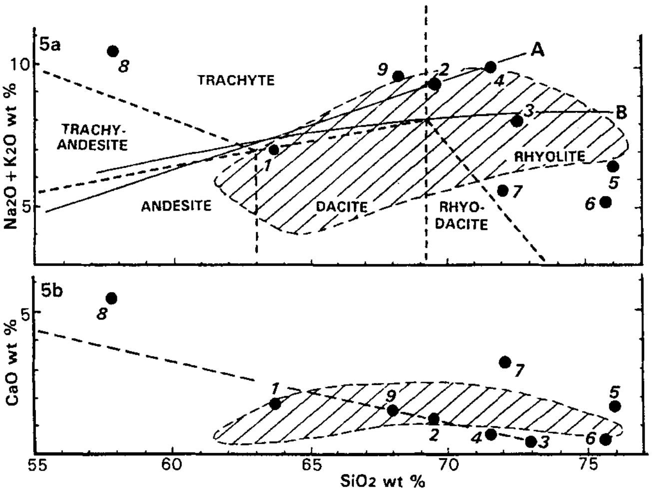

Fig. 5. Total alkalis and CaO vs SiO_2 diagrams, two samples from Smulikowski (1968), nos. 8 (Smulikowski, no. 19, table 2) and 9 (Smulikowski, no. 18), are included. 5a: Total alkalis vs SiO_2. Solid circles with numbers: present samples. A, variation trend of $Na_2O + K_2O$, including the least modified rocks (samples 2 and 4); B, alkaline-subalkaline division after Irvine & Baragar (1971). Broken lines, classification of felsic rocks; lined area, area of the felsic igneous rocks from the Skålfjellet metavolcanic rocks (Ohta, Teben'kov and Czerny, unpublished data). 5b: CaO vs SiO_2. Same symbols as in 5a. Dashed line, variation trend of CaO.

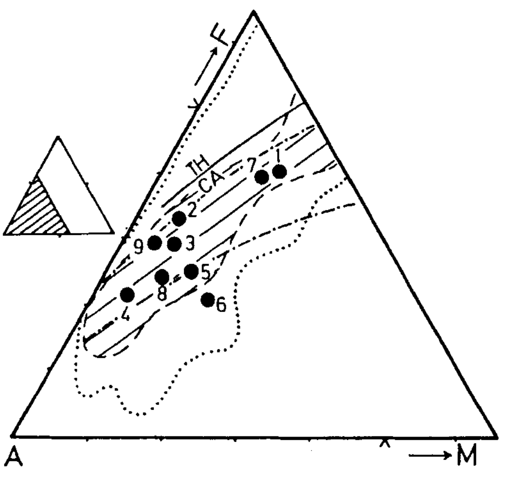

Fig. 6. AFM diagram with two samples from Smulikowski (1968) included. Solid curve: tholeiite-calcalkalic boundary (Ivrine & Baragar 1971), area inside dashed-dot curves: field of common calcalkalic rocks (Ringwood 1974), area inside dotted curve: Scandinavian leptites (Magnusson 1970; Parak 1975; Lundberg & Smellie 1979), solid circles and lined area: same as Fig. 5a.

Table 4. Trace element analyses of the dated rocks. The analyses were carried out in the VNII OCEANGEOLOGIJA Spectra Laboratory of St. Petersburg, Russia. The values with an asterisk (*) are determined by mass-spectrometric analysis; nd = not determined; — = not detected. av-I = average of the I-type; av-S = average of the S-type granites; av-sh = average of post-Archean shales. All three averages from Taylor & McLennan (1985) are shown for reference.

