

Composition and Origin of Relict Clinopyroxenes from a Subduction Complex, South Shetland Islands, Antarctica

(clinopyroxene | subduction complex | Scotia Arc | West Antarctica)

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INTRODUCTION

Metamorphic rocks of the South Shetland and South Orkney islands (Fig. 1) have been grouped together in the Scotia metamorphic complex (Tanner *et al.*, 1982; Dalziel, 1982, 1984), interpreted as an accretionary subduction complex (Smellie & Clarkson, 1975; Smellie, 1981; Dalziel, 1982, 1984). The main arguments to support this interpretation are the presence of rock types with oceanic affinity, the tectonic setting between Pacific ocean floor and a remnant magmatic arc on the Antarctic Peninsula, and the occurrence of blueschists (Rivano & Cortés, 1976; Smellie & Clarkson, 1975; Dalziel, 1982, 1984).

Within the South Shetland Islands these rocks are located at Smith Island (63S, 62°30'W) and at Elephant and surrounding islands (61S, 55°W, Fig. 1). Possibly these two occurrences represent material accreted at different times, since radiometric data from Smith Island indicate a metamorphic age between 47 and 58 Ma (Hervé *et al.*, 1990; Grunow *et al.*, 1992), whereas most ages from Elephant and surrounding islands fall in the range 80 to 120 Ma (Tanner *et al.*, 1982; Hervé *et al.*, 1990, 1991; Trouw *et al.*, 1990; Grunow *et al.*, 1992).

Hervé *et al.* (1983) reported the presence of relict igneous clinopyroxenes in a sample from Cape Smith, northern Smith Island (Fig. 1). Based on the chemical composition, they interpreted these pyroxenes as being derived from basaltic magmas of ocean floor environment. Dalziel (1984) and Trouw *et al.* (1991) mention the occurrence of such pyroxenes at northern Elephant Island and at southern Smith Island. The objective of this paper is to extend on the work of Hervé *et al.* (1983), reporting the chemical composition of relict clinopyroxenes from four samples, two from southern Smith Island and two from northern Elephant Island, and to discuss their tectonic significance.

The microprobe analyses were obtained at the Institute for Earth Sciences, Utrecht University, the Netherlands, using a JEOL microprobe with accelerator voltage of 15 kV and beam diameter of approximately one micron.

LOCAL GEOLOGY AND PETROGRAPHY

Smith Island

Interlayered blue and green phyllites and schists, with minor intercalations of metachert, calc-silicate rock, pink marble and pelitic grey phyllite, crop out on this island, on which no major lithologic contacts or metamorphic isograds have been reported (Dalziel, 1984; Trouw, 1988; Grunow *et al.*, 1992).

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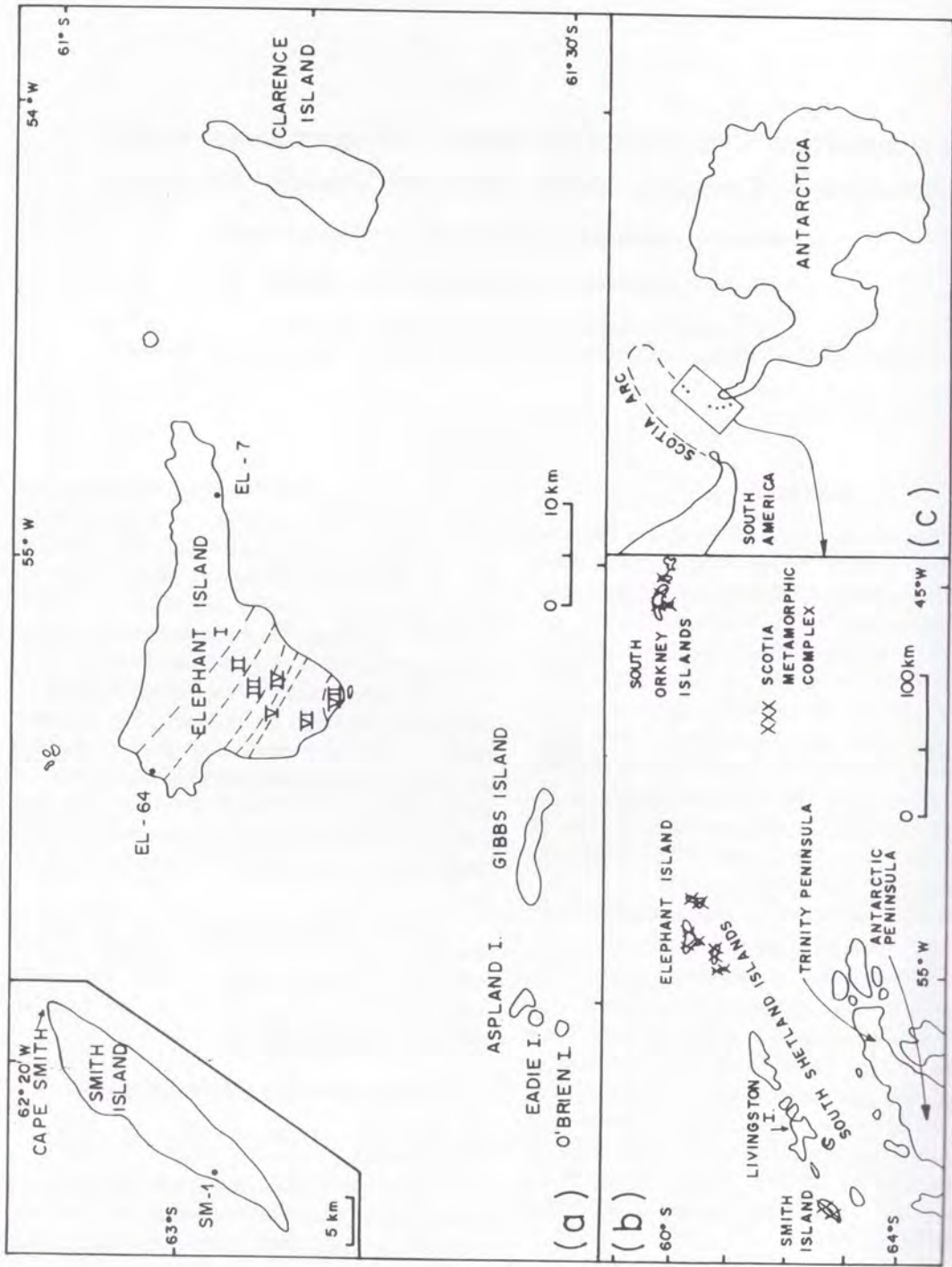


