



K-Ar dating of basic intrusions at Bellsund, Spitsbergen, Svalbard

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Abstract: Nine samples of basic (dolerite, gabbro) intrusions collected at Bellsund, South Spitsbergen, have been K-Ar dated. Three dates, between 87.8 and 102.9 Ma, obtained from dolerite sills which intrude Carboniferous and Permian deposits in Van Keulenfjorden point to a Cretaceous age of intrusive activity (Diabasodden Suite). The K-Ar dates obtained from dolerite and gabbro which intrude Upper Proterozoic metasedimentary terrane of Chamberlindalen form two groups: the dates between 97.1 and 178.6 Ma point to a Mesozoic age of the intrusions (Diabasodden Suite); the dates from a tectonized gabbroid (280.9–402.0 Ma) might point to a Late Palaeozoic age of the intrusion. No K-Ar dates which would indicate a Proterozoic age of the basic intrusions were obtained.

Key words: Arctic, Spitsbergen, dolerite intrusions, Mesozoic, Late Palaeozoic, K-Ar dating.

Introduction

Basic rocks, mainly dolerite sills and dykes called the Diabasodden Suite (Mørk *et al.* 1999; Dallmann *et al.* 2002), are widespread in the Svalbard archipelago (Fig. 1). Predominantly they intrude Devonian through Cretaceous deposits of the main Spitsbergen basin and its eastern forefield – the Edgeøya-Barentsøya area (*e.g.*, Harland 1997; Mørk *et al.* 1999). They are less frequent in the pre-Devonian metamorphic basement in north and west Spitsbergen. Their Late Jurassic–Early

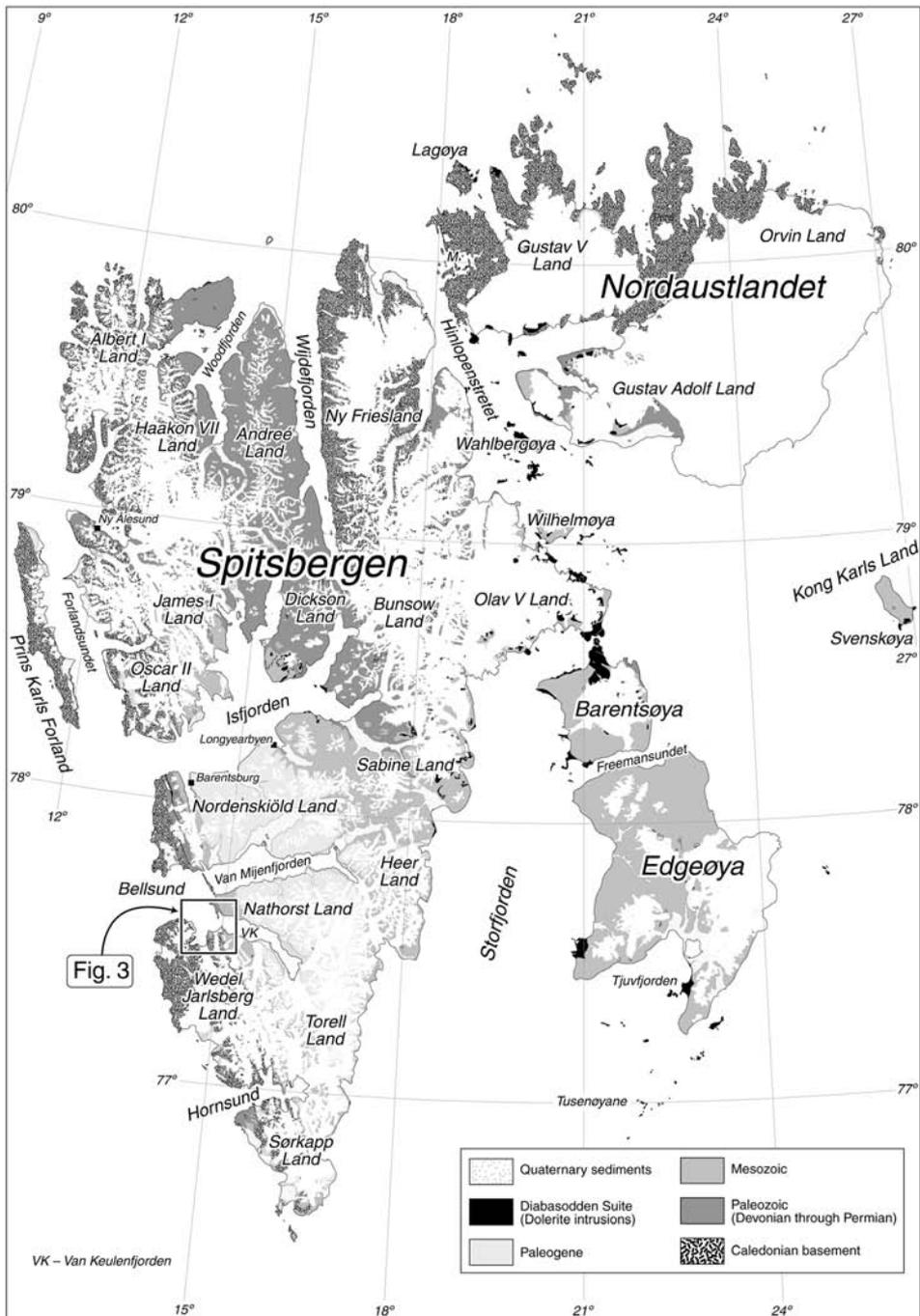


Fig. 1. A simplified geological map of Svalbard showing the area investigated in the present paper. Geology after Dallmann *et al.* (2002).

