GEOCHEMISTRY OF A MESOZOIC ISLAND-ARC ASSEMBLAGE AND OCEAN-FLOOR BASALTS FROM SOUTH GEORGIA

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ABSTRACT. XRF major- and trace-element analyses of 58 andesitic breccias, tuffs and mudstones of the Annenkov Island Formation and associated plutonic and volcanic rocks which crop out on Hauge Reef and the Pickersgill Islands off the south-west coast of the sub-Antarctic island of South Georgia show calc-alkaline trends. The tuffs, mudstones and intermediate intrusive rocks are part of a coeval island-arc volcanic suite that formed as a result of subduction of Pacific oceanic crust during the late Jurassic–early Cretaceous. Analysis of 11 samples of pillowed and massive lavas exposed on one of the islands of Hauge Reef (Pillow Island) confirms that they have tholeiitic affinities. They belong to the uppermost part of the segment of oceanic crust which lies beneath the marginal shelf of the back-arc basin and developed as the island arc separated from the (South American) continental landmass. Mafic sills within the andesitic tuffs and mudstones of the island-arc assemblage also have tholeiitic affinities and may have a similar origin to the pillowed lavas, suggesting that subduction was contemporaneous with back-arc spreading. The chemistry of the andesitic greywackes (Cumberland Bay Formation) which infilled the back-arc basin is dissimilar in certain respects to that of the island-arc volcanic and plutonic rocks in the general source area. Possible reasons for these differences are discussed.

New geochemical data from radiometrically dated Cretaceous and Tertiary calc-alkaline plutonic rocks of the Antarctic Peninsula are presented for comparison and show similar trends to the South Georgia island-arc igneous suite.

ALTHOUGH most of South Georgia consists of andesitic greywackes, which infilled a back-arc basin during the late Jurassic–early Cretaceous, scattered remnants of a contemporaneous island-arc assemblage are preserved on a few small islands (Annenkov Island, Pickersgill Islands, Low Reef and Hauge Reef) off the south-west coast of South Georgia (Fig. 1). The geology of these islands and of the adjoining coastline has recently been described in detail by Tanner and others (1981), and related to the island-arc–back-arc basin system of South Georgia (Dalziel and others, 1974, 1975; Suárez and Pettigrew, 1976; Storey and others, 1977; Tanner, in press). This paper presents for the first time the geochemistry of rocks from Hauge Reef and the Pickersgill Islands, and confirms the relationships and conclusions of Tanner and others (1981). Some of the plutonic rocks have been dated (Tanner and Rex, 1979) by K-Ar and Rb-Sr methods (Table I). For comparative purposes, the geochemistry of Cretaceous and Tertiary calc-alkaline plutonic rocks from the Antarctic Peninsula described by Gledhill and others (in press) is also included.

Hauge Reef, Low Reef and the Pickersgill Islands were visited by teams of British Antarctic Survey geologists in 1975–76 (D. I. M. Macdonald, B. C. Storey and P. W. G. Tanner) and in 1976–77 (D. I. M. Macdonald and B. F. Mair) using inflatable Gemini craft operated from RRS *John Biscoe*. Hauge and Low Reefs are a conspicuous line of small rocky islands rising to 50 m a.s.l. which lie between Annenkov Island and Hauge Strait (Fig. 1). Samples from the three main islands were analysed together with rock specimens from part of Low Reef (Fig. 2) and from four islands of the Pickersgill Islands, which are a group of five main islands 22 km south-south-east of Hauge Reef and 13 km from the South Georgia mainland (Fig. 2).

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On most of the islands of Hauge Reef and the Pickersgill Islands gently inclined, finely banded andesitic tuffs and mudstones are intruded by hornblende- and biotite-andesites, occasional metabasic sills, and gabbro, monzodiorite and granodiorite stocks and plutons. In contrast to the above, the easternmost island of Hauge Reef (Pillow Island) is formed of basic, pillowed and massive lavas with thin interbanded tuffs and mudstones. Thick-bedded and non-stratified conglomerates and breccias crop out on Low Reef.

These rocks are part of the island-arc assemblage of Annenkov Island described by Pettigrew (1981). The tuffs and mudstones are part of the Lower Tuff Member and the andesitic breccias are part of the Upper Breccia Member of the Annenkov Island Formation. The Lower Tuff

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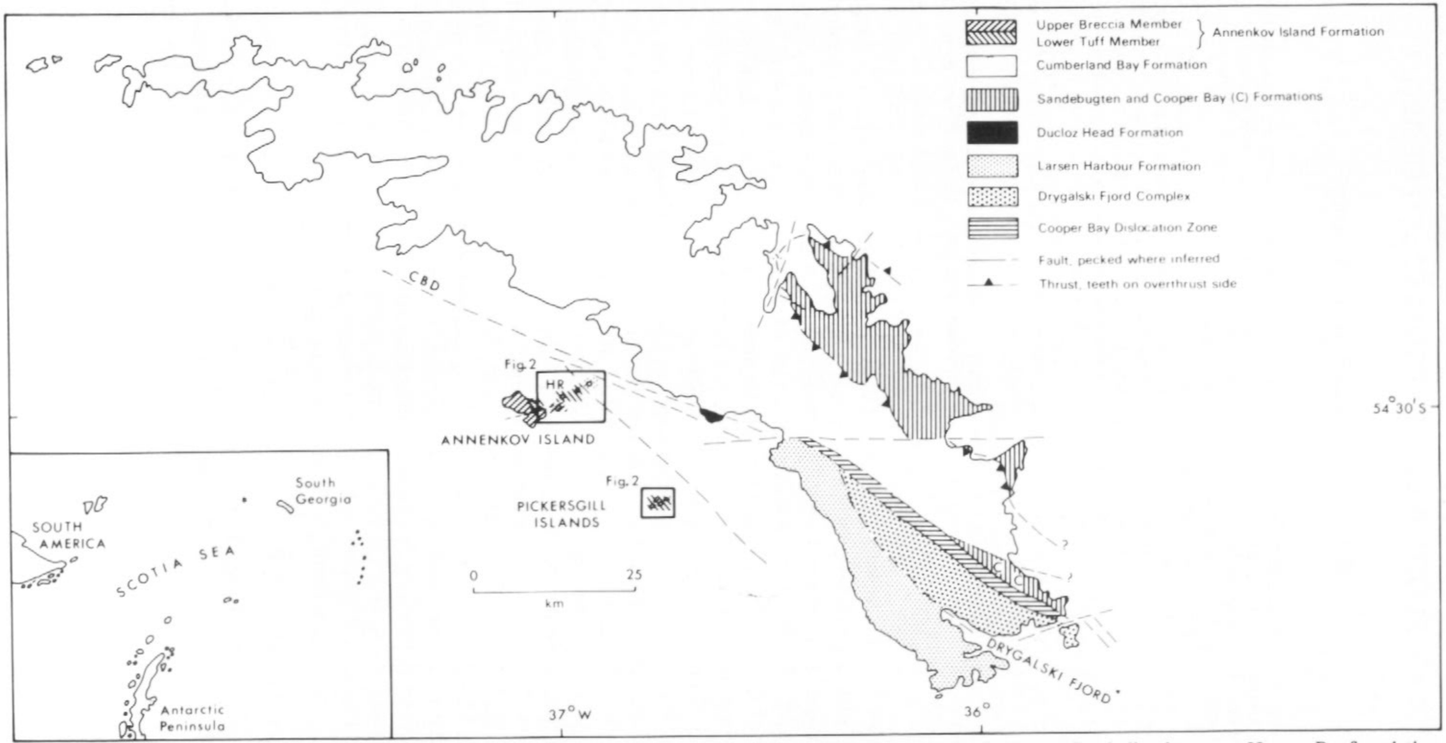

Fig. 1. Geological map of South Georgia. CBD stands for Cooper Bay dislocation, HR for Hauge Reef. Hauge Strait lies between Hauge Reef and the mainland of South Georgia.

TABLE I. DETAILS OF ANALYSED SPECIMENS WHICH HAVE BEEN RADIOMETRICALLY DATED

Locality	*Station number*	*Method*	*Mineral*	*Age* (Ma)
Hauge Reef	M.2365.D	K-Ar	hornblende	92±6
Pickersgill Islands	M.3165.A M.3165.B M.3165.D M.3165.F M.3165.J	Rb-Sr	whole rock	81±10
Stonington Island (Marguerite Bay)	BR.101.1 BR.101.5 BR.101.8A BR.101.8B	Rb-Sr	whole rock	119±1
Debenham Islands (Marguerite Bay)	BR.102.25A BR.102.28A BR.102.28B	Rb-Sr	whole rock	109±1
Anvers Island (Palmer Archipelago)	BR.104.1 BR.104.5 BR.104.8	Rb-Sr	whole rock	35±6
Argentine Islands (Graham Coast)	BR.103.7 BR.103.11A BR.103.11B	Rb-Sr	whole rock	72±1
	BR.103.11	K-Ar	biotite	57±2

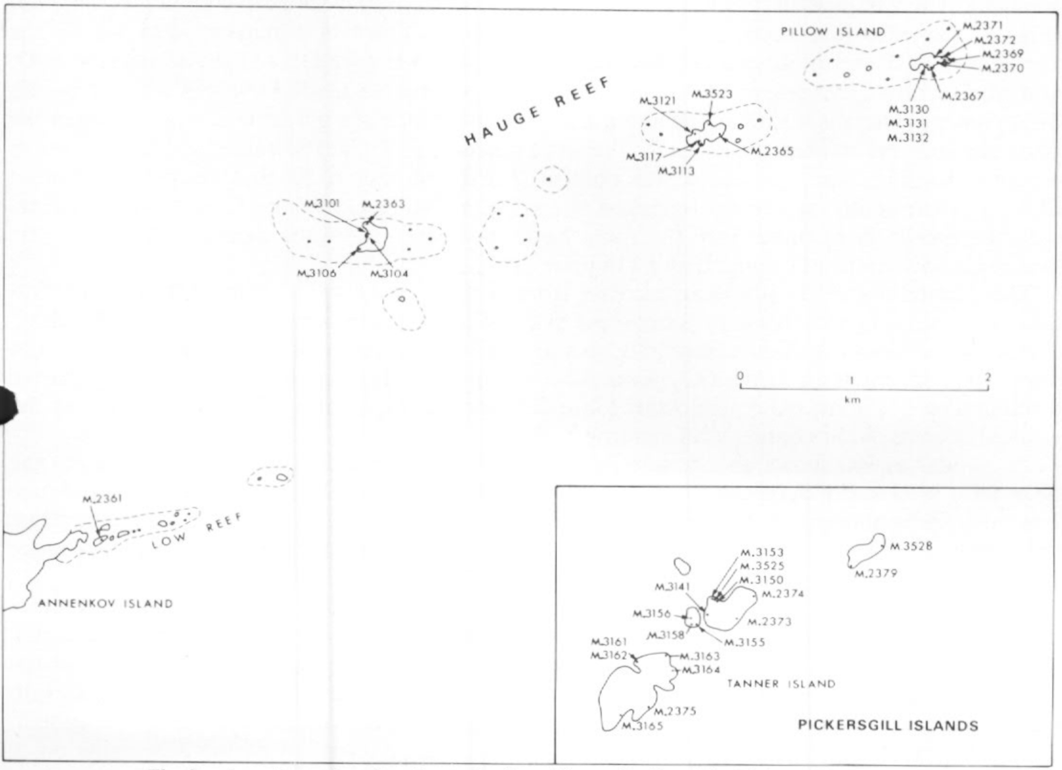

Fig. 2. Locations of analysed samples from Hauge Reef and the Pickersgill Islands.

