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K-Ar AGES OF IGNEOUS AND METAMORPHIC ROCKS FROM MCMURDO, SØR RONDANE AND DUMONT D'URVILLE, ANTARCTICA

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Abstract: K-Ar radiometric ages were determined for igneous and metamorphic rocks from the Antarctic Margin. Twenty-five volcanics of 11 sites from McMurdo Sound resulted in between 0.08-Ma and 4.15-Ma. Two syenites from the Sør Rondane Mountains were about 400 Ma and three granitic rocks from Dumont d'Urville were around 1000 Ma.

1. Introduction

Many types of fresh lithologies with ages from Archean to Quaternary have been found in Antarctica, and have attracted many earth scientists, in particular, paleomagnetists who are interested in continental drift and/or paleointensity of earth magnetism. The paleomagnetic studies should be done with rock samples of which the ages have been determined with radiometric dating methods. In this paper, the authors will present K-Ar ages for representative igneous and metamorphic rocks from McMurdo Sound, Sør Rondane Mountains and Dumont d'Urville where FUNAKI (1984) and others have carried out paleomagnetic studies.

2. Geology and Samples

2.1. McMurdo Sound

Volcanism occured sporadically in this region in the Plio-Pleistocene (MANKINEN and COX, 1988). The representative volcanic ejecta were collected from Hut Point Peninsula and Cape Royds on Ross Island and from Taylor Valley (Fig. 1). The sampling sites on the Hut Point Peninsula are illustrated in Fig. 2. Petrographic descriptions for all the samples are listed in the Appendix. MANKINEN and COX (1988) reported paleomagnetic data combined with previously published geologic and geochronologic data, and determined the general sequences of volcanic rocks of the McMurdo volcanic province. Previous reports have shown K-Ar ages of Black Knob to be 0.43 ± 0.07 Ma (ARMSTRONG, 1978), Cape Royds to be 0.68 ± 0.14 Ma (TREVES, 1967), Half Moon Crater to be 1.0 ± 0.15 Ma (ARMSTRONG, 1978), Castle Rock to be 1.1 ± 0.4 Ma (KYLE and TREVES, 1974), and Observation Hill to be 1.18 ± 0.03 Ma (FORBES *et al.*, 1974), respectively. ARMSTRONG (1978)

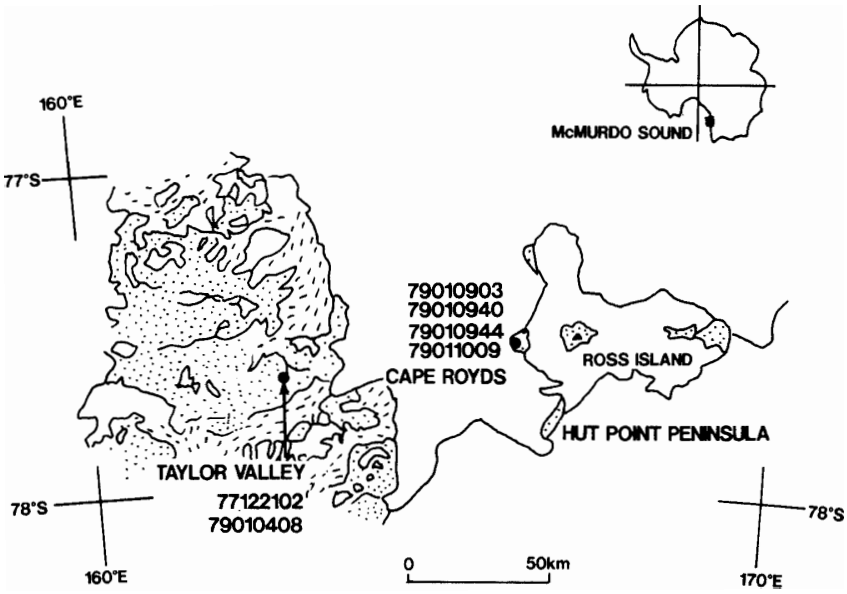

Fig. 1. A topographic map of the McMurdo Sound region and the sampling sites (modified after FUNAKI, 1984).

