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Geochemistry of the Lower Proterozoic Granulite-Facies Grant Syenite Gneiss, Barra Velha, Santa Catarina State, Southern Brazil

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Abstract - A syenite body was discovered and studied in the Santa Catarina Granulitic Complex, close to the beaches of Grant and Barra Velha. The quarry, located on km-91 of BR-101 highway, was sampled for geochemical whole rock studies and also of its individual minerals. The syenite body is in structural and metamorphic equilibrium with the containing hypersthene-bearing tonalitic and basaltic granulites. Major, trace and rare-earth elements analyses on rock samples indicate syenitic to quartz dioritic compositions, saturated in alumina and silica. They have high contents of K, Na, Sr and Ba and low contents of Zr and Ti. Total REE is high in chondrite-normalized patterns and indicates strong fractionation of the light REE, similar to those for the Itiúba Syenite from Bahia State and for the Linden Syenite from Minnesota, USA. Overall geochemistry, on the other hand, is remarkably similar to the Archean Cléricy Pluton from Canada. The REE are strongly concentrated in allanite, clinopyroxene and sphene strongly. A Sm-Nd mineral isochron indicates metamorphic crystallization at *ca.* 2.2 Ga. The syenite is depleted in HFSE, and this may indicate a sudduction-zone tectonic environment of generation of the magma.

The foregoing results are based on 12 whole rock chemical analyses for major and some trace elements, three whole rock REE analyses, two electron microprobe analyses on each of seven minerals and Sm/Nd isotopic determinations on five minerals.

Key words: syenite, granulite, Paleoproterozoic

INTRODUCTION

Potassic syenites are rare in older terranes, particularly in granulite-facies areas. There are only a few published references to these in Brazil. This paper reports on a new syenite body in Santa Catarina and on its geochemistry and probable origin.

The syenite body is well exposed in a quarry located 100 m West of Km-91 of Br-101 highway, on top of a hill, close to the Grant and Barra Velha beaches in the State of Santa Catarina, Southern Brazil (Fig. 1). Surrounding topography is flat-lying and soil cover is thick in the region, so that there are few rock outcrops; in consequenc;e, the size of the body was not fully determined. The potassic syenites and quartz-diorites from the quarry are designated as the Grant Syenite Gneiss, with reference to the Grant beach located nearby. A few other outcrops of similar syenites are known in the region, which means that there is a syenitic suite in the Santa Catarina Granulite Complex.

The Grant syenite gneiss is one of the lithologies of the Santa Catarina Granulite Complex, which has been studied by several authors (Miniolli, 1972; Hartmann *et al.*, 1979; Moreira & Marimon, 19 tonalites, trondhjemites, mafic granulites, ultramafites (mostly pyroxenites), sillimanite gneisses, quartzites and banded iron formations.

The geochemical data for the Grant syenite gneiss exposed in the quarry are used to interpret its magmatic evolution involved and also the geotectonic environment of intrusion and timing of metamorphism.

GEOLOGIC AND PETROGRAPHIC ASPECTS

Two major outcrops of the Grant syenite gneiss are known, one in the studied quarry and the other in the road from Itajaí to Luís Alves. In the quarry, the gneiss has strong sub-vertical centimetre to meter-thick banding. The bands are alternately dark and light coloured, depending on the prevailance of dark or light mineral constituents.

The main minerals are light gray oligoclase, pink microcline, green-black ferroaugite, black hornblende and biotite. Quartz occurs in small amounts, and the minerals allanite, apatite, sphene, opaques are rare accessories; zircon is extremely rare. Calcite was identified by wet chemical methods at UFRGS and occurs in the matrix of the syenite as well as in fractures. Microcline and light green epidote occur in veins. The gneiss is bimodal in composition (Tabs. 1 and 2) and corresponds mostly to syenites and quartz-diorites in a QAP diagram.