Member is conformably underlain by basic lavas exposed on Pillow Island which are believed to be the uppermost part of a segment of oceanic crust that can be correlated with the Larsen Harbour Formation on South Georgia (Tanner and others, 1981). Radiometric dating and palaeontological work suggest that the time range represented by the Lower Tuff and Upper Breccia Members is Neocomian to Aptian–Albian (Tanner and Rex, 1979; Thomson and others, in press), and that some of the sills and intrusions are Upper Aptian in age and contemporaneous with the sediments. Dating of some of the specimens gave a Rb-Sr age of 81±10 Ma and a K-Ar age of 92±6 Ma (Table I).

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A total of 58 samples (Tables II and III) were analysed using a Philips PW 1450 automatic X-ray fluorescence spectrometer. Major and trace elements were determined on 46 mm diameter pressed-powder discs. They have been divided according to rock type (Streckeisen, 1973), as follows: 1, mafic sills; 2, diorites and monzodiorites; 3, quartz-monzodiorites; 4, hornblende-andesites; 5, biotite-andesites; 6, granodiorites; 7, aplites and microgranites; 8, tuffs and mudstones (Lower Tuff Member); 9, andesitic breccias (Upper Breccia Member) and 10, pillowed and massive lavas. The locations of the samples are shown in Fig. 2. Groups 1–9 comprise the island-arc assemblage; rocks in group 10 are part of an ocean-floor basalt series and are described separately.

Island-arc assemblage

As illustrated on the AFM diagram (Fig. 3) and selected element-variation diagrams (Fig. 4), the trends of the major elements, when plotted against SiO_2, are typical of a calc-alkaline province. The variation in rock-type composition is shown on the normative an–ab–or diagram (Fig. 5) (classification according to O'Connor (1965)). There is a marked decrease in the concentration of the major oxides TiO_2, Al_2O_3, CaO, MgO and Fe_2O_3, a slight decrease in P_2O_5 and MnO, and an increase in the concentration of K_2O and Na_2O+K_2O values with increasing SiO_2 content. There is a similar variation, although the trends are not so well marked, when the trace elements are plotted against SiO_2; there is a decrease in Zn and Sr values and an increase in Rb and Th values with increase in SiO_2 content. The distribution of Rb and Th is similar to that of K_2O. There is little systematic variation in La, Ce, Y, Nb or Ga values. Cr and Ni values are, with the exception of those from the more basic members, below the determination limit; the mafic sills have up to 111 ppm Ni and 236 ppm Cr.

The distribution of Ba shows an increase from 40 ppm at 44.8% SiO_2 to 1 000 ppm at 70% SiO_2 with a marked decrease in Ba content in the silica-rich samples (80 ppm at 76.5% SiO_2). The analyses from the Hauge Reef andesites are more enriched in Ba, with values up to 1 474 ppm occurring at the 57.7% SiO_2 level. The variation in Ba content may indicate extensive fractionation of intermediate plagioclase (Saunders and others, in press). This is supported by the marked decrease in Sr content with increase in SiO_2.

Zr, similar to Ba, shows an asymmetric distribution with an increase in Zr content up to the 68% SiO_2 level and a decrease from 68% to 77% SiO_2. The hornblende-andesites from Hauge Reef also show abnormally high Zr contents up to the 68% SiO_2 level. This is in strong contrast to tholeiitic rock suites (Saunders and others, 1979; Weaver and others, in press), which produce Zr-rich siliceous differentiates.

The concentration of two light rare-earth elements (REE) (Fig. 6) varies from 33 times chondrite levels in the basic rocks to 100 times chondrite levels in the more acid rocks. Yttrium, which has a similar charge and ionic radius to Hd and closely resembles the behaviour of the heavy rare-earth elements, suggests a marked decrease in the heavy REE relative to light with high Ce/Y ratios. With a decrease in normalized Y values, there is a corresponding decrease in the normalized Ce/Y ratio (Fig. 7). This trend implies the involvement during differentiation of garnet or hornblende which selectively take the heavy rare-earth elements and Y into their

Table II. Chemical Analyses of rocks from Hauge Reef and the Pickersgill Islands

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO_2	44.8	42.8	52.2	50.3	55.4	59.1	62.6	54.4	60.9	60.6	61.1	56.5	57.7	61.1	59.1	61.3	52.1	58.5
TiO_2	1.48	1.81	1.03	0.97	0.62	0.49	0.44	0.58	0.41	0.40	0.45	0.47	0.46	0.39	0.47	0.38	0.72	0.46
Al_2O_3	13.6	12.0	17.4	17.8	18.6	18.4	16.8	17.5	17.2	17.4	17.1	16.5	17.1	17.2	16.7	17.3	17.3	17.4
t Fe_2O_3	12.15	13.23	9.43	9.11	7.71	6.89	4.75	7.11	5.11	4.94	5.43	5.15	5.18	4.06	5.06	4.09	9.38	5.60
MnO	0.19	0.22					0.08	0.17	0.14	0.14	0.15	0.20	0.18	0.07	0.07	0.07	0.21	0.13
MgO	10.7	11.8	5.9	6.5	4.8	3.8	1.80	3.2	1.90	1.7	2.1	1.9	2.1	1.5	1.9	1.4	4.7	2.1
CaO	8.91	6.02	9.95	10.83	8.51	7.08	4.60	8.85	6.04	6.06	6.14	6.75	4.99	4.34	5.14	4.29	8.37	7.28
Na_2O	2.70	3.0	2.7	3.1	3.6	3.7	3.4	3.2	4.1	4.3	4.0	3.8	4.7	4.6	4.0	4.7	3.0	3.2
K_2O	0.27	0.07	1.87	1.10	1.86	2.40	3.27	1.54	2.23	2.09	2.27	2.83	2.84	2.80	2.83	2.84	2.72	1.87
P_2O_5	0.17	0.23	0.43	0.57	0.45	0.40	0.23	0.34	0.23	0.24	0.24	0.34	0.34	0.23	0.30	0.24	0.38	0.30
TOTAL	94.97	91.18	100.91	100.28	101.55	102.26	97.97	96.89	98.26	97.87	98.98	94.44	95.59	96.29	95.57	96.61	98.88	96.84
TRACE ELEMENTS																		
Cr	236	151	<10	20	<10	<10	<10	<10	<10	<10	<10	14	<10	<10	<10	<10	<10	<10
Ni	111	39	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6	<6
Zn	63	84	70	87	58	48	32	58	42	42	45	45	43	21	21	22	87	39
Rb	7	<3	40	24	51	62	97	36	58	47	60	64	64	49	54	51	48	40
Sr	310	137	887	1 023	928	735	335	579	509	525	500	1 032	1 143	1 222	1 132	1 223	676	719
Y	27	33	17	19	22	24	7	18	17	15	17	17	17	19	20	19	17	13
Zr	107	158	53	63	86	87	176	78	130	135	121	175	187	201	196	207	102	122
Nb	<3	4	<3	6	<3	<3	6	5	7	5	6	11	9	14	12	13	<3	5
Ba	44	75	452	534	653	761	930	532	691	776	672	1 363	1 747	1 310	1 414	1 307	1 100	811
La	15	23	12	13	19	18	23	23	21	25	23	32	32	53	52	54	25	28
Ce	16	23	34	37	48	44	27	34	36	33	32	48	49	83	74	82	37	41
Pb	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9	11	9	9	9	<9	<9
Th	<9	<9	<9	<9	<9	<9	10	<9	<9	10	<9	10	9	20	19	22	<9	9
Ga	21	18	19	27	24	21	18	20	20	20	20	25	27	26	27	25	22	20
W	15	10	178	70	120	232	588	259	455	425	489	118	130	277	253	221	69	158
Fe*/Mg	1.32	1.30	1.86	1.64	1.87	2.12	3.06	2.58	3.12	3.37	3.00	3.14	2.86	3.14	3.09	3.39	2.31	2.94
K/Rb	320	—	388	380	303	321	280	355	319	369	314	367	368	474	435	462	470	383
Rb/Sr	0.02	—	0.05	0.02	0.05	0.08	0.29	0.06	0.11	0.09	0.12	0.06	0.06	0.04	0.05	0.04	0.07	0.06
Ba/Sr	0.14	0.55	0.51	0.52	0.70	1.03	2.78	0.92	1.36	1.48	1.34	1.32	1.53	1.07	1.25	1.07	1.63	1.13
Zr/Nb	—	39.5	—	10.5	—	—	29.33	15.6	18.6	27.0	20.17	15.91	20.78	14.36	16.33	15.92	—	24.40