Cretaceous age has been determined by K-Ar dating (Gayer *et al.* 1966; Burov *et al.* 1977; Vincenz *et al.* 1981; Nejbort *et al.* in press).

In the Hornsund area (SW Wedel Jarlsberg Land), dolerite dykes cut metasediments and metavolcanics of Middle–Upper Proterozoic age (Birkenmajer and Morawski 1960; Birkenmajer 1986, 1990). They were K-Ar dated at Early Cretaceous (Vincenz *et al.* 1981).

In the Bellsund area (NW Wedel Jarlsberg Land), to the south of Recherchefjorden, numerous basic intrusions were mapped, but not radiometrically dated, in a Proterozoic terrane of Chamberlindalen (Dallmann *et al.* 1990). Therefore, the main aim of the present work was to elucidate the question whether these rocks are Proterozoic in age or belong to the Mesozoic Diabasodden Suite.

Samples of basic intrusive rocks were collected in 2002 at Bellsund (Figs 1–4) by K. Birkenmajer and K.P. Krajewski. Their petrographic character was studied by M. W. Lorenc, and the K-Ar ages were determined by Z. Pécskay. Geochemical analyses and/or closer studies on metamorphic/metasomatic transformations of the rocks in question were beyond the scope of the present paper.

The K-Ar dating involved 6 samples of dolerite and gabbro intrusions which occur within the Upper Proterozoic metasedimentary complex of Chamberlindalen, south of Recherchefjorden. Additionally, 3 samples from dolerite sills intruded in Upper Palaeozoic sedimentary sequence in western part of Van Keulenfjorden (see Figs 2–4) were K-Ar dated for comparison purposes.

Geological setting

Basic rocks (gabbro, dolerite, greenstone and serpentinite) have been recognized and mapped south of Bellsund, between Recherchebreen in the east and Chamberlindalen in the west, within a terrane consisting mainly of Proterozoic metasediments (Dallmann *et al.* 1990). Birkenmajer (2004) has distinguished there (Fig. 2): the Upper Proterozoic Sofiebogen Group, represented in the succession by the Slyngfjellet Formation (metaconglomerate), the Höferpynten Formation (mainly dolostone) and the Gåshamna Formation (mainly phyllite, with quartzite and carbonate intercalations).

According to Dallmann *et al.* (1990), basic rocks of the Chamberlindalen area are the products of continental within-plate igneous activity. Some of them (*e.g.*, at Asbestodden) had been transformed by hydrothermal solutions into serpentinite which is crossed by asbestos-quartz veins.

Chamberlindalen and vicinity: sample location and petrography

Six samples (Nos 60/1, 2; 61/1-3 and 75) of basic intrusive rocks from the Proterozoic Chamberlindalen terrane (Figs 3, 4A) were petrographically studied.

