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Anorthosites and Gabbroic Bodies in Northern Cape Breton Island, Nova Scotia

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Several lensoidal anorthositic bodies of probable Precambrian age, are exposed in northern Cape Breton Island within a central fault-bounded block of quartzofeldspathic gneisses. One of these, the Red River anorthosite complex (c.11 km long and up to 1 km wide) ranges from anorthosite to anorthositic gabbro with high Al_2O_3 and Sr contents and large positive Eu anomalies resulting mainly from plagioclase accumulation.

Following an episode of polyphase deformation and amphibolite facies metamorphism, a monzodiorite-gabbro body of unknown age was intruded into both the anorthosite and its host rocks. The geochemistry of this intrusion indicates that it is calc-alkaline. Granite sheets, intrusive into the monzodiorite-gabbro body, do not appear to be comagmatic based upon the trace element chemistry. These sheets may be correlated with granitic plutons in the Cape North area which have been dated at 330 ± 23 Ma.

Plusieurs masses anorthositiques, vraisemblablement d'âge précambrien, affleurent de manière lenticulaire au sein d'un amas central de gneiss quartzofeldspathique, bordé par des failles, dans le nord de l'île du Cap-Breton. Parmi celles-ci, le complexe d'anorthosite de Red River (d'environ 11 km de longueur et jusqu'à 1 km de largeur) s'étage des anorthosites aux gabbros anorthositiques, montre de hauts contenus en Al_2O_3 et Sr et a fourni des anomalies élevées en Eu résultant principalement de l'accumulation des plagioclases.

Après un épisode de déformation polyphasée et métamorphisme au faciès amphibolite, un corps de monzonite et gabbro d'âge inconnu s'est introduit tant dans l'anorthosite que dans ses encaissants. La géochimie de cette intrusion trahit une nature calco-alcaline. La chimie des éléments en traces tend à nier le comagmatisme des granites en nappe intrusifs dans le corps de monzodiorite-gabbro. Ceux-ci s'apparentent plutôt aux plutons granitiques dans la région de Cape North qui sont datés à 330 ± 23 Ma.

INTRODUCTION

The basement rocks west of the Aspy Fault in northern Cape Breton Island have generated widely divergent interpretations. Brown (1973) and Currie (1975) correlated them with Grenvillian basement in the Humber Zone of ancient North America. Neale and Kennedy (1975) correlated some of them with the Gander Zone of Newfoundland. Kepple (1982) included these basement rocks in the Avalon Zone, because rocks of the George River Group and its equivalents may be traced from southern Cape Breton Island northwards across

MARITIME SEDIMENTS AND ATLANTIC GEOLOGY
22, 136-147 (1986)

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the Aspy Fault (Keppie, 1979). A critical factor in Brown's (1973) correlation with Grenvillian basement is the presence of anorthosite bodies restricted to the area west of the Aspy Fault. These bodies were first mapped by Neale (1963, 1964), with their petrography being described by Jenness (1966). However, only a general comparison with the anorthosites in the Grenville Province can be made using these data. In order to provide a better data base for comparisons, an area west of the Aspy Fault was mapped (Macdonald and Smith, 1980; Smith and Macdonald, in press). This paper addresses the geochemistry of the anorthosites and a later gabbroic pluton.

The anorthosite lenses, the largest of which, the Red River complex is about 11 km long and up to 1 km wide, lie within a narrow NNE trending central block of quartzofeldspathic gneiss about 30 km long and 2-8 km wide included in the Blair River complex by Raeside and Barr (1986) (Fig. 1). This central block is bounded by steep to moderately dipping mylonite zones. To the east of the central block occurs an assemblage of marbles, pelitic mica schists and gneisses, which may be correlated with the Cape North Group (Macdonald and Smith, 1980), and with the George River Group (Keppie, 1979). The discontinuity between the equivalents of the Cape North Group and the central block, together with their contrasting lithologies, makes any direct correlations tenuous. This conclusion was confirmed by Raeside <u>et al.</u> (1986).

Although exposed contacts between the anorthosite and the host rocks are uncommon, a thin lens of gabbroic anorthosite intrudes the gneisses south of the Cabot Trail on a north-flowing tributary of Grand Anse River. Both the anorthosite and the gneisses of the central block have suffered polyphase deformation, which has generally transposed the contacts into parallelism. Fabric elements in the central block display a wide variation in attitude. Deformation was accompanied by amphibolite facies metamorphism and anatexis leading to the injection of granitic sheets in the central block. An isolated exposure of fine-grained, pyroxene-bearing rock occurs at the western margin of the main anorthosite body near the northern margin of Figure 1, however, it is not clear whether it is part of the anorthosite or host rock. A similar rock type occurs in the tongue of the anorthosite projecting from the western side of the body in the centre of Figure 1, where it appears to be part of the anorthosite complex.

The rocks equivalent to the Cape North Group have also undergone polyphase deformation, although fabric elements show a more consistent orientation than in the central block. Foliations are generally NNE-SSW trending and lineations usually have a gentle plunge. Associated metamorphism generally decreases from upper amphibolite facies in the west to lower greenschist facies in the east (Macdonald and Smith, 1980). However, retrograde metamorphism occurs adjacent to the mylonite zone. In the absence of any data to the contrary, it is inferred that the deformational and metamorphic event in the Cape North Group correlates with that in the central block. While none of these specific units has been isotopically dated, a two-point Rb-Sr whole rock isochron from possible correlative gneisses occurring just east of Figure 1 at Black Brook yielded an age of 550 ± 80 Ma (Cormier, 1972, recalculated by Keppie and Smith, 1978). This age is interpreted to approximate the time of metamorphism, and suggests correlation with the Late Precambrian Cadomian Orogeny (Keppie, 1982).