All but the vein minerals are of high-grade metamorphic origin, with partial recrystallization in

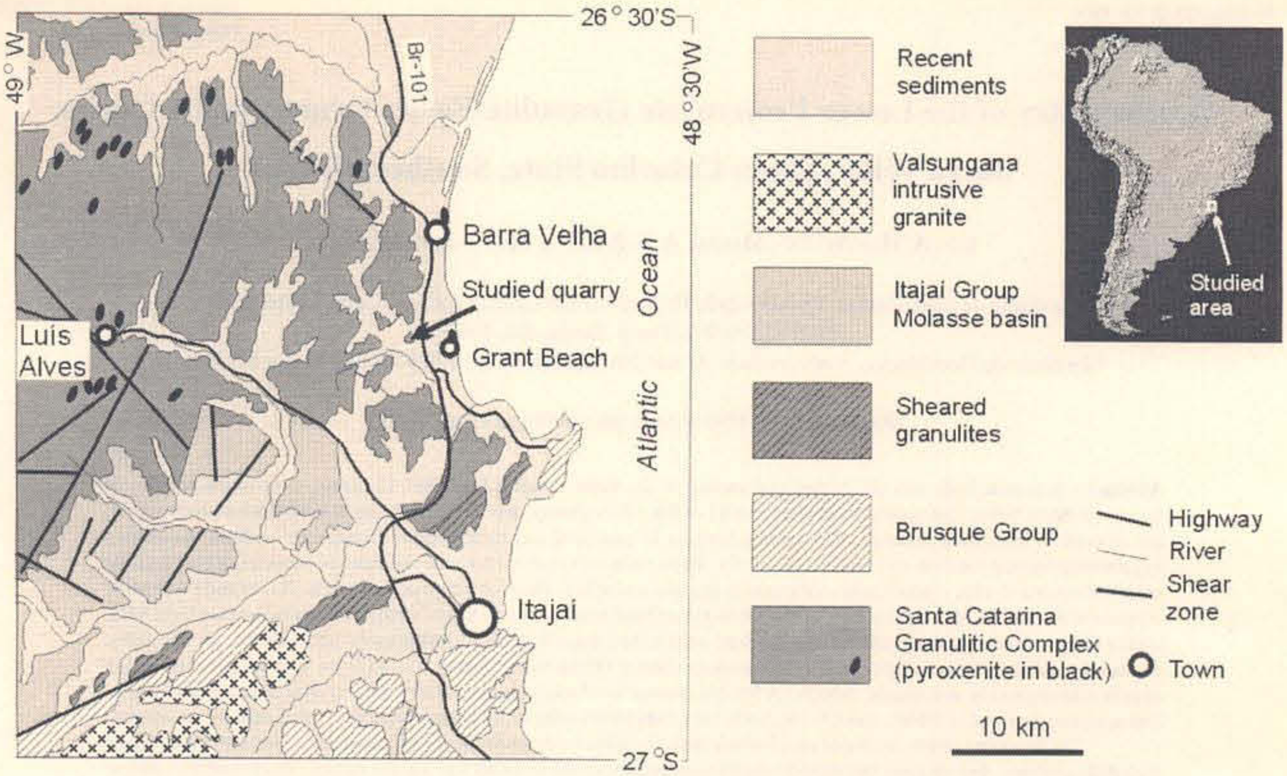

Figure 1 - Geological map of the region surrounding the Grant syenite gneiss from Barra Velha to Luís Alves in Santa Catarina State, southern Brazil, with location of the studied quarry. Inset of South America from USGS.

later lower-grade events. Hornblende is present as isolated crystals but also surrounds pyroxene grains. The same mineral phases are observed in the syenites and the quartz-diorites. The vein minerals correspond to a greenschist-facies metamorphic event, probably associated with the extensive transcurrent shear zones which cut the granulites in the region.

Table 1 - Modal composition of studied gneisses (vol. %).

	4	5	6	7	9	10	11	12	13	14
Microcline	68	0	0	0	60	65	50	12	68	0
Plagioclase	10	56	45	79	8	15	18	35	10	54
Quartz	10	10	7	8	6	9	8	12	5	15
Clinopyroxene	6	4	29	8	12	4	14	13	2	4
Hornblende	6	2	29	1	0	0	2	14	1	15
Biotite	0	20	0	0	0	0	0	0	0	5
Opaque minerals	2	0	3	tr	tr	1	1	1	1	4
Calcite	4	6	0	0	4	5	4	3	3	0
Apatite	0	2	12	4	8	0	2	5	1	1
Sphene	tr	0	4	0	2	1	1	4	7	0
Epidote	tr	tr	0	tr	0	0	0	1	1	1
Allanite	0	0	0	0	0	0	0	0	tr	0
Zircon	0	tr	0	0	tr	0	0	0	0	tr
Chlorite	0	0	0	0	0	0	0	0	1	1
Muscovite	0	0	0	0	0	0	0	0	0	tr
Total	100	100	100	100	100	100	100	100	100	100

GEOCHEMISTRY

Sampling was restricted to the quarry. Analyses were performed for major, trace and rare earth elements (REE) for twelve whole-rock samples. Samples were analysed by X-ray fluorescence at Universidade Federal do Rio Grande do Sul, Porto Alegre, and by ICP at GEOSOL laboratories, Belo Horizonte. The minerals allanite, sphene, clinopyroxene, hornblende, plagioclase, microcline and biotite were separeted by magnetic and density methods, in the UFRGS/Geosciences laboratories, followed by handpicking of the purest grains. Cores of crystals were analysed in a Shimadzu electron microprobe in the Shimadzu factory in Kyoto, Japan, with 15 Kv beam intensity and defocussed beam.