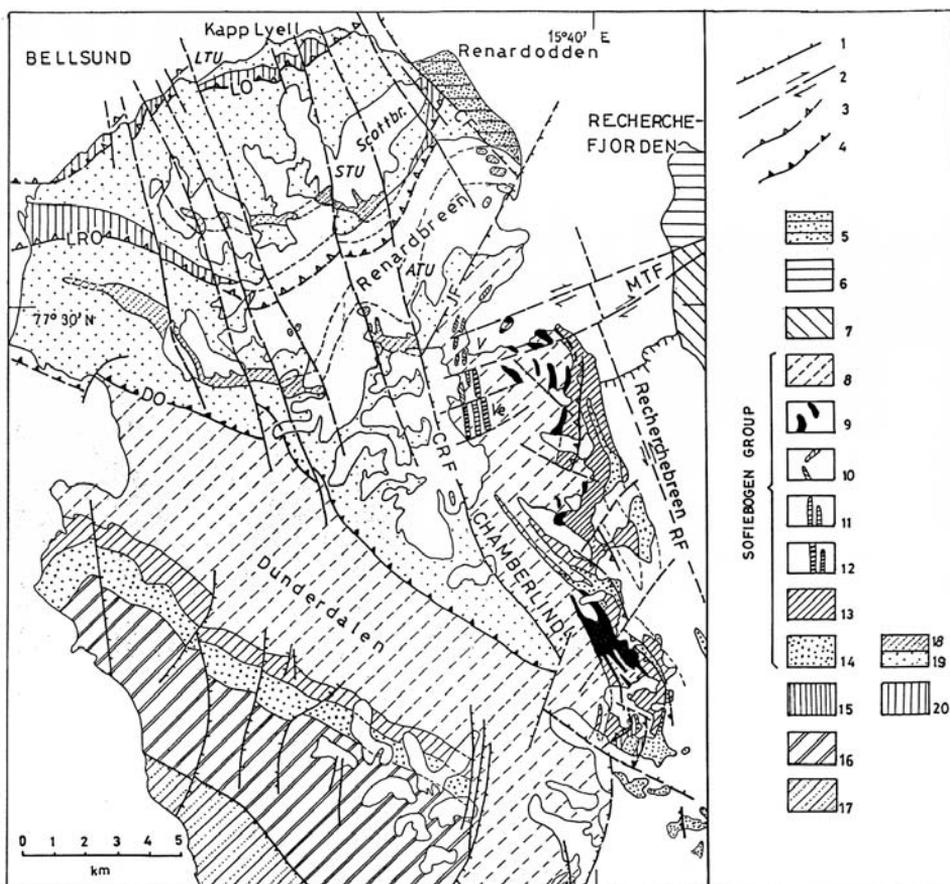


Fig. 2. Selected tectonic/structural elements in the area south of Bellsund (from Birkenmajer 2004). 1 – Tertiary dip-slip faults (barbs on downthrown side), 2 – Tertiary strike-slip faults, 3 – minor Caledonian overthrusts (barbs towards upper unit), 4 – major Caledonian overthrusts (barbs towards upper unit), 5 – Tertiary deposits (Calypsostranda Graben), 6 – Reinodden Block (Carboniferous–Mesozoic platform cover), 7 – Martinfjella Block (Late Proterozoic–Early Ordovician rocks), 8, 10–14 – Sofiebogen Group (Upper Proterozoic), 8 – Gåshamna Fm. (phyllite and chlorite schists), 9 – selected stratabound mafic intrusions within the Gåshamna Fm., 10–12 intercalations within the Gåshamna Fm. (10 – quartzite, 11 – limestone, 12 – dolostone), 13 – Höferpynten Fm., 14 – Slyngfjellet Fm., 15 – ?Bergskardet Fm. (Deilegga Gp., Middle Proterozoic), 16 – rocks of the Thiisfjellet anticlinorium (Middle Proterozoic), 17 – rocks of the Fløysletta synclinorium (?Middle–?Early Proterozoic), 18, 19 – Kapp Lyell diamictite (18 – upper: *green*, 19 – lower: *yellow*), 20 – Bergskardet Fm. (Deilegga Gp., Middle Proterozoic), V – Vestervågen, Ve – Vestliknausane.

Sample 60/1: dolerite. Rubypynten (Observatoriefjellet). — This is a fine-crystalline, dark-grey-green rock with ophitic structure. Plagioclase forms two generations with clear lamellae of albite and pericline twins: the older, more calcic euhedral andesine phenocrysts (An_{45-50}) are almost entirely sericitized and rich in fine secondary epidote; the younger andesine phenocrysts (An_{38-40}) are subhedral, rather fresh, smaller than the former, sometimes slightly deformed.