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
SiO_2	57.3	59.6	54.76	58.4	56.3	53.6	58.3	65.7	69.9	69.8	74.5	73.7	76.2	76.6	52.6	53.7	61.1	64.9
TiO_2	0.48	0.58	0.65	0.51	0.72	0.7	0.47	0.22	0.21	0.21	0.15	0.18	0.10	0.10	0.93	1.19	0.30	0.69
Al_2O_3	17.2	18.0	15.8	17.5	18.1	17.1	18.7	16.5	15.4	15.4	14.8	14.5	14.0	13.9	21.2	15.3	12.0	14.9
t Fe_2O_3	6.15	7.18	6.10	6.94	8.43	7.61	6.89	2.60	2.60	2.50	1.33	1.64	0.65	0.65	7.66	9.83	4.44	7.65
MnO	0.12		0.12	0.16	0.20	0.16		0.14	0.05	0.04	0.02	0.02	0.02	0.03				
MgO	2.5	3.7	2.8	3.7	3.8	3.3	3.3	2.3	0.9	0.9	0.4	0.4	0.1	0.1	4.2	4.1	1.3	2.4
CaO	7.21	6.22	6.77	7.13	8.20	10.32	7.40	0.99	2.61	2.64	1.90	1.5	0.62	0.59	7.54	3.59	8.52	1.76
Na_2O	3.1	4.2	4.2	3.3	3.8	2.3	3.7	6.3	3.1	3.2	3.1	2.8	3.9	4.3	2.5	5.5	1.8	1.7
K_2O	1.74	2.65	1.97	1.90	2.07	1.17	1.92	3.05	4.95	5.0	4.97	5.69	5.36	4.86	1.15	1.86	5.12	2.86
P_2O_5	0.30	0.40	0.46	0.32	0.50	0.31	0.28	0.12	0.10	0.10	0.04	0.05	0.02	0.01	0.25	0.16	0.25	0.10
TOTAL	96.10	102.33	93.63	99.86	102.12	96.57	100.96	97.92	99.82	99.79	101.21	100.48	100.97	101.14	98.03	95.23	94.83	96.96
TRACE ELEMENTS																		
Cr	<10	<10	24	15	<10	38	20	<10	<10	<10	<10	<10	<10	<10	<10	10	10	30
Ni	<6	<6	7	<6	<6	11	<6	<6	<6	<6	<6	<6	<6	<6	9	15	10	21
Zn	36	39	28	51	47	72	98	19	12	15	8	12	<6	<6	16	280	60	21
Rb	52	109	30	37	40	22	43	70	97	97	105	113	140	193	44	19	59	96
Sr	684	941	880	737	748	810	913	663	328	335	310	274	84	29	334	152	77	134
Y	13	27	21	14	23	17	14	12	7	6	5	6	6	8	22	57	39	37
Zr	120	129	170	117	119	102	95	137	149	145	101	125	58	69	106	129	99	138
Nb	5	<3	10	3	5	4	<3	11	3	<3	4	6	6	9	4	7	7	9
Ba	363	790	1 257	860	612	431	754	1 174	977	987	655	853	253	83	176	357	1 010	416
La	30	21	36	17	18	23	17	31	11	12	16	17	20	34	12	16	23	27
Ce	40	50	58	42	47	33	45	49	17	19	23	24	21	37	29	51	47	55
Pb	<9	<9	<9	<9	<9	<9	<9	13	<9	<9	<9	<9	<9	<9	<9	28	10	<9
Th	<9	<9	10	<9	<9	<9	9	11	10	10	19	21	32	46	<9	<9	<9	15
Ga	22	24	22	24	23	24	23	21	14	14	15	13	14	17	29	14	13	21
W	231	166	96	115	109	114	118	219	876	987	1 112	975	1 031	1 149	124	50	45	89
Fe*/Mg	2.85	2.26	2.53	2.17	2.57	2.67	2.44	1.31	3.35	3.22	3.86	4.75	7.53	7.53	2.13	2.80	3.98	3.72
K/Rb	278	202	545	426	430	442	371	362	424	428	393	418	318	209	217	813	720	247
Rb/Sr	0.08	0.1	0.03	0.05	0.05	0.03	0.05	0.11	0.30	0.29	0.34	0.41	1.67	6.65	0.13	0.13	0.77	0.72
Ba/Sr	0.53	0.84	1.43	1.17	0.82	0.53	0.83	1.77	3.00	2.95	2.11	3.11	3.01	2.86	0.53	2.35	13.1	3.10
Zr/Nb	24.0	—	17.0	39.0	23.8	25.5	—	12.45	49.67	—	25.3	20.83	9.67	7.67	26.5	18.4	14.1	15.3

	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
SiO_2	63.5	78.6	55.1	62.0	60.1	71.7	61.6	48.8	44.2	49.1	45.1	44.9	45.5	47.7	46.8	48.2	50.6	49.9
TiO_2	0.75	0.54	0.51	0.66	0.58	0.64	0.32	1.51	1.99	1.82	1.95	1.82	1.82	1.74	1.78	1.85	1.86	1.88
Al_2O_3	15.4	10.7	17.7	15.5	18.6	13.1	16.5	12.7	11.9	12.0	12.1	12.3	12.2	12.0	12.1	12.7	13.2	13.2
t Fe_2O_3	7.07	5.16	10.65	6.43	5.9	5.93	4.46	11.42	13.21	12.88	13.21	14.88	14.89	13.79	13.42	12.78	12.19	13.20
MnO								0.21	0.24	0.25	0.29	0.13	0.13	0.13	0.13	0.27	0.25	0.24
MgO	2.1	1.0	4.2	3.0	1.5	1.7	1.6	7.4	7.9	7.6	8.0	9.5	9.7	7.2	9.5	6.3	4.0	5.8
CaO	2.48	2.98	4.87	3.82	7.11	2.14	2.21	5.21	8.05	5.60	6.82	3.95	3.98	3.79	4.94	6.97	5.78	5.79
Na_2O	2.3	1.9	2.4	3.0	2.4	1.7	5.9	2.3	3.1	3.8	3.3	3.4	3.5	3.8	3.8	3.9	3.6	4.2
K_2O	3.48	0.91	2.44	2.74	1.17	2.48	3.86	4.08	0.55	0.60	0.43	0.07	0.07	0.03	0.04	1.22	1.41	1.25
P_2O_5	0.11	0.04	0.10	0.11	0.11	0.09	0.15	0.30	0.36	0.30	0.34	0.35	0.34	0.32	0.30	0.34	0.32	0.33
TOTAL	97.19	101.83	97.97	97.26	97.47	99.48	96.60	93.93	91.50	93.95	91.54	91.30	92.13	90.50	92.81	94.53	93.21	95.79
TRACE ELEMENTS																		
Cr	30	20	<10	<10	<10	20	<10	77	60	62	59	65	62	71	59	56	60	51
Ni	29	23	<6	17	<6	13	<6	17	12	13	11	14	13	8	11	15	13	11
Zn	44	102	110	15	68	43	145	108	103	81	96	112	113	94	88	100	91	97
Rb	142	33	63	96	32	79	113	88	9	13	8	<3	<3	<3	<3	26	34	24
Sr	200	199	468	223	436	180	431	377	237	293	331	82	81	52	76	397	410	360
Y	32	18	11	33	59	21	15	41	35	39	40	37	36	36	36	41	40	39
Zr	146	88	138	127	318	92	134	141	118	117	118	110	107	105	108	119	125	116
Nb	8	4	5	6	16	5	<3	3	<3	3	<3	4	3	3	5	<3	<3	3
Ba	369	510	741	523	972	600	1 104	763	152	175	112	41	35	33	30	224	258	213
La	23	14	12	19	25	20	30	21	23	24	25	23	23	22	22	22	22	21
Ce	50	27	26	44	63	40	53	29	28	25	31	30	33	28	28	31	25	29
Pb	<9	10	10	<9	15	15	10	<9	<9	<9	9	<9	<9	<9	<9	<9	<9	<9
Th	15	<9	<9	10	23	9	15	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9
Ga	23	13	25	21	14	18	19	18	19	20	21	22	20	20	19	21	24	19
W	108	213	90	114	227	176	148	6	11	9	12	8	11	39	12	26	63	15
Fe*/Mg	3.93	6.02	2.96	2.50	4.59	4.07	3.25	1.79	1.94	1.97	1.91	1.81	1.78	2.22	1.64	2.35	3.53	2.64
K/Rb	203	229	321	237	303	260	284	385	507	383	446	—	—	—	—	390	344	432
Rb/Sr	0.71	0.17	0.13	0.43	0.07	0.44	0.26	0.23	0.04	0.04	0.02	—	—	—	—	0.07	0.08	0.07
Ba/Sr	1.85	2.56	1.58	2.34	2.23	3.33	2.56	2.02	0.64	0.60	0.34	0.50	0.43	0.64	0.40	0.56	0.63	0.59
Zr/Nb	18.3	22.0	27.6	21.2	19.9	18.4	—	47.0	—	39.0	—	27.5	35.7	35.0	36.0	—	—	38.7

Fe* = total iron as Fe^{2+}.
t Fe_2O_3 = total iron as Fe_2O_3.