Fig. 1. Location map of analyzed samples: (a) Elephant Island group with inset of Smith Island; metamorphic zones I-VII are indicated on Elephant Island; (b) location of the South Shetland and South Orkney Islands; (c) location of discussed region with respect to South America and Antarctica.

Intense deformation of at least two superposed phases (Dalziel, 1984; Trouw, 1988; Grunow *et al.*, 1992) obliterated most sedimentary features. However, thin and medium scale bedding may be recognized locally, especially along metachert or marble layers.

The first metamorphic classification was made by Rivano & Cortés (1976), who reported coexisting lawsonite and sodic amphibole in a sample from Cape Smith. For this reason they considered the sequence to belong to the glaucophane schist facies. Grunow *et al.* (1992) preferred to place the rocks of this island in the crossite-epidote blueschist facies because of the widespread occurrence of epidote and actinolite. In the course of our studies (Trouw, 1988; Trouw *et al.*, 1991) approximately fifty thin sections from five localities have been investigated. In none of these does lawsonite occur in contact with sodic amphibole, so we agree with Grunow *et al.* (1992) on the metamorphic facies. The main metamorphic minerals in mafic rocks are chlorite, epidote, albite, actinolite, blue amphibole, quartz and calcite. In addition, two groups of light green metamorphic pyroxene with respectively 10 and 20% jadeite component were described by Grunow *et al.* (1992). Similar pyroxenes have also been recognized by Trouw *et al.* (1998), often partially replacing relict igneous ones, with a jadeite component reaching 40%. The metachert layers, principally composed of quartz, locally bear tiny spessartine-rich garnets. Piemontite, stilpnomelane and haematite are common in calcitic marbles and calc-silicate rocks. Lawsonite is mainly restricted to grey phyllites, composed of quartz, white mica, chlorite and epidote.

Five samples with relict clinopyroxenes have been collected, three from Cape Smith and two from point SM-1, in the southern part of the island (Fig. 1). These last two samples, SM-1-26 and SM-1-48 were selected for pyroxene analysis.

SM-1-26 is a homogeneous green schist cut by veins composed of quartz and chlorite. Major components are epidote (30%), chlorite (16%), and relic clinopyroxene (17%). Minor constituents are albite (10%), sodic amphibole (5%), actinolite (5%), calcite (5%), quartz (4%), metamorphic clinopyroxene (3%), chalcopryrite (3%) and pyrite (2%). Grains of relict clinopyroxene up to 0.5 mm in diameter are set in a finer grained matrix. They

exhibit weak pink pleochroism and are in some places partly substituted by greenish metamorphic clinopyroxene of aegirine-augite and omphacite composition.

SM-1-48 is also a green schist with conspicuous relict clinopyroxene crystals (10%) of up to 2.0 mm in diameter. The schist is composed of epidote (24%), chlorite (15%), albite (15%), quartz (8%), actinolite (8%), sodic amphibole (7%), calcite (5%), metamorphic clinopyroxene (4%), chalcopryrite (3%) and pumpellyite (1%). The relict clinopyroxenes have a distinct pink pleochroism and high birefringence colours. They are partly substituted by metamorphic aegirine-jadeite, chloromelanite or aegirine-augite. The well developed foliation curves around the crystals, often affected by microboudinage with chlorite and amphibole in the necks and fractures (Fig. 2).

Elephant Island

Grey, green and blue schists and phyllites with minor intercalations of metachert, marble, calc-silicate rock and amphibolite are the main rock types of this island, described in detail by Allen (1982), Dalziel (1984), Marsh & Thomson (1985), Trouw *et al.* (1986, 1991), Valladares (1991), and Grunow *et al.* (1992). The structures, similar to those of Smith Island, have been described by Dalziel (1984), Trouw (1988) and Grunow *et al.* (1992).

The metamorphic grade increases towards the south of the island. Trouw *et al.* (1991) have emphasized similarities with Sanbagawa type metamorphism, subdividing the island into three metamorphic zones: the chlorite zone with pumpellyite, the garnet zone with blue amphibole and the biotite zone with hornblende. Further work (Valladares, 1991; Trouw *et al.*, 1998) lead to a more refined subdivision into seven metamorphic zones, separated by the following isograds: blue amphibole in, spessartine in, almandine in, blue amphibole out, biotite in, and oligoclase in (forming rims around albite). Relict clinopyroxenes have been found only in the first two of these seven zones. The first zone is characterized by the presence of chlorite, pumpellyite, actinolite, epidote, albite and stilpnomelane in most mafic assemblages, whereas white mica and quartz are the main minerals in pelitic rocks. This zone may be attributed to the pumpellyite-actinolite facies. The

Fig. 1 — Location map of analysed samples; (a) Elephant Island group with inset of South Island; metamorphic zones I-VII are indicated on Elephant Island; (b) location of the South Shetland and South Orkney Islands; (c) location of discussed region with respect to South America and Antarctica.