The geochemical composition of the studied syenitic gneisses shows a SiO_2 range from 50 to 63 wt%. There is also continuity of composition for the majority of the other elements studied, when plotted against SiO_2 (Tab. 3, Figs. 2 and 3). Positive correlation with SiO_2 is shown by Al_2O_3, whereas Fe_2O_3, FeO, MgO and CaO have a negative correlation. The exception is K_2O, which shows two populations around 4 and 8 wt%. This bimodal distribution of K_2O content may be due to accumulation of clinopyroxene in the K_2O-poor compositions as is true in quartz-diorites. The fractions enriched in K_2O may be closer to the

Table 2 - Chemical analyses (wt%) of minerals from the studied gneisses. Analyses in cores of crystals from several rock samples. OH obtained by difference from 100 %; - = not analysed; all = allanite, bt = biotite, sph = sphene, hb = hornblende, pl = plagioclase, mc = microcline, cpx = clinopyroxene

	All	All	Cpx	Cpx	Bt	Bt	Sph	Sph	Hb	Hb	Pl	Pl	Mc	Mc
SiO_2	31,70	31,57	50,76	52,75	35,91	36,09	29,97	30,33	40,38	40,37	62,46	63,13	64,03	63,55
TiO_2	-	-	0,20	0,01	2,22	2,15	35,38	35,81	1,01	0,64	-	-	-	-
Al_2O_3	14,88	14,80	1,61	0,96	14,97	15,04	-	-	12,15	12,57	24,18	24,08	19,42	19,40
FeO	15,79	15,94	18,38	13,26	20,35	20,47	-	-	20,30	20,53	-	-	-	-
MnO	0,23	0,24	1,08	1,13	0,32	0,47	-	-	0,55	0,50	-	-	-	-
MgO	0,50	0,50	6,12	9,81	10,71	10,73	-	-	8,24	8,12	-	-	-	-
CaO	12,56	12,66	20,88	22,33	0,01	0	27,47	27,48	11,60	11,43	4,41	4,36	0	0
Na_2O	-	-	1,35	0,87	-	-	-	-	1,67	1,68	8,67	8,74	1,07	0,49
K_2O	-	-	-	-	9,55	9,81	-	-	1,86	1,93	0,17	0,27	15,22	15,86
Cl	0,01	0,01	-	-	0,06	0,04	-	-	0,10	0,11	-	-	-	-
F	0,04	0,04	-	-	0,11	0,13	0,30	0,30	0,12	0,12	-	-	-	-
OH	2,08	4,63	-	-	5,77	4,91	6,26	5,49	1,96	1,89	-	-	-	-
BaO	-	-	-	-	-	-	-	-	-	-	0,09	0	0,84	0,63
Cr_2O_3	-	-	0,06	0,02	-	-	-	-	0,01	0,07	-	-	-	-
Y_2O_3	0	0	0,02	0,01	0	0,09	0,33	0,21	0	0,01	0	0	0	0
La_2O_3	7,73	7,80	0,13	0,03	0	0,04	0,28	0,38	0,03	0	0	0,07	0	0,08
Ce_2O_3	11,18	11,30	-	-	-	-	-	-	-	-	-	-	-	-
Pr_2O_3	0,84	-	-	-	-	-	-	-	-	-	-	-	-	-
Nd_2O_3	2,27	-	-	-	-	-	-	-	-	-	-	-	-	-
Sm_2O_3	0	-	-	-	-	-	-	-	-	-	-	-	-	-
ThO_2	0,17	-	-	-	-	-	-	-	-	-	-	-	-	-
UO_2	0	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	100	100	100,6	101,2	100	100	100	100	100	100	100	100,6	100,6	100