In the central block, this deformational and metamorphic event was followed by the intrusion of a monzodiorite-gabbro body and then by the intrusion of granitic and syenitic plugs and sheets. This was followed by shear zone deformation along the two mylonite zones, which was accompanied

GEOLOGICAL MAP OF THE RED RIVER ANORTHOSITE COMPLEX

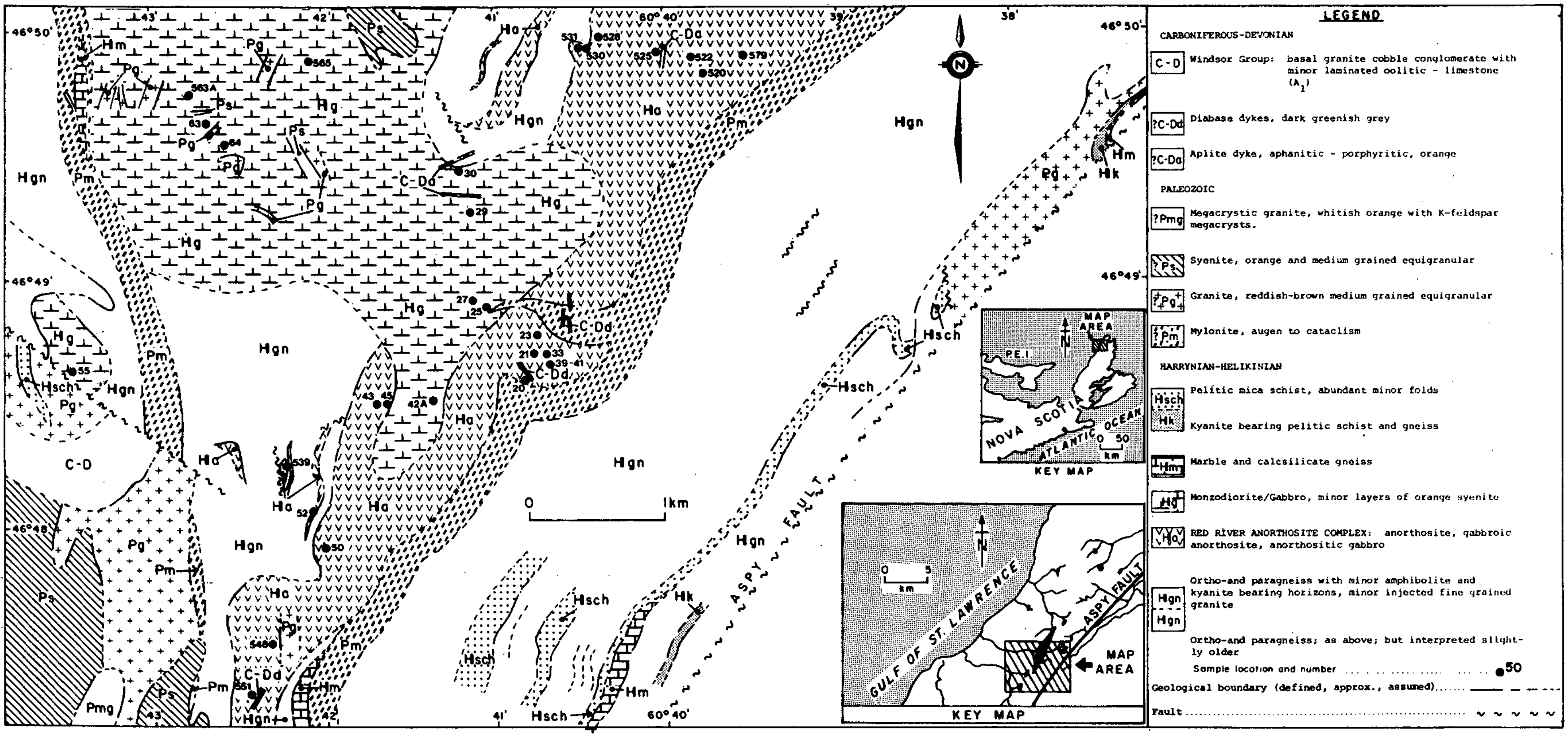

Figure 1. Simplified geological map.

by retrograde metamorphism. Finally the mylonites were cut by diabase dykes.

The Red River anorthosite complex is considered to be representative of all the Cape Breton Island anorthosites (Jenness, 1966). It is mainly composed of rocks ranging from anorthosite to anorthositic gabbro, which are interlayered with one another on a metre scale across the eastern part of the body, as exposed on a northward-flowing tributary of the Red River. Within one layered unit the transition from anorthositic gabbro through gabbroic anorthosite to anorthosite is generally gradual, although the contact between neighbouring units is often sharp. This layering is inferred to represent cumulitic banding. There does not appear to be any systematic increase in one component towards either side of the body except that the pyroxene-bearing rocks occur only along the western side of the complex. However, the grading within individual units is towards the east. These two factors suggest that the top of the body lies to the east.

The anorthosite varies from massive and equigranular through foliated to locally mylonitic. Texturally, the rocks vary from protoclastic through porphyroclastic to recrystallized granoblastic, while grain size varies from 1 to 5 mm. The anorthosite is typically composed of plagioclase (An 35-50), with some amphibole and accessory biotite, muscovite, quartz, chlorite, sericite, epidote, calcite, sphene, apatite, and zircon. The plagioclase crystals are generally sorted by size and are aligned parallel to the layering, whereas the amphibole sometimes displays an ophitic texture in the more mafic rock types. This suggests some mechanism of crystal accumulation for the plagioclase. The percentage of amphibole increases with the mafic content becoming c.60% in the anorthositic gabbro. The mineralogy of these rocks is mainly the result of amphibolite facies metamorphism with retrograde effects adjacent to the mylonite zones. However, relict igneous pyroxene is occasionally preserved in the cores of some amphiboles in the more mafic rocks. Pyroxene-bearing rocks exposed along the western margin of the Red River anorthosite are composed mainly of clino- and orthopyroxene, plagioclase and amphibole. Electron microprobe analyses of these co-existing pyroxenes indicates an equilibration temperature of 870-930^{o} C at pressures in excess of 5 kb. (Mitchell, 1979).