Fig. 2 — Relict clinopyroxene crystal set in fine grained metamorphic matrix (sample SM-1-48); the shaded areas close to the rim of the crystal are altered to metamorphic pyroxene; diameter of crystal is 1.5 mm; note a fragment of dark pyroxene torn off the main crystal by microboudinage at the right hand side of the figure; plane polarised light.

transition towards the second zone is marked by the income of blue amphibole and locally jadeitic pyroxene in mafic assemblages, by the disappearance of pumpellyite, and by the presence of lawsonite in some pelitic rocks. Hence this zone fits the crossite-epidote blueschist facies. Further details of the metamorphic zones are given in Trouw *et al.* (1998).

Relict minerals occur either as detrital clasts in metasand- or siltstones, or as igneous remnants in mafic schists, probably derived from lavas, sills or dykes. The first type includes crystals of clinopyroxene and hornblende whereas the second type is restricted to clinopyroxene. One out of two mafic samples from point EL-7 (Fig. 1, sample EL-7-7), has been selected for clinopyroxene analysis. The other selected sample has been collected at point EL-64 (Fig. 1, sample EL-64-8H).

EL-7-7 is a homogeneous mafic rock mainly composed of epidote (25%), chlorite (20%), actinolite (14%) and albite (15%). The relict clinopyroxenes (6%) are colourless, up to 0.3 mm in diameter, and surrounded by chlorite and actinolite. Accessory minerals are stilpnomelane, pum-

pellyite, sphene, pyrite and white mica whereas quartz and calcite occur in veins.

EL-64-8H is a rock with interstratified blue-green and grey laminae, probably of sedimentary/volcaniclastic origin. The bulk composition is difficult to estimate because the rock is very fine grained. Major components are epidote (34%), crossite (19%), white mica (13%), chlorite (11%) and quartz (10%). Metamorphic clinopyroxene (7%) is of chloromelanitic and omphacitic composition. Quartz and chlorite occur in veins. Only three clastic fragments of relict clinopyroxene, of up to 0.4 mm in diameter, possibly derived from a single crystal, occur in the analysed section.

CHEMICAL COMPOSITION AND ORIGIN

The chemical composition of the analysed clinopyroxenes is given in Tables I, II and III. Each analysis represents a single point in a pyroxene crystal. Usually one to three points were analysed in any crystal so the total number of analyses per sample corresponds roughly to twice the number of analysed crystals. Using the end-member calculation proposed by Papike *et al.* (1974), the analyses plot in the classification dia-

TABLE I
Chemical composition of analysed relict clinopyroxenes from Elephant Island.

	EL - 7 - 7												EL - 64 - 8H	
	50.06	50.66	50.53	50.34	50.57	50.55	50.47	49.87	50.40	48.88	50.60	49.03	52.31	51.75
SiO ₂	50.06	50.66	50.53	50.34	50.57	50.55	50.47	49.87	50.40	48.88	50.60	49.03	52.31	51.75
TiO ₂	1.45	1.12	1.40	1.20	1.27	1.30	1.27	1.33	1.33	1.55	1.22	1.42	0.62	0.67
Al ₂ O ₃	3.00	2.83	3.33	3.57	3.80	3.17	2.68	3.02	2.55	4.21	3.53	2.74	2.74	2.87
Cr ₂ O ₃	0.23	0.31	0.18	—	0.34	0.13	0.13	0.30	—	0.26	0.19	0.16	0.75	0.77
FeO ^I	9.20	9.71	9.96	8.90	9.24	9.37	10.03	9.01	9.76	9.84	8.88	12.52	7.54	6.42
MnO	0.25	0.30	0.19	0.25	0.25	0.18	0.23	0.26	0.30	0.30	0.26	0.40	0.18	0.25
MgO	15.22	15.47	15.14	14.24	14.26	15.12	15.22	14.71	14.71	14.96	14.69	13.81	18.06	18.01
CaO	19.55	19.78	19.70	20.57	20.05	20.20	19.39	20.54	20.34	19.60	20.55	18.44	18.69	19.29
Na ₂ O	0.34	0.36	0.38	0.34	0.35	0.32	0.38	0.38	0.32	0.38	0.34	0.39	0.49	0.30
K ₂ O	—	—	—	—	—	—	—	—	—	—	—	—	—	0.16
Total	99.32	100.54	100.81	99.41	100.14	100.34	99.80	99.42	99.79	100.06	100.29	98.92	101.51	100.51