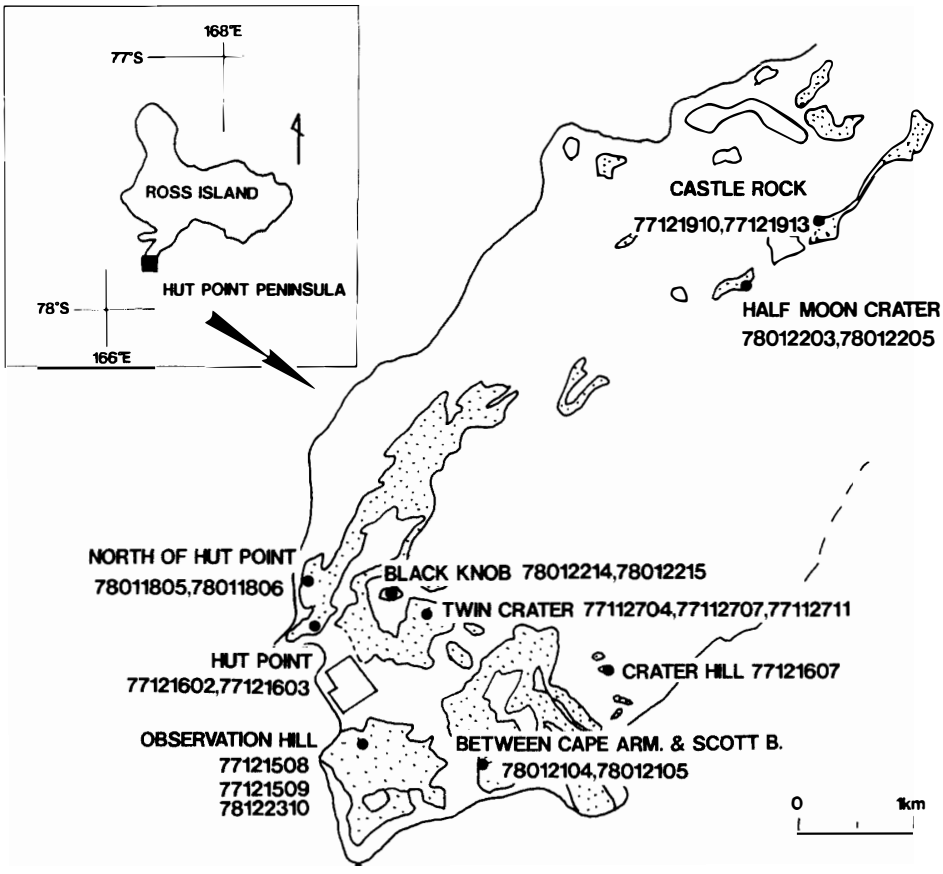

Fig. 2. Sampling sites of Hut Point Peninsula (modified after FUNAKI, 1984).

reported K-Ar ages (1.5 Ma to 4.6 Ma) of rocks from Taylor Valley, and gave the ages 2.93±0.10 Ma and 2.87±0.15 Ma for the basaltic rocks. We also collected basaltic rocks from the same location as ARMSTRONG (1978) did.

2.2. *Sør Rondane Mountains*

The Sør Rondane Mountains in East Antarctica consist of medium- to high-grade metamorphic rocks, and various plutonic and minor dike rocks (SHIRAISHI and KAGAMI, 1992). GREW (1982) compiled radiometric age data in this region ; the gneisses have U-Pb zircon ages of 2700 Ma, 950-970 Ma and 520-600 Ma, and the plutonic rocks have only zircon age of 520-600 Ma. TAKIGAMI and FUNAKI (1991) reported ^{40}Ar-^{39}Ar and K-Ar ages of K-feldspar and biotite from igneous and metamorphic rocks and suggested igneous activity of 440-500 Ma and metamorphism of 350-400 Ma. They also reported a K-Ar biotite age of 662±23 Ma from gneiss. SHIRAISHI and KAGAMI (1992) obtained Sm-Nd and Rb-Sr whole rock isochron ages around 1000 Ma for granulite facies metamorphic rocks, 624±18 Ma Sm-Nd internal mineral isochron age of hornblende, biotite and plagioclase, and 556±26 and 483±12 Ma Rb-Sr mineral ages of hornblende, biotite and plagioclase. Sampling sites in the Sør Rondane Mountains are illustrated in Fig. 3. Petrographic descriptions of the samples are shown in the Appendix.

