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The Ilha Anchieta Quartz Monzonite: the southernmost expression of ca. 500 Ma post-collisional magmatism in the Ribeira Belt

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ABSTRACT

The Ilha Anchieta Quartz Monzonite (IAQM) occupies most of the homonymous island in the coast of the state of São Paulo, and is intrusive into foliated rocks of the ∼565 Ma Ubatuba Charnockite. The main petrographic variety is a porphyritic biotite-hornblende quartz monzonite with 2-4 cm tabular microcline megacrysts set in a medium-grained groundmass and magmatic foliation. Outcrop-scale structures indicate cumulative processes (modal and grain-size magmatic banding) and interaction with basic magmas (mafic microgranular enclaves). Lithogeochemical data indicates that the main variety is intermediate to acid (SiO_2 = 63-67%), alkali-calcic, metaluminous and magnesian (**mg#** ∼30), showing moderate Sr (300-400 ppm) and Ba (∼1500 ppm) contents and relatively high HFSE (Nb = 40 ppm; Zr = 550-700 ppm). The older charnockites are more silicic (SiO_2 = 71-78%), ferroan (**mg#** = 12-16), and have very low Sr (13-80 ppm) contents, resulting in Ba/Sr ratios remarkably higher than the IAQM (10 *versus* 4). LA-MC-ICPMS U-Pb zircon dating of the IAQM yielded 499.7 ± 5.9 Ma. This is the youngest magmatic age identified so far in the crystalline basement of the state of São Paulo, and indicates that the pluton is the southernmost expression of the post-collisional "G5" magmatism in the Ribeira Belt.

Key words: granite, lithogeochemistry, LA-ICPMS, zircon U-Pb dating, Ribeira Belt.

INTRODUCTION

Granitic rocks are major constituents of the coastal areas of southeast Brazil, but most occurrences are known only at a reconnaissance scale, which is in part attributable to the difficulty of mapping due to dense vegetation and mountainous terrain. Lack of detailed work is particularly true in the northern shoreline of the state of São Paulo, where even excellent rock exposures near popular beaches have not yet attracted the attention of geologists. As a result, this region, formed by high-metamorphic grade rocks and several granite bodies, including the Ubatuba Charnockite (Gasparini and Mantovani 1979), remains as one of the least studied portions of the Neoproterozoic Ribeira Belt.

Regional correlations indicate that the geology of the northern shoreline of São Paulo is an extension to the SSW of the Neoproterozoic Oriental Terrane (Heilbron et al. 2008), thought to represent a magmatic arc setting. The Rio Negro Magmatic Arc (Tupinambá et al. 2000) is thought to have evolved by eastward-directed subduc-

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tion of the São Francisco paleoplate until 635-620 Ma and was accreted to it at ca. 580-550 Ma, a time interval when large amounts of "syn-collisional" granites were generated (Campos Neto and Figueiredo 1995, Silva et al. 2005, Heilbron et al. 2008).

Few precise magmatic ages were obtained in rocks from Oriental Terrane in the state São Paulo, and none fall in the range thought to correspond to subduction-related magmatism in the Rio Negro Arc. ID-TIMS monazite ages obtained in migmatites and in a muscovite-biotite granite from the Natividade da Serra batholith (Janasi et al. 2003 and unpublished data) are similar at ∼590 Ma, and would probably correspond to early stages of the "syn-collisional" period. The ID-TIMS zircon age of the Ubatuba Charnockite (∼565 Ma) is the youngest magmatic age obtained so far in a granite from this region. This age still falls within the "syn-collisional" range defined in Rio de Janeiro (Heilbron et al. 2008) and is the same as that of enderbites intruding the Rio Negro Magmatic Arc ("early post-collisional phase of enderbite magmatism" of Campos et al. 2004). An important difference, however, is the "within-plate" geochemical signature of the Ubatuba charnockites (Gasparini and Mantovani 1979).

Geological mapping of the Ilha Anchieta recently completed for the *Secretaria do Meio Ambiente do Estado de São Paulo* (J.M. Azevedo Sobrinho et al. 2004, unpublished report) has shown that most of the island is constituted by a quartz monzonite pluton intrusive into the Ubatuba Charnockite, unraveling the latest events of granite generation within the Oriental Terrane in São Paulo. This paper presents the geology, petrography, whole-rock chemistry and LA-MC-ICPMS U-Pb zircon dating of the Ilha Anchieta Quartz Monzonite. Our results demonstrate that this pluton can be correlated with the youngest event of granite generation reported in the Ribeira Belt further north ("G5" granites of Pedrosa-Soares et al. 2001, Wiedemann et al. 2002, dated around 515-480 Ma), which therefore extended over a broader region, reaching the southern region of São Paulo.

GEOLOGICAL SETTING

The Neoproterozoic Ribeira Belt in southeast Brazil is an orogenic belt developed along the SE border of the São Francisco craton during the convergence with another plate/microplate located to the east (Brito Neves et al. 1999, Heilbron and Machado 2003). Tectonic models for the evolution of the central part of the Ribeira Belt (state of Rio de Janeiro) propose east-vergent subduction of the São Francisco paleoplate, forming the Rio Negro Magmatic Arc in the Oriental Terrane that was eventually accreted to the São Francisco continent through a frontal collision that would have lasted from 590 to 550 Ma (Heilbron and Machado 2003). This was followed by the accretion of the Cabo Frio Terrane in a new collisional or docking event at 535-510 Ma (Schmitt et al. 2004) and finally by orogen collapse at 510-480 Ma.