O = 6

Si	1.870	1.875	1.862	1.881	1.879	1.870	1.880	1.864	1.883	1.815	1.873	1.866	1.886	1.883
Al ^{IV}	0.130	0.124	0.138	0.119	0.121	0.130	0.118	0.133	0.112	0.184	0.127	0.123	0.114	0.117
Tet.	2.000	1.999	2.000	2.000	2.000	2.000	1.997	1.997	1.996	1.999	2.000	1.989	2.000	2.000
Al ^{IV}	0.002	—	0.007	0.039	0.046	0.008	—	—	—	—	0.027	—	0.002	0.006
Cr	0.007	0.009	0.005	—	0.010	0.004	0.004	0.009	—	0.008	0.006	0.005	0.021	0.022
Fe ²	0.224	0.223	0.231	0.241	0.268	0.223	0.242	0.205	0.244	0.188	0.225	0.333	0.136	0.120
Fe ³	0.064	0.078	0.076	0.037	0.019	0.067	0.070	0.077	0.061	0.117	0.050	0.066	0.091	0.076
Mg	0.847	0.853	0.831	0.793	0.790	0.834	0.845	0.819	0.819	0.828	0.810	0.783	0.970	0.976
Mn	0.008	0.009	0.006	0.008	0.008	0.006	0.007	0.008	0.009	0.009	0.008	0.013	0.005	0.008
Ti	0.041	0.031	0.039	0.034	0.035	0.036	0.036	0.037	0.037	0.043	0.034	0.041	0.017	0.018
Oct.	1.193	1.204	1.195	1.152	1.176	1.178	1.204	1.156	1.171	1.194	1.160	1.240	1.244	1.226
Exc. Oct.	0.193	0.204	0.195	0.152	0.176	0.178	0.204	0.156	0.171	0.194	0.160	0.240	0.244	0.226
Ca	0.783	0.773	0.778	0.824	0.798	0.801	0.774	0.823	0.814	0.780	0.815	0.752	0.722	0.752
Na	0.025	0.026	0.027	0.025	0.025	0.022	0.027	0.028	0.023	0.027	0.024	0.029	0.034	0.023
M ₂	1.001	1.003	1.000	1.001	0.999	1.001	1.005	1.006	1.009	1.001	0.999	1.021	1.000	1.001
WO	42.22	41.79	42.26	44.34	43.01	43.11	41.58	44.55	43.37	43.42	44.06	40.25	39.48	40.69
EN	45.71	46.16	45.17	42.69	42.54	44.88	45.40	44.37	43.62	46.10	43.80	41.93	53.06	52.83
FS	12.07	12.05	12.57	12.97	14.45	12.02	13.02	11.08	13.01	10.48	12.14	17.82	7.46	6.48

TABLE II
Chemical composition of analysed relict clinopyroxenes from sample SM-1-26, Smith Island.

	SM - 1 - 26											
SiO ₂	52.37	51.28	52.93	50.81	51.60	51.02	51.90	50.75	50.66	51.99	50.98	51.19
TiO ₂	0.82	0.88	0.55	0.98	0.95	0.97	1.02	1.02	0.98	0.88	0.97	0.87
Al ₂ O ₃	3.06	2.74	1.93	3.08	3.25	2.97	2.93	3.08	2.97	2.99	2.87	2.97
Cr ₂ O ₃	0.31	0.48	0.39	0.29	0.15	0.35	0.16	—	0.18	—	—	—
FeO ^I	7.76	6.52	7.45	8.31	8.23	8.72	9.10	9.35	9.98	9.03	7.54	9.53
MnO	0.13	0.21	0.21	0.15	0.22	0.18	0.21	0.27	0.23	0.28	0.19	0.34
MgO	17.59	15.83	17.21	16.71	16.47	16.00	15.97	15.65	16.38	17.10	16.03	14.18
CaO	19.31	20.54	18.90	18.93	19.43	18.90	20.20	18.50	18.30	17.94	19.73	19.13
Na ₂ O	0.22	0.27	0.61	0.30	0.36	0.69	0.31	0.30	0.30	0.24	0.34	0.96
K ₂ O	—	—	—	—	0.08	0.07	—	0.10	—	—	—	0.07
Total	101.60	98.77	100.32	99.58	100.74	99.93	101.80	99.06	99.98	100.67	98.69	99.25
	O = 6											
Si	1.891	1.912	1.935	1.877	1.887	1.886	1.886	1.899	1.873	1.905	1.901	1.912
Al ^{IV}	0.109	0.088	0.065	0.123	0.113	0.114	0.114	0.101	0.127	0.095	0.099	0.088
Tet.	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al ^{IV}	0.021	0.032	0.108	0.012	0.027	0.015	0.012	0.034	0.003	0.035	0.028	0.043
Cr	0.009	0.014	0.011	0.008	0.004	0.010	0.005	—	0.005	—	—	—
Fe ²	0.185	0.191	0.179	0.187	0.196	0.191	0.214	0.261	0.223	0.248	0.194	0.232
Fe ³	0.050	0.013	0.049	0.069	0.055	0.078	0.063	0.031	0.086	0.028	0.041	0.066
Mg	0.947	0.879	0.938	0.920	0.897	0.881	0.865	0.873	0.903	0.934	0.891	0.789
Mn	0.004	0.007	0.007	0.005	0.007	0.006	0.006	0.009	0.007	0.009	0.006	0.011
Ti	0.022	0.025	0.015	0.027	0.026	0.027	0.028	0.029	0.027	0.024	0.027	0.024
Oct.	1.237	1.160	1.216	1.229	1.213	1.209	1.192	1.237	1.253	1.278	1.187	1.165
Exc. Oct.	0.237	0.160	0.216	0.229	0.213	0.209	0.192	0.237	0.253	0.278	0.187	0.165
Ca	0.747	0.820	0.740	0.749	0.761	0.748	0.787	0.742	0.725	0.705	0.788	0.766
Na	0.015	0.020	0.043	0.021	0.026	0.043	0.021	0.022	0.022	0.017	0.025	0.070
M ₂	0.999	1.000	1.000	0.999	1.000	1.000	1.000	1.001	1.000	1.000	1.000	1.001
WO	39.77	43.40	39.86	40.36	41.04	41.10	42.17	39.55	39.19	37.34	42.09	42.85
EN	50.39	46.52	50.49	49.55	48.38	48.40	46.37	46.53	48.79	49.50	47.56	44.18
FS	9.84	10.09	9.65	10.09	10.58	10.50	11.46	13.92	12.03	13.16	10.35	12.97

TABLE III
Chemical composition of analysed relict clinopyroxenes from sample SM-1-48, Smith Island.