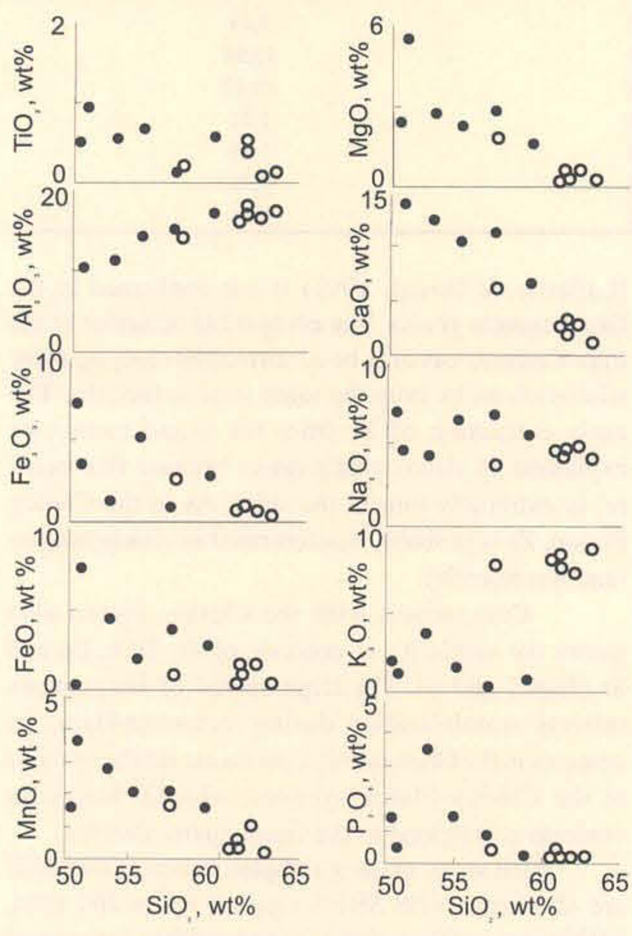

Figure 2 - Harker variation diagram of major elements for the Grant syenite gneis. Open symbols = syenites; closed symbols = quartz diorites.

liquid composition and correspond to more typical syenites. Correlation of some elements (e.g., Al_2O_3, MgO) with SiO_2 close to curved lines indicates fractional crystallization as the cause for these variations. The classifiction has two modes and confirms that the rocks from the Grant Syenite are in fact syenites and quartz diorites (Fig. 4).

The minor elements Ti and P decrease in quantity as SiO_2 increases indicating their compatibility with the bulk chemical composition

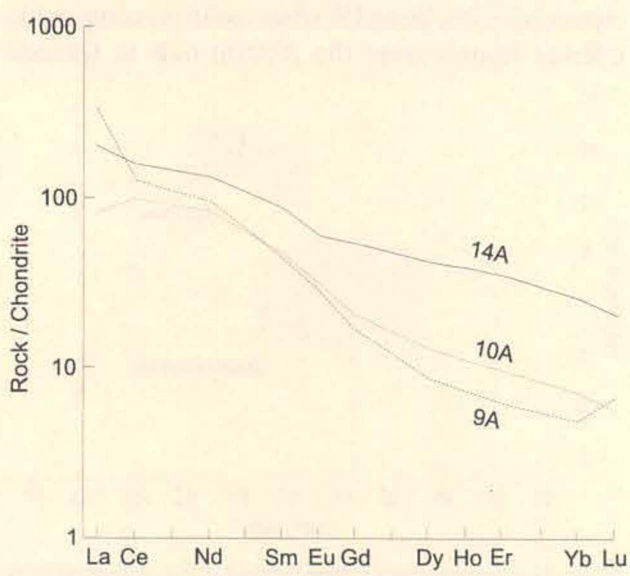

Figure 3 - Chondrite-normalized REE diagram for three Grant syenite gneiss.

Table 3 - Chemical composition of major (wt%) and trace (ppm) elements of the studied gneisses. - = not determined.