2.3. *Dumont d'Urville*

The Dumont d'Urville region is situated around the Wilkes Subglacial Basin, which trends north, parallel to the transatlantic mountains, and has exposure of high-grade metamorphic rocks of Proterozoic. GREW (1982) reported Rb-Sr biotite ages from pegmatite and granite of 1530 and 1543 Ma, respectively. Samples were collected from Ile Cuvier near Ile du Lion and from Ile des Petrels (Fig. 4). Petrographic descriptions of the samples are shown in the Appendix.

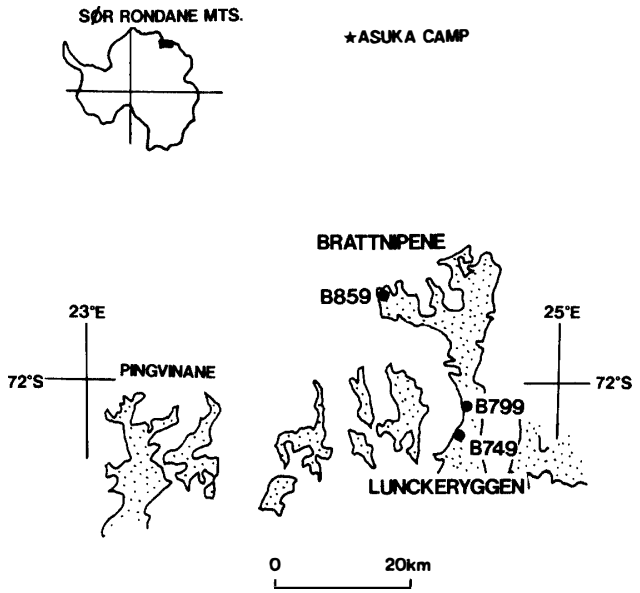

Fig. 3. Sampling sites in the Sør Rondane Mountains (modified after TAKIGAMI and FUNAKI, 1991).

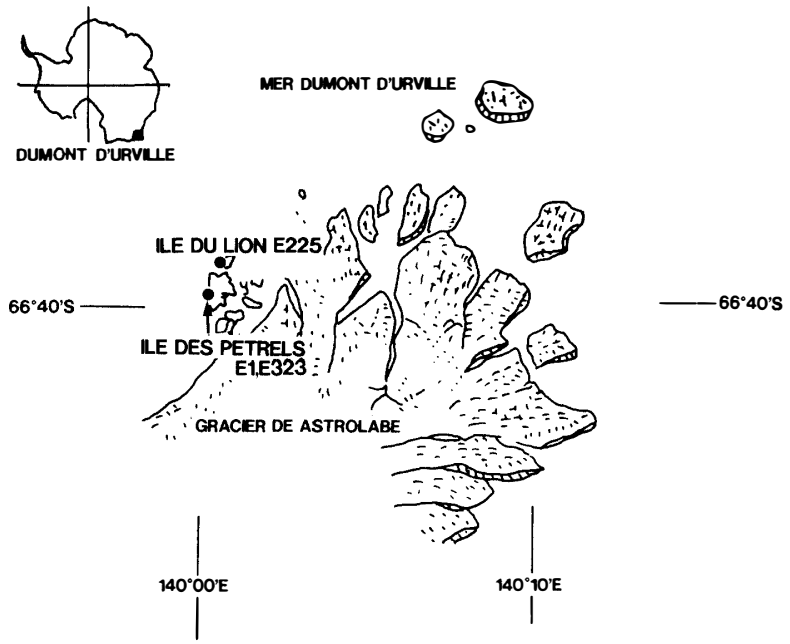

Fig. 4. Sampling sites in Dumont d'Urville (modified after Institut Geographique National en 1954).

3. Experiments

K content was analysed by flame photometry at Toyo University using a 1000 ppm Cs buffer. The detailed analytical method was described in UENO (1991). Experimental error of the K content was assumed to be 5% based on multiple analyses of the standard samples (JB-2, JB-3 and JG-1a by Geological Survey of Japan described in ANDO *et al.*, 1989).