	SM - 1 - 48														
SiO ₂	45.25	46.25	47.60	50.57	49.53	48.24	46.72	47.34	50.75	47.15	46.94	46.89	47.28	50.55	47.47
TiO ₂	2.99	2.89	1.45	1.38	1.38	1.63	2.59	2.17	1.22	2.55	2.77	1.93	2.07	1.37	2.17
Al ₂ O ₃	6.76	6.95	4.95	3.25	2.99	5.65	5.31	5.04	3.46	5.74	5.46	6.16	5.63	3.21	4.55
Cr ₂ O ₃	0.18	—	0.63	—	—	0.38	—	—	—	—	0.15	0.48	0.12	—	—
FeO ^I	9.62	9.42	6.57	7.47	7.81	7.06	9.83	9.94	7.82	9.55	10.70	7.10	7.77	8.35	10.27
MnO	0.21	0.22	0.18	0.18	0.23	0.06	0.26	0.22	0.19	0.22	0.31	0.19	0.19	0.17	0.27
MgO	11.51	12.02	13.94	14.31	14.03	13.30	12.09	11.91	14.21	12.24	11.74	13.22	12.93	13.89	11.99
CaO	22.02	22.00	22.50	22.23	22.26	22.23	21.52	21.73	22.46	22.23	21.45	22.85	22.93	21.81	21.63
Na ₂ O	0.53	0.57	0.40	0.38	0.35	0.36	0.55	0.63	0.38	0.54	0.63	0.30	0.46	0.63	0.63
K ₂ O	—	0.06	0.08	—	—	—	—	0.11	—	—	0.06	—	—	0.08	0.12
Total	99.08	100.38	98.40	99.77	98.58	98.96	98.90	99.11	100.49	100.29	100.23	99.12	99.38	100.08	99.10

O = 6

Si	1.714	1.725	1.791	1.878	1.865	1.808	1.771	1.792	1.872	1.761	1.763	1.755	1.768	1.876	1.799
Al ^{IV}	0.286	0.275	0.209	0.122	0.133	0.192	0.229	0.208	0.128	0.239	0.237	0.245	0.232	0.124	0.201
Tet.	2.000	2.000	2.000	2.000	1.998	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al ^{IV}	0.016	0.030	0.010	0.020	—	0.058	0.008	0.017	0.023	0.013	0.005	0.027	0.016	0.016	0.002
Cr	0.005	—	0.019	—	—	0.011	—	—	—	—	0.004	0.014	0.014	—	—
Fe ²	0.171	0.169	0.079	0.180	0.166	0.164	0.199	0.201	0.177	0.176	0.219	0.106	0.114	0.183	0.204
Fe ³	0.134	0.124	0.128	0.052	0.080	0.057	0.113	0.114	0.065	0.122	0.117	0.116	0.129	0.076	0.121
Mg	0.650	0.668	0.782	0.792	0.787	0.743	0.683	0.67	0.781	0.681	0.657	0.738	0.721	0.768	0.677
Mn	0.007	0.007	0.006	0.006	0.007	0.002	0.008	0.007	0.006	0.007	0.010	0.006	0.006	0.005	0.009
Ti	0.085	0.081	0.041	0.039	0.039	0.046	0.074	0.062	0.034	0.072	0.078	0.054	0.058	0.038	0.062
Oct.	1.067	1.080	1.064	1.088	1.080	1.081	1.085	1.072	1.085	1.071	1.091	1.062	1.048	1.087	1.075
Exc.															
Oct.	0.067	0.080	0.064	0.088	0.080	0.081	0.085	0.072	0.085	0.071	0.091	0.062	0.048	0.087	0.075
Ca	0.894	0.879	0.907	0.884	0.898	0.893	0.874	0.881	0.888	0.889	0.863	0.917	0.919	0.867	0.878
Na	0.039	0.041	0.029	0.027	0.026	0.026	0.040	0.046	0.027	0.039	0.046	0.022	0.033	0.045	0.046
M ₂	1.000	1.000	1.000	0.999	1.004	1.000	0.999	0.999	1.000	1.000	1.000	1.001	1.001	0.999	0.999
WO	52.12	51.22	51.31	47.66	48.51	49.60	49.79	50.24	48.10	50.91	49.62	52.07	52.40	47.70	49.92
EN	37.90	38.92	44.21	42.67	42.53	41.28	38.90	38.30	42.33	38.99	37.77	41.90	41.09	42.25	38.49
FS	9.98	9.86	4.48	9.67	8.96	9.12	11.31	11.46	9.57	10.10	12.60	6.20	6.51	10.05	11.60