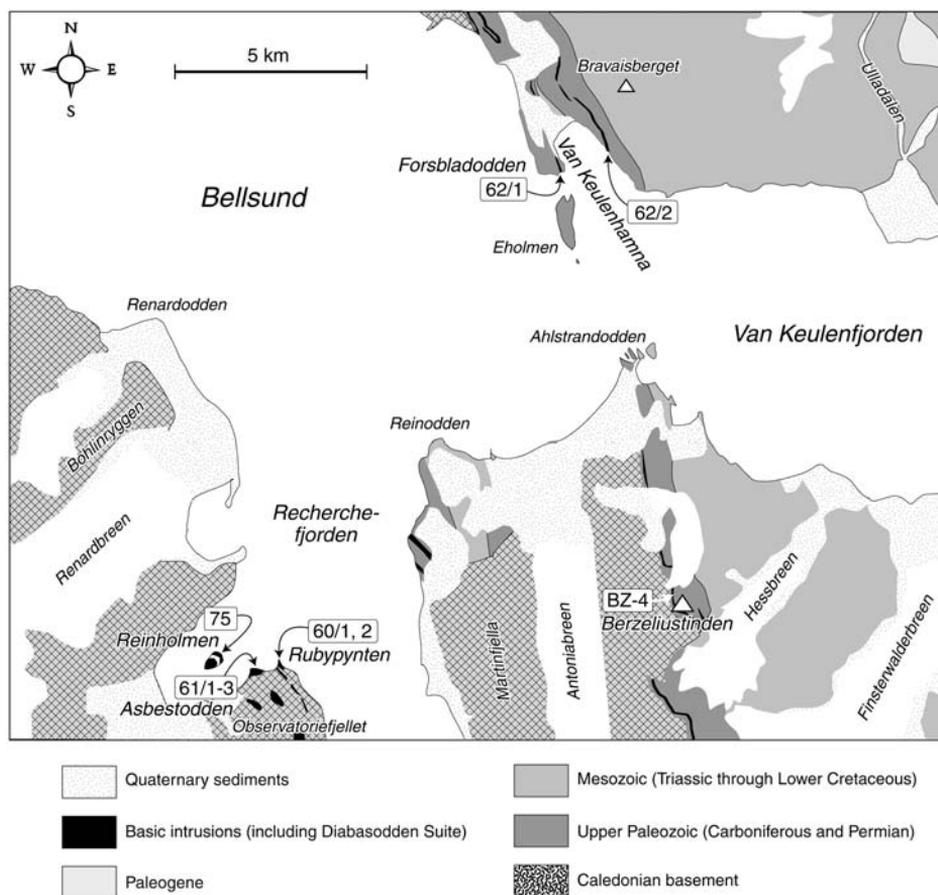


Fig. 3. Geological map of the southern part of Bellsund and western part of Van Keulenfjorden showing location of basic intrusions investigated in this paper. Geological features after Dallmann *et al.* (1990), simplified.

Clinopyroxene (augite $z/\gamma = 38\text{--}40^\circ$) occurs as relatively large subhedral phenocrysts with numerous inclusions of very fine euhedral plagioclase. Partial chloritization follows from outer parts of phenocrysts and along microcracks. Orthopyroxene (enstatite) is less frequent than clinopyroxene, its subhedral phenocrysts affected by partial chloritization are of similar size as those of the clinopyroxene. Small aggregates of fine epidote, or of serpentine-group minerals, locally occur. Fine apatite needles (indicative of rapid cooling of magma) and opaque minerals (iron oxides) are common.

Metagabbro and greenstone have been distinguished at Observatoriefjellet in geological map by Dallmann *et al.* (1990). Country rocks of this dolerite intrusion are represented by dolostones of the Höferpynten Formation (Upper Proterozoic).

Sample 60/2: dolerite. Rubypynten (Observatoriefjellet). — Mineral content and rock character are the same as in sample 60/1. The only difference consists