	4	5	6	7	9	10	11	12	13	14	15	16
SiO_2	62,83	50,17	52,6	56,53	56,75	60,94	61,86	54,32	60,75	58,93	50,77	61,00
TiO_2	0,17	0,49	0,54	0,15	0,26	0,41	0,08	0,65	1,91	0,59	0,93	0,57
Al_2O_3	17,43	17,58	11,18	14,73	14,44	17,78	16,54	14,11	16,82	17,08	9,98	16,95
Fe_2O_3	0,36	7,04	1,32	0,97	2,71	0,00	0,89	5,19	0,92	2,93	3,55	1,02
FeO	0,67	0,10	4,47	3,89	1,10	1,74	1,87	2,02	0,43	2,93	7,55	1,01
MnO	0,03	0,16	0,28	0,22	0,17	0,05	0,11	0,21	0,04	0,16	0,37	0,06
MgO	0,28	2,32	2,69	2,86	1,88	0,38	0,83	2,30	0,22	1,72	5,40	0,73
CaO	1,75	7,58	12,4	11,39	6,33	2,50	3,01	10,56	3,05	6,76	13,85	3,30
Na_2O	4,18	6,87	4,31	6,87	3,77	4,45	4,99	6,47	4,58	5,66	4,58	4,58
K_2O	9,28	2,06	3,74	0,46	8,17	8,76	7,80	1,88	8,49	1,01	1,28	8,15
P_2O_5	0,05	1,41	3,45	0,96	0,51	0,10	0,19	1,51	0,18	0,36	0,53	0,17
L.I.	1,10	2,73	1,34	0,47	2,83	1,08	1,01	0,73	0,81	0,64	0,88	0,82
H_2O	0,11	0,13	0,13	0,01	0,05	0,01	0,01	0,05	0,15	0,07	0,28	0,05
Total	98,24	98,64	99,51	98,97	98,2	99,19	100,0	98,35	98,84	99,73	98,41	98,41
Zr	283	311	171	269	170	316	163	300	240	250	132	277
Rb	84	42	23	10	77	77	83	24	76	<5	<5	61
Ba	4061	796	2648	209	2791	6278	3511	1320	3696	714	1301	5992
Sr	1833	1740	942	1708	940	2012	1038	1480	1344	778	599	1760
Cr	-	-	-	-	27	24	-	-	-	39	-	-
Co	-	-	-	-	<5	<5	-	-	-	<5	-	-
Ni	-	-	-	-	8	6	-	-	-	14	-	-
La	-	-	-	-	81,73	19,56	-	-	-	50,01	-	-
Ce	-	-	-	-	80,95	63,03	-	-	-	102,2	-	-
Nd	-	-	-	-	43,11	41,14	-	-	-	62,66	-	-
Sm	-	-	-	-	6,65	7,3	-	-	-	13,03	-	-
Eu	-	-	-	-	1,67	1,87	-	-	-	3,45	-	-
Gd	-	-	-	-	3,45	4,24	-	-	-	10,56	-	-
Dy	-	-	-	-	3,13	3,38	-	-	-	10,42	-	-
Ho	-	-	-	-	0,42	0,61	-	-	-	2,21	-	-
Er	-	-	-	-	0,98	1,58	-	-	-	5,89	-	-
Yb	-	-	-	-	0,79	1,16	-	-	-	4,31	-	-
Lu	-	-	-	-	0,16	0,14	-	-	-	0,51	-	-

However, the trace elements Zr, Rb, Ba and Sr range widely in composition and show poor correlation with SiO_2. Thus, the compatible geochemistry of the trace elements Zr, Rb, Ba and Sr observed in the comparable Cléricy Pluton from the Abitibi belt in Canada

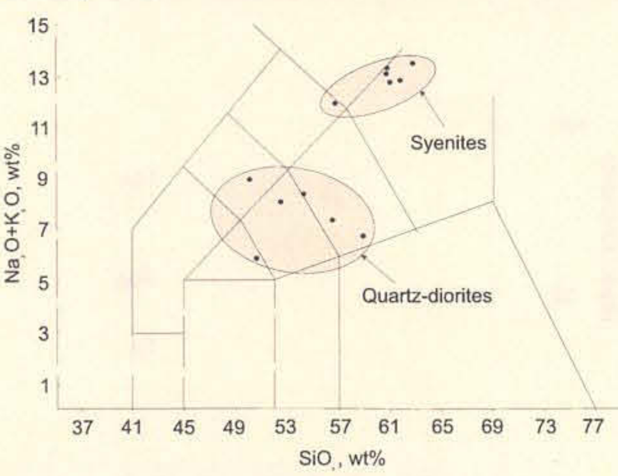

Figure 4 - Chemical classification diagram of the studied gneisses corresponding to syenites as liquids and quartz-diorites as cumulates.

(Laflèche & Dostal, 1991) is not confirmed in the Grant syenite gneiss. The compatible behavior of the trace elements can only be confirmed by studying more silica-rich rocks from the same suite in the area. The early extraction of Zr from the liquid cannot be explained by zircon precipitation because this mineral is extremely rare in the suite. As in the Cléricy Pluton, Zr is probably concentrated in clinopyroxene (and hornblende).