A monzodiorite-gabbro body intrudes the Red River anorthosite on its western side. At the contact, the monzodiorite is finer grained, indicating chilling against the anorthosite. Since this intrusion post-dates the main deformational/metamorphic event which affected both the anorthosites and the host rocks, it is clear that it is not genetically related to the anorthosites. The main lithology is monzodiorite and gabbro, but other rock types include quartz monzodiorite, monzonite, diorite, tonalite and granodiorite. The intrusion is generally massive and equigranular, with a grain size of 4-5 mm and is mainly composed of variable proportions of amphibole, plagioclase (An 30-50), and K-feldspar, with minor quartz, biotite, muscovite, and relicts of pyroxene in the cores of some amphiboles. Accessory minerals include sphene, apatite and opaque minerals; secondary minerals such as epidote, clinozoisite, chlorite, sericite, and calcite are the products of retrograde greenschist facies metamorphism. The body is intruded by sheets of alkali granite, aplite, and syenite. The syenite sheets consist of K-feldspar, plagioclase, and biotite, with accessory chlorite, sericite, epidote, sphene and opaque minerals. The granite mineralogy is similar to that of the syenite except for the additional presence of quartz. The granite sheets are lithologically similar to granites in the Cape North area (Macdonald and Smith, 1980), which have been dated as

330 ± 23 Ma old using a Rb-Sr whole-rock isochron (Cormier, 1980).

SAMPLING AND ANALYTICAL NOTES

The thirty-seven samples analyzed were selected from about 150 samples collected by Smith and Macdonald (1982) from the southern end of the Red River anorthositic complex and surrounding areas. The major elements were determined by wet methods at the Technical University of Nova Scotia, Halifax. The data on Rb, Sr, Ba, La, Ce, Zr and Nb were obtained by X-ray fluorescence. In addition, rare-earth elements (REE), Sc, Co, Cr, Th and Hf in nine samples were determined by instrumental neutron activation. The accuracy and precision of the trace element analyses were given by Dostal and Capedri (1979). In general, the precision of trace elements is better than 10%.

GEOCHEMISTRY

Major element analyses together with their norms and the concentrations of Rb, Sr, Ba, La, Ce, Zr and Nb for representative samples of the Red River anorthositic complex are given in Table 1 and those from the monzodiorite-gabbro intrusion are reported in Table 2. The abundances of REE, Th, Hf, Sc, Cr and Co for nine selected samples are shown in Table 3.

MAJOR ELEMENTS

Anorthosite Complex

The rocks of the anorthositic complex are characterized by a low SiO_2 content (<57%) and low MgO/FeO_{tot} and K_2O/Na_2O ratios, features typical of anorthositic suites in general (Simmons and Hanson, 1978). On the basis of chemical composition and petrography, the rocks can be divided into anorthosites and anorthositic gabbros both of which have a cumulate character. Anorthosites and anorthositic gabbros, when plotted on the Al_2O_3 vs ACM (Al_2O_3 + CaO + MgO) diagram of Martingole (1974) for Grenvillian anorthositic suites (Fig. 2) fall into or close to the fields of

TABLE 1

CHEMICAL ANALYSES OF REPRESENTATIVE SAMPLES OF ANORTHOSITIC COMPLEX

	ANORTHOSITE							ANORTHOSITIC GABBRO							PYROXENE-RICH ROCK	
	528	39	525	579	41	539	548	49	531	23	21	33	52	551	530	45
SiO_2 (%)	52.78	54.43	54.90	55.43	55.93	56.96	56.53	52.36	51.86	54.10	52.11	52.83	51.94	54.24	48.78	49.55
TiO_2	0.50	0.50	0.27	0.20	0.12	0.25	0.28	2.22	0.27	0.97	1.52	0.75	2.41	0.60	1.64	1.54
Al_2O_3	26.29	26.18	27.05	26.92	25.70	24.90	26.34	20.72	24.82	23.86	23.82	22.20	20.53	20.74	15.27	13.42
Fe_2O_3	0.68	0.51	0.10	0.63	0.76	0.81	0.60	2.03	0.31	1.59	1.67	0.62	3.06	1.64	1.93	3.14
FeO	1.60	1.21	0.50	0.64	0.28	0.33	0.29	5.08	3.17	1.87	2.27	3.92	4.48	3.63	7.51	8.41
MnO	0.03	0.02	0.03	0.02	0.00	0.02	0.14	0.08	0.06	0.07	0.04	0.07	0.11	0.01	0.17	0.18
MgO	0.85	1.24	0.29	0.37	0.15	0.47	0.21	3.38	3.86	1.39	2.03	3.57	2.62	4.05	7.35	7.13
CaO	9.84	8.00	8.61	8.33	7.85	7.08	7.69	6.90	8.07	7.11	9.12	7.18	6.76	6.59	13.41	11.57
Na_2O	4.87	5.29	5.85	5.67	5.97	6.40	6.36	4.40	4.16	5.17	4.95	4.45	5.02	4.80	2.08	2.57
K_2O	0.63	0.97	0.57	0.65	1.00	1.24	1.13	0.27	0.27	1.78	0.62	0.70	1.31	1.95	0.10	0.41
P_2O_5	0.01	0.13	0.08	0.11	0.08	0.04	0.11	0.18	0.03	0.20	0.38	0.13	0.33	0.22	0.10	0.11
L.O.I.	1.15	1.81	0.96	1.25	1.20	1.91	0.94	2.06	2.54	2.19	1.36	2.80	1.73	1.71	2.04	2.10
Total	99.23	100.29	99.21	100.22	99.04	100.41	100.62	99.68	99.42	100.30	99.89	99.22	100.30	100.18	100.38	100.13
Rb (ppm)	23	46	19	20	43	40	32	9	19		17	15	14	12	7	12
Sr	978	932	1062	918	895	1075	877	595	776	876	862	661	619	632	126	319
Ba		308	429	386	392	527	576	370	112	925	287	289	307	481		96
Nb	8	9	10	9	9	11	9	8	8	9	10	8	8	7	7	8
Zr	80	72	58	55	50	67	59	71	51	10	93	50	91	43	57	81
La	12	6	6	6	6	13	8	6	2	13	9	6	7	7	4	5
Ce	23	13	13	14	13	22	14	15	4	25	21	12	18	16	10	12
CIPW norms (wt.%)																
Q		0.9		1.8	0.4			4.6	1.3	0.1		1.4				0.2
Or	3.8	5.8	3.4	3.9	6.0	7.4	6.7	1.6	1.6	10.7	3.7	4.3	7.9	11.7	0.6	2.5
Ab	42.0	45.5	50.4	48.5	51.8	54.0	51.8	38.1	36.3	44.6	42.5	39.1	42.9	41.0	17.9	22.2
An	49.0	39.5	43.0	41.0	39.3	35.4	37.2	34.0	41.1	34.7	41.5	36.1	30.2	30.0	32.6	24.4
Ne						0.5	1.1									
Di	0.6										1.6		1.3	1.8	28.0	27.2
Hy	0.2	4.0	0.5	1.2	0.4			12.9	15.4	4.2	3.4	15.1	7.6	5.6	14.0	15.7
Fo	1.3		0.3			0.8	0.4				0.9		0.2	4.0	0.5	
Fa	1.1		0.2								0.1			1.9	0.3	
Mt	1.0	0.7	0.1	0.9	0.6	0.3	0.6	3.0	0.4	2.4	2.5	0.9	4.6	2.4	2.8	4.6
Il	1.0	1.0	0.5	0.4	0.2	0.5	0.5	4.3	0.5	1.9	2.9	1.5	4.6	1.2	3.2	3.0
Ap		0.3	0.2	0.2	0.2	0.1	0.4	0.4	0.1	0.4	0.8	0.3	0.7	0.5	0.2	0.2
Cor		2.2	1.3	2.1	0.7	0.3	1.1	1.1	3.2	1.0		1.4				