Mafic sills		
1.	M.2363.3	Hauge Reef.
2.	M.3106	Hauge Reef.
Diorite-monzodiorite		
3.	M.2379.2	Pickersgill Islands.
4.	M.3158	Pickersgill Islands.
Quartz-monzodiorite		
5.	M.2375.8	Tanner Island, Pickersgill Islands.
6.	M.2375.10B	Tanner Island, Pickersgill Islands.
7.	M.3165.A	Tanner Island, Pickersgill Islands.
8.	M.3165.B	Tanner Island, Pickersgill Islands.
9.	M.3165.D	Tanner Island, Pickersgill Islands.
10.	M.3165.F	Tanner Island, Pickersgill Islands.
11.	M.3165.J	Tanner Island, Pickersgill Islands.
Hornblende-andesites		
12.	M.2363.B	Hauge Reef.
13.	M.2363.D	Hauge Reef.
14.	M.2365.D	Hauge Reef.
15.	M.2365.E	Hauge Reef.
16.	M.2365.G	Hauge Reef.
17.	M.2373.4	Pickersgill Islands.
18.	M.2373.7A	Pickersgill Islands.
19.	M.2374.1	Pickersgill Islands.
20.	M.2375.7	Tanner Island, Pickersgill Islands.
21.	M.3113	Hauge Reef.
22.	M.3141	Pickersgill Islands.
23.	M.3163	Tanner Island, Pickersgill Islands.
24.	M.3525.4B	Pickersgill Islands.
25.	M.3528.7	Pickersgill Islands.
Biotite-andesite		
26.	M.3522.1B	Hauge Reef.
Granodiorite		
27.	M.3164	Tanner Island, Pickersgill Islands.
28.	M.3164.B	Tanner Island, Pickersgill Islands.
Aplite dykes		
29.	M.3155	Pickersgill Islands.
30.	M.3156	Pickersgill Islands.
31.	M.3161	Tanner Island, Pickersgill Islands.
32.	M.3162	Tanner Island, Pickersgill Islands.
Lower Tuff Member		
33.	M.2365.4B	Tuffaceous sandstone, Hauge Reef.
34.	M.3101.A	Andesitic tuff, Hauge Reef.
35.	M.3104.B	Tuffaceous mudstone, Hauge Reef.
36.	M.3117	Mudstone, Hauge Reef.
37.	M.3121	Mudstone, Hauge Reef.
38.	M.3150	Mudstone, Pickersgill Islands.
39.	M.3153	Tuffaceous sandstone, Pickersgill Islands.
40.	M.3523.7	Tuffaceous mudstone, Hauge Reef.
41.	M.3525.6	Hornfelsed tuff, Pickersgill Islands.
42.	M.3528.8	Hornfelsed shale, Pickersgill Islands.
Upper Breccia Member		
43.	M.2361.3	Andesite breccia, Low Reef.
Lavas, Pillow Island, Hauge Reef		
44.	M.2367.2	Columnar basalt.
45.	M.2367.1B	Pillow lava.
46.	M.2370.1	Massive lava.
47.	M.2370.2	Massive lava.
48.	M.2371.2	Pillow lava.
49.	M.2371.2B	Pillow lava.
50.	M.2372.1	Pillow lava.
51.	M.2372.2	Pillow lava.
52.	M.3130	Columnar basalt.
53.	M.3131	Columnar basalt.
54.	M.3132	Columnar basalt.

TABLE III. CHEMICAL ANALYSES OF THE UPPER BRECCIA MEMBER FROM ANNENKOV ISLAND

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	47.62	47.75	51.23	52.16	53.00	53.30	53.84	53.95	54.01	54.25	55.04	56.25	57.67	58.80	59.13
TiO_2	0.49	0.66	0.93	0.84	0.84	0.75	0.80	0.82	0.67	0.55	0.65	0.59	0.54	0.47	0.54
Al_2O_3	11.88	13.56	16.03	16.35	15.97	13.30	17.01	17.00	18.73	15.90	18.09	18.52	16.45	18.80	18.10
t Fe_2O_3	6.73	7.58	10.03	8.76	9.52	8.19	8.66	8.82	8.92	6.42	7.27	7.27	6.60	6.54	6.52
MnO															
MgO	4.02	4.39	6.71	6.82	6.67	5.82	4.90	5.23	4.21	3.87	4.14	3.64	3.51	2.99	3.02
CaO	19.96	14.48	6.98	6.84	6.84	9.95	6.95	7.01	5.49	10.82	6.84	6.88	5.12	4.83	3.98
Na_2O	2.39	3.57	3.73	4.23	3.50	2.20	4.03	3.72	6.29	3.66	3.34	4.22	3.94	4.71	5.99
K_2O	1.34	2.16	1.53	1.00	1.31	1.47	1.93	1.61	2.08	2.19	1.71	0.96	3.24	2.96	2.02
P_2O_5	0.21	0.21	0.42	0.22	0.37	0.14	0.40	0.33	0.44	0.23	0.26	0.14	0.21	0.29	0.27
TOTAL	94.64	94.38	97.59	97.22	98.02	95.12	98.52	98.49	100.84	97.89	97.34	98.47	97.28	100.39	99.75
								TRACE ELEMENTS							
Cr	54	53	14	120	27	90	18	25	11	38	40	31	31	12	7
Ni	35	44	19	75	17	231	19	19	14	48	22	26	24	17	12
Zn	60	64	89	63	87	60	95	89	66	65	67	54	64	42	63
Rb	23	67	22	19	17	31	38	27	48	47	43	14	54	78	45
Sr	553	546	953	471	809	576	806	792	439	641	1 714	159	486	690	1 103
Y	17	18	20	18	22	19	25	22	26	18	17	14	17	17	22
Zr	108	120	157	127	150	122	149	138	134	152	206	116	155	178	214
Nb	6	5	5	6	5	6	5	6	6	6	7	8	6	6	5
Ba	350	637	470	470	438	432	541	475	492	659	959	228	957	1 051	1 088
La	23	18	29	22	31	22	28	28	28	27	39	20	27	33	29
Ce	35	36	47	36	43	39	47	46	48	43	57	31	44	52	58
Pb	9	9	11	9	9	10	9	10	9	14	14	9	11	10	9
Th	9	9	9	<9	9	9	9	9	9	10	10	9	10	13	11
Ga	21	19	58	20	27	19	25	25	21	20	25	52	20	24	15
W	7	7	12	9	14	15	23	24	23	30	15	12	22	69	50
Fe*/Mg	1.95	2.02	1.74	1.50	1.67	1.64	2.06	1.97	2.47	1.94	2.05	2.33	2.19	2.56	2.52

Fe* = total iron as Fe^{2+}.
t Fe_2O_3 = total iron as Fe_2O_3.

1. M.1157.5
2. M.1188.2
3. M.1151.6C
4. M.1196.8
5. M.1151.6B
6. M.1159.3
7. M.1151.1
8. M.1151.2
9. M.1178.3
10. M.1157.6
11. M.1196.13
12. M.1188.1
13. M.1196.10
14. M.1200.2
15. M.1169.2

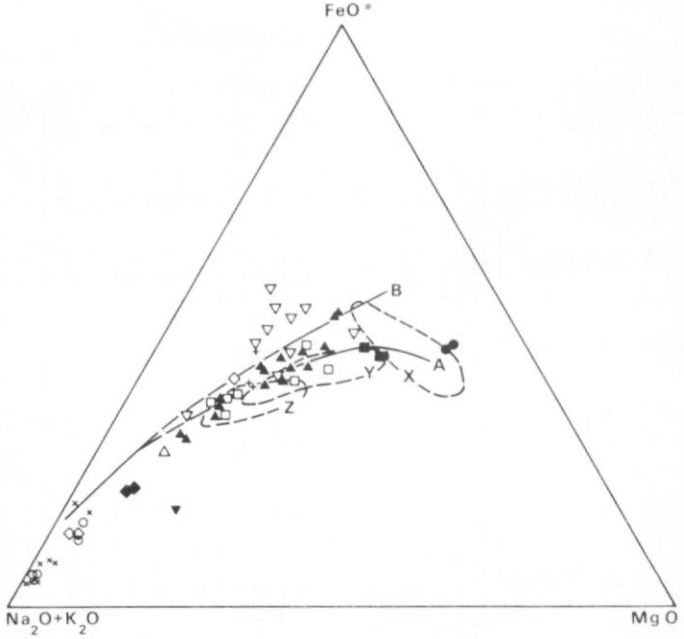


Fig. 3. AFM diagram for Hauge Reef (excluding Pillow Island), Pickersgill Islands and Antarctic Peninsula samples. Line A is the trend of Antarctic Peninsula plutons (Saunders and others, in press); B, Mount Lassen suite (Nockolds and Allen, 1953).
The enclosed fields are: X, "spilites" of Pettigrew (1981); Y, breccias of the Upper Breccia Member; Z, Annenkov Island andesites. Analyses for the X and Z fields are taken from Mair (1979) and those for field Y are given in Table III. FeO* = total iron as Fe^{2+}.

●	Mafic sills	▽	Lower Tuff Member	Annenkov Island Formation
■	Diorite-monzodiorite	△	Upper Breccia Member	
□	Quartz-monzodiorite	◇	Argentine Islands	Antarctic Peninsula
▲	Hornblende-andesite	+	Anvers Island	
▼	Biotite-andesite	×	Marguerite Bay	
◆	Granodiorite	⊕	Cumberland Bay Formation (see Fig. 4)	
○	Aplite and microgranite			

structure (Arth and Barker, 1976); precipitation of pyroxene and plagioclase generally shows an increase in normalized Y with little change in the Ce/Y ratio.

Although the rocks show calc-alkaline trends, there is some variation in the distribution of the samples ($20\% > CaO+MgO < 12\%$) on the discrimination plots (Fig. 8) of Pearce and Can[illegible] (1973). The majority fall within the calc-alkaline fields but the mafic sills and diorite–monzodiorites fall within the combined ocean-floor basalt/calc-alkaline fields on the Ti–Zr–Y diagram and the mafic sills within the ocean-floor basalt field on the Ti–Zr plots; the dioritic rocks fall within a common calc-alkaline and ocean-floor basalt field on the Ti–Zr diagram. Although there is a considerable spread of data points on the Ti–Zr–Sr diagram (probably due to the mobility of Sr during the alteration of the rocks), the mafic sills lie within and close to the ocean-floor basalt field. It thus appears that the basic members of the suite may be derived from the magma source which formed the floor of the back-arc basin. On the AFM diagram (Fig. 3), the tuffs and mudstones show some enrichment in FeO*, a feature characteristic of tholeiitic rocks. However, they show clear calc-alkaline trends and fall within the calc-alkaline field on the discrimination diagrams, and the enrichment in FeO* may be due to the mafic minerals being preferentially concentrated during deposition of the sediments, many of which are ash-fall tuffs.