In the south of this area in the of state of São Paulo, the accretion of the Ribeira Belt occurred through oblique strike-slip convergence to a NW-trending belt formed by the previous (∼630-610 Ma) collision between the São Francisco and Paranapanema cratons (Brito Neves et al. 1999, Campos Neto 2000). Two main geologic domains constitute the Ribeira Belt in São Paulo, from west to east: (1) the Embu Domain, dominated by medium-grade metasupracrustal rocks of uncertain age (<1.0 Ga? Alves 2009) metamorphosed at ∼800 Ma and followed by different episodes of crust-derived granite magmatism, the most voluminous at 600-580 Ma (Janasi et al. 2003), and (2) the Coastal Domain, largely composed of orthogneisses and granitic rocks, with smaller exposures of high-grade migmatites, in part of supracrustal derivation. Rocks from the Coastal Domain show relatively young Sm-Nd T(DM) (often <1.5 Ga, compared to ∼2.0 Ga or older in the Embu Domain); the high-grade metamorphism peaked at ∼590 Ma. This last age coincides with the few dated "syn-orogenic" granites (e.g., Natividade da Serra, dominated by muscovite-biotite granite; Janasi et al. 2003). The Ubatuba Charnockite is younger, as shown by unpublished ID-TIMS zircon dating (∼565 Ma; C. Tassinari, personal communication), and consists of a quartz mangerite-charnockite-granite association with coeval dioritic bodies; the rocks are commonly affected by solid-state foliation, but show a within-plate geochemical signature (Gasparini and Mantovani 1979, R. Neumann, Unpublished Master Dissertation, Universidade de São Paulo 1993). Still younger granitic plutons, although suspected from the less deformed character of some occurrences (e.g., Guarujá Granite, Dias

Neto et al. 2008, Santos Granite, A.T.S.F. Silva et al. 1977, unpublished report), were not studied in detail or dated so far.

The last magmatic manifestations in this region are Cretaceous tholeiitic and alkaline dike swarms and stocks of syenite-gabbro association related to continent rifting and subsequent opening of the South Atlantic.

LOCAL GEOLOGY

Geological Map of Ilha Anchieta

The geological map of Ilha Anchieta is presented in Figure 1. The oldest rocks recognized in the island appear at its westernmost portion as a ∼N-S 0-2 km wide strip of foliated charnockites and associated leucogranites from the Ubatuba Charnockite. The rest of the island is occupied by the younger Ilha Anchieta Quartz Monzonite (IAQM), whose intrusive character in relation to the charnockitic rocks has been observed in several outcrops along the island's western coast. It shows a magmatic foliation with average direction N-S dipping 55-85°E; the foliation of both the IAQM and the older charnockites shows an inflection from NNE in the north to NNW in the south of the island, suggestive of an inward-dipping body that is round-shaped in plan view.

The charnockites are greenish rocks with low color index (CI = 4-7) and syenogranitic composition (Table I; Fig. 2); a solid-state foliation is evidenced by the elongated shape of quartz and mafic minerals (Fig. 3a). In many localities, the charnockites are seen to gradually pass into pinkish granites; quartz-rich hololeucocratic granites with CI∼2 may occur in association with the charnockites or predominate in many outcrops, but were not distinguished at the mapping scale.

The predominant rock type in the IAQM is a porphyritic biotite-hornblende quartz monzonite with CI = 10-15 and abundant tabular pinkish K feldspar megacrysts up to 2-4 cm long in a medium-grained groundmass (Fig. 3b). A flow foliation evidenced by the preferred alignment of K feldspar megacrysts is usually well developed. A border facies with slightly lower CI (8-12) is present in several portions close to the western contact with the enclosing charnockites; closely packed oriented tabular K feldspar megacrysts (on average ∼2 cm long) and a lesser proportion of matrix result in a "trachytoid" texture (Fig. 3c). Modal analyses of these two varieties (Table I; Fig. 3) indicate compositions close to the limit between the quartz monzonite and monzogranite fields (15-18% quartz; 31-39% plagioclase). More felsic granites (CI<5) occur as discrete meter-sized bodies of pink inequigranular syenogranite (cf. modal analysis of sample IA-10e in Table I) that intrude the predominant porphyritic quartz monzonite in several outcrops (Fig. 3d). Thin aplitic dikes are the last magmatic expressions of the IAQM.

Subvertical diabase dikes oriented N45-60E with thicknesses varying from <1 to ∼10 m appear in several localities of Ilha Anchieta, and are related to the Serra do Mar Dike Swarm of the Cretaceous (∼140-134 Ma) Paraná-Etendeka Large Igneous Province (Valente et al. 2007). An interesting feature associated with one of these tholeiitic dikes crops out at the western portion of Ilha Anchieta: a magmatic breccia produced by the interaction between the basaltic magma and the enclosing foliated charnockites/granites. The breccia is exposed over an area of tens of meters, and is constituted of dm-sized subangular blocks of charnockite/granite in a "hybrid" rock matrix ("spotted" quartz diorite); petrographic evidences indicate that smaller granite fragments enclosed in the diabase were partially to totally melted (J.M. Azevedo Sobrinho et al. 2004, unpublished results). Some of the mafic dikes present in the island may be related to the ∼85 Ma alkaline magmatism, which generated several of the dikes exposed onshore (Garda 1996), but this could not be confirmed in this study.

Outcrop-scale Structures in the IAQM

The border IAQM trachytoid facies exhibits near the contact with the enclosing charnockites abundant centimeter- to meter-sized xenoliths of these rocks (Fig. 4a). In one locality (Fig. 4b) the IAQM gets progressively darker and finer-grained over ∼1 m towards the contact with the charnockite.

Mafic microgranular enclaves with elliptical shape are fairly common in the porphyritic granite. They are mostly centimeter-sized and show evidence of plastic-state interaction with the host granite, such as molding around megacrysts. K feldspar xenocrysts with sizes varying from identical to smaller than those of the host granite are common; hornblende-mantled quartz xenocrysts are less abundant, though remarkably developed when present (Fig. 4c).