	1	2	3	4	5	6	7	av-I	av-S	av-sh
Rb	*122	*151	*171	*143	*150	—	—	132	180	160
Sr	*122	*126	*192	*843	*152	290	42	253	139	200
Co	9	5	5	5		8	—	12	13	23
Ni	31	24	16	19	37	23	10	9	17	55
Sc	12	5	6	5	5	5	n.d.	15	14	16
Y	82	37	59	80	130	65	25	27	32	27
Cu	19	36	9	16	20	68	8	11	12	50
Zr	600	800	580	400	1600	650	149	143	170	210
Mo	7	7	7	7	7	7	n.d.	—	—	—
Ga	12	10	25	26	11	26	n.d.	16	17	20
V	56	10	10	17	5	17	20	74	72	150
Ba	480	450	700	620	620	500	460	520	480	650
Cr	10	46	79	56	20	150	240	27	46	110

granite (Taylor & McLennan 1985). The present rocks reveal distinct differences from the I-type granite, but show general similarity to the S-type, except for TiO_2 V and Ni, and rather good correlation with the pattern of the average shales (Taylor & McLennan 1985), except for V, Cr, Ni and Co. The reasons of these dissimilarities can not be explained as in the case of definite igneous rocks, since they may contain some sedimentary materials. High values of Cr can be explained by a possible supply of chromite from the gabbro-anorthosite rocks of the Skålfjellet Subgroup, which contain cumulate facies of chromite (Czerny et al. 1993). The trace element characteristics suggest an addition of areno-argillaceous materials into the present rocks, during both igneous and sedimentary processes. The high K_2O

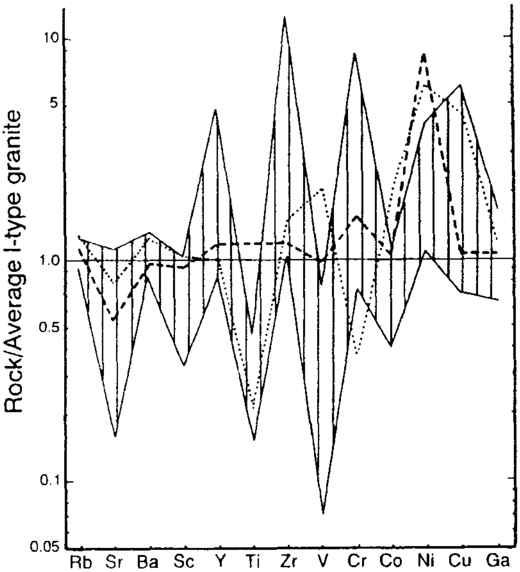

Fig. 7. Analysed trace elements normalised to the average I-type granites (Taylor & McLennan 1985). Vertical lines, present rocks; broken line, average S-type granites; dotted line, average post-Archean shales (both from Taylor & McLennan 1985).

nature infers a crustal origin, if this nature is primary.

It is difficult to state that all present samples belong to a comagmatic series from their chemical data. However, general similarities of chemical nature between the present rocks and the felsic rocks of the Skålfjellet metavolcanites indicate that they belong to the same igneous rock group, and this is supported by the observed lateral transition between this metaconglomerate unit and upper Skålfjellet Subgroup. Uncertainty of a comagmatic nature for the samples makes the interpretation of isotopic results ambiguous; however, some considerations can be attempted within the limit of data quality.

Table 5. Percentages of the two morphotypes of separated zircons. M-1 = morphotype 1; M-2 = morphotype 2.

Sample no.	M-1	M-2
1	70	30
2	100	0
3	100	0
4	98	2
5	99	5
6	95	10
7	90	

Zircons

Separated zircon grains were grouped into two morphotypes (Table 5 and Fig. 8):

(1) Intact crystals with (111) and (110) facets and their fragments, 0.07–0.1 mm in size, with length/width ratios of 1.2–1.5, are by far the most prevalent type. They are unzoned, transparent with smooth surface to half-transparent with rough surface, mainly colourless, though some are pale pink in colour.

(2) Grains having complex natures are grouped together in this type. Some have half-transparent inner and turbid (possible due to rough surface) outer parts and show lilac colour, and are fragments of idiomorphic grains. Zoned grains represent up to 2–3% of the total zircon population. Some are rounded, and oval grains have scale-like surfaces and tiny ridge-trough patterns on the pyramidal facets, similar to corroded grains (Krasnobaev 1985). The fractions of this morphotype certainly contain some inherited or detrital zircon grains.