TABLE 2

CHEMICAL ANALYSES OF REPRESENTATIVE SAMPLES
OF MONZODIORITE-GABBRO INTRUSION

	55	64	63	274	30	29	25	565
SiO_2 (%)	51.47	52.35	55.09	55.63	62.69	66.50	74.19	75.73
TiO_2	1.57	2.30	1.45	1.27	1.69	0.70	0.10	0.23
Al_2O_3	18.44	16.82	17.64	15.83	14.70	16.09	15.46	12.09
Fe_2O_3	3.48	3.51	3.09	2.32	3.18	1.49	0.39	0.62
FeO	3.81	4.85	3.75	5.67	4.28	2.12	0.44	1.07
MnO	0.15	0.19	0.14	0.12	0.11	0.04	0.01	0.02
MgO	4.31	3.65	3.12	4.61	1.28	1.44	0.20	0.66
CaO	7.32	6.30	4.70	7.70	2.95	2.85	2.98	1.36
Na_2O	4.01	3.57	4.28	3.68	3.76	4.23	4.89	4.97
K_2O	2.15	2.93	2.59	1.73	3.35	2.22	0.85	1.07
P_2O_5	0.40	0.58	0.53	0.26	0.56	0.15	0.03	0.04
L.O.I.	2.37	2.34	2.89	1.53	1.77	1.81	0.76	1.38
Total	99.48	99.39	99.27	100.35	100.32	99.64	100.30	99.24
Rb (ppm)	54	95	71	25	35	38		31
Sr	780	675	621	481	235	350		179
Ba	1135	934		554	1267	789		380
Nb	33	36	42	10	26	10		10
Zr	171	155	220	168	704	188		120
La	51	68		17	55	20		17
Ce	102	131		44	122	42		34
CIPW norms (wt.%)								
Q		3.1	6.2	4.7	20.3	25.4	26.0	39.2
Or	13.1	17.9	15.9	10.4	20.1	13.4	5.0	6.5
Ab	34.9	31.2	37.6	31.7	32.3	36.6	41.6	43.0
An	26.7	21.9	21.0	21.9	11.5	13.5	14.7	6.6
Di	6.5	5.5	10.3	12.5				
Hy	8.9	9.5	7.6	12.4	5.9	5.3	0.8	2.9
Fo	0.6							
Fa	0.1							
Mt	5.2	5.2	4.7	3.4	4.7	2.2	0.6	0.9
Il	3.1	4.3	2.9	2.4	3.3	1.4	0.2	0.4
Ap	0.9	1.3	1.2	0.6	1.2	0.3	0.1	0.1
Cor			0.4		0.7	1.9	1.1	0.4

TABLE 3

ABUNDANCES OF SEVERAL TRACE ELEMENTS IN SELECTED SAMPLES

	A				AG			PG	G
	528	39	41	539	49	21	33	530	64
Th (ppm)	1.5	0.6	0.4	3.5		0.5	0.5		25.6
Hf	0.8	0.8	0.4	0.6	1.6	1.2	0.7	1.8	4.7
La	11.6	3.4	3.2	9.9	4.5	7.2	4.7	3.4	75.6
Ce	22.5	8.0	6.8	16.7	10.6	17.8	11.1	9.6	151.
Sm	1.6	1.1	0.8	1.4	1.4	2.5	1.6	2.4	9.6
Eu	0.81	0.81	0.90	0.98	0.98	1.26	0.83	0.89	2.24
Tb	0.22	0.17	0.11	0.17	0.25	0.37	0.24	0.57	0.75
Yb	0.67	0.54	0.36	0.54	0.71	0.92	0.70	1.92	2.81
Lu	0.10	0.08	0.05	0.08	0.11	0.15	0.11	0.29	0.42
Sc	4.2	3.1	0.8	1.4	9.9	7.1	7.3	41.5	16.8
Cr	29.5	36.8	6.2	17.0	74.0	49.4	156.	222.	10.8
Co	10.3	6.5	2.5	2.4	30.1	12.5	24.3	48.2	27.1

A - anorthosite; AG - anorthositic gabbro; PG - pyroxene rich rock; G - gabbro from monzodiorite-gabbro intrusion.