Comparison with the Cléricy Pluton also shows the similarity of contents of Zr, TiO_2, Ba and Sr (Figs.5 and 6). The large spread of Ba contents reflects remobilization during metamorphism. Ba contents in the Grant syenitic gneiss are similar to those of the Cléricy Pluton syenites, whereas lower Ba contents correspond to the Grant quartz-diorites.

REE study of three samples indicates that REE are abundant, with ΣREE ranging up to 260 ppm, LREE from 100 to about 300 chondritic values and HREE between 10 to 50 times chondrite abundances

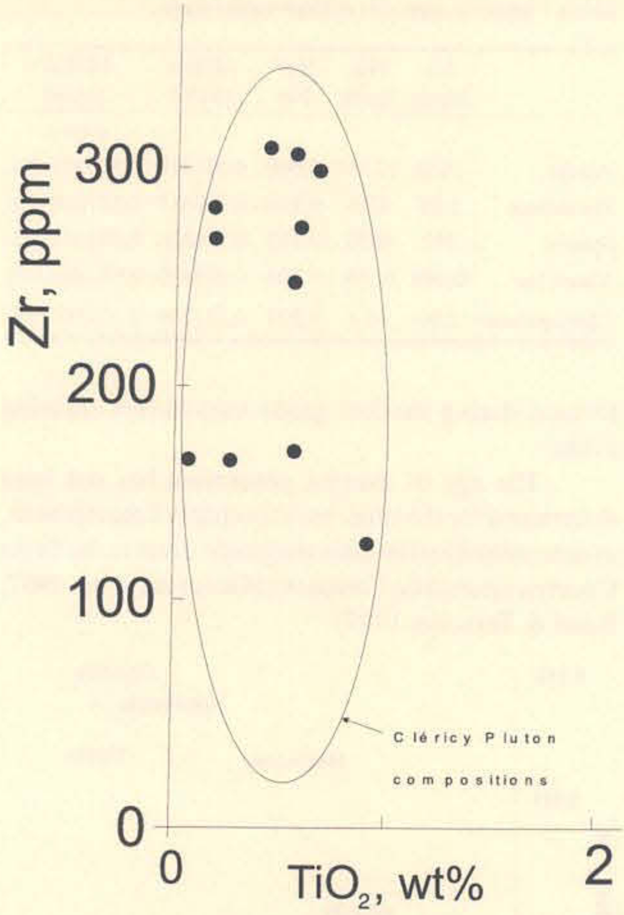

Figure 5 - Zr x TiO_2 diagram for the studied samples; spots are compositions of Grant gneiss syenites and quartz-diorites.

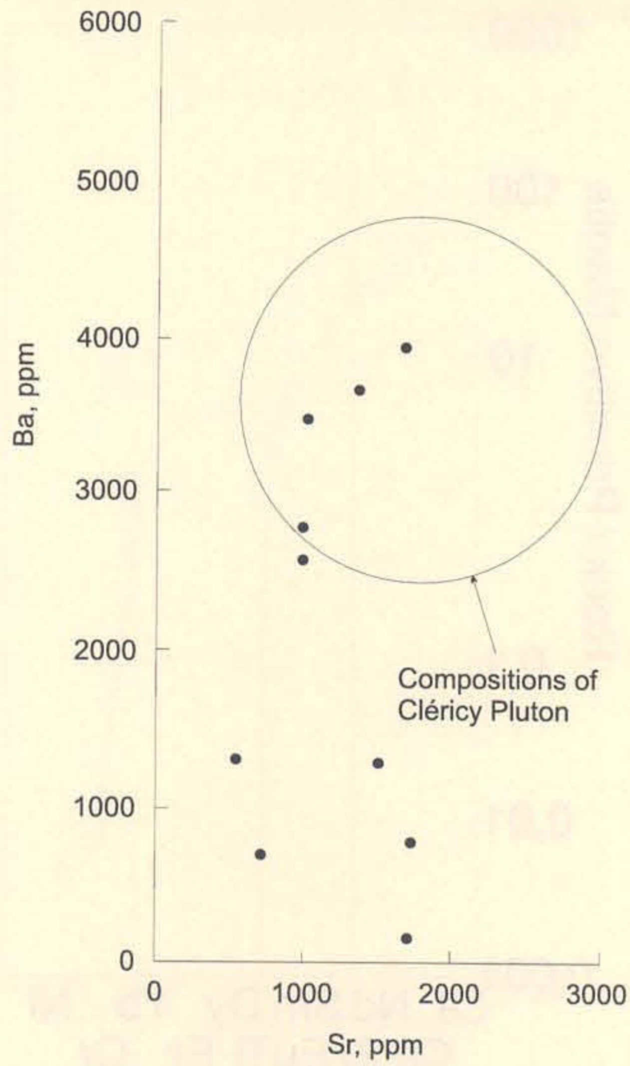

Figure 6 - Ba x Sr diagram for the studied samples; spots are compositions of Grant gneiss syenites and quartz-diorites.