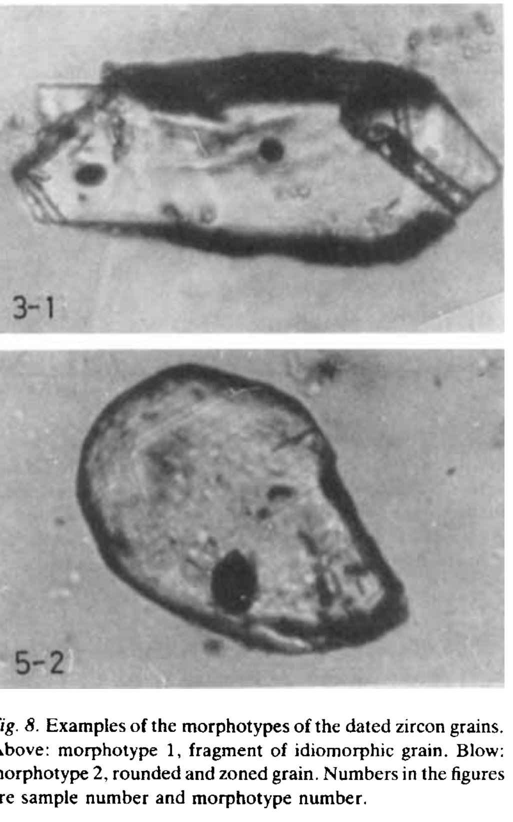

Fig. 8. Examples of the morphotypes of the dated zircon grains. Above: morphotype 1, fragment of idiomorphic grain. Blow: morphotype 2, rounded and zoned grain. Numbers in the figures are sample number and morphotype number.

These morphotypes are denoted -1 and -2 after sample numbers in Table 6 and Figs. 9 and 10.

Table 6. Uranium and lead isotope date. Zircon morphotypes are indicated by the second numbers following the sample numbers. Radiogenic ratios were corrected for fractionation 0.11 ± −0.4% per AMU, blank 0.05 ng for U and 0.5 ng for Pb with composition $^{206}Pb/^{204}Pb = 18.08$, $^{207}Pb/^{204}Pb = 15.26$, $^{208}Pb/^{204}Pb = 37.75$, and common lead according to Stacey & Kramers (1975) for age of 1200 Ma (magmatic zircon) and 2500 Ma (inherited zircon). Errors in 2 sd. Rho = m Error correlation $^{207}Pb/^{235}U$–$^{206}Pb/^{238}U$.

	Loading	Radiog.	Common	U	measured isotop ratio			Radiog. isotop ratios						Rho	Age		
	(mg)	Pb(ppm)	Pb(ppm)	(ppm)	206Pb/204Pb	206Pb/207Pb	206Pb/208Pb	207Pb/206Pb	error%	207Pb/235U	error%	206Pb/238U	error%		207Pb/206Pb	207Pb/235U	206Pb/238U
1–1	5.00	34.49	0.41	175.2	2855	10.81	4.68	0.088	0.14	2.15	0.28	0.18	0.25	0.87	1380	1164	1051
1–2	1.70	75.13	0.89	259.1	2968	7.65	6.14	0.126	0.33	4.61	0.40	0.26	0.22	0.56	2019	1750	1512
3–1	13.00	33.72	0.54	139.2	2768	11.85	2.96	0.079	0.17	2.19	0.43	0.20	0.39	0.91	1183	1178	1175
4–1	8.20	153.10	0.87	670.6	8478	12.26	4.37	0.080	0.25	2.25	0.36	0.20	0.25	0.71	1198	1197	1197
5–1	4.90	32.10	0.77	136.9	1629	11.43	3.20	0.079	1.41	2.16	1.43	0.20	0.23	0.16	1172	1168	1167
6–1	4.50	28.34	0.77	117.0	1555	11.41	2.26	0.787	0.26	2.03	0.44	0.19	0.35	0.81	1125	1104	1164
6–2	0.30	217.29	10.70	982.4	851	8.51	5.83	0.102	0.59	2.92	0.69	0.21	0.31	0.52	1659	1388	1219
7–1	1.50	31.14	8.29	163.3	186	6.39	2.54	0.083	1.84	1.95	1.92	0.17	0.35	0.31	1270	1099	1015
7–2	2.50	87.65	3.24	283.6	1235	6.87	6.26	0.135	0.31	5.28	0.45	0.28	0.32	0.72	2167	1865	1606

Analytical method

Uranium and lead isotope analyses were carried out on 0.3–13.0 mg fractions of both morphotypes of zircon from all samples which are possible to