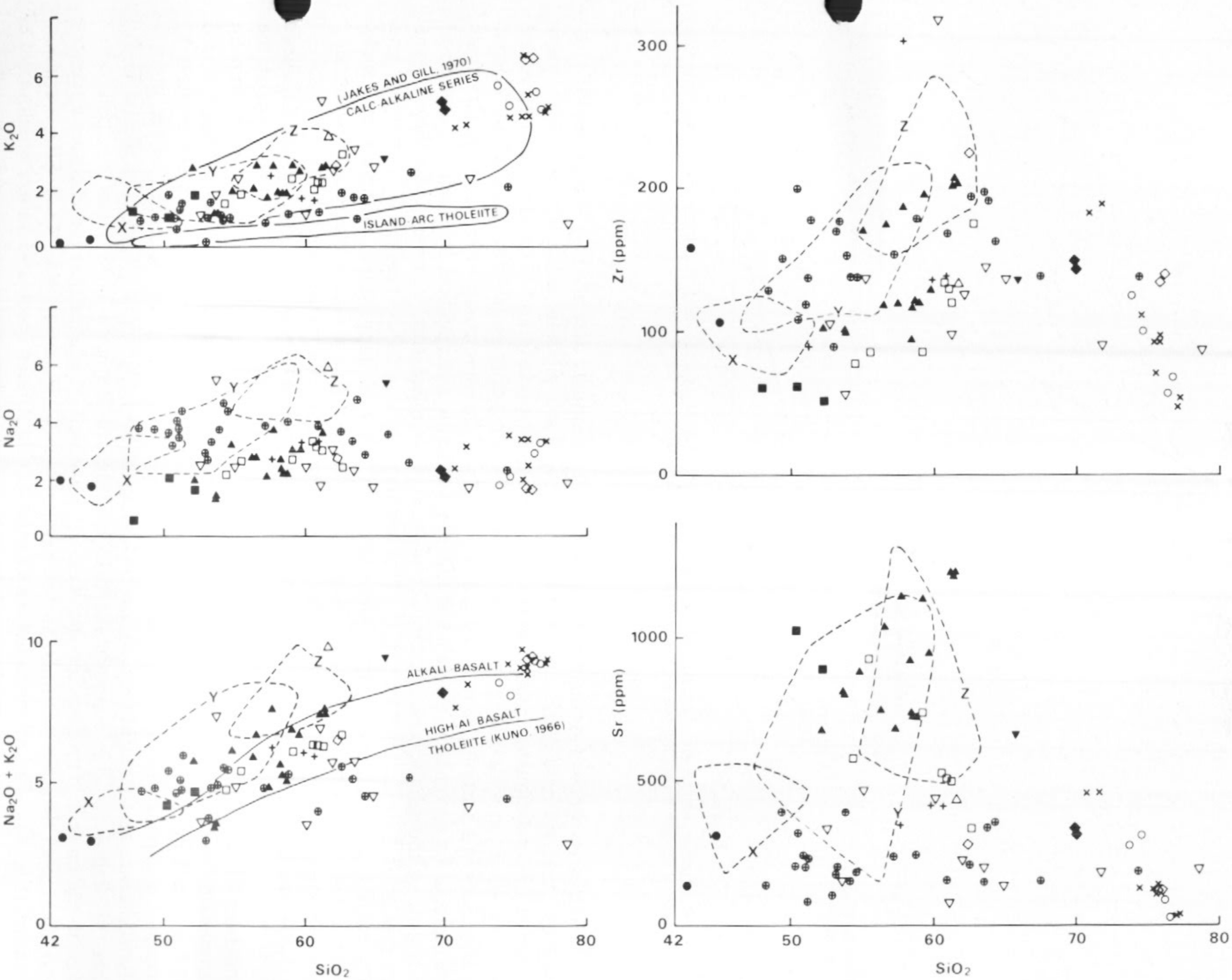


Fig. 4. K$_2$O, Na$_2$O, Na$_2$O+K$_2$O, Zr and Sr against SiO$_2$ variation diagrams for Hauge Reef, Pickersgill Islands, Antarctic Peninsula and Cumberland Bay Formation samples. The 26 samples included from the Cumberland Bay Formation are: M.165.1, M.204.1, M.206.1, M.231.1, M.390.1, M.393.1, M.626.2, M.631.2, M.632.2, M.951.1, M.955.1, M.983.1, M.1018.1, M.1031.9, M.1157.3, M.1197.1, M.1403.1, M.1408.1, M.1411.1, M.1494.1, M.1475.1, M.1442.1, M.1507.1, M.1677.1, M.1680.1, M.1688.1 (Clayton, 1982). For symbols, see Fig. 3.

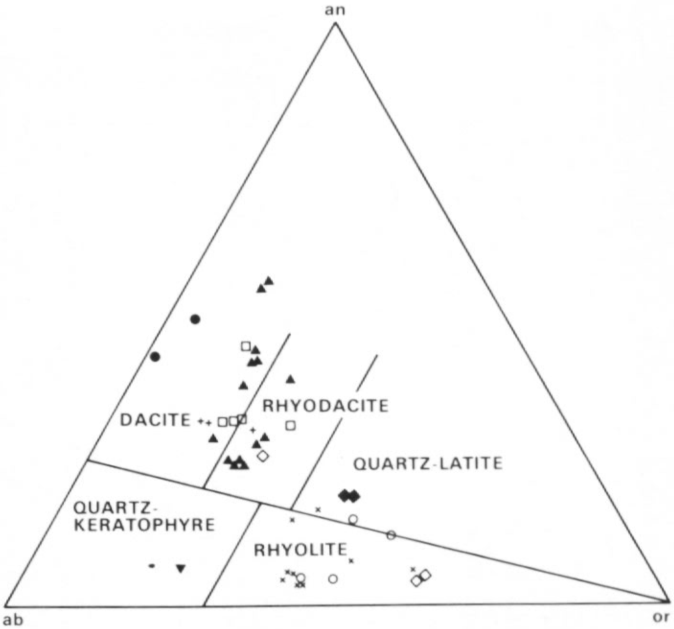
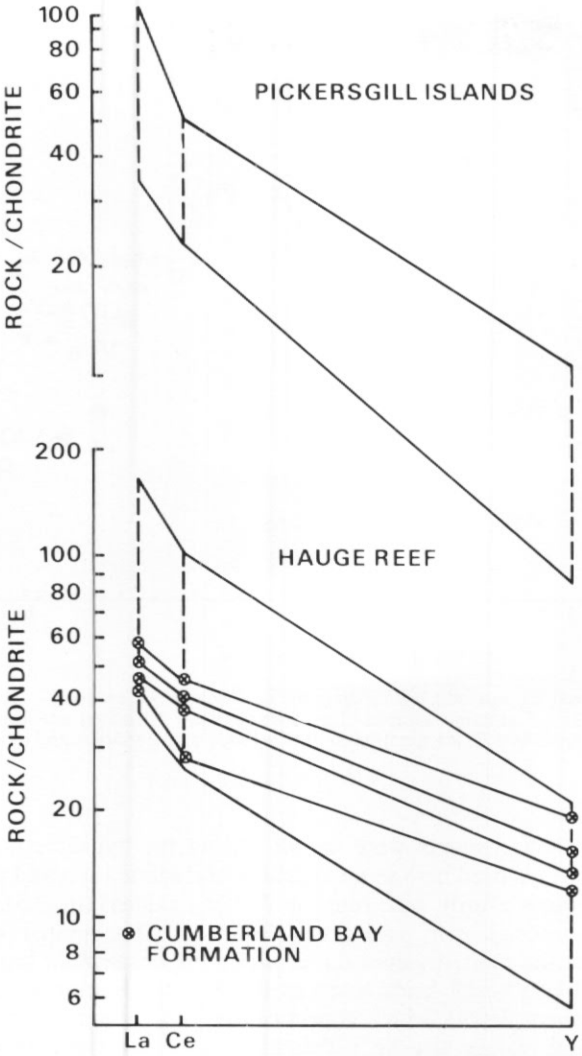


Fig. 5. Normative an–ab–or diagram for Hauge Reef, Pickersgill Islands and Antarctic Peninsula samples. Classification after O'Connor (1965). For symbols, see Fig. 3.

The intrusive rocks of Annenkov Island, which were initially described by Pettigrew (1981) as "spilites" and andesites, are part of the same island-arc plutonic suite. The andesites show intrusive field relationships and contain hornblende, plagioclase and occasional clinopyroxene phenocrysts in an andesitic matrix. The "spilites" which occur as sills have augite and feldspar phenocrysts in a partially altered fine-grained matrix of andesitic composition; some phenocrysts are replaced by secondary minerals identified by Pettigrew as serpentine, bowlingite, chlorite and iddingsite. Although the replacement is in most cases complete, small remnants of orthopyroxene are present in thin section M.1151.35. This confirms the conclusion reached by Pettigrew, who suggested that the pseudomorphs were probably after orthopyroxene. Although the rocks described as spilites contain basaltic plagioclase phenocrysts, the matrix plagioclase is andesitic in composition, which suggests the rocks are orthopyroxene-clinopyroxene-andesites.

XRF analysis of 31 rocks (Mair, 1979) indicated two compositional groups: the "spilites" (field X on Figs 3, 4 and 9) fall in the compositional range SiO_2 43.7–51.04%, whilst the andesites (field Z) fall in the range 55.0–62.0%. This appears to be the result of incomplete sampling as this gap is bridged by 15 homogeneous andesitic breccias (field Y on Figs 3, 4 and 9) from the Upper Breccia Member (our data; Table III). The Upper Breccia Member (field Y) occupies a similar field to the intrusive andesites, diorite–monzodiorite suite and the quartz-monzodiorites on the AFM (Fig. 3), Zr–SiO_2 (Fig. 4), Sr–SiO_2 (Fig. 4), Ti–Y (Fig. 9) and Ti–Zr (Fig. 9) diagrams. This supports the field evidence of Pettigrew (1981) and the palaeontological–radiometric data (Tanner and Rex, 1979), which concludes that the intrusive andesites and the Upper Breccia Member are contemporaneous. However, the Na_2O–SiO_2 variation diagram (Fig. 4) indicates enhanced Na_2O values in the Upper Breccia Member, which may be the effect of submarine alteration.

The intrusive and extrusive rocks from Annenkov Island thus form a continuous magmatic suite of andesite-type rocks, which have calc-alkaline trends (Mair, 1979) and which fall in the



ig. 6. Simulated rare-earth element patterns for Hauge Reef, Cumberland Bay Formation and Pickersgill Islands rocks using XRF values for La, Ce and Y.

calc-alkaline field on the discrimination plots of Pearce and Cann (1973). The andesites of Annenkov Island are enriched in K_2O, Rb, Sr and Ba, relative to typical island-arc suites (Gill, 1970); this may be due to contamination by continental crust and supports previous suggestions (Dalziel and others, 1974) that the island arc may have formed on a fragment of continental crust.