(Fig. 3). No Eu anomaly was observed, which may be explained either due to a high Eu^{+3}/Eu^{+2} ratio in the original syenitic melt or to the well-known decrease of the Eu partition coefficient with the increase of magma alkalinity. LREE paterns are convex upward, similar to those of the clinopyroxene curves. A more detailed interpretation is hampered by the small number of analyses and restricted compositional range, but it seems that ETR decreases with increase of SiO_2. This is probably due to crystallization of abundant sphene and apatite along with clinopyroxene in the mafic lithologies from the quarry.

Cr of about 30 ppm and Ni of about 10 ppm are similar to those of the Cléricy pluton and thus in agreement with the general geochemical similarity of the two rock bodies.

Normalization of some incompatible elements in relation to primitive mantle (Fig. 7) yields patterns with a strong negative Ti anomaly suggesting that the geological environment of magma generation was compressive in a thick crust. Depletion in Cr and Ni is observed. Negative anomaly of HFSE in orogenic magmas is explained by Keleman *et al.* (1990) due to the interaction of ascending magmas generated in a subduction zone with depleted mantle peridotite. The extensive interaction of the liquid with olivine, pyroxene and spinel produced this negative anomaly, because these minerals have fairly high crystal/liquid partition coefficients for the HFSE.

The chemical composition of minerals from the syenite (Tab. 2) shows that allanite and sphene are typically enriched in REE, biotite is enriched in Ti, and microcline is enriched in Ba. Hornblende is pargasitic in composition. Plagioclase has an oligoclase composition and the clinopyroxene is ferrosalite, contrasting with the sodic pyroxenes found in the Cléricy Pluton. Equilibrium textures show this mineral to be of high-grade metamorphic origin entirely different from the precursor igneous mineral. Therefore, an igneous mineral was analysed in the Cléricy Pluton, whereas in the Grant syenitic gneiss the mineral analysed belongs to the granulite facies and thus explains the difference in composition between the two areas.

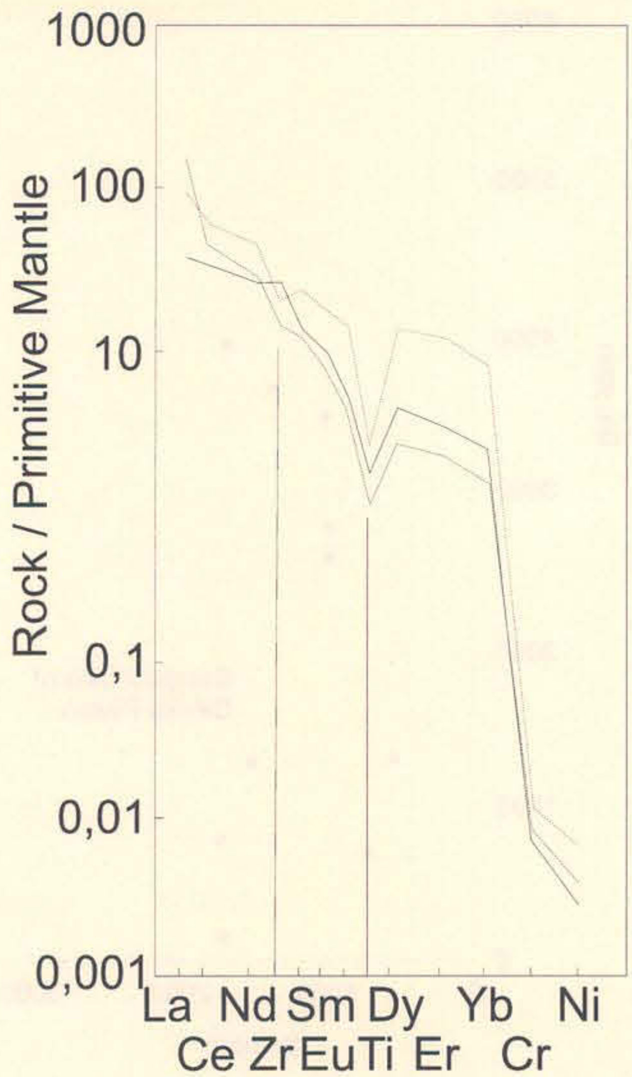

Figure 7 - Primitive mantle normalized incompatible elements composition of three Grant syenite samples.