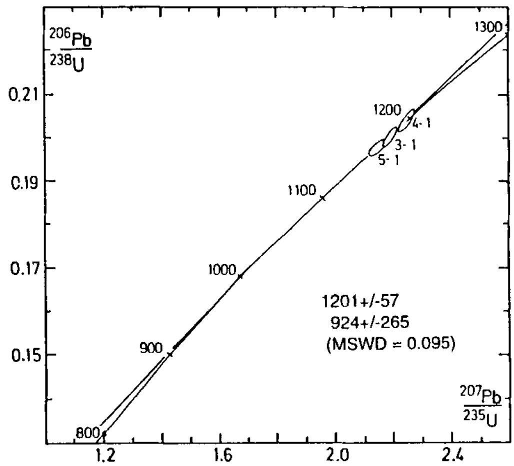

Fig. 9. U-Pb isotope diagram for samples 3, 4 and 5. Fraction 4-1 plots on the concordia. The fractions 3-1, and 5-1 are slightly off the concordia. The cord includes all three fractions, and its lower intercept is uncertain, since it is subparallel to the concordia.

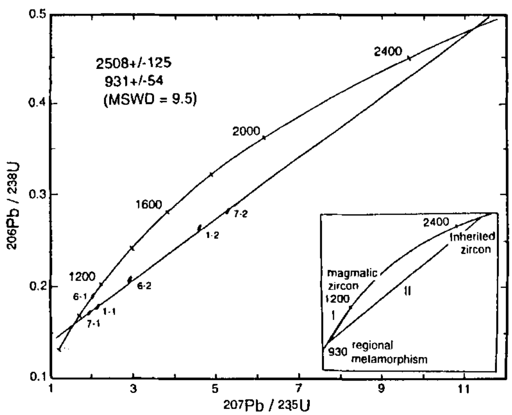

Fig. 10. Composite U-Pb isotope diagram for samples 1, 6 and 7. The composite chord consists of 1-1, 1-2, 6-2, 7-1 and 7-2 zircon fractions. The fraction 6-1 lies near the concordia, near the 3-1 and 5-1 fractions (Fig. 9). Inserted figure shows the preferred interpretation of the results.

analyse at the geochemical laboratory of Kola Science Center, Apatity, Russia. Samples 2, 3, 4, and 5 do not contain enough amount of morphotype 2 zircon for analyses and sample 2-1 was unsuccessful in analysis.

The treatment of zircons for dating following the procedure of Krogh (1973). Uranium and lead concentrations and lead isotopic composition were determined using an MI-1201-T mass-spectrometer with a single collector, employing a specially cleaned silica gel emitter and H_3PO_4 on the evaporating rhenium ribbon filament. The lead blank during the analysis was less than 0.5 ng and that of uranium 0.05 ng. The analytical error of the isotope measurements of lead was 0.2%. The error of the isotopic dilution techniques, using ^{208}Pb and ^{235}U spikes is estimated to be 1%. The analytical procedures were calibrated by running the All-Union IGFM-87 and NBS-981 standards. The age calculation has been done using the program of Ludwig (1991a, b).

Results

Results of the isotope analyses are shown in Table 6 and Figs. 9 and 10. Samples 3, 4 and 5 plot closely to each other; therefore, they are shown separately in Fig. 9.

Specimen 4-1, which is a solid quartz porphyry clast with little penetrative cleavage, lies on the concordia (Fig. 9) and gives an age of 1198 ± −5 Ma. Samples 3-1 and 5-1 are slightly off from the concordia and a chord through them and 4-1 gives an upper intercept age of 1201 ± −57 Ma. The lower intercept of the chord, 924 ± −265 Ma, is with a large uncertainty, since the cord is subparallel to the concordia, but a small partial resetting is suggested by the lower intercept. Alternatively, samples 3-1 and 5-1 show an age a few million years younger than that of sample 4-1, as does sample 6-1 (Fig. 10) which is almost on the concordia and shows ca. 1110 Ma.

The 1-1 and 1-2 zircon fractions define a chord with a lower intercept age of 919 ± −16 Ma and an upper intercept age of 2456 ± −31 Ma (Fig. 10). The two morphotype fractions from sample 7 yield a lower intercept age of 933 ± −9 Ma and an upper intercept age of 2538 ± −24 Ma.