Ocean-floor basalt suite

The pillow and massive lavas exposed on Pillow Island in Hauge Reef show tholeiitic trends on the AFM diagram (Fig. 10) and lie within the ocean-floor basalt field on Ti–Zr and Ti–Zr–Y plots (Fig. 8). The scatter of points on the Ti–Zr–Sr/2 diagram is probably due to the mobility of

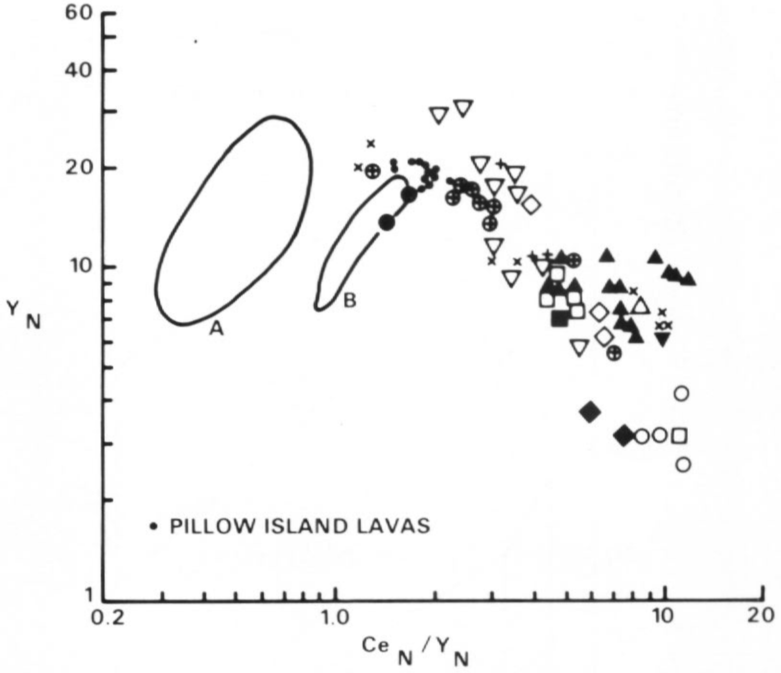


Fig. 7. Chondrite-normalized Y_N against Ce_N/Y_N diagram for Hauge Reef, Pickersgill Islands, Antarctic Peninsula and Cumberland Bay Formation samples. Lavas from Pillow Island (•) are also included. Field A, mid-ocean ridge basalt field; field B, marginal-basin basalts (both from Saunders and others (1979)). For symbols see Fig. 3.

Sr. As SiO_2 and the alkali elements were mobile during the hydrothermal metamorphism of ocean-floor rocks, Fe*/Mg is used here as an indicator of fractionation and a variation index.

Although the rocks show a fairly wide range in Fe*/Mg values (1.6–3.5), they show a narrow range of major- and trace-element variations (Fig. 11). This limited variation prevents a discussion of trends but the plotted values do lie within the ocean-floor basalt field and close to documented marginal-basin basalt fields, such as those of the Sarmiento Complex of southern Chile (Saunders and others, 1979), which is part of the same island-arc–back-arc basin system as South Georgia. These values also lie within those given by the adjacent Larsen Harbour Formation on South Georgia (Mair, 1979) (Fig. 11) and support the correlation of the two units (Tanner and others, 1981).

Using Y as an indicator of the behaviour of the heavy rare-earth elements (Fig. 12), the rocks, in keeping with their tholeiitic trend, are only slightly enriched in light rare-earth elements and lie close to the marginal-basin basalt field (Saunders and others, 1979) on the Y_N against Ce_N/Y_N diagram (Fig. 7). Also similar to ocean-floor basalts, the lavas are mainly olivine-normative with occasional samples lying in the quartz-normative field (Fig. 13).

Cumberland Bay Formation

Trendall (1959) first suggested that the andesitic greywackes of the Cumberland Bay Formation (CBF), which provide the major sedimentary infill of the back-arc basin, were derived from the island arc, and subsequent work has shown that lithic and mineral clasts from the CBF can be petrographically matched with plutonic and volcanic rocks from Annenkov Island (Tanner and others, 1981). A geochemical study of the CBF by Clayton (1982) showed mainly

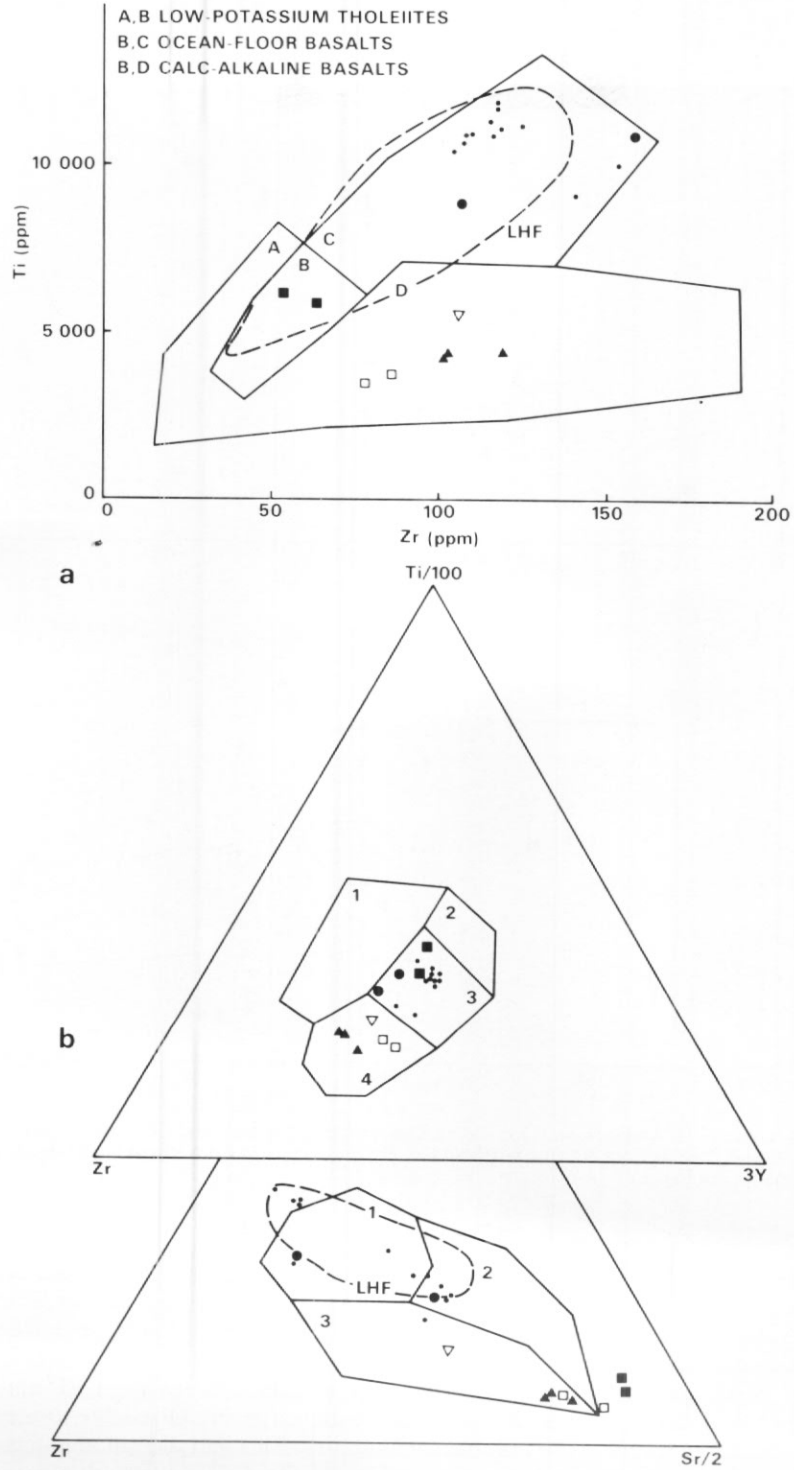


Fig. 8. Ti–Zr, Ti/100–Zr–3Y and Ti/100–Zr–Sr/2 discrimination plots for Hauge Reef (including Pillow Island, •) and Pickersgill Islands samples with 20% >CaO+MgO>12%. Fields from Pearce and Cann (1973). LHF, Larsen Harbour Formation (Mair, 1979). For symbols, see Fig. 3. For Fig. 8b (top): 1 within-plate basalts; 2, 3 low-potassium tholeiites; 3 ocean-floor basalts; 3, 4 calc-alkaline basalts. For Fig. 8b (bottom): 1 ocean-floor basalts; 2 low-potassium tholeiites; 3 calc-alkaline basalts.