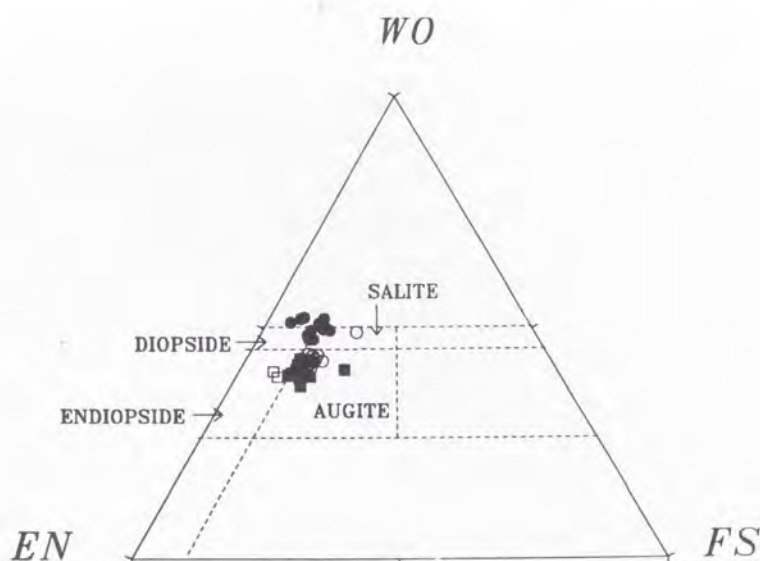


Fig. 3 — Classification diagram for calcic pyroxenes after Poldervaart & Hess (1951); open circles, EL-7-7; open squares, EL-64-8H; closed squares, SM-1-26; closed circles, SM-1-48.

gram of Poldervaart & Hess (1951) in the fields of augite, endiopsidite, diopsidite and salite (Fig. 3). In the $\text{SiO}_2\text{-Al}_2\text{O}_3$ diagram used by Le Bas (1962) to discriminate between pyroxenes derived from subalkaline, alkaline and peralkaline rocks, the analyses from Elephant Island plot almost exclusively in the subalkaline field (Fig. 4). The ones from Smith Island are divided. SM-1-26 is subalkaline, whereas SM-1-48 plots mainly in the peralkaline field (Fig. 4). Another diagram, ALZ-TiO_2 , also used by Le Bas for similar discrimination, shows almost identical results (Fig. 5). Leterrier *et al.* (1982) proposed yet another diagram plotting Ca+Na cations versus Ti . Our analyses plotted in this diagram show a clear division of SM-1-48 in the alkali basalts field and all other samples in the subalkaline basalts field (Fig. 6). The same authors (Leterrier *et al.*, 1982) used a diagram plotting Ti+Cr versus Ca for subalkaline basalts (Fig. 7) to discriminate between pyroxenes derived from non-orogenic tholeiites (field D) and pyroxenes derived from orogenic basalts (field O). All the analyses from subalkaline basalts fall in the field of non-orogenic tholeiites in this diagram. A similar relation can be observed in Fig. 4 where all analyses from subalkaline and alkaline rocks plot in the ocean floor basalts field given by Nisbet & Pearce (1977). Two more diagrams, also from Nisbet & Pearce (1977), support

the interpretation that the pyroxenes from Elephant Island and from SM-1-26 are derived from ocean floor basalts (Figs. 8 and 9), whereas most analyses from SM-1-48 fall outside the ocean floor basalts field. Finally in the diagram of the discriminating functions F1 and F2 (Nisbet & Pearce, 1977), also conceived to discriminate between different tectonic environments of the source rocks, all analyses from Elephant Island and SM-1-26 plot in the fields of ocean floor basalts (mixed with other fields) and the SM-1-48 analyses fall principally in the field of within plate alkali basalts (Fig. 10).

The principal conclusion from the foregoing is that the pyroxenes fall in two groups, one derived from subalkaline basaltic rocks (Elephant Island and SM-1-26) and the other from alkali basalts (SM-1-48). In terms of tectonic setting, the subalkaline basaltic rocks seem to correspond to ocean floor basalts, originated at a mid-ocean ridge, whereas the alkali basalts fit in the group of within plate alkali basalts, generated along fracture zones or at ocean islands.

DISCUSSION

The results presented above confirm partly earlier conclusions concerning the oceanic origin of metamorphic mafic rocks from Smith Island and northern Elephant Island (Hervé *et al.*, 1983;

ALZ
Fig. 3

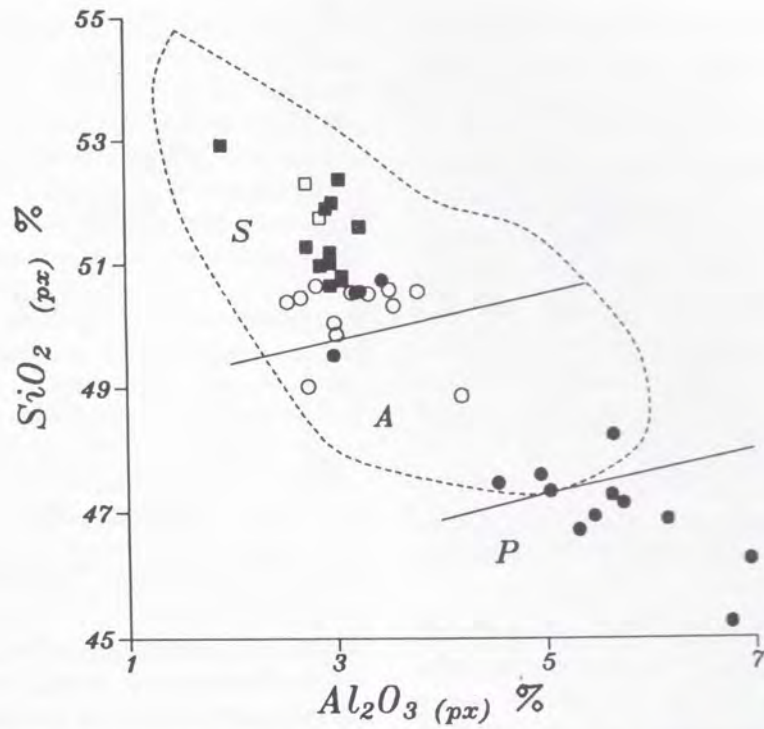


Fig. 4 — Al_2O_3 - SiO_2 diagram of Le Bas (1962) to discriminate source rocks according to pyroxene composition; S = subalkaline rocks, A = normal alkaline rocks, P = peralkaline rocks; field marked by dashed line is ocean floor basalts field of Nisbet & Pierce (1977); symbols as in Fig. 3.