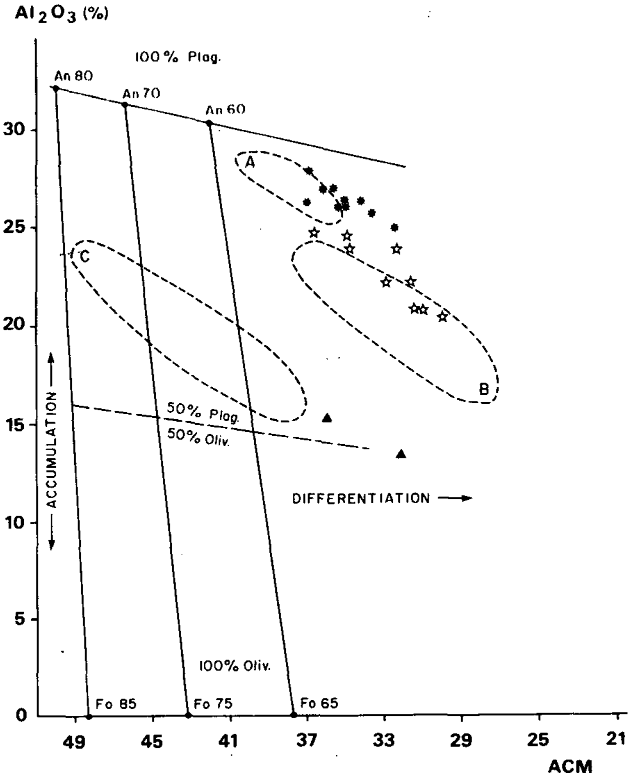

Figure 2. Al_2O_3 vs ACM (Al_2O_3 + CaO + MgO) diagram of Martignole (1974) with calculated values for "pure" anorthosites (100% plagioclase), "pure" dunites (100% olivine) and troctolite (50% plagioclase + 50% olivine). Solid lines are tie lines between olivine and plagioclase in equilibrium; dashed lines delineate the fields for anorthosites (A), anorthosites-leuconorites (B) and leucotroctolites-olivine gabbros (C) as defined by Martignole (1974). Symbols: circle - anorthosite; star - anorthositic gabbro; triangle - pyroxene-rich rocks.

Grenvillian anorthosite and anorthosite-leuconorite suites, respectively. Figure 2 also suggests that the analyzed anorthosites are relatively evolved since rocks with high ACM values are lacking.

Anorthosites and anorthositic gabbros from Cape Breton have high CaO/Na_2O ratios. However, they differ in the variations of CaO and Na_2O with respect to SiO_2. In anorthosites, CaO decreases but Na_2O increases with increasing SiO_2; in anorthositic gabbro, both elements remain constant relative to the variations of SiO_2. Whereas some anorthositic gabbros have low TiO_2 comparable to anorthosites from Cape Breton, others are high in TiO_2 (>2%) suggestive of the accumulation of opaques. Pyroxene-bearing rocks (samples 45 and 530), which are closely associated with anorthosites and contain significant amounts of both clino- and orthopyroxene (>50%) in addition to amphibole and plagioclase, have high FeO_{tot}, MgO and CaO and low Al_2O_3 abundances. They are similar to rocks of other anorthositic complexes (e.g. Philpotts, 1966) and are also comparable to pyroxenite of the granulitic Drumberg layered complex (Weaver and Tarney, 1980).

Monzodiorite-Gabbro Pluton

The rocks of the pluton show large variations in chemical compositions with SiO_2 content ranging from 51 to 68%, whereas the granitic sheets intruding the pluton have even higher SiO_2 (68-74%). Most of the rocks of the pluton are low in MgO and FeO_{tot} and high in Al_2O_3 and CaO. Their composition and variation trend resemble Precambrian calc-alkaline series (e.g. Jahn et al. 1980, Condie and Nuter, 1981). The presence of orthopyroxene and quartz in some rocks is consistent with the subalkaline character of the rocks. Some of the rocks are also similar to norite-mangerite series from some anorthositic complexes (Philpotts, 1966) but, in comparison with many monzonitic rocks related to anorthosites (Duchesne et al. 1974), these rocks are generally lower in P_2O_5. The highly variable contents of potassium in the rocks including even those of comparable major element composition indicate that the potassium was probably affected by metamorphism.

TRACE ELEMENTS

Anorthosite Complex

The Rb abundances in anorthositic rocks are low (<50 ppm) but, in most rocks, still significantly higher than in comparable rocks from other

Grenvillian anorthositic complexes (e.g. Reynolds et al. 1969, Simmons and Hanson, 1978). The K/Rb ratio is highly variable (120–1350) although generally low (<400) compared to the high values typical of Grenvillian anorthositic suites (Reynolds et al. 1969; Duchesne and Demaiffe, 1978). The low K/Rb ratios are probably due to secondary processes as Rb does not correlate with other incompatible but less mobile elements such as La and Zr. The Ba content is commonly within the range reported for equivalent rocks from other Grenvillian anorthositic massifs (Simmons and Hanson, 1978). In the Red River anorthosites and anorthositic gabbros, Sr displays a positive correlation with CaO and Al_2O_3 indicating that the distribution of this element is mainly controlled by the accumulation of plagioclase. In addition, Sr in anorthosites increases with increasing differentiation as indicated by the decrease of An in plagioclase or the MgO/FeO_{tot} ratio of the rocks. A similar Sr variation in anorthositic rocks was reported by Duchesne and Demaiffe (1978) and attributed to the increase of the Sr partition coefficient of plagioclase with differentiation.

The Red River anorthosites and anorthositic gabbros have low total REE abundances with chondrite-normalized patterns distinctly enriched in light REE (LREE) and displaying large positive Eu anomalies (Fig. 3). The patterns are similar in shape and abundances to analyses of anorthositic rocks reported by Philpotts et al., (1966), Green et al. (1972) and Simmons and Hanson (1978). Two anorthosite samples (528 and 539) have more pronounced LREE enrichment ($[La/Sm]_N$ = 4) and smaller Eu anomalies than the other samples. The differences in REE among anorthosites may be the result of the presence of trapped residual liquid. An alternate explanation - the presence of a variable amount of apatite - is not consistent with the comparable concentration of P_2O_5. The contents of Zr and Nb in anorthositic rocks are low and relatively constant. The rather low levels of incompatible elements are typical of anorthositic complexes composed mainly of adcumulates (Weaver et al. 1981). The REE pattern of pyroxene-bearing rock (sample 530) has a convex shape with a slight LREE depletion and with abundances about 10 times those of chondrites (Fig. 3). The shape reflects accumulation of pyroxene which has a similar convex pattern with a peak in the middle REE.