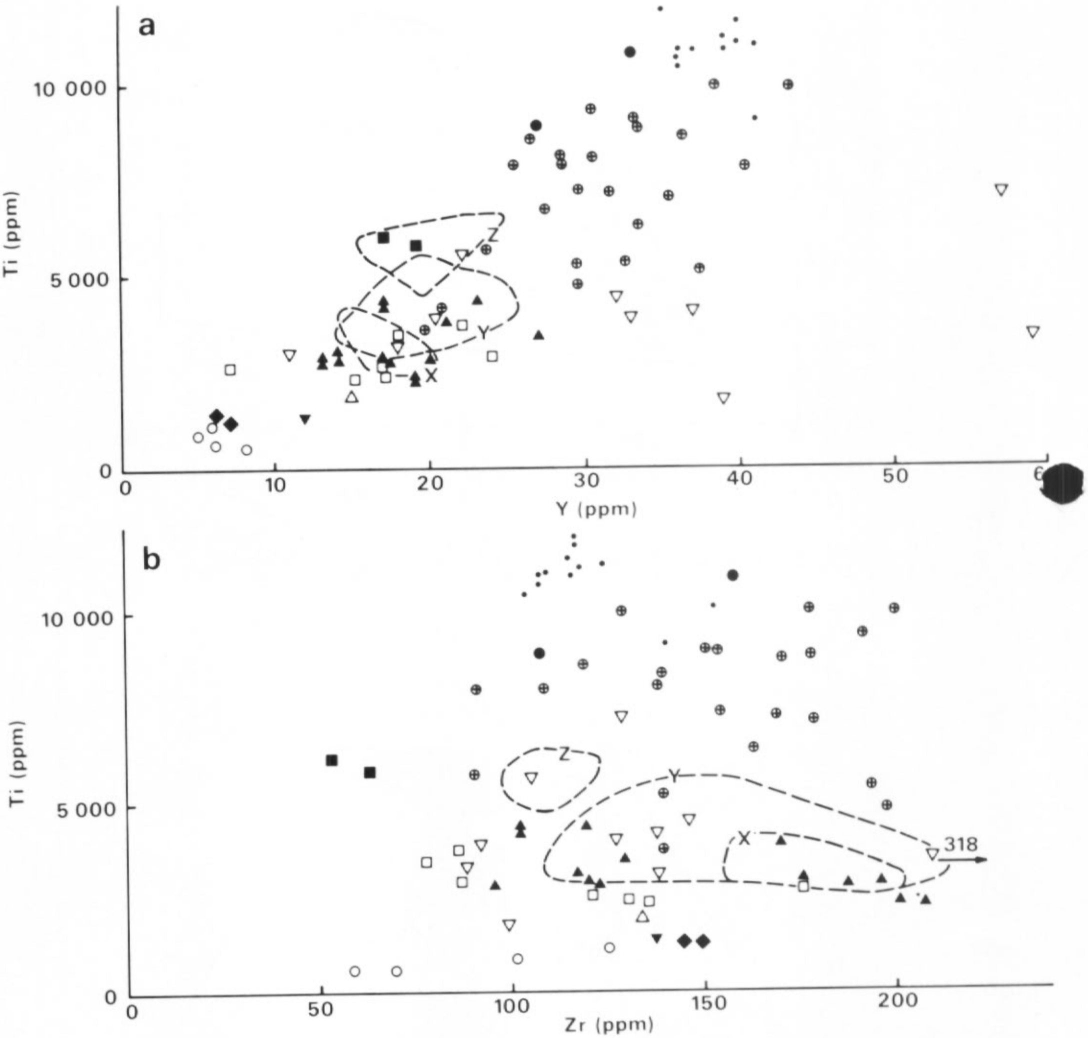


Fig. 9. Ti–Y and Ti–Zr variation plots for Hauge Reef, Pickersgill Islands and Cumberland Bay Formation samples. X, Y and Z fields from Annenkov Island (see Fig. 3). The lavas from Pillow Island (•) are also included. F[illegible] symbols, see Fig. 3.

calc-alkaline trends for these volcaniclastic rocks. We have chosen 26 samples of coarse-grained sandstone from the material analysed by Clayton as being representative of lithic clasts and are therefore closely similar to the source rocks in their chemistry; the analyses have been plotted on the variation diagrams for comparison with the island-arc suite.

Several important geochemical differences are evident between the CBF and the island-arc suite: the CBF is depleted in K_2O and Sr and enriched in Na_2O relative to the latter, and has similar enriched Zr levels to the hornblende-andesites. This variation in amounts of Na_2O, K_2O and Sr may be due to differences in the mobility of these elements during the higher grade of metamorphism of the Cumberland Bay Formation (? prehnite–pumpellyite facies) compared with the Annenkov Island Formation (zeolite facies). On the Ti–Y and Ti–Zr variation plot

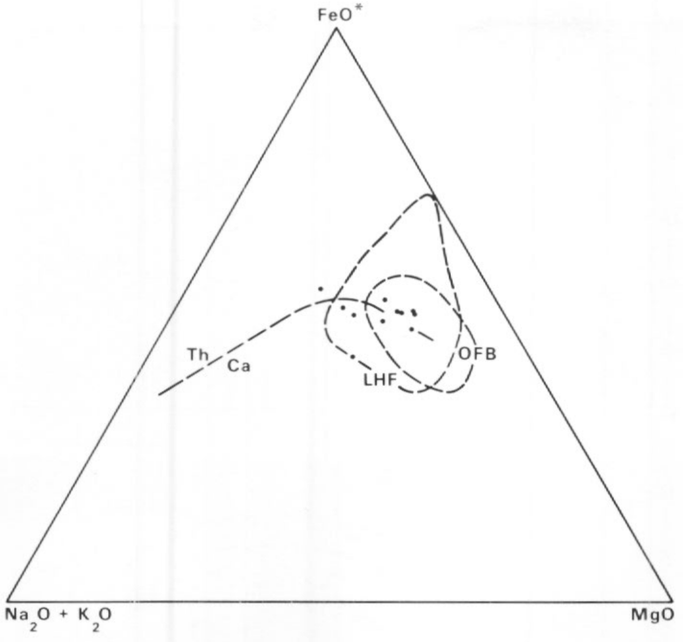


Fig. 10. AFM diagram of lavas from Pillow Island. The tholeiitic (Th)–calc-alkaline (Ca) boundary is from Irvine and Barager (1971). LHF, pillow lavas from the Larsen Harbour Formation (Mair, 1979); OFB, ocean-floor basalts (Bailey and Blake, 1974).

(Fig. 9) the analyses lie on a similar trend, although there is marked separation of the fields for similar SiO_2 values. The Cumberland Bay Formation is enriched in Ti and Y relative to the island-arc suite. Similarly, as shown in Fig. 6, the Cumberland Bay Formation is enriched in heavy rare-earth elements and depleted in light rare-earth elements relative to the island-arc suite.

It is difficult to decide whether these differences are meaningful because, whereas the Cumberland Bay Formation shows little variation in petrography of the clasts between the lower and upper stratigraphical levels (Winn, 1978; Tanner and others, 1981) and the geochemistry is relatively well defined, that of the contemporaneous island-arc suite is not. Most of the igneous rocks sampled from the island arc are of post-Aptian age (Tanner and Rex, 1979) and together with the Upper Breccia Member (Aptian–Albian or younger) are outside of the time range represented by the Cumberland Bay Formation. The only rocks which can be strictly compared with the Cumberland Bay Formation are the tuffs, tuffaceous sandstones and sills of the Lower Tuff Member (Upper Jurassic to Aptian–Albian). Even here, the comparison is doubtful because a detailed study of the turbidites of the Cumberland Bay Formation has shown that they originated mainly from a source south-east of present-day South Georgia (Tanner, in press; Macdonald and Tanner, in press) and may have been sampling a different geochemical province than the locally derived material within the Lower Tuff Member. Thus any comparison between the chemistry of the Cumberland Bay Formation and that of the island-arc suite requires that the latter shows neither spatial nor temporal variation in geochemistry from the Upper Jurassic to Aptian–Albian, a premise of doubtful value for an island arc evolving over such a long period. We conclude that the difference in geochemistry between the two groups of rocks is of doubtful significance and should not be used as a basis for further interpretation (cf. Macdonald, 1980).

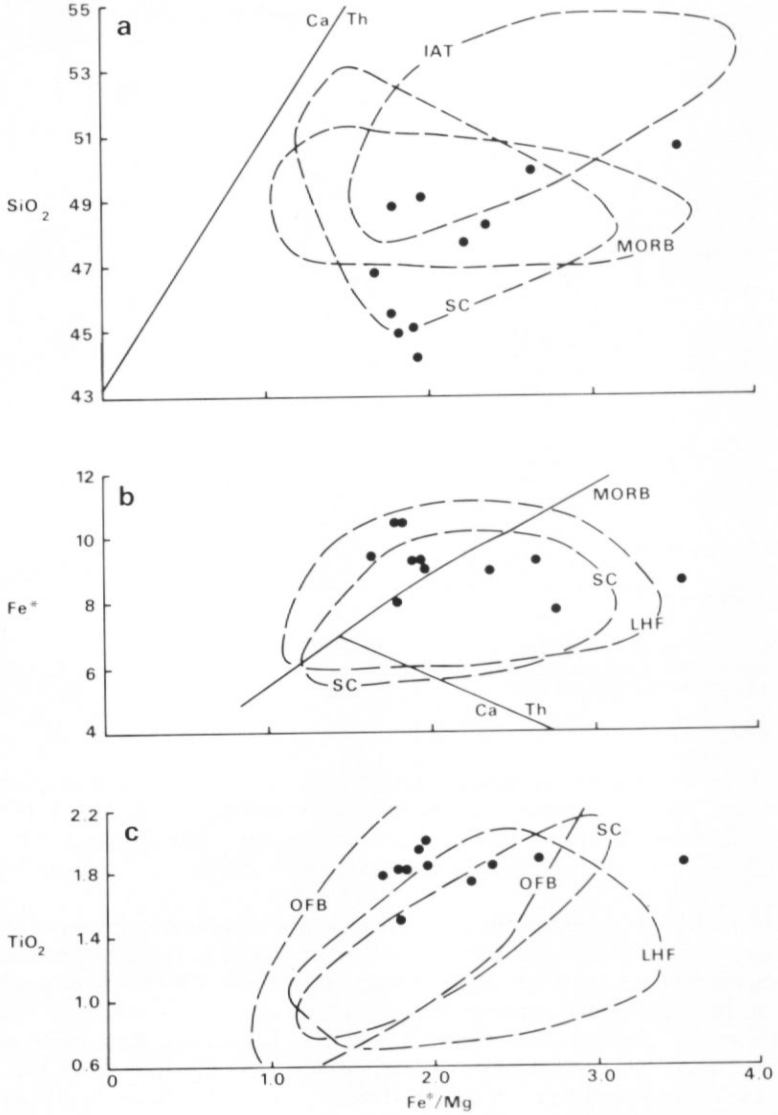


Fig. 11. SiO_2, Fe* and TiO_2 versus Fe*/Mg variation diagrams for lavas from Pillow Island. LHF, Larsen Harbour Formation (Mair, 1979); fields from Saunders and others (1979): SC, Sarmiento Complex; MORB, mid-ocean ridge basalts; IAT, island-arc tholeiites. Th, tholeiitic and Ca, calc-alkaline trends are from Miyashiro (1973). Fe* = total iron as Fe^{2+}.