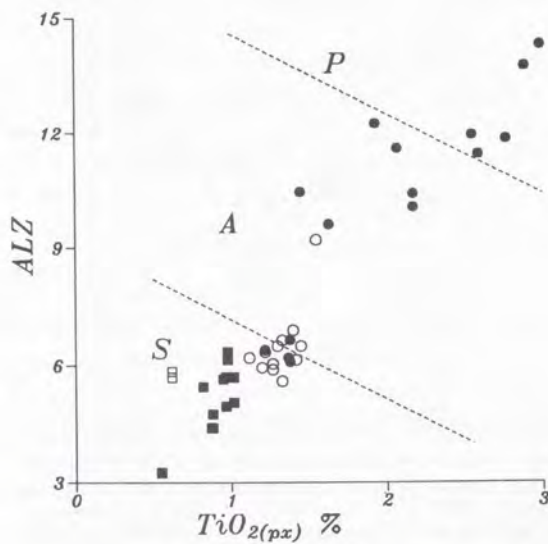


Fig. 5 — TiO_2 -ALZ diagram of Le Bas (1962); S, A and P as in Fig. 4; symbols as in Fig. 3.

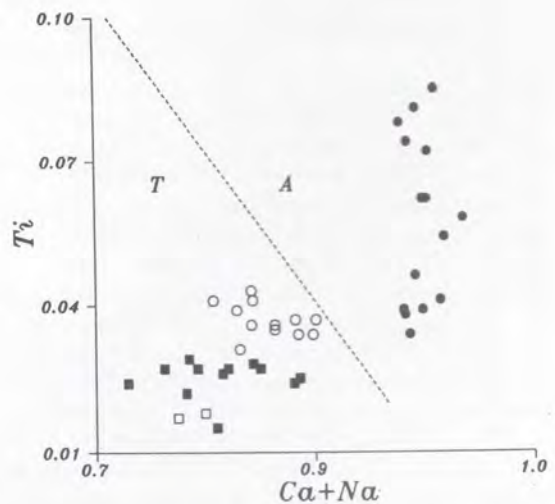


Fig. 6 — $Ca+Na$ against Ti diagram of Letierrier *et al.* (1982); T = subalkaline basalts; A = alkaline basalts; symbols as in Fig. 3.

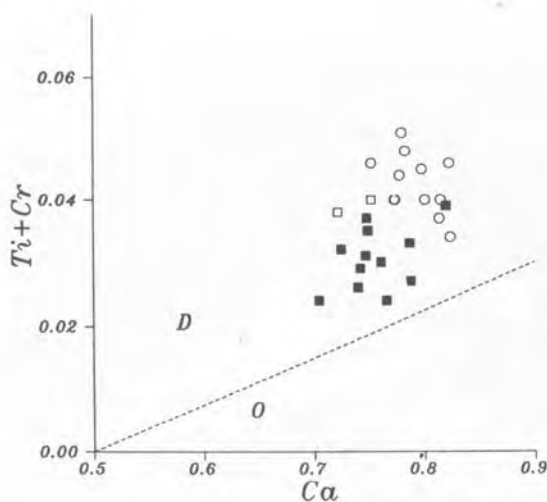


Fig. 7 — Ca versus Ti+Cr diagram of Letierrier *et al.* (1982); O = orogenic basalts; D = nonorogenic tholeiites; symbols as in Fig. 3.

Dalziel, 1984; Trouw *et al.*, 1991; Grunow *et al.*, 1992; Valeriano *et al.*, 1997). Including the analyses presented by Hervé *et al.* (1983), two out of three samples from Smith Island and two from Elephant Island indicate that relict clinopyroxenes had their origin in subalkaline ocean floor basalts. Whole rock chemical analyses in mafic rocks from Elephant Island also point predominantly to such an origin (Valladares, 1991). However, one

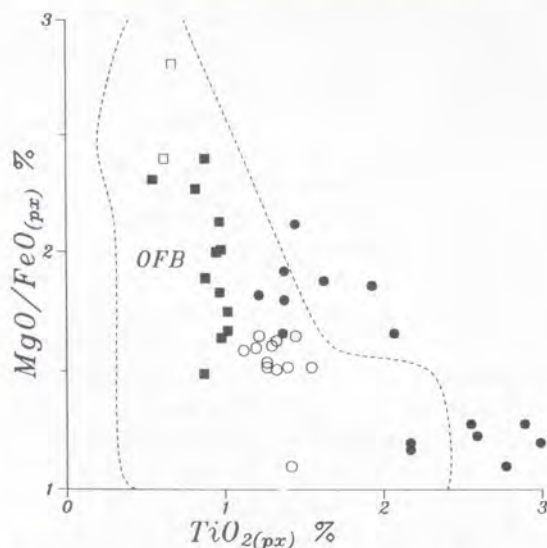


Fig. 8 — TiO₂ against MgO/FeO diagram of Nisbet & Pearce (1977) to discriminate tectonic environment of source rocks according to pyroxene composition; OFB = ocean floor basalts; symbols as in Fig. 3.