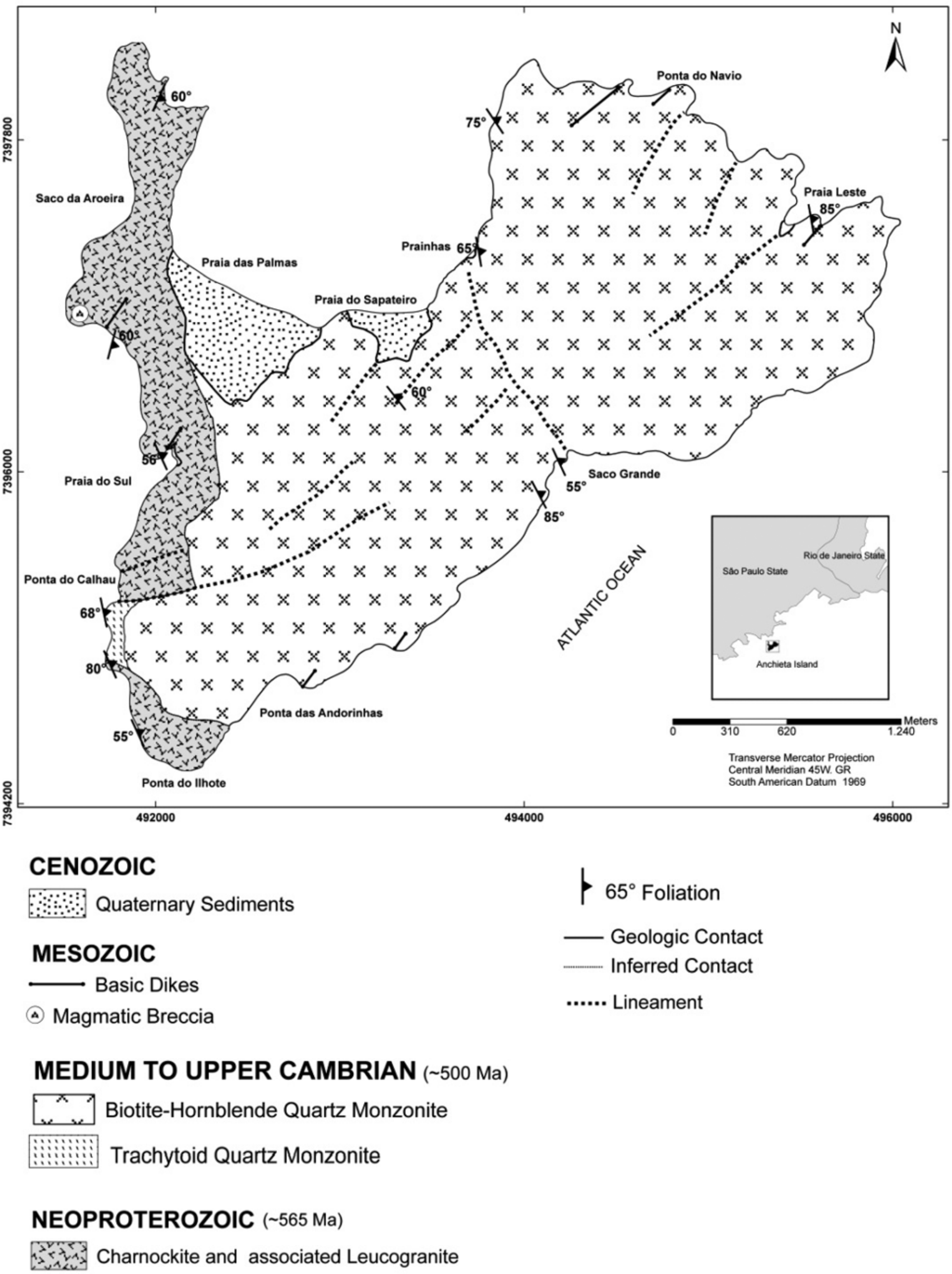

Fig. 1 – Geological map of Ilha Anchieta.

TABLE I
Modal analyses data of IAQM and enclosing charnockitic-granitic rocks.

Rock type	p-QM	p-QM	t-QM	t-QM	inq-G	chk	chk	chk	lg
Sample / Mineral (%)	IA10c	IA33b	IA15	IA34a	IA10e	IA20a	IA24	IA11	IA20
Quartz	16.8	14.9	18.2	14.6	30.6	23.6	27.2	26.4	47.5
Plagioclase	35.7	31.4	38.7	32.6	19.8	21.0	21.4	20.0	17.8
K feldspar	31.0	42.1	31.8	44.0	45.6	51.4	44.6	49.8	32.5
Hornblende	7.2	8.7	4.9	3.4	1.4	2.8	1.8	2.2	Tr
Biotite	6.8	1.4	4.9	4.0	1.8	1.6	3.4	0.8	1.9
Orthopyroxene	—	—	—	—	—	—	0.8	—	—
Fe-Ti oxide	1.7	1.1	1.5	1.2	0.4	Tr	0.6	0.6	0.1
Apatite	Tr	0.4	Tr	0.2	0.2	Tr	Tr	Tr	Tr
Zircon	0.2	Tr	Tr	Tr	0.2	Tr	Tr	Tr	Tr
Titanite	Tr	—	Tr	—	Tr	—	—	—	—
Allanite	0.2	—	—	—	Tr	—	0.2	0.2	0.2
Sericite	Tr	Tr	Tr	Tr	Tr	—	—	Tr	Tr
Carbonate	0.5	Tr	—	—	—	—	—	—	—
Q	20.1	16.9	20.5	16.0	31.9	24.6	29.2	27.4	48.6
A	37.1	47.6	35.9	48.2	47.5	58.5	47.9	51.8	33.2
P	42.8	35.5	43.6	35.8	20.6	21.9	22.9	20.8	18.2
M	16.1	11.6	11.3	8.8	4.0	4.4	6.8	3.8	2.2

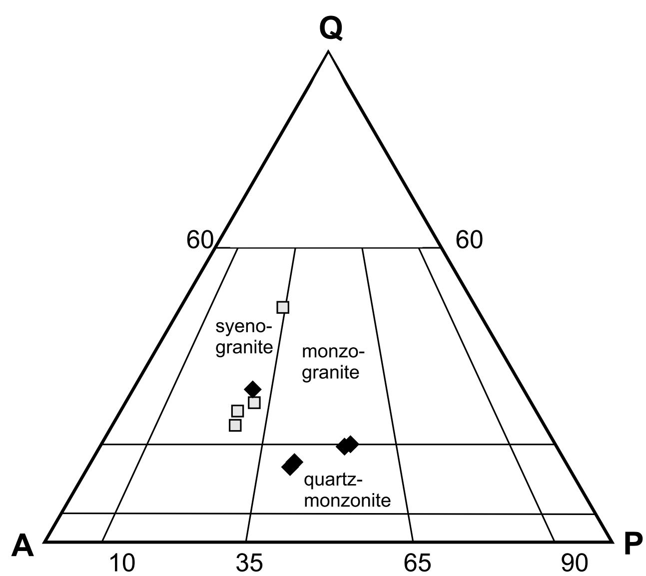

Fig. 2 – QAP diagram (Streckeisen 1976) with results of modal analyses of IAQM and enclosing charnockitic-granitic rocks. Orhopyroxene-bearing syeno- and monzogranites are classified as charnockites.