Monzodiorite-Gabbro Pluton

The rocks of the intrusive body have variable contents of Rb, Ba, Nb, Zr, La and Ce. Some of the variations in trace elements, particularly Rb, may be due to secondary processes. The low content of some incompatible elements (e.g. Nb, Zr, La, Ce) in rocks with SiO_2 >68% suggests that the granitic sheets were not derived from gabbros or diorites by fractional crystallization. The monzodiorite-gabbros and granitic sheets also show significant differences in element ratios such as Zr/Nb and Nb/La. The high content of REE, Nb and Ba in some gabbros and diorites resembles that of alkali basalts. This similarity also includes the REE pattern of sample 64 which is marked by strong LREE enrichment and the absence of a Eu anomaly. However, these rocks differ from Recent alkali basalts by rather high Al_2O_3 content, the absence of normative nepheline and depletion of Nb relative to La (Nb/La <1), typical of rocks of orogenic zones (Pearce, 1982).

DISCUSSION

The Red River anorthosites and anorthositic gabbros have a cumulate nature. They are the result mainly of plagioclase accumulation as suggested by their texture, mineralogy, high Al_2O_3 and Sr content, high CaO/Na_2O, Na_2O/K_2O and Sr/Ba ratios and low REE abundances, accompanied by chondrite-normalized patterns showing distinct

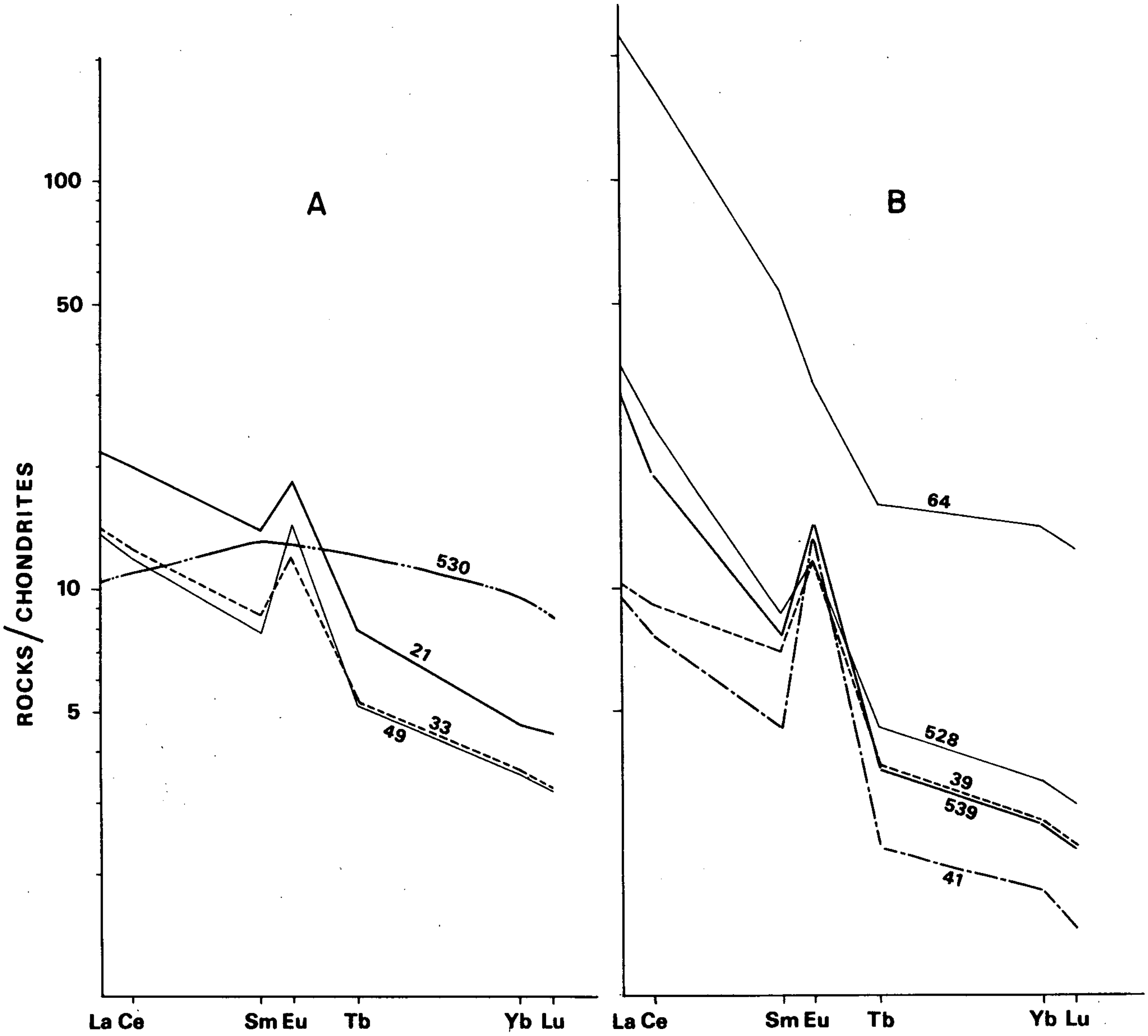

Figure 3. Chondrite-normalized REE abundances (A) in anorthositic gabbros (samples 21, 33, 49) and pyroxene-rich rock (sample 530); (B) in anorthosites (samples 39, 41, 528, 539) and gabbro from the monzodiorite-gabbro intrusion (sample 64). Chondritic values of Frey et al. (1968) were used.