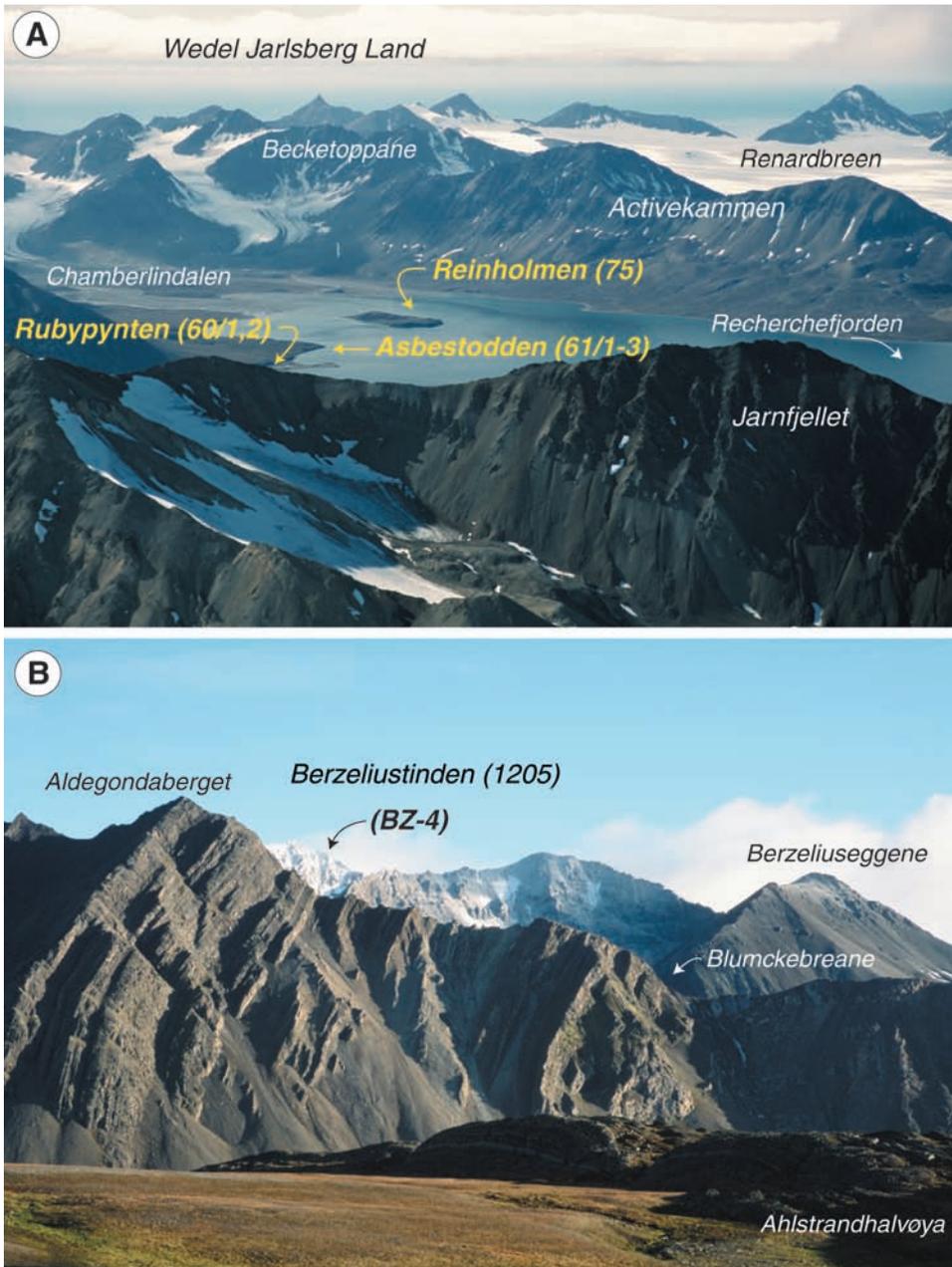


Fig. 4. Field photos of the southern part of Bellsund and western part of Van Keulenfjorden showing location of basic intrusions investigated in this paper. **A.** Southwestern margin of Recherchefjorden seen from the the summit of Berzeliustinden. The area is dominated by the Proterozoic Sofiebogen Group that hosts isolated basic intrusive bodies. **B.** Northern face of Berzeliustinden seen from Ahlstrandodden in Van Keulenfjorden. The massif shows a complex thrust structure consisting of Proterozoic through Jurassic rock sequence that hosts a folded dolerite sill in the Carboniferous Reinodden Formation.

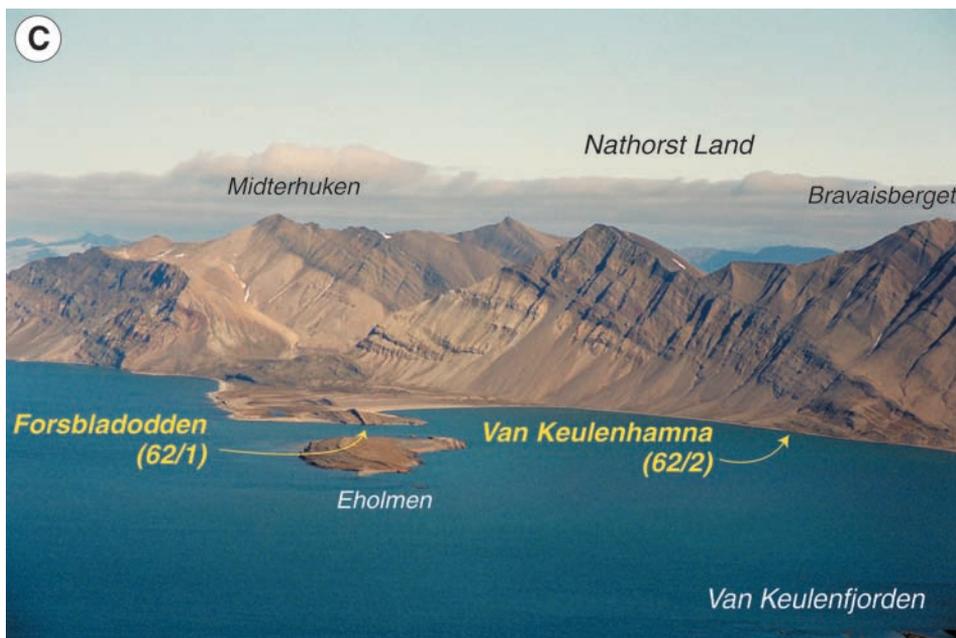


Fig. 4. C. Northwestern margin of Van Keulenfjorden seen from the summit of Berzeliustinden. A monoclinial tectonic structure consists of the Upper Palaeozoic through Lower Cretaceous sedimentary sequence that hosts subparallel dolerite sills in the Gipshuken Formation.

in light-grey-green colour, finer grain size, and more advanced alteration expressed by larger amount of chlorite, sericite, epidote and titanite.

Country rocks of the dolerite intrusion are represented by dolostones of the Höferpynten Formation (Upper Proterozoic).

Sample 61/1: metadolerite. Asbestodden. — This is a grey-green rock with porphyric structure. Its groundmass consists mainly of subhedral plagioclase crystals (andesine An_{38-40}) showing traces of albite- and, rarely, pericline twins; they are strongly sericitized, partly albitized. Pyroxene (augite $z/\gamma = 38^\circ$) phenocrysts are strongly chloritized: locally, they show distinct opacite rims consisting of titanite and iron oxides. Pyroxene phenocrysts are commonly overgrown with secondary titanite and calcite. Subhedral amphibole (brown hornblende, $z/\gamma = 18^\circ$) phenocrysts, of similar size as the pyroxene, are partly chloritized along margins and microfractures; they contain numerous inclusions of fine apatite and euhedral titanite. Apatite is common in the groundmass in form of long euhedral columellas: their oblique extinction and biaxial optical character point to a carbonate apatite. Secondary chlorite and calcite are very common in the groundmass.

Country rocks of the metadolerite are represented by the Gåshamna Formation (Upper Proterozoic). Dallmann *et al.* (1990, p. 16, and geological map) determined the Asbestodden exposure as serpentinite.