Magmatic layering is locally conspicuous and may indicate that cumulative processes were important in the formation of the porphyritic IAQM. The best exposures of these features were found in outcrop IA-10 (Saco Grande locality), where modal and grain-size layering parallel to the steep-dipping magmatic foliation is observed. Most commonly, the layering begins with medium-grained equigranular mafic-rich centimeter-sized layers that are in sharp contact with the underlying "normal" porphyritic quartz monzonite and gradually pass into lighter felsic rocks (Fig. 4d); this sequence is repeated cyclically for a few meters. One possible inter-

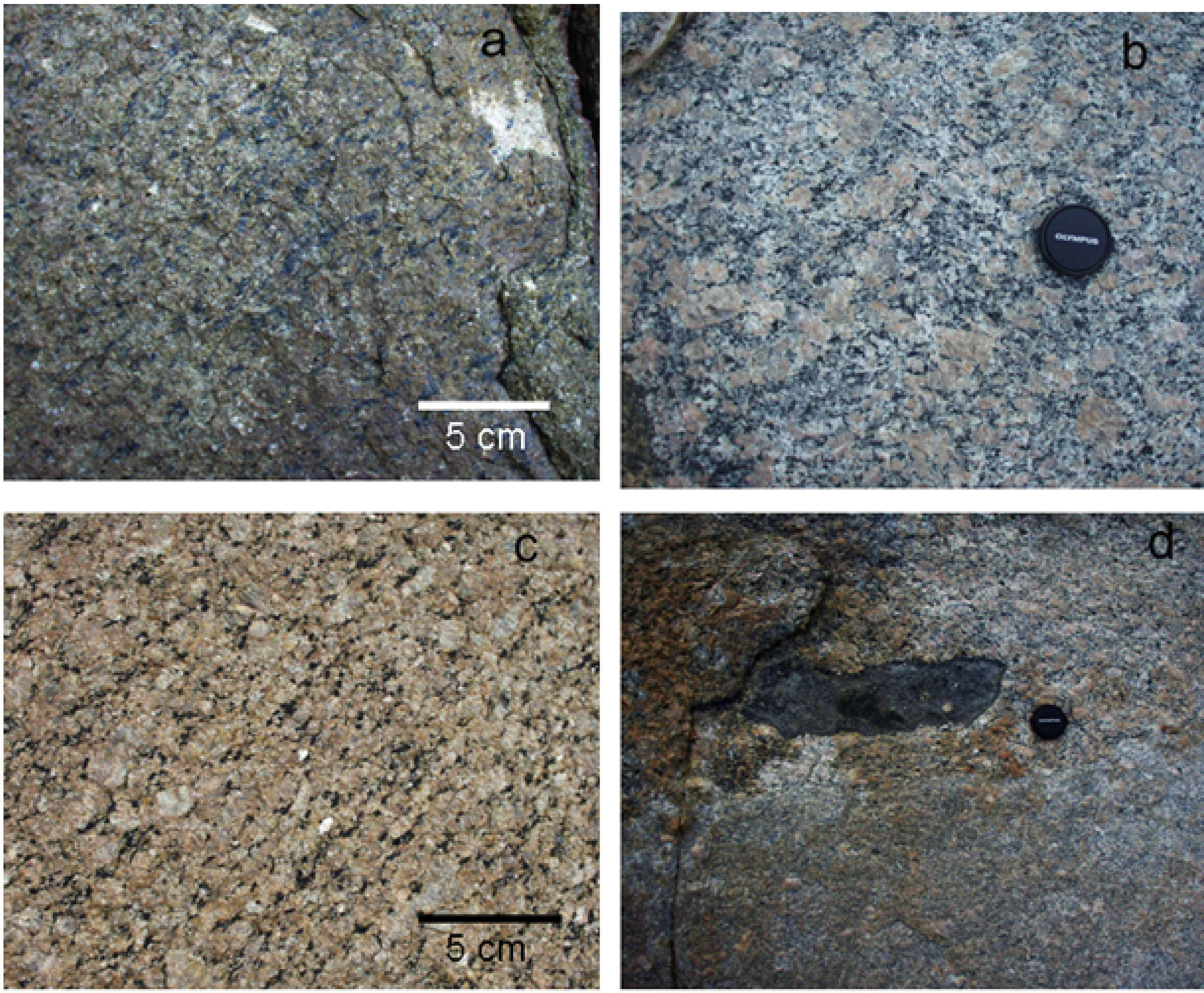

Fig. 3 – Field images of the main granite rock varieties found in Ilha Anchieta. (a) foliated charnockite; (b) porphyritic quartz monzonite; (c) trachytoid quartz monzonite (note the lower mafic content and a more evident flow foliation); (d) inequigranular granite with an elliptical dark enclave.

pretation for such structures is that they developed at the bottom of a magma chamber over a nearly horizontal substrate; in this case, their attitude would be an evidence that the pluton was subject to eastward tilting, and the fault affecting layering in Fig. 4d would be originally of normal character.

PETROGRAPHY

The Ubatuba Charnockite: Foliated Charnockite and Leucogranite

The charnockites are typically medium-grained, leucocratic (CI<7), inequigranular rocks of syenogranitic composition showing visible effects of solid-state deformation. Part of the fine-grained groundmass material has a granoblastic texture and is a product of recrystallization. The main minerals are, in order of abundance, K-feldspar, quartz, oligoclase, reddish-brown biotite, hornblende and orthopyroxene. Accessory minerals are Fe-Ti oxides, apatite, zircon and allanite.

Quartz as elongated xenomorphic grains defines the rock foliation, and may show undulous extinction. K-feldspar, also as elongated crystals with irregular to round borders, shows string perthite and is devoid of chessboard twinning. Plagioclase of oligoclase to andesine composition shows, in some cases, anti-perthitic intergrowths and may appear as myrmekite along the K feldspar borders.