GEOCHEMISTRY OF THE ANTARCTIC PENINSULA PLUTONIC SUITE

The newly analysed samples (Table IV), all of which are taken from Cretaceous–Tertiary suites of radiometrically dated plutonic rocks belonging to the Antarctic Peninsula volcanic arc, show calc-alkaline trends similar to those of the Hauge Reef and Pickersgill Islands rocks. The results also compare closely with those of Saunders and others (in press) for the northern part of the Antarctic Peninsula volcanic arc.

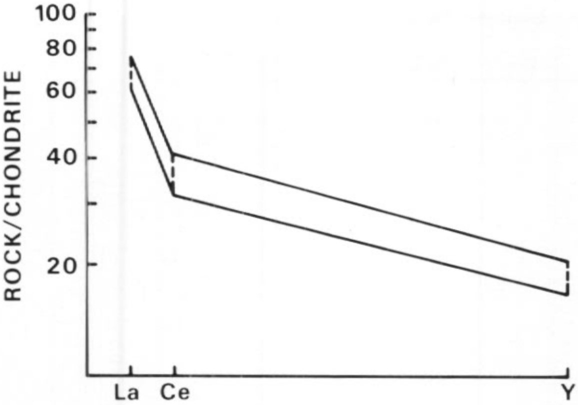


Fig. 12. Simulated rare-earth element pattern of lavas from Pillow Island using XRF values for La, Ce, and Y.

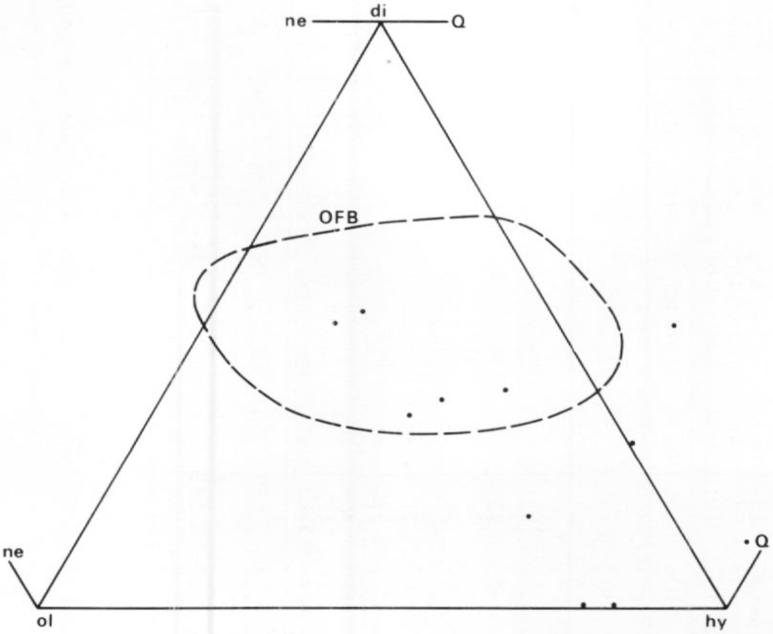


Fig. 13. Normative di–ol–hy diagram for lavas from Pillow Island. OFB, ocean-floor basalt field from Saunders and others (1979).

DISCUSSION AND CONCLUSIONS

The geochemistry of the Hauge Reef and Pickersgill Islands rocks for the most part supports the conclusions of Tanner and others (1981). The tuffs and mudstones of the Lower Tuff Member, the andesitic breccias of the Upper Breccia Member and the andesitic plutons and sills of Annenkov Island, Hauge Reef and the Pickersgill Islands are part of a coeval calc-alkaline island-arc complex which we infer to have resulted from subduction of Pacific Ocean floor during the late Jurassic–early Cretaceous. The arc possibly formed on a fragment of continental crust, as indicated by high K_2O, Rb, Sr and Ba values, that was split off from the South

TABLE IV. CHEMICAL ANALYSES OF ANTARCTIC PENINSULA PLUTONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	71.5	75.4	70.6	75.7	75.3	75.6	77.1	74.4	76.9	62.3	75.7	76.0	57.6	59.8	60.6
TiO_2	0.22	0.05	0.22	0.08	0.14	0.14	0.09	0.14	0.09	0.78	0.27	0.27	1.04	0.57	0.57
Al_2O_3	16.1	14.9	15.6	14.5	14.4	14.3	14.1	14.3	14.0	15.2	13.8	13.8	16.1	16.7	16.6
t Fe_2O_3	1.90	0.51	1.88	0.81	0.90	0.90	0.44	0.96	0.50	6.09	1.55	1.55	7.51	5.73	5.70
MnO	0.05	0.01	0.05	0.02	0.04	0.04	0.03	0.05	0.03	0.13	0.03	0.03	0.15	0.14	0.13
MgO	0.5	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.1	2.0	0.4	0.4	2.3	2.4	2.4
CaO	2.15	0.83	2.11	1.01	0.75	0.75	0.54	0.65	0.51	5.05	0.64	0.64	6.41	6.28	6.30
Na_2O	4.12	2.98	3.40	3.5	4.41	4.4	4.35	4.58	4.32	3.7	2.7	2.7	3.7	4.3	4.3
K_2O	4.30	6.71	4.23	5.36	4.60	4.62	4.95	4.59	4.85	2.86	6.63	6.68	2.51	1.71	1.66
P_2O_5	0.07	0.01	0.07	0.01	0.02	0.02	0.01	0.02	0.01	0.15	0.01	0.01	0.29	0.19	0.18
TOTAL	100.91	101.50	98.26	101.09	100.76	100.97	101.71	99.89	101.04	98.26	101.73	102.11	97.61	97.82	98.44
							TRACE ELEMENTS								
Cr	<10	<10	<10	<10	<10	<10	<10	<10	<10	20	<10	<10	<10	<10	<10
Ni	<6	<6	<6	<6	<6	<6	<6	<6	<6	10	<6	<6	<6	<6	7
Zn	22	<6	23	8	7	7	<6	9	<6	53	20	20	67	47	46
Rb	158	215	155	184	137	136	178	146	181	80	122	121	93	54	52
Sr	462	122	459	135	127	127	35	127	30	285	124	123	347	419	413
Y	13	39	14	48	13	13	20	16	20	31	14	12	40	21	21
Zr	190	72	183	96	94	95	55	112	49	226	135	140	303	137	135
Nb	8	16	8	12	8	9	11	11	10	8	3	4	7	4	4
Ba	950	284	942	367	594	605	80	642	72	402	375	373	359	344	298
La	35	12	36	14	35	33	16	31	15	29	22	21	34	23	22
Ce	54	19	57	26	52	53	30	53	26	49	36	32	52	39	35
Pb	35	50	30	33	15	17	20	15	15	10	16	18	9	<9	<9
Th	30	30	25	36	20	23	25	20	25	12	39	34	9	11	14
Ga	22	18	23	17	17	16	16	16	16	22	13	13	20	21	19
W	891	1 133	924	1 278	1 182	1 129	1 258	877	1 582	498	1 058	1 068	387	376	481
Fe*/Mg	4.41	5.91	21.80	9.39	5.22	5.22	5.09	5.56	5.80	3.53	4.49	4.49	3.79	2.77	2.75
K/Rb	226	259	227	242	279	282	231	261	222	297	451	458	224	263	265
Rb/Sr	0.34	1.76	0.34	1.36	1.08	1.07	5.09	1.15	6.03	0.28	0.98	0.98	0.27	0.13	0.13
Ba/Sr	2.06	2.33	2.05	2.72	4.68	4.76	2.29	5.06	2.40	1.41	3.02	3.03	1.04	0.82	0.72
Zr/Nb	23.75	4.5	22.9	8.0	11.8	10.6	5.0	10.2	4.9	28.3	45.0	35.0	43.3	34.3	33.8

Fe* = total iron as Fe^{2+}.
t Fe_2O_3 = total iron as Fe_2O_3.

Granite from Stonington Island, Marguerite Bay.
1. BS 101.1
2. BS 101.5
3. BS 101.8A
4. BS 101.8B

Granite from the Debenham Islands, Marguerite Bay.
5. BS 102.22
6. BS 102.22B
7. BS 102.25A
8. BS 102.28A
9. BS 102.28B

Granodiorite from the Argentine Islands.
10. BS 103.7
11. BS 102.11
12. BS 103.11B

Tonalite from Anvers Island.
13. BS 104.1
14. BS 104.5
15. BS 104.8

American continental margin by emplacement of basic magma and by sea-floor spreading. The pillowed and massive lavas of Pillow Island are not part of this calc-alkaline suite but show tholeiitic trends and are probably part of the ocean crust (Larsen Harbour Formation) that formed the floor of the marginal shelf to the back-arc basin during the late Jurassic. The occasional mafic sills which intrude the Lower Tuff Member have affinities with this tholeiitic magma and their presence within the calc-alkaline sediments indicates that there was some overlap between the calc-alkaline volcanic activity of the magmatic arc (derived by multi-stage subduction processes) and the tholeiitic activity (derived by partial melting of the mantle) within the back-arc basin. A similar situation exists in South America where sills within Upper Jurassic silicic volcanic rocks and the Hardy Formation (island-arc derived sediments) have geochemical affinities with both the tholeiitic basalts forming the ophiolite lenses and calc-alkaline rocks of the adjacent Patagonian batholith (Bruhn and others, 1978).

The chemistry of andesitic greywackes of the Cumberland Bay Formation, which infilled the back-arc basin, is dissimilar to that of the volcanic and hypabyssal rocks of the island-arc suite, despite close similarities between them in other respects.

The differences in chemistry may be due to: variations in the mobility of certain elements during metamorphism of zeolite and prehnite–pumpellyite facies; variations produced by sedimentary processes such as turbidite deposition and ash fall; differences in age between the two suites; and differences in source-area geochemistry. No firm conclusions can be drawn from the data available.

The presence of pillowed lavas, related to ocean-floor basalts conformably overlain by tuffs and mudstones with calc-alkaline affinities within Hauge Reef gives further evidence of the close association in the geological record of island arcs and ocean floor (Upadhyay and Neale, 1979) and of ophiolites evolved adjacent to island arcs in western Pacific-type marginal-basin situations (Karig, 1974). Ophiolites overlain by calc-alkaline pyroclastic sediments are not found in mid-ocean ridge situations.

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