Sample 61/2: metagabbro. Asbestodden. — The rock is black, fine-crystalline, strongly altered, with porphyric structure. Its groundmass consists of cryptocrystalline or, locally, very fine serpentinite (probably α -chrysotile). Two generations of amphiboles, being the dominant phenocrysts, are present. The older generation is represented by subhedral crystals of brown hornblende ($z/\gamma = 18^\circ$) which is partly chloritized and rich in fine inclusions of opaque minerals. The younger generation is represented by relatively large, fresh anhedral crystals showing very deep embayments (a result of intense corrosion), filled with serpentinite. The second generation amphiboles show very weak pleochroism. Orthopyroxene (enstatite) rarely occurs: its shape resembles that of the younger amphibole generation. Some orthopyroxene phenocrysts show zonal structure, their outer zone being stronger pleochroic and richer in iron. Biotite crystals are dark-brown, with numerous very fine inclusions of apatite. Irregular agglomerations of opaque minerals (iron oxides) and fine apatite needles occur in the groundmass.

Sample 61/3: gabbro. Asbestodden. — This is a grey-green rock showing porphyric structure, with directionally elongated phenocrysts which are 8–12 mm long and 1–2 mm thick. This fabric seems to be of tectonic origin. The groundmass consists of fine-crystalline quartz-feldspar laminae and very fine chlorite lenses and aggregates exhibiting blue pleochroism; fine apatite columellae, secondary calcite, sericite and chlorite (with green pleochroism) occur between them. Single subhedral plagioclase phenocrysts show traces of albite twins (due to intense sericitization, their optical determination was not possible). They are often replaced by secondary chlorite, titanite and calcite. Amphibole (green hornblende $z/\gamma = 18^\circ$) forms euhedral columellae elongated parallel with mylonitic structure. They are fresh, usually twinned, with numerous apatite inclusions. Secondary chlorite sometimes surrounds the amphibole crystals, secondary calcite fills some microfractures. Interstitial anhedral crystals of potassium feldspar (microcline microperthite) rarely occur. They are partly albitized, enriched in haematite pigment, and contain fine apatite inclusions. Strain-shadows typical of mylonites are very common near hornblende phenocrysts: they consist of chlorite and calcite, sometimes with single fine phengite.

Sample 75: dolerite (microgabbro). Reinholmen. — This is a grey-green rock with ophitic structure. Euhedral and subhedral plagioclase (andesine An_{38-40}) shows albite- and, more seldom, pericline twins. Its crystals are partly sericitized and albitized, the albitization proceeds from margins inwards. Subhedral and euhedral clinopyroxene (augite $z/\gamma = 40^\circ$) phenocrysts are surrounded by twinned and zoned plagioclase; it sometimes contains fine euhedral plagioclase inclusions. Very weak chloritization is marked along margins and microfractures. Numerous apatite needles occur between plagioclase and pyroxene crystals, probably being the evidence of a chilling process. Chlorite aggregates (probably pseudomorphs), subhedral titanite crystals with opaque inclusions, and relatively rare isotropic iron oxides occur in the groundmass.

In geological map of the area, Dallmann *et al.* (1990) marked this exposure as metagabbro and greenstone.

Van Keulenfjorden area: sample location

Three samples (Nos BZ-4, 62/1 and 62/2) were collected at western part of Van Keulenfjorden from dolerite sills of the Diabasodden Suite which intrude Carboniferous and Permian deposits (Figs 3, 4B, C), for the purpose of comparison with the Chamberlindalen results. They were K-Ar dated (see Table 1).

Sample BZ-4: Berzeliustinden (1205 m, near top of the mountain): dolerite sill intruding the Middle Carboniferous Reinodden Formation (Fig. 4B);

Sample 62/1: Forsbladsodden: dolerite sill intruding the Upper Permian Kapp Starostin Formation (Fig. 4C);

Sample 62/2: Van Keulhamna: dolerite sill intruding the Upper Carboniferous Gipshuken Formation (Fig. 4C).

Potassium-argon age determination

Rock samples collected in the field weighed about 1kg each. Care was taken to avoid weathered rocks and those abounding in xenoliths. Thin rock sections were examined prior to crushing the samples. Approximately 30–50 g of the 200–300 μm fraction was separated from each sample using copper sieves. The fine powder obtained was elutriated with water and dried up in oven. A portion of each separate was ground in agate mortar and used for potassium determination. Due to fine-crystalline character of the dolerites and other basic rocks, whole rock samples were dated. In case of the Asbestodden coarser-grained gabbro, both whole-rock fraction and separated hornblende mineral fraction were dated.

Potassium determination. — Powder samples were digested in acids (HF, HNO_3 and H_2SO_4) in teflon beakers, dissolved in 0.2 M HCl, and analysed for potassium content by flame photometry with a Na-buffer and Li internal standard. Multiple runs of inter-laboratory standards (Asia 1/65, LP-6, HD-B1) indicated the accuracy and reproductability of this method to be within 2–3%.