Orthopyroxene is xenomorphic and in part altered to greenish phyllosilicate masses along fractures and

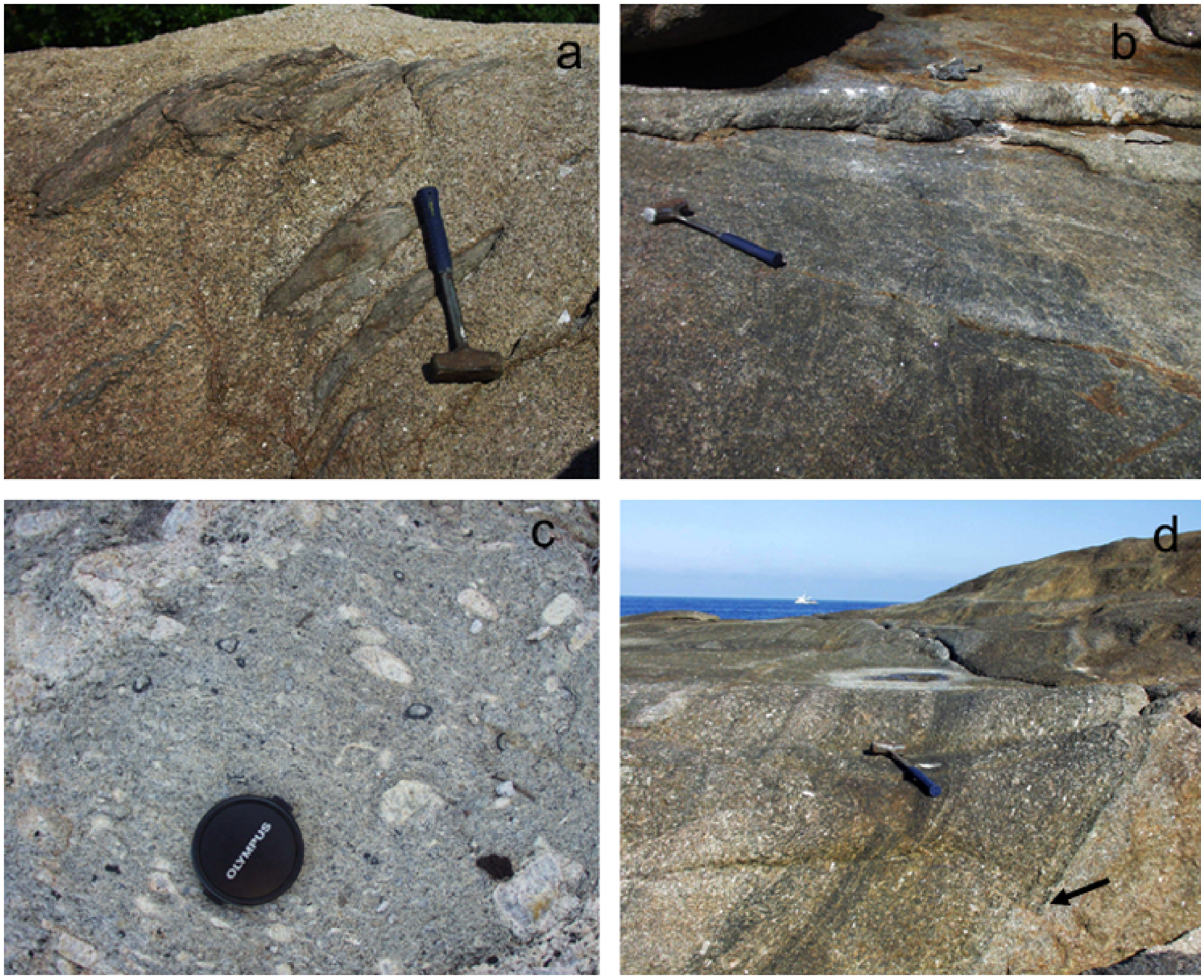

Fig. 4 – Field images of some outcrop-scale structures in the IAQM. (a) xenoliths of foliated charnockite in trachytoid quartz monzonite near the contact; (b) detail of the contact between trachytoid quartz monzonite (left) and charnockite; to the right of the hammer, the quartz monzonite turns progressively darker; charnockite corresponds to the lighter portion at the extreme right of the photograph; (c) detail of a dark microgranular enclave with hornblende + biotite-mantled quartz and microcline xenocrysts; (d) quartz monzonite showing modal and grain-size magmatic banding moderately east-dipping; note a ∼10 cm displacement of layering by a brittle fault (indicated by an arrow).

cleavages. Hornblende and biotite are commonly associated with the pyroxene; when secondary, biotite shows symplectitic intergrowths with quartz.

The foliated leucogranites differ from the texturally similar charnockites to which they are often associated by the pink color, lower CI (<4), lack of orthopyroxene, and higher abundance of quartz, which may reach up to 40% in volume.

The Ilha Anchieta Quartz Monzonite

The predominant rock type in the IAQM is a porphyritic biotite-hornblende quartz monzonite with CI∼15-10. The porphyritic texture is defined by tabular to oval-shaped microcline megacrysts in part aligned by magmatic flow set in a medium to coarse-grained matrix. Microcline, often with vein or patch perthite, may show chessboard twining; it always has a "dirty" aspect due to alteration to clay minerals. Plagioclase (oligoclase-andesine) is xenomorphic to subidiomorphic, and may be slightly to moderately replaced by sericite or, less often, saussuritized. Myrmekite is common at the contacts with microcline. Quartz is xenomorphic, and may show undulose extinction.

The mafic minerals, reddish-brown biotite and green hornblende, usually occur in association, and do not show any evident orientation. The accessory minerals (zircon, titanite, apatite, allanite and Fe-Ti oxides) tend to occur in association forming mafic aggregates. Hornblende may be partly replaced by greenish biotite and/or actinolite; as part of these reactions, some opaque minerals and titanite form along cleavages or fractures or occur as coronas around the original crystals. Greenish biotite may also replace the original dark biotite, and shows opaque minerals along its cleavage.