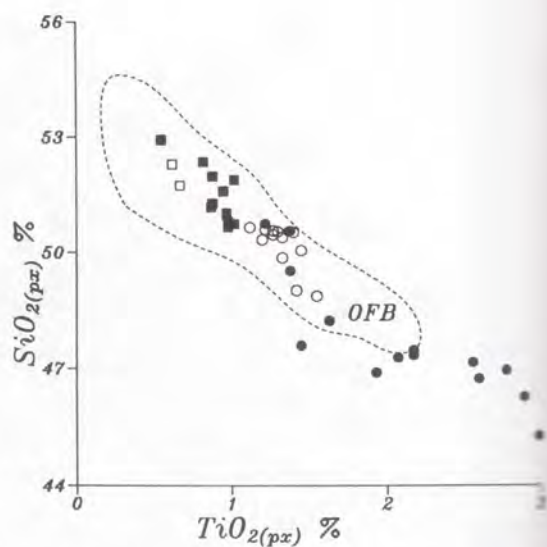


Fig. 9 — TiO₂-SiO₂ diagram of Nisbet & Pearce (1977); OFB = ocean floor basalts; symbols as in Fig. 3.

sample from Smith Island (SM-1-48) contains clinopyroxenes apparently derived from within plate alkaline basalt. This means that part of the mafic rocks of Smith Island may have been generated in an ocean island setting or along a fracture zone (Wilson, 1989; Shibata *et al.*, 1979). The fact that

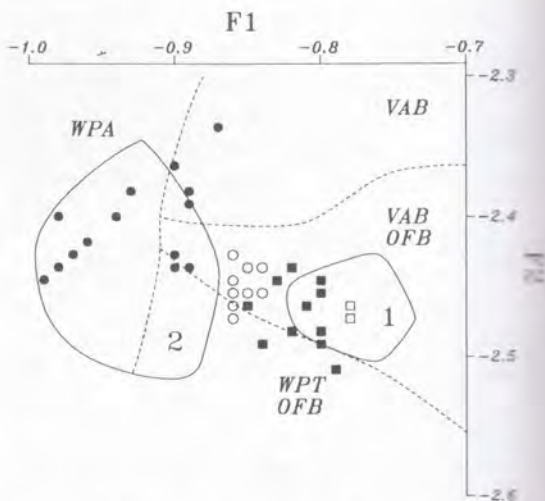


Fig. 10 — Diagram of discriminant functions F1 and F2 of Nisbet & Pearce (1977) for pyroxenes from different tectonic environments; fields labelled as follows: WPA, within plate alkali basalts; VAB, volcanic arc basalts; OFB, ocean floor basalts; WPT, within plate tholeiites; field 1 surrounded by continuous line indicates analyses from Smith Island published by Hervé *et al.* (1983); field 2 refers to analyses from Trinity Peninsula Group, published by Hyden & Tanner (1981); symbols as in Fig. 3.

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Smith Island is localized at the end of a major fracture zone, called the Hero fracture zone (Dalziel, 1984), argues in favour of the last possibility. The coexistence at the same outcrop (SM-1, Fig. 1) of rocks from different tectonic settings could be explained as a consequence of tectonic mixing in a subduction zone, affecting both ocean floor, generated at a mid-ocean ridge, and oceanic fracture zone materials.

Other published chemical compositions of relict clinopyroxenes in the same region are from pillow basalt flows intercalated within the slightly metamorphosed sedimentary sequence of the Trinity Peninsula Group (TPG; Hyden & Tanner, 1981). This group, essentially composed of siliciclastic turbidity current sequences, crops out extensively on Trinity Peninsula, the north-eastern extreme of the Antarctic Peninsula (Fig. 1). It has similar counterparts on Livingston Island and on the eastern South Orkney Islands (Fig. 1). The group, of probable Permo-Triassic age (Thomson, 1975; Dalziel, 1984), has been interpreted as deposited either in a forearc basin (Smellie, 1981), or in a trench slope basin (Storey & Garrett, 1985). The pyroxene analyses presented by Hyden & Tanner (1981) plot mainly in the within plate alkaline basalt field (Fig. 10), very similar to the ones from SM-1-48. The authors suggest that the metamorphosed pillow lavas from the TPG originated in a fracture zone in an oceanic plate. In the context of the results presented above, this means that the apparent sharp contrast in depositional setting between the continent derived TPG and the at least partly ocean floor derived subduction complex appears now possibly to be less sharp. Both units contain mafic rocks probably derived from a fracture zone in an oceanic plate.

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SUMMARY

Metamorphic rocks on Elephant and Smith Islands, South Shetland Islands, constitute part of the Scotia metamorphic complex, interpreted as an accretionary subduction complex. They include blueschists and are probably of Mesozoic to Cenozoic age. Relict clinopyroxenes thought to be of igneous origin are locally preserved. The chemical composition of these pyroxenes has been analysed in four samples, two from each island. The pyroxenes from Elephant Island and from one sample of Smith Island have compositions compatible with an origin in subalkaline basaltic rocks of ocean floor setting. However, pyroxenes from the other sample of Smith Island have a composition indicative of an origin in alkali basalts that may have been generated along a fracture zone or in an ocean island setting.

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