Argon measurements. — Approximately 0.5 g samples wrapped in aluminium foil were preheated for about 24 h at 150–200° in a vacuum. Argon was extracted from the samples by RF fusion in Mo crucibles, in previously backed stainless steel vacuum system. ^{38}Ar spike was added from gas pipette system and the evolved gases were cleaned using Ti and SAES getters and liquid nitrogen traps, respectively. The purified Ar was transported directly into the mass spectrometer, and Ar isotope ratio was measured in the static mode, using a 15-cm radius magnetic sector-type mass spectrometer constructed at the Institute of Nu-

clear Research of the Hungarian Academy of Sciences in Debrecen. Details of the instruments, the applied methods, and results of calibration were described elsewhere (Odin *et al.* 1982, Balogh 1985).

Age calculation. — Atomic constants suggested by Steiger and Jäger (1977) were used for calculating the ages. All analytical errors represent one standard deviation (*i.e.* 68% analytical confidence level). Since we base our analytical errors on the long-time stability of instruments, and on the deviation of our results obtained on standard samples from the inter-laboratory mean, the analytical errors are likely to be overestimated.

The K-Ar ages of suites of volcanic and metamorphic rocks generally are in good agreement with geological expectations. However, both the Ar and K concentrations may undergo changes during the geological history of the rocks, due to diffusion, solution or ion exchange. Consequently, the K-Ar ages are considered valid, if they can be supported by geological, stratigraphical and petrographical data as well. The results of K-Ar dating of the Bellsund basic intrusive rock samples are shown in Table 1.

Table 1
Potassium-argon age determination of basic intrusive rock samples from Bellsund, Spitsbergen (wr – whole rock; h – hornblende)

Lab. No	Sample No	Rock type		K (%)	⁴⁰ Ar _{rad} (%)	⁴⁰ Ar _{rad} (ccSTP/g)	K-Ar Age (Ma)
Chamberlindalen							
5949	60/1	dolerite	wr	0.80	56.7	5.458×10 ⁻⁶	167.3±6.8
5950	60/2	dolerite	wr	1.00	22.3	3.888×10 ⁻⁶	97.1±6.1
5951	61/1	metadolerite	wr	0.56	23.0	7.932×10 ⁻⁶	331.8±20.5
5952	61/2	metagabbro	wr	1.45	66.3	1.058×10 ⁻⁵	178.6±5.8
5953	61/3	gabbro	wr	3.30	91.6	3.900×10 ⁻⁵	280.9±10.5
			h	1.35	89.1	2.358×10 ⁻⁵	402.0±15.1
5954	75	dolerite	wr	0.66	57.5	2.875×10 ⁻⁶	109.4±5.2
Van Keulenfjorden							
6207	BZ-4	dolerite	wr	0.58	49.8	2.387×10 ⁻⁶	102.9±4.3
6208	62/1	dolerite	wr	0.34	20.9	1.189×10 ⁻⁶	87.8±6.2
6209	62/2	dolerite	wr	0.64	58.7	2.266×10 ⁻⁶	89.1±3.6

Basic Mesozoic volcanism of the Barents Sea Province

Basic intrusions of tholeiitic composition, with a white-trap modification, are a characteristic feature of Mesozoic platform development in Svalbard (Tyrell and Sandford 1933; Birkenmajer 1981; Harland *et al.* 1997). Together with Franz Josef Land, they form the Barents Sea Province of basic magmatism confined to the NW edge of the Eurasian Plate. This magmatism is represented in Spitsbergen, Nordaustlandet and on islands east of Storfjorden (Barentsøya, Edgeøya and Tusenøyane) by

dolerite dykes and sills (Late Jurassic through Late Cretaceous: mainly Early Cretaceous), in Kong Karls Land by capping lavas (Barremian or later), and on islands of Franz Josef Land by lavas and tuffs (Hauterivian through Cenomanian). The basic (tholeiitic) magmatism was a response to the initial stage of continental-crust break-up that ultimately led to the Eurasia/Laurentia plates separation and full opening of the North Atlantic-Arctic Basin during the Eocene and Oligocene.

The basic magmatism ceased in the Barents Sea Province during the Late Cretaceous (Campanian), prior to the formation of the Tertiary sedimentary basins in Spitsbergen. Rafted dolerite pebbles appeared for the first time in Lower Tertiary marine strata of eastern Spitsbergen (Birkenmajer and Narębski 1963; Birkenmajer *et al.* 1971).

The K-Ar ages obtained on Spitsbergen dolerites by Gayer *et al.* (1966) showed a wide time distribution, 149 Ma (latest Jurassic) through 110 Ma (Early Cretaceous: Aptian–Albian). Limits of chronostratigraphic units are after Gradstein *et al.* (2004). Structural evidence from east-central Spitsbergen indicated a Berriasian age for some of the intrusions that cut the Agardhfjellet (Callovian to Volgian) but predate the Rurikfjellet (Valanginian to Hauterivian) deposition (Parker 1966).

Burov *et al.* (1977) performed 45 K-Ar age determinations on dolerite rocks in Svalbard: these dates cluster around 140 ± 5 Ma (Berriasian–Valanginian) and 105 ± 5 Ma (Albian).