Sm-Nd ISOTOPES ON MINERALS

Sm-Nd isotopes were determined at the Open University (UK) on allanite, microcline, hornblende, sphene and clinopyroxene (Tab. 4). All isotopic analyses were carried out in a clean air laboratory using PTFE bombs to ensure complete dissolution of all minerals phases. Sm and Nd were measured on a FINNIGAN MAT 261 mass spectrometer, which runs the analyses automatically using software developed by D.W. Wright and P.W.C. Van Kalsteren. The $^{143}Nd/^{144}Nd$ ratio is corrected for mass fractionation assuming a $^{146}Nd/^{144}Nd = 0{,}7219$.

The mineral isochron indicates a calculated age of approximately 2.2 Ga, which represents the time of crystallization of the high temperature metamorphic minerals analysed (Fig.8). Microcline plots off the isochron and was not included in the calculation of age. In the quarry microline is strongly remobilized in veins and irregular masses which probably

Table 4 – Sm/Nd isotopic data of Grant syenite gneiss.

	Sm (ppm)	Nd (ppm)	Sm/ Nd	147Sm/ 144Nd	143Nd/ 144Nd error 2
Allanite	1030	17100	0,060	0,036375	0.510265+/-4
Hornblende	2,76	12,8	0,216	0,139315	0.511666+/-6
Sphene	952	4950	0,192	0,116226	0.511444+/-2
Microcline	0,499	0,709	0,704	0,085819	0.511146+/-41
Clinopyroxene	2,36	10,4	0,227	0,137209	0.511784+/-5

formed during the low grade transcurrent shearing event.

The age of magma generation has not been determined for the suite, but is probably Late Archean, as determined for the main magmatic event in the Santa Catarina Granulitic Complex (Mantovani *et al.*, 1987; Basei & Teixeira, 1987).

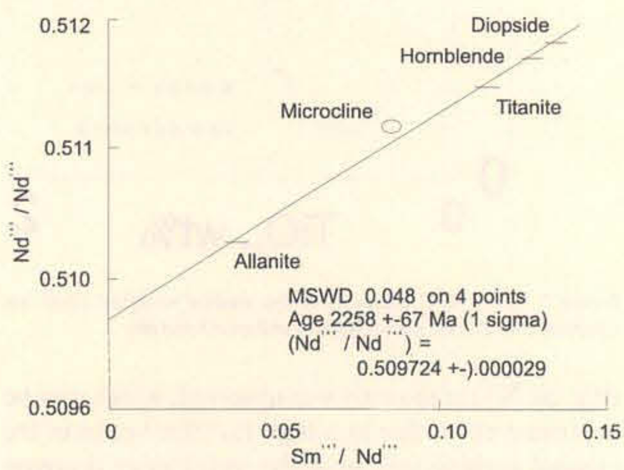

Figure 8 – Sm/Nd isochron diagram for Grant syenite minerals.

CONCLUSIONS

The Grant syenite gneiss occurs regionally as small irregularly shaped bodies within the Santa Catarina Granulitic Complex, has a composition varying from syenite to quartz-diorite, and its magmatic evolution was primarily controlled by precipitation of clinopyroxene and feldspars. The fractionation of the trace elements is best explained by crystallization of sphene and apatite as early phases and the absence of zircon from the majority of samples may be due to the concentration of Zr in clinopyroxene. The early crystallization of clinopyroxene accounts for several aspects of the geochemical evolution of the magma such as the bimodal K_2O content and its very low content in the quartz-diorites.

It is suggested that this potassic syenite was injected into the crust in a late-orogenic compressive regime. The Grant syenite differs from typical intraplate syenites because of its oversaturation in silica and low content of Ti and HFSE. The high-grade metamorphism occurred at 2.2 Ga, as determined by a Sm-Nd mineral isochron. The geochemical data indicate that the regional granulite-facies event was isochemical for the studied syenitic gneiss samples, with the exception of Ba.

The Grant syenite is rather chemically similar to the igneous nonmetamorphosed Cléricy Pluton syenites from the Archean of Canada. Rock bodies of this type may have concentrations of Au and usually show low metallogenetic potential for Nb, Ta and Y.

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