Ar analysis was performed by a noble gass mass spectrometer (Modified VG5400) installed in the Institute for Study of the Earth's Interior, Okayama University. About 0.1-0.5 g of sieved samples between 250 μm and 180 μm were used for analyses of McMurdo Sound rocks, which were expected to be within 0.5 and 3.0 Ma. About 50 mg of samples were analysed for other regions where the rock ages were expected to be older than 500 Ma. Samples were wrapped with Al foil 8 μm thick and put into a sample holder. The samples from McMurdo Sound were set at once with a working standard sample YZ1-6 (0.236 ± 0.004 Ma with K content of 1.41 wt%, *cf*. NAGAO *et al.*, 1991), separately from other old samples which were set up with a working standard sample MMhb-1 (517.5 ± 4.5 Ma with K content of 1.58 wt%, *cf*. SAMSON and ALEXANDER, 1987). Analyses were carried out in a computer controlled peak jumping mode. Details of the analytical technique and the age calculation will be reported elsewhere (NAGANO *et al.*, in preparation).

4. Results and Discussion

The results of K-Ar analyses are shown in Tables 1, 2 and 3. The errors of K-Ar ages

Table 1. Summary of K-Ar ages in McMurdo Sound.

		Rock type	K (Wt%)	Weight (g)	^{36}Ar (10^{-10} cm^3 STP/g)	$^{40}Ar/^{36}Ar$	$^{40}Ar_{rad}$ (10^{-8} cm^3 STP/g)	Age (Ma)	$^{40}Ar_{air}/^{40}Ar_{total}$ (%)
Cape Royds	79010903*	Kenyte	3.35	0.5498	3.956±0.072	322.96±0.64	1.067±0.030	0.082±0.005	91.7
	79010940*	Kenyte	3.52	0.4830	6.911±0.101	311.81±0.57	1.093±0.041	0.080±0.005	94.9
	79010944*	Kenyte	3.23	0.5582	5.456±0.083	314.47±0.58	1.008±0.033	0.080±0.005	94.1
	79011009*	Kenyte	3.15	0.5626	5.422±0.082	313.66±0.54	0.957±0.031	0.078±0.005	94.4
Taylor Valley	77122102**	Ankaramite	1.28	0.1544	22.721±0.267	358.90±0.74	14.29±0.22	2.87±0.15	82.5
	79010408**	Ankaramite	1.19	0.1516	16.745±0.226	410.06±1.25	19.18±0.25	4.15±0.21	72.2
Hut point Penisula Crater Hill	77121607*	Ankaramite	1.11	0.2238	22.813±0.257	303.19±0.51	1.641±0.114	0.39±0.04	97.6
Twin Crater	77112704*	Ankaramite	1.25	0.2561	4.645±0.089	343.72±1.06	2.216±0.060	0.46±0.03	86.1
	77112707*	Ankaramite	1.24	0.2576	5.723±0.097	336.40±0.83	2.312±0.057	0.48±0.03	88.0
	77112711**	Ankaramite	1.20	0.2016	5.627±0.114	333.78±1.00	2.126±0.066	0.46±0.03	88.7
Between Cape Arm. & Scott B.	78012104**	Ankaramite	1.35	0.2122	3.829±0.096	355.55±1.67	2.280±0.078	0.44±0.03	83.2
	78012105*	Ankaramite	1.32	0.2363	16.376±0.193	313.34±0.53	2.840±0.089	0.55±0.03	94.5
North of Hut Point	78011805*	Olivine basalt	1.63	0.2435	6.956±0.106	359.79±1.06	4.437±0.090	0.70±0.04	82.3
	78011806**	Olivine basalt	1.55	0.2198	7.025±0.113	352.08±0.97	3.940±0.085	0.65±0.04	84.1
Hut Point	77121602**	Olivine basalt	1.52	0.2904	20.141±0.236	353.31±0.76	11.54±0.18	1.95±0.10	83.8
	77121603**	Olivine basalt	1.46	0.2200	16.241±0.194	320.20±0.59	3.930±0.099	0.69±0.04	92.4
Castle Rock	77121910**	Olivine basalt	1.55	0.2217	15.529±0.187	324.74±0.62	4.463±0.103	0.74±0.04	92.2
	77121913*	Olivine basalt	1.57	0.2178	29.984±0.331	310.38±0.64	4.312±0.188	0.71±0.05	95.4
Black Knob	78012214**	Olivine basalt	1.30	0.3942	0.916±0.088	461.88±12.34	1.514±0.020	0.30±0.02	64.1
	78012215**	Olivine basalt	1.29	0.3614	5.278±0.111	371.08±1.41	3.971±0.062	0.79±0.04	79.8
Half Moon Crater	78012203*	Hornblende basalt	3.38	0.2340	16.450±0.193	352.94±0.90	9.367±0.164	0.71±0.04	83.9
	78012205*	Hornblende basalt	1.91	0.2101	10.144±0.175	365.34±1.20	7.033±0.155	0.95±0.05	81.0
Obs. Hill	77121508**	Trachyte	3.73	0.2011	18.245±0.218	399.67±0.92	18.95±0.25	1.31±0.07	74.1
	77121509**	Trachyte	3.57	0.2552	17.482±0.198	496.40±2.13	17.48±0.20	1.26±0.06	59.6
	78122310**	Trachyte	3.28	0.3100	12.064±0.168	428.57±1.47	16.05±0.20	1.26±0.06	69.1