The 6-2 fraction plots near the chord of the fractions from samples 1 and 7. The composite chord of the fractions 1-1, 1-2, 7-1, 7-2 and 6-2 gives a lower intercept age of 931 ± −54 Ma and an upper intercept age of 2508 ± −125 Ma with MSWD = 9.5. The samples incorporated in this composite chord are phyllitic rocks and a pegmatitic rock and the three fractions of morphotype 2 among them certainly contain inherited and/or detrital zircon grains.

Interpretation and conclusion

Due mainly to metamorphic modifications, the dated samples can not be proved by their comagmatic origin by petrographic and chemical examinations. The discords showing high upper intercept ages suggest the presence of detrital and/or inherited zircon grains in the samples, therefore some samples are not pure igneous rocks, but the matrix of conglomerate. It is difficult to give any conclusive interpretation of the isotopic data. However, since all dated samples are from one monomictic conglomerate unit, the clasts are supposed to be derived from the same igneous source and the matrix is the same material as the laterally equivalent Gulliksenfjellet quartzies. Some explanations will be attempted based on the assumption above, though alternative interpretations are possible.

The concordia age of fraction 4-1 and the upper intercept age of the chord through fractions 3-1, 4-1 and 5-1 ca. 1200 Ma, are considered to be the magmatic age of the rhyolite and quartz porphyry, since the zircon grains in these fractions are euhedral and homogeneous crystals. Fractions 3-1, 5-1 and 6-1 may give younger ages of the igneous activity which prolonged for some million years.

The lower intercept ages obtained by various chords are in a range of 919–933 Ma and are considered to imply partial resetting by later regional metamorphism (Fig. 10, I in inserted figure). This age is conformable with a preliminary Rb-Sr whole rock age of 936 ± −15 Ma obtained from garnet-biotite schists of the Isbjørnhamna Group by Gavrilenko et al. (1993). We tried isotopic analyses of some rocks from the group, but the results show a large scatter and unsuccessful. The Isbjørnhamna Group is conformably underlying the Skålfjellet Subgroup (Czerny et al. 1993; Ohta & Dallmann 1994) at all observed localities of their contact. Accordingly, the regional metamorphism of an intermediate-pressure series, greenschist-middle amphibolite facies grade, which affected the

Skålfjellet igneous rocks and the sediments of the Isbjørnhamna Group, is considered to be of Grenvillian age.

The upper intercept ages, ca. 2500 Ma, obtained from the fractions of samples 1, 6 and 7, suggest the presence of a Late Archean or Early Proterozoic crystalline basement that was either partly incorporated at depth or supplied detrital zircons at the surface to the present rocks (Fig. 10, II in inserted figure). Samples 1 and 7 have no sign of ca. 1100–1200 Ma. This suggests that sample 1 is a sedimentary matrix of the metaconglomerate. Sample 7, a pegmatitic rock, can be explained as a segregated dyke containing detrital zircon grains derived from the wall rocks, mainly matrix of the conglomerate. This interpretation confirms that the lower intercept age of Fig. 10 indicates a regional metamorphism, but not an igneous age.

A similar, but somewhat young upper intercept age of ca. 2100 Ma, has been obtained as the protolith age of the eclogite in Motalafjella about 150 km north along the western coast of Spitsbergen (Bernard-Griffiths et al. 1993). A metamorphic zircon age of ca. 2400 Ma has been reported from the gneisses of the Eskolabreen Formation, structurally lowest lithological unit in southern Ny Friesland, northeastern Spitsbergen (Balašov et al. 1993).

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References

Balashov, Yu. A., Larionov, A. N., Gannibal, L. F., Sirotkin, A. N., Tebenkov, A. M. Ryungenen, G. I. & Ohta, Y. 1993: An Early Proterozoic U-Pb zircon age from an Eskolabreen Formation gneiss in southern Ny Friesland, Spitsbergen. *Polar Res. 12(2)*, 147–152.

Bernard-Griffiths, J., Peucat, J. J. & Ohta, Y. 1993: Age and nature of some protoliths in the Caledonian blueschist-eclogite complex of western Spitsbergen: a combined approach using U-Pb, Sm-Nd and REE geochemistries. *Lithos 30*, 81–90.