The 110 ± 5 Ma date obtained from a dolerite dyke (Vincenz *et al.* 1981), which crosses the Middle Proterozoic phyllites at Vimsodden, south-west Wedel Jarlsberg Land (Birkenmajer 1986, 1990), stressed the importance of the Early Cretaceous (Aptian–Albian) stage of intrusive activity. Another dyke from the same area yielded a 66.8 ± 4.3 Ma K-Ar date (apparently Maastrichtian; probably a minimum age). Both dykes occur within a Proterozoic metasedimentary terrane, part of the Tertiary Fold Belt of West Spitsbergen.

The dolerite sills which intrude flat-lying, unfolded Triassic–Jurassic rocks exposed around Storfjorden, eastern Spitsbergen, yielded Early Cretaceous ages from 125.5 ± 3.6 Ma (Barremian–Aptian) to 78.3 ± 2.6 Ma (Campanian), with discrete peaks of intrusive activity at 115.6 Ma (Aptian), 102.1 Ma (Albian) and 79.1 Ma (Campanian) – Pécskay *et al.* (2007), Nejbort *et al.* (in press).

Geological age interpretation of basic rocks from Chamberlindalen and vicinity

The basic intrusive rocks investigated by us may be grouped as follows (1–4):

(1) Three dolerite sills (samples Nos BZ-4, 62/1 and 62/2) which intruded Carboniferous–Permian rocks at Van Keulenfjorden, occur within eastern part of the Alpine Spitsbergen Foldbelt. Their K-Ar dates range between late Early Cretaceous (102.9 ± 4.3 Ma: Albian) and early Late Cretaceous (87.8 ± 6.2 and 89 ± 3.6

Ma: Coniacian), being in agreement with radiometric ages of the Diabasodden Suite in Svalbard (cf. Gayer *et al.* 1966, Burov *et al.* 1977, Vincenz *et al.* 1981).

(2) Similar Early Cretaceous K-Ar ages were obtained from two dolerites which intruded Upper Proterozoic rocks of Chamberlindalen and vicinity: 109.4 ± 5.22 Ma (Albian: dolerite, sample No 75, Reinholmen) and 97.1 ± 6.1 Ma (Albian–Cenomanian: dolerite, sample No 60/2, Rubypynten). These intrusions belong to a younger intrusive phase of the Diabasodden Suite;

(3) Two basic intrusions which intruded the Upper Proterozoic Gåshamna Formation phyllites at Chamberlindalen yielded Jurassic K-Ar ages: the 167.3 ± 6.8 Ma (Middle Jurassic) date was obtained from a dolerite sill (sample No 60/1) at Rubypynten (Observatoriefjellet); the 178.6 ± 5.8 Ma (Early/Middle Jurassic) date was obtained from a metagabbro (sample No 61/2) at Asbestodden. These basic rocks might represent an older intrusive phase of the Diabasodden Suite;

(4) Three apparently Late Palaeozoic K-Ar dates were obtained from basic rocks which intruded the Upper Proterozoic rocks in northern part of Chamberlindalen/SW Recherchefjorden. Of the two K-Ar dates from a gabbro intrusion at Asbestodden (sample No 61/3), the older one, 402.0 ± 15.1 Ma (on hornblende), apparently indicates an Early Devonian age of the intrusion; however, this analytical age may be older than the real geological age due to some excess argon incorporated in the hornblende. The younger whole-rock date, 280.9 ± 10.5 Ma, apparently indicates an Early Permian age; however, it might be treated as a result of reheating and overprinting caused by hydrothermal alteration related to asbesthos formation at a later date (during Mesozoic).

The K-Ar date 331.8 ± 20.5 Ma from metadolerite intrusion at Asbestodden, apparently indicates an Early Carboniferous age of the rock.

Conclusions

- Radiometric dating of basic intrusions which occur within the Late Proterozoic terrane of Chamberlindalen, suggests that we deal here with two separate epochs of the intrusive activity: the Late Palaeozoic epoch and the Jurassic–Cretaceous one. None of our samples yielded a Proterozoic K-Ar age.
- The older magmatic epoch of the Chamberlindalen area is represented by gabbro and metadolerite intrusions at Asbestodden. The hornblende date, 402.0 ± 15.1 Ma from the gabbro, might correlate with late-Caledonian (Early Devonian) magmatism. In Ny Friesland (north Spitsbergen), porphyric granite intrusions have been K-Ar dated (on biotite) at 385–402 Ma (see Gayer *et al.* 1966, table 1, and fig. 1: specimens 1–5).
- Two much younger whole-rock K-Ar dates, 331.8 ± 20.5 Ma and 280.9 ± 10.5 Ma, respectively, might reflect reheating caused by hydrothermal solutions which, probably during Mesozoic, transformed a part of the Early Devonian basic rock at Asbestodden into asbesthos.

- The K-Ar dates 178.6 ± 5.8 Ma (metagabbro), and 167 ± 6.8 Ma (dolerite), represent the Jurassic members of the Diabasodden Suite.
- The K-Ar dates 97.1 ± 6.1 Ma and 109.4 ± 5.2 Ma, represent the Early Cretaceous members of the Diabasodden Suite.

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