Analytical errors for K concentrations were estimated to be 5%. ±indicates one standard deviation. *Whole rock samples removed magnetite by hand magnet were used for analyses. **Whole rock samples were used for analyses.

are represented as one standard deviation.

4.1. *McMurdo Sound*

Samples have been collected from three separate volcanic regions ; Cape Royds, Hut Point Peninsula and Taylor Valley (Fig. 1). They are all very fresh except for some samples which show oxidation texture (Nos. 78012203, 78012205, 77121508, 78122310), and have partly altered olivine (No. 77121607). Olivine has no potassium, suggesting that the partial alteration has no significant effect on the K-Ar age of the whole rock sample. Oxidation occurs in general in clinker part of flowing lava. The samples with oxidation texture also present no critical problem in K-Ar analysis of rocks older than 1 Ma, though this type of sample sometimes has unusual argon isotope systematics (OKADA *et al.*, 1991).

The four kenytes from Cape Royds are about 0.08 Ma, indicating that the volcanic activity in this area continued at least from 0.68 Ma, as reported by TREVES (1967) up to the Latest Pleistocene.

The two ankaramites from Taylor Valley are 2.87 ± 0.15 and 4.15 ± 0.21 Ma in age, indicating volcanic activity with time span longer than 1.2 million years in the region. The younger age (2.87 ± 0.15) is similar to the ages reported by ARMSTRONG (1978), who dated the rocks below Marr Glacier where we collected this sample, while the older one is closer to the age (4.64 ± 0.12 and 4.5 ± 0.7 Ma) of the dikes east of Solas Glacier in Taylor Valley by ARMSTRONG (1978).

Table 2. Summary of K-Ar ages in the Sør Rondane Mountains.

	Rock type	K (wt %)	Weight (g)	^{36}Ar (10^{-10} cm^3 STP/g)	$^{40}Ar/^{36}Ar$	$^{40}Ar_{rad}$ (10^{-4} cm^3 STP/g)	Age (Ma)	$^{40}Ar_{air}/^{40}Ar_{total}$ (%)
B749	Syenite	8.18	0.0513	27.504 ± 0.657	49826 ± 1749	1.432 ± 0.033	*402 ± 20	0.6
B799	Syenite	7.70	0.0490	24.466 ± 0.429	49629 ± 1567	1.310 ± 0.026	*392 ± 19	0.6
B859	Basalt	1.84	0.0603	18.888 ± 0.328	32458 ± 0709	0.636 ± 0.008	**724 ± 30	0.9

Analytical errors for K concentrations were estimated to be 5%.
$\pm$ indicates one standard deviation.
Whole rock samples removed magnetite by hand magnet were used for analyses.
*K-feldspar is partly altered to clay minerals.
**Thermally metamorphosed sample. The calculated age is without geological significance.