Birkenmajer, K. 1959: Report on the geological investigations of the Hornsund area, Vestspitsbergen, in 1958. Part I. The Hecla Hoek formation. *Bull. Acad. Pol. Sci., Ser. Sci. Chim. Geól. Gèol. Géogr., 7(2)*, 129–136.

Birkenmajer, K. 1975: Caledonides of Svalbard and plate tectonics. *Bull. Geol. Soc. Den. 24*, 1–19.

Birkenmajer, K. 1981: The geology of Svalbard, the western part of the Barents Sea, and the continental margin of Scandinavia. Pp. 265–322 in Nairn, E. M., Churkin, M. Jr., & Stehli, F. G. (eds.): *The Arctic Ocean. The Ocean basins and margins 5, The Arctic Ocean*, Chap. 6, 265–329.

Birkenmajer, K. 1991: Origin of the Vendian tilloids (Early Proterozoic), south Spitsbergen. *Bull. Acad. Pol. Sci., Earth Sci. 39*, 39–40.

Birkenmajer, K. 1992: Precambrian succession at Hornsund, south Spitsbergen. A lithostratigraphic guide. *Stud. Geol. Polon. 98*, 67–105.

Birkenmajer, K. & Narebski, W. 1960: Precambrian amphibolite complex and granitization phenomena in Wedel-Jarlsberg Land, Vestspitsbergen. *Stud. Geol. Polon. 4*, 37–82.

Bjornerud, M. G. 1990: Upper Proterozoic unconformity in northern Wedel-Jarlsberg Land, southwest Spitsbergen: Lithostratigraphy and tectonic implications. *Polar Res. 8*, 127–140.

Chappel, B. W. & White, A. J. R. 1974: Two contrasting granite types. *Pacific Geol. 8*, 173–174.

Czerny, J., Lipień, G., Manecki, A. Piestrzynński, A. 1992: Geology and ore-mineralization of the Hecla Hoek succession (Precambrian) in front of Werenskioldbreen. *Stud. Geol. Polon. 98*, 67–105.

Czerny, J., Kieres, A., Manecki, M. & Rajchel, J. 1993: Geological map of the SW part of Wedel-Jarlsberg Land, Spitsbergen 1:25,000, with the text. Institute of Geology and Mineral Deposits, University of Mining and Metallurgy, Krakow. 61 pp.

Dallmann, W. K., Hjelle, A., Ohta, Y., Salvigsen, O. Bjornerud, M. G., Hauser, E. C., Maher, H. D. & Craddock, C. 1990: Geological map Svalbard 1:100,000, B11G, Van Keulenfjorden. *Norsk Polarinst. Temakart 15*. 58 pp.

Dallmeyer, R. D., Peucat, J. J., Hirajima, T. & Ohta, Y. 1990: Tectono-thermal chronology within a blueschist-eclogite complex, west-central Spitsbergen, Svalbard: Evidence from 40Ar/39Ar and Rb/Sr mineral ages. *Lithos 24*, 291–304.

Gavrilenko, B. V., Balašov, Ju. A., Teben'kov, A. M. & Larionov, A. N. 1993: U-Pb ranneproterozojskij vozrast "reliktovogo" cirkona iz vysokokalievych kvarcevych porfirov Zemli Vedel'-Jarlsberga JuZ Špicbergena (U-Pb early Proterozoic age of "relict" zircon from high potassium quartzose porphyries of Wedel-Jarlsberg Land, SW Spitsbergen). *Geochimija 1*, 154–158.

Harland, W. B. 1978: A reconsideration of Late Precambrian stratigraphy of southern Spitsbergen. *Polarforsch. 48*, 44–61.

Harland, W. B., Hambrey, M. L. & Waddams, P. 1993: Vendian geology of Svalbard. *Norsk Polarinst. Skr. 193*. 150 pp.

Hauser, E. C. 1982: *Tectonic evolution of a segment of the West Spitsbergen Fold belt in northern Wedel-Jarlsberg Land*. Ph.D. Thesis, University of Wisconsin. 188 pp.