The more felsic granites (CI$<$7) intrusive into the porphyritic biotite-hornblende quartz monzonite are texturally distinct. They show a seriated inequigranular texture with scattered up to 1.5 cm long microcline phenocrysts set in a fine- to medium-grained matrix. Mafic and accessory minerals are the same as in the porphyritic granites, though in lower proportion. Sericite-muscovite may occur partly replacing the feldspars or biotite. Fe-Ti oxides are in part mantled by titanite.

Aplitic dikes with saccaroidal texture and very low CI ($<$3) still show the same mafic mineralogy of the granites, with brownish biotite and traces of hornblende as very small crystals dispersed in the rock. Plagioclase is strongly sericitized, and albite rims occur along the contacts of plagioclase and microcline.

GEOCHRONOLOGY: LA-MC-ICPMS DETERMINATIONS IN ZIRCON

PROCEDURES

Field relationship indicates that the IAQM intrudes the Ubatuba Charnockite, which was up to now the youngest granitic rock dated in the coastal area of São Paulo. Zircon crystals were extracted from sample IA-10d using standard mineral separation procedures including rock milling, heavy mineral concentration using a Wiffley Table, heavy liquids and a Frantz Isodynamic Separator at the Instituto de Geociências, Universidade de São Paulo.

About 80 clean zircon crystals, mostly free of fractures and inclusions, were handpicked and mounted in a 1 inch-wide cylindrical epoxy mount. Backscattered images of all crystals were obtained in order to investigate internal structures and to help selecting the best areas for laser incidence. LA-MC-ICPMS analyses were performed at the Radiogenic Isotope Facility, University of Alberta, Canada. Data were acquired using a NuPlasma MC-ICP-MS (Nu Instruments, UK) coupled to a UP213 laser ablation system (New Wave Research, USA); the MC-ICP-MS instrument is equipped with 12 Faraday cups and three discrete-dynode secondary electron multipliers (Simonetti et al. 2005, 2008). Ablated particles are transported with a He carrier gas and mixed with nebulized thallium (via a DSN-100 dessolvating nebulizing system) prior to entering the plasma. Correction for laser induced elemental fractionation (LIEF) was achieved by concurrent analysis of the international SHRIMP zircon standard BR266 (Stern and Amelin 2003). The measured Pb/U values for the standard are compared to the 'accepted' values (obtained by ID-TIMS), and normalization factors are determined using a 'standard-sample bracketing' technique. The measured ^{205}Tl/^{203}Tl ratio from the nebulized Tl solution ($\sim$1 ppb in 2% HNO_3) is used to correct the measured Pb isotope ratios for instrumental mass bias. The analytical protocol adopted here yields 2σ relative standard deviations that are between 0.3 to 1% (^{207}Pb/^{206}Pb) and 1 to 3% (^{206}Pb/^{238}U and ^{207}Pb/^{235}U). Details of the *in-situ* dating technique are described in Simonetti et al. (2005, 2008).

RESULTS

A total of thirty-five 40μm-wide laser spots were performed in sample IA-10d; results are presented in Table II and Figure 5. Most analyses are nearly concordant; the weighed mean ^{207}Pb/^{206}Pb age obtained for 22 spots with $<$7% discordance is 499.7$\pm$5.9 Ma (2σ; MSWD $=$ 1.0), considered as the best estimate of the crystallization age of the Ilha Anchieta Quartz Monzonite. The weighed mean ^{238}U/^{206}Pb age of the same 22 spots yields 510.3$\pm$7.0 Ma and a higher MSWD (3.0).

A few analyses show evidence of inheritance with slightly older age; in particular, points 18B and C are concordant at $\sim$540 Ma, and point 20-2 is concordant at 593$\pm$18 Ma. The analyses indicating the presence of zircon inheritance and/or those that display significant discordance ($>$8%) were not used in the age calculations.

DISCUSSION

The age around 500 Ma obtained for the Ilha Anchieta Quartz Monzonite in this study is remarkable within the regional geological framework since it is the youngest magmatic age reported so far in the crystalline basement of the state of São Paulo. The Coastal Domain in São Paulo is recognized as younger compared to terranes

TABLE II
Results of LA-MC-ICPMS U-Pb dating of Ilha Anchieta Quartz Monzonite IA10D.