LREE enrichment and a large positive Eu anomaly. The low abundances of P_2O_5, Zr, Hf, Nb, La and Ce suggest that intercumulus liquid was effectively expelled. The higher proportions of ferromagnesian minerals in anorthositic gabbros relative to anorthosites are reflected by their high FeO_{tot}, MgO, Sc, Cr and Co contents. In the pyroxene-bearing rocks of the anorthosite complex, the mineralogy, the high FeO_{tot}, MgO, CaO, Sc and Cr contents, but relatively low Al_2O_3, Sr and Ba contents, and the flat REE pattern, are consistent with the accumulation of pyroxenes. On this basis, the pyroxene-bearing rocks are probably genetically related to the anorthositic complex, as suggested by field relationships, although sample 530 could be a granulite facies part of the country rock.

Trace element modelling can be used to estimate the composition of the parental magmas for anorthositic rocks. Relicts of pyroxenes rimmed by amphibole and the occurrence of abundant epidote, etc., indicate that the observed mineralogy does not correspond to the original mineral assemblage of the anorthosite suite. Thus for geochemical modelling the CIPW norms are assumed to be the original modes of the rock (cf. Simmons and Hanson, 1978). In addition, the rocks with low REE abundances and with large positive Eu anomalies are considered to be adcumulates containing only a negligible amount of interstitial liquid. The abundances of trace elements in parental magmas (liquids in equilibrium with the cumulate phases) are then calculated according to the equation $C^l = C^s/D_O$, where C^s = concentration in the solid (cumulate), C^l = concentration in the liquid (magma), and D_O = the bulk partition coefficients obtained from normative proportions (Table 1) and the partition coefficients of Simmons and Hanson (1978) and Irving (1978). Figure 4 shows the calculated REE concentration in parental magmas of anorthosite (41), anorthositic gabbro (21) and pyroxene-bearing rock (530). The calculated REE patterns for the parental magmas of these rocks are rather similar indicating that they could have been derived from a similar, or considering the approximations involved in the calculations, even a single parental magma during its various stages of differentiation. All other samples of the anorthositic complex could also have been derived from a comparable parental magma. The calculated REE abundances of the parental magma resemble the composition of parental magmas of several large anorthositic massifs in the Grenville and Nain provinces of the Canadian Shield (Fig. 4) postulated by Simmons and Hanson (1978). However, unlike the Grenvillian anorthosite complexes, the Red River anorthositic gabbro is a cumulate and does not correspond to a parental magma. The relatively low ACM values (Fig. 2) indicate that the anorthosites and anorthositic gabbros from Cape Breton Island crystallized from a relatively evolved magma. Although the pyroxene-bearing rocks are probably genetically related to the anorthosites on the basis of their composition and field relations, there is no petrographic evidence that they are cumulates. In this case it may be concluded that the main mafic cumulate part of the layered intrusive has been separated from the anorthosite by shearing, probably during the main deformation/metamorphic event.

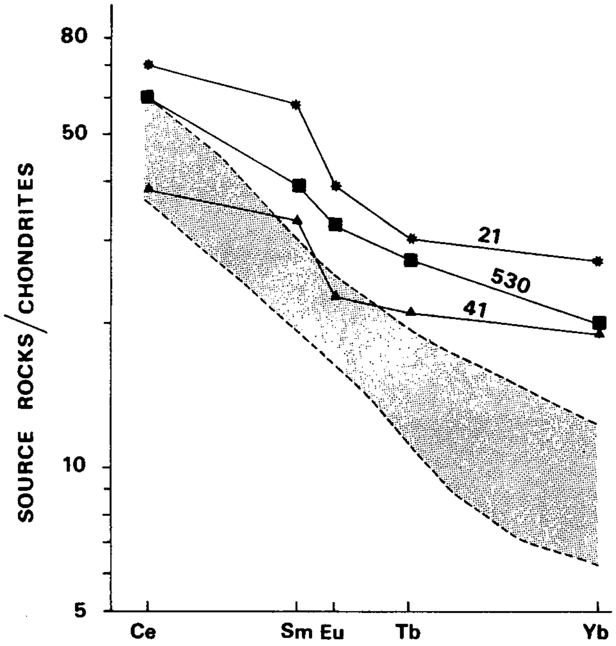

Figure 4. Calculated chondrite-normalized REE patterns for the parent magmas of anorthosite (sample 41), anorthositic gabbro (sample 21) and pyroxene-rich rock (sample 530). The shaded area represents the field of the parental magmas for anorthosites from the Adirondack Mountains (New York), Burwash area (Ontario) and Nain complex (Labrador) as calculated by Simmons and Hanson (1978).

CONCLUSION

An anorthositic complex occurs in the northwestern tip of Cape Breton Island in the form of several small isolated lenses up to 11 km long and 1 km wide, which are surrounded by metamorphic rocks of amphibolite facies. The complex includes anorthosites and anorthositic gabbros which have a cumulate nature and compositionally resembles massif-type anorthosites. The rocks of the complex commonly display deformational structures and metamorphic textures and have been affected together with surrounding rocks by amphibolite facies metamorphism followed by retrograde metamorphism. The estimated REE composition of the parental magma is similar to those of several large anorthositic massifs in the Grenville and Nain provinces of the Canadian Shield, suggested by Simmons and Hanson (1978). However, the lack of associated mangerites and voluminous granulite facies country rocks indicates that they are probably higher level intrusions than those of the Grenville Province which represent lower crust. Unfortunately, the available geochemical signature of the Cape Breton anorthosites is not distinctive enough to use as a discriminant as compared with those of the Grenville Province. Thus, other factors must be considered, such as the nature of the country rocks and the geochronology. Much of this data is still to be acquired, although Raeside and Barr (1986) believe that the Blair River complex is part of the Grenville basement, after comparing lithologies and geophysical characteristics.

BROWN, P.A. 1973. Possible cryptic suture in Southwest Newfoundland. Nature, 146, pp. 9-10.

CONDIE, K.C. and NUTER, J.A. 1981. Geochemistry of the Dubois greenstone succession: an Early Proterozoic biomodal volcanic association in west-central Colorado. Precambrian Research 15, pp. 131-155.