Table 3. Summary of K-Ar ages at Dumont d'Urville.

	Rock type	K (wt %)	Weight (g)	^{36}Ar (10^{-10} cm^3 STP/g)	$^{40}Ar/^{36}Ar$	$^{40}Ar_{rad}$ (10^{-4} cm^3 STP/g)	Age (Ga)	$^{40}Ar_{air}/^{40}Ar_{total}$ (%)
E-1	Syenite	7.40	0.0533	47.705 ± 0.732	69431 ± 3278	3.354 ± 0.209	0.900 ± 0.057*	0.4
E-225	Quartz monzonite	5.61	0.0531	31.253 ± 0.816	93757 ± 6400	3.073 ± 0.175	1.04 ± 0.06*	0.3
E-323	Granite	3.26	0.0528	31.921 ± 0.842	68518 ± 3288	2.314 ± 0.095	1.26 ± 0.06*	0.4

Analytical errors for K concentrations were estimated to be 5%.
$\pm$ indicates one standard deviation.
Whole rock samples were used for analyses.
*K-feldspar is partly altered to clay mineral.

In the Hut Point Peninsula region, four types of volcanic rocks, ankaramite, olivine basalt, hornblende basalt and trachyte, were collected from nine volcanic domains. Ankaramites from Crater Hill, Twin Crater, and between Cape Armitage and Scott Base have ages varying from 0.39 to 0.55 Ma, belonging to the youngest volcanics in the region. Trachytes from Observation Hill are about 1.3 Ma in age, the oldest in the region. Basalts from other domains have an intermediate age range from about 0.7 to 0.95 Ma, except for two extremely old (1.95 ± 0.10 Ma) and young (0.30 ± 0.02 Ma) rocks from Hut Point and Black Knob.

4.2. Sør Rondane Mountains

The two syenites (Nos. B749, B799) from Lunckeryggen show whole rock K-Ar ages of 402 and 392 Ma, respectively. These ages are slightly younger than the total fusion biotite and K-feldspar age (413-498 Ma) of the ^{40}Ar-^{39}Ar method by TAKIGAMI and FUNAKI (1991) who collected syenites (Nos. B740, B788) from the same domain.

The basalt (No. B859) from Brattinipene was thermally metamorphosed in microscopic observation. The calculated age of 724 Ma of this sample might be overestimated, and is without geological significance.

4.3. Dumont d'Urville

The syenite (No. E1), granite (No. E323) and quartz monzonite (No. E225) are 0.900, 1.26 and 1.04 Ga in age respectively. The ages are significantly younger than the Rb-Sr biotite age of about 1.5 Ga found by GREW (1982). This might also be also due to rejuvenation by alteration because these samples have some secondary minerals.

5. Summary

We obtained the K-Ar ages of the igneous and metamorphic rocks from the Antarctic Margin as follows.

(1) In McMurdo Sound, new K-Ar data have been added, ranging from 0.08 to 4.15 Ma.

(2) For the Sør Rondane Mountains, about 400 Ma has been obtained from partly altered samples.

(3) For Dumont d'Urville, 0.90-1.26 Ga is obtained from partly altered samples.

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Appendix. Rock types and constituent minerals (after Tokiko TIBA).

Abbreviations: ph: phenocryst gr: groundmass ap: apatite bi: biotite
cpx: clinopyroxene gl: glass hm: hematite ho: hornblende
il: ilmenite mt: magnetite ol: olivine op: opaque mineral
pl: plagioclase qz: quartz

McMurdo Sound	
79010903:	Kenyte, fresh ph: anorthoclase with dusty inclusions and inclusions of cpx, op. gr: pl, anorthoclase, cpx, op, bi.
79010940:	Kenyte, fresh ph: anorthoclase with dusty inclusions and inclusions of sodic cpx, ol, cpx, op, ap. gr: pl, anorthoclase, op, bi, cpx.
79010944:	Kenyte, fresh ph: anorthoclase with inclusions of cpx and ap and dusty inclusions, sodic augite, op, ol. gr: pl (sodic), cpx, op.

Appendix (continued).