Hoel, A. 1918: Rapport préliminare de l'expédition norvégienne de 1918 au Spitsberg. *Geogr. 32*, 231–235.

Irvine, T. N. & Baragar, W. R. A. 1971: A guide to the chemical classification of the common volcanic rocks. *Can. J. Earth Sci. 8*, 523–548.

Krasil'ščikov, A. A. & Kovaleva, G. A. 1979: Precambrian rock-stratigraphic units of the west coast of Spitsbergen. Pp. 81–88 in Winsnes, T. S. (ed.): The geological development of Svalbard during the Precambrian, Lower Palaeozoic, and

Devonian Norsk Polarinstitutt Symposium on Svalbard's Geology, Oslo, 2–5 June 1975. *Skr. 167.*

Krasnobaev, A. A. 1985: Morfologičeskie i geochimičeskie svojstva poligenetičeskich cirkonov (Morphological and geochemical properties of polygenetic zircons. Pp. 30–55 in Čajkovskij V. K. (ed.): *Geologičeskoe izučenie dokembrija akcessornymi mineralami* (Geological study of the Precambrian by means of accessory minerals). Nauka, Moscow.

Kretz, R. 1983: Symbols for rock-forming minerals. *Am. Mineral. 68*, 277–279.

Krogh, T. E. 1973: A low-contamination method for hydrothermal dissolution of zircons and extraction of U and Pb for isotopic age determinations. *Geochem. Cosmochem. Acta 37*, 485–494.

Ludwig, K. R. 1991a: PBDAT-a computer program for processing Pb-U-Th isotope data, version 1-20, *U.S.G.S. Open File Report*, 88–542.

Ludwig, K. R. 1991b: A plotting and regression program for isotope data, version 2-56. *U.S.G.S. Open File Report*, 91–445.

Lundberg, B. & Smellie, J. A. T. 1979: Painorova and Mertainen Iron ores. Two deposits of the Kiruna iron ore type in northern Sweden. *Econ. Geol. 74*, 1137–1152.

Magnusson, N. H. 1970: The origin of the iron ores in central Sweden and the history of their alterations. Part I. *Sver. Geol. Unders. C, 643*. 127 pp.

Miyashiro, A. 1974: Volcanic rock series in island arcs and active continental margins. *Am. J. Sci. 274*, 321–355.

Miyashiro, A. & Shido, F. 1975: Theoleiitic and calcalkalic series in relation to the behaviors of Titanium, Vanadium, Chromium, and Nickel. *Am. J. Sci. 275*, 265–277.

Ohta, Y. 1994: Caledonian and Precambrian history in Svalbard: A review, and an implication of escape tectonics. *Tectonophys. 231*, 183–194.

Ohta, Y., & Dallmann, W. K. (eds.) 1994: Geological map of Svalbard 1 : 100,000, sheet B12G Torellbreen. Digital version.

Orvin, A. K. 1940: Outline of the geological history of Spitsbergen. *Skr. Svalb. Ishavet 78*, 57 pp.

Parak, T. 1975: The origin of the Kiruna iron ores. *Sver. Geol. Unders. C, 709*, 209 pp.

Ringwood, A. E. 1974: The petrological evolution of island-arc systems. *J. Geol. Soc. Lon. 130*, 183–204.

Smulikowski, W. 1965: Petrology and some structural data of lower metamorphic formations of the Hecla Hoek succession in Hornsund, Vestspitsbergen. *Stud. Geol. Polon. 18*, 7–107.

Smulikowski, W. 1968: Some petrological and structural observations in the Hecla Hoek succession between Werenskioldbreen and Torellbreen, Vestspitsbergen. *Stud. Geol. Polon. 21, Part 6*, 97–161.

Stacey, J. S. & Kramers, J. D. 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth Planet. Sci. Lett. 26*, 207–221.

Taylor, S. R. & McLennan, S. M. 1985: *The continental crust: its composition and evolution*. Blackwell Scientific Publications, Oxford. 312 pp.

Teben'kov, A. N. 1984: Pozdnedokembrijskie magmatičeskie formacii Zapadnogo Špicbergena. (Late Precambrian magmatic formations on West Spitsbergen.) *Vestnik Leningradskogo Gosudarstvennogo Universiteta 4(24)*, 88–93.