Anal#	Spot size microns	^{206}Pb cps	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	2σ error	$^{207}Pb/^{235}U$	2σ error	$^{206}Pb/^{238}U$	2σ error	ρ	$^{207}Pb/^{206}Pb$ age (Ma)	2σ error	$^{206}Pb/^{238}U$ age (Ma)	2σ error	discord.%
10A-2	40	526371	infinite	0,05684	0,00067	0,6211	0,0254	0,0790	0,0032	0,958	485	±26	490	±20	–1,0
10B	40	935255	infinite	0,05754	0,00062	0,6255	0,0218	0,0785	0,0027	0,953	512	±24	487	±17	4,9
10B-2	40	777729	infinite	0,05773	0,00083	0,6318	0,0206	0,0794	0,0025	0,900	519	±31	492	±15	5,2
11	40	284190	infinite	0,05764	0,00150	0,6766	0,0356	0,0866	0,0041	0,869	516	±57	535	±25	–3,7
11B	40	195576	infinite	0,05713	0,00103	0,6401	0,0325	0,0817	0,0040	0,935	497	±40	506	±25	–1,9
12A	40	257950	infinite	0,05725	0,00070	0,6571	0,0269	0,0850	0,0034	0,954	501	±27	526	±21	–4,9
12B	40	188812	infinite	0,05695	0,00063	0,6502	0,0218	0,0848	0,0028	0,945	490	±25	525	±17	–7,2
12C	40	293112	infinite	0,05745	0,00064	0,6532	0,0234	0,0838	0,0030	0,950	509	±25	519	±18	–1,9
12D	40	326203	infinite	0,05763	0,00062	0,6498	0,0244	0,0839	0,0031	0,958	516	±24	519	±19	–0,7
12E	40	246474	infinite	0,05764	0,00062	0,6687	0,0255	0,0860	0,0033	0,961	516	±23	532	±20	–3,0
13	40	221288	infinite	0,05717	0,00070	0,6379	0,0237	0,0834	0,0030	0,945	498	±27	516	±19	–3,7
13-2	40	308930	38616,3	0,05704	0,00071	0,6277	0,0225	0,0810	0,0028	0,939	493	±27	502	±18	–1,8
9B	40	62515	infinite	0,05788	0,00107	0,6195	0,0235	0,0861	0,0030	0,875	525	±40	533	±18	–1,4
8A	40	266861	infinite	0,05718	0,00060	0,6272	0,0225	0,0813	0,0029	0,957	498	±23	504	±18	–1,1
3	40	258852	infinite	0,05711	0,00062	0,6529	0,0210	0,0845	0,0027	0,942	496	±24	523	±17	–5,4
4B	40	375053	infinite	0,05674	0,00118	0,6178	0,0236	0,0797	0,0027	0,839	481	±46	495	±17	–2,7
4C-2	40	101369	2252,7	0,05717	0,00243	0,6424	0,0348	0,0850	0,0030	0,620	498	±94	526	±18	–5,6
16A	40	646458	infinite	0,05671	0,00058	0,6272	0,0202	0,0802	0,0026	0,950	480	±23	497	±16	–3,5
18A	40	272546	4542,4	0,05730	0,00097	0,6298	0,0249	0,0811	0,0030	0,903	503	±37	502	±19	0,1
19	40	262456	infinite	0,05651	0,00060	0,6204	0,0199	0,0802	0,0026	0,945	473	±23	497	±16	–5,2
19B	40	239530	infinite	0,05750	0,00079	0,6332	0,0217	0,0809	0,0027	0,918	511	±30	502	±17	1,8
20	40	571659	28582,9	0,05733	0,00081	0,6797	0,0229	0,0864	0,0028	0,909	504	±31	534	±17	–6,0
Discordant & inherited grains															
10A	40	44134	infinite	0,05847	0,00110	0,6806	0,0240	0,0961	0,0030	0,847	547	±41	592	±19	–8,1
9A	40	156688	infinite	0,05642	0,00061	0,6335	0,0204	0,0830	0,0026	0,943	469	±24	514	±16	–9,5
9C	40	77270	infinite	0,05833	0,00077	0,6830	0,0225	0,0922	0,0029	0,917	542	±29	569	±18	–4,9
8B	40	142615	142615,1	0,05624	0,00066	0,6228	0,0207	0,0822	0,0027	0,937	462	±26	509	±17	–10,3
7A	40	114894	14361,8	0,05563	0,00121	0,6603	0,0240	0,0880	0,0027	0,802	438	±48	544	±17	–24,2
2A	40	57427	infinite	0,05665	0,00297	0,6396	0,0384	0,0866	0,0027	0,486	478	±116	535	±16	–12,0
4A	40	177207	16109,8	0,05699	0,00119	0,6828	0,0299	0,0884	0,0035	0,880	491	±46	546	±22	–11,2
4C	40	119494	infinite	0,05591	0,00063	0,6466	0,0203	0,0858	0,0027	0,935	449	±25	531	±16	–18,2
17A	40	219259	infinite	0,05633	0,00064	0,6506	0,0219	0,0842	0,0028	0,943	465	±25	521	±17	–12,0
18B	40	68258	infinite	0,05813	0,00098	0,6492	0,0229	0,0876	0,0029	0,879	535	±37	541	±18	–1,3
18C	40	116444	infinite	0,05831	0,00096	0,6943	0,0233	0,0884	0,0027	0,872	541	±36	546	±17	–0,9
20-2	40	976358	17129,1	0,05974	0,00071	0,7947	0,0249	0,0964	0,0030	0,927	594	±26	593	±18	0,1
21	40	283093	infinite	0,05644	0,00066	0,6917	0,0221	0,0897	0,0028	0,933	470	±26	554	±17	–17,9

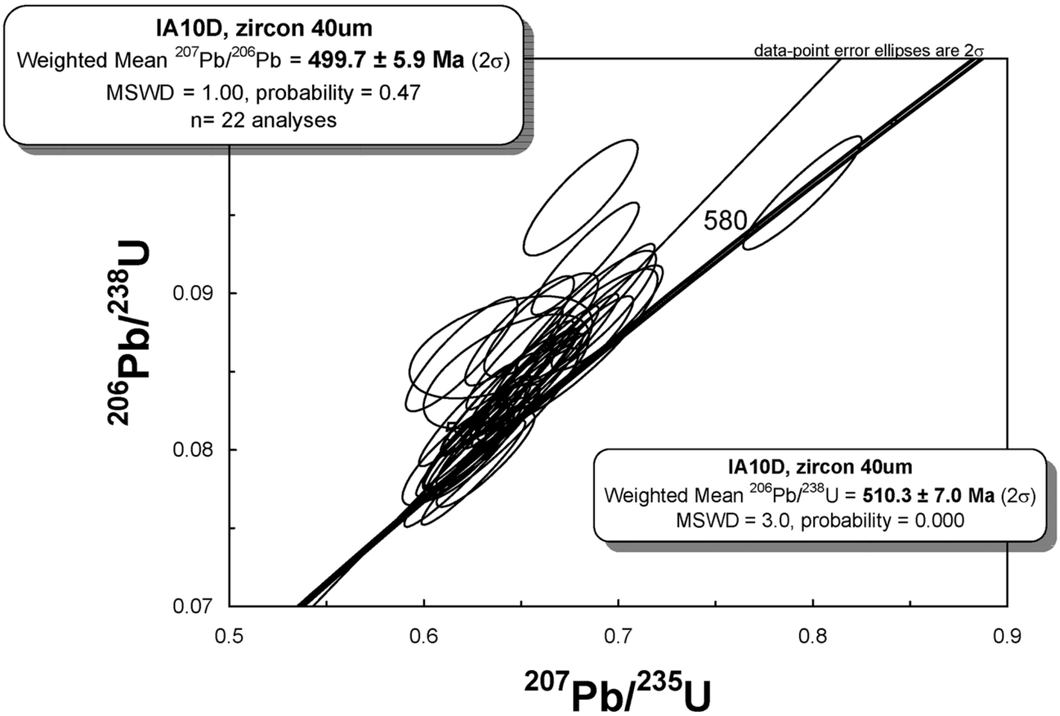

Fig. 5 – U-Pb Concordia diagram showing the results of LA-MC-ICPMS dating of zircon crystals from sample IA-10d.

located inland within the Ribeira Belt; syn-orogenic granites are typically ∼590 Ma (e.g., Janasi et al. 2003), and the youngest intrusion investigated prior to this study is the Ubatuba Charnockite, with a U-Pb ID-TIMS zircon age of ∼565 Ma. In spite of its "within-plate" geochemical signature, the Ubatuba Charnockite is thoroughly affected by a solid-state foliation and based on field relationships is older than the Ilha Anchieta Quartz Monzonite.