79011009 :	Kenyte, fresh ph : anorthoclase with inclusions of op and cpx and dusty inclusions. gr : pl (sodic), cpx, op.
77121607 :	Ankaramite ph : ol-partly altered to iddingsite, cpx. gr : pl, cpx, op, ol.
77112704 :	Ankaramite, fresh ph : ol, cpx. gr : pl, cpx, op, brown gl.
77112707 :	Ankaramite, fresh ph : ol, cpx. gr : pl, cpx, op, brown gl.
77112711 :	Ankaramite, fresh ph : ol, cpx, pl, op. gr : pl, cpx, op, brown gl.
78012104 :	Ankaramite, fresh ph : ol, cpx. gr : pl, cpx, op, brown gl.
78012105 :	Ankaramite, fresh ph : ol, cpx. gr : pl, cpx, op, ol ?, brown gl.
78011805 :	Olivine basalt, fresh ph : cpx, ol. gr : pl, cpx, op (mt, il), brown gl, ol ?, accretional lapilli.
78011806 :	Olivine basalt, fresh ph : ol, cpx. gr : pl, cpx, op (mt, il), brown gl, ol ?, mesostases-cpx, il, hm, mt, brown gl.
77121602 :	Olivine basalt, fresh ph : ol, cpx. gr : pl, ol, cpx, op (mt, il), brown gl.
77121603 :	Olivine basalt, fresh ph : ol, cpx. gr : pl, cpx, ol, op, brown gl.
77121910 :	Olivine basalt, porous, fresh microph : ol, op. gr : pl, cpx, ol ?, op, brown gl, hm.
77121913 :	Olivine basalt, porous, fresh microph : ol, cpx. gr : pl, cpx, ol ?, op (mt, il), bi, gl.
78012214 :	Olivine basalt, fresh ph : ol, cpx. gr : pl, cpx, op (mt, il), brown gl.
78012215 :	Basalt, fresh ph : cpx, ol, pl. gr : pl, cpx, ol, op.
78012203 :	Hornblende basalt (oxidized, pre-eruption) ph : brown ho (opacitized), opx ?, cpx. gr : pl, cpx, mt (partly oxidized to hm), hm, ap.
78012205 :	Hornblende basalt (oxidized, pre-eruption) ph : brown ho (opacitized), cpx gr : pl, cpx, hm, opx, gl.
77121508 :	Trachyte (oxidized, pre-eruption) microph : ho (opacitized). gr : pl (sodic), ho, op, gl.
77121509 :	Trachyte (oxidized, pre-eruption) microph : ho (opacitized), anorthoclase. gr : pl, ho, op, gl.
78122310 :	Trachyte (oxidized, pre-eruption) microph : ho (opacitized), anorthoclase. gr : anorthoclase, ho, op, bi.
77122102 :	Ankaramite ph : ol-partly oxidized along cracks, cpx. gr : pl, op, hm, cpx.
79010408 :	Ankaramite, porous, fresh ph : ol, cpx. gr : pl, cpx, op, hm, ol (mantled with op grains).

Appendix (continued).

Sør Rondane Mountains	
B749:	Syenite major : K-feldspar with exsolved patches and bi inclusions in prefered orientation and partly altered to clay mineral, pl, green ho, bi, qz. minor : titanite, carbonite (calcite), ap, zircon, op.
B799 :	Syenite major : K-feldspar with exsolved patches and bi inclusions in prefered orientation and partly altered to clay mineral, pl, green ho, qz, bi. minor : ap, titanite, zircon, op.
B859 :	Basalt, thermally metamorphosed ph : cpx, opx mantled with cpx, pl. gr : pl, bi, cpx, smectite, op.
Dumont d'Urville	
E1 :	Syenite major : K-feldspar with dusty inclusion, exolved patches, inclusions of hematite, partly altered to clay mineral. minor : ho, bi, op, zircon.
E225 :	Quartz monzonite major : K-feldspar with dusty inclusion and partly altered to clay mineral, pl, qz, bi. minor : op, zircon.
E323 :	Granite major : K-feldspar partly altered to clay mineral, qz, pl. minor : op, bi, ho, zircon, titanite, secondary actinolite, clay mineral.