CORMIER, R.F. 1972. Radiometric ages of granitic rocks, Cape Breton Island, Nova Scotia. Canadian Journal of Earth Sciences, 9, pp. 1074-1086.

CORMIER, R.F. 1980. New Rubidium/Strontium ages in Nova Scotia. Dept. of Mines and Energy Report 80-1, pp. 231-233.

CURRIE, K.L. 1975. Studies of granitoid rocks in the Canadian Appalachians. Geological Survey of Canada Paper 75-1A, pp. 265-270.

DOSTAL, J. and CAPEDRI, S. 1979. Rare earth elements in high grade metamorphic rocks from the western Alps. Lithos 12, pp. 41-49.

DUCHESNE, J.C., ROELANDTS, I., DEMAIFFE, D., HERTOGEN, J., GIJBELS, R. and DE WINTER, J. 1974. Rare-earth data on monzonoritic rocks related to anorthosites and their bearing on the nature of the parental magma of the anorthositic series. Earth and Planetary Science Letters, 24, pp. 325-335.

DUCHESNE, J.C. and DEMAIFFE, D. 1978. Trace elements and anorthosite genesis. Earth and Planetary Science Letters, 38, pp. 249-272.

FREY, F.A., HASKIN, M.A., POETZ, J. and HASKIN, L.A. 1968. Rare-earth abundances in some basic rocks. Journal of Geophysical Research, 73, pp. 6085-6098.

GREEN, T.H., BRUNFELT, A.O. and HEIER, K.S. 1972. Rare-earth element distribution and K/Rb ratios in granulites, mangerites and anorthosites, Lofoten-Vesteraalen, Norway. Geochimica et Cosmochimica Acta, 36, pp. 241-257.

IRVING, A.J. 1978. A review of experimental studies of crystal/liquid trace element partitioning. Geochemica et Cosmochimica Acta, 42, pp. 743-770.

JAHN, B.M., AUVRAY, B., BLAIS, S., CAPDEVILA, R., CORNICHET, J., VIDAL, F. and HAMEURT, J. 1980. Trace element geochemistry and petrogenesis of Finnish greenstone belts. Journal of Petrology 21, pp. 201-244.

JENNESS, S.E. 1966. The anorthosite of northern Cape Breton Island. Nova Scotia, a petrological enigma. Geological Survey of Canada, Paper 66-21, p. 25.

KEPPIE, J.D. 1979. Geological map of Nova Scotia. Nova Scotia Department of Mines and Energy. Scale 1:500,000.

KEPPIE, J.D. 1982. Tectonic map of Nova Scotia. Nova Scotia Department of Mines & Energy. Scale 1:500,000.

KEPPIE, J.D. and SMITH, P.K. 1978 Compilation of isotopic age data of Nova Scotia. Nova Scotia Dept. of Mines Report 78-4.

MACDONALD, A.S. and SMITH, P.K. 1979. Red River Anorthosite Complex. Nova Scotia Dept. Mines, Report 79-1, Report of Activities 1978, p. 103.

MACDONALD, A.S. and SMITH, P.K. 1980. Geology of Cape North area, northern Cape Breton Island, Nova Scotia. Nova Scotia Dept. of Mines and Energy Paper 80-1, 60 p.

MARTIGNOLE, J. 1974. L'évolution magmatique du complexe de Morin et son rapport au probleme des anorthosites. Contributions to Mineralogy and Petrology 44, pp. 117-137.

MITCHELL, P.L. 1979. Studies of the rare-earth element geochemistry and mineral chemistry of the anorthosites and related rocks near Pleasant Bay, Cape Breton Island, Nova Scotia. B.Sc. thesis, Dalhousie University. 107 p.

NEALE, E.R.W. 1963. Pleasant Bay, Nova Scotia. Geological Survey of Canada, Map 1119A.

NEALE, E.R.W. 1964. Geology, Pleasant Bay, Cape Breton Island, Nova Scotia. Geological Survey of Canada, Map 1150A.

NEALE, E.R.W. and KENNEDY, M.J. 1975. Basement and cover rocks at Cape North, Cape Breton Island, Nova Scotia. Maritime Sediments, 2, pp. 1-4.

PEARCE, J.A. 1982. Trace element characteristics of lavas from destructive plate boundaries. In Andesites. Edited by R.S. Thorpe. Wiley-Interscience, New York, N.Y., pp. 526-546.

PHILPOTTS, A.R. 1966. Origin of the anorthosite-mangerite rocks in southern Quebec. Journal of Petrology, 7, pp. 1-64.

PHILPOTTS, J.A., SCHNETZLER, C.C. and THOMAS, H.H. 1966. Rare-earth abundances in an anorthosite and a mangerite. Nature 212, p. 805.

REYNOLDS, R.C., WHITNEY, P.R. and ISACHSEN, Y.W. 1969. K/Rb ratios in anorthositic and associated charnockitic rocks of the Adirondacks and their petrogenetic implications. In: Origin of anorthosites and related rocks. (Y.W. Isachsen, Ed.) New York State Museum Memoir 18, pp. 267-280.

RAESIDE, R.P. and BARR, S.M. 1986. Possible Grenville basement in the Cape Breton Highlands, Nova Scotia. Geological Association of Canada Program with Abstracts 11, p. 116.

RAESIDE, R.P., BARR, S.M., WHITE, C.E. and DENNIS, F.A.R. 1986. Geology of the northernmost Cape Breton Highlands, Nova Scotia. Geological Survey of Canada Paper 86-1A, pp. 291-296.

SIMMONS, E.C. and HANSON, G.N. 1978. Geochemistry and origin of massif-type anorthosites. Contributions to Mineralogy and Petrology 66, pp. 119-135.

SMITH, P.K. and MACDONALD, A.S., in press. The geology of the Red River Anorthosite Complex. Nova Scotia Dept. Mines & Energy.

WEAVER, B.L. and TARNEY, J. 1980. Rare-earth geochemistry of Lewisian granulite-facies gneisses, N.W. Scotland: implications for the petrogenesis of the Archaean lower continental crust. Earth and Planetary Science Letters 51, pp. 279-296.