The new U-Pb zircon age reported here for the Ilha Anchieta Quartz Monzonite provides evidence that it is the southernmost occurrence of magmatism related to the ∼510-480 Ma belt of "I-type" K-rich granites and associated mafic rocks ("G-5") known to extend from latitude 16°S in the state of Bahia to 22°S in south Rio de Janeiro (Pedrosa-Soares et al. 2001, Wiedemann et al. 2002).

GEOCHEMISTRY

Nine samples representative of the main petrographic varieties of the IAQM and enclosing charnockite-leucogranite suite were analyzed for major and trace elements by XRF at the Instituto de Geociências, Universidade de São Paulo, according to the procedures described by Mori et al. (1999).

Our preliminary results indicate that the IAQM has a restricted compositional range with intermediate SiO_2 contents (63-67 wt%), whereas the enclosing charnockite-leucogranite rocks (CHLG) are richer in SiO_2 (71-78%) (Table III). The IAQM is metaluminous (A/CNK = 0.85-0.92), alkali-calcic and magnesian (**mg#** ∼30); this contrasts with the ferroan (**mg#** = 12-16) metaluminous to slightly peraluminous (A/CNK = 0.94-1.03) character of the CHLG (Fig. 6; fields of Frost et al. 2001).

Variation diagrams using SiO_2 as the differentiation index are presented in Figures 7 and 8; for comparison, trends of the main Ubatuba Charnockite Batholith (UCB) (R. Neumann, unpublished data, Master Dissertation, Universidade de São Paulo, 1993) are also shown. It can be observed that the CHLG samples perfectly fit along the UCB trend, which is continuous between 65 and 78 wt% SiO_2, corresponding to its more differentiated compositions. Compared to the UCB trend, the IAQM is clearly richer in MgO, TiO_2, P_2O_5 and Sr, and has much lower Ba/Sr (4-5 *versus* ∼10 in typical CHLG samples, which show remarkably low Sr con-

TABLE III
Results of chemical analysis of granitic and charnockitic rocks from Anchieta Island.

	Ilha Anchieta Granite					Charnockite-leucogranite suite			
	IA-33B p-QM	IA-10C p-QM	IA-34A tr-QM	IA-15 tr-QM	IA-10E ineq-G	IA-24A chk	IA-20A chk	IA-11 glg	IA-20 glg
SiO_2	62.28	64.24	65.71	66.20	72.67	70.64	74.02	75.16	77.59
TiO_2	1.32	0.99	1.00	0.94	0.34	0.45	0.27	0.22	0.16
Al_2O_3	15.14	14.64	14.56	14.54	13.48	13.52	12.74	12.18	11.88
Fe_2O_3	6.66	5.43	5.26	4.85	2.35	3.87	2.37	2.14	1.45
MnO	0.11	0.11	0.10	0.09	0.04	0.06	0.04	0.04	0.03
MgO	1.52	1.11	1.10	0.98	0.36	0.37	0.21	0.15	0.12
CaO	3.71	2.87	2.51	2.33	1.14	1.63	1.04	0.78	0.63
Na_2O	3.75	3.33	4.06	4.02	3.13	3.23	2.64	2.64	2.82
K_2O	4.43	4.85	4.98	5.10	5.35	5.68	5.86	5.80	5.27
P_2O_5	0.46	0.34	0.29	0.27	0.09	0.07	0.03	0.02	0.01
LOI	0.44	0.87	0.40	0.22	0.78	0.10	0.37	0.36	0.28
Total	99.82	98.78	99.97	99.53	99.72	99.62	99.59	99.49	100.24
Ba	1618	1385	1380	1435	567	819	602	386	82
Ce	163	181	160	104	116	232	269	305	103
Cl	179	128	297	223	59	<50	<50	<50	<50
Co	14	8	9	6	<6	<6	<6	<6	<6
Cr	<13	<13	<13	<13	<13	<13	<13	<13	<13
Cu	9	<5	<5	<5	<5	<5	<5	7	<5
F	2445	2239	2035	1838	<550	564	564	<550	569
Ga	23	22	22	21	21	19	18	17	18
La	110	136	114	59	90	185	219	252	83
Nb	39	43	46	44	10	14	<9	<9	10
Nd	106	88	88	47	62	113	133	153	60
Ni	7	<5	<5	<5	<5	<5	<5	<5	<5
Pb	22	24	24	21	34	16	18	19	26
Rb	149	180	152	156	179	164	161	157	202
S	<300	<300	<300	<300	<300	<300	<300	<300	<300
Sc	16	14	15	<14	<14	<14	<14	<14	<14
Sr	413	315	311	319	118	81	58	35	13
Th	13	24	26	32	30	51	45	40	79
U	<3	4	6	8	13	11	13	15	16
V	81	58	51	40	12	20	20	<9	<9
Y	66	69	65	58	33	53	46	40	34
Zn	103	99	97	88	50	60	56	51	39
Zr	655	553	704	637	276	520	400	280	161
mg#	31.3	28.9	29.4	28.7	23.4	16.0	14.1	12.3	14.2
A/CNK	0.85	0.92	0.88	0.89	1.04	0.94	1.01	1.01	1.03
N/K	1.29	1.04	1.24	1.20	0.89	0.86	0.68	0.69	0.81
Ba/Sr	3.9	4.4	4.4	4.5	4.8	10.1	10.1	11.0	6.3
Zrsat	875	877	895	888	869	886	876	842	796

Zrsat = zircon saturation temperatures, in degrees Celsius; **mg#** = molecular MgO/(MgO+FeO(total)); A/CNK = molecular Al_2O_3/(CaO+Na_2O+K_2O); N/K = molecular Na_2O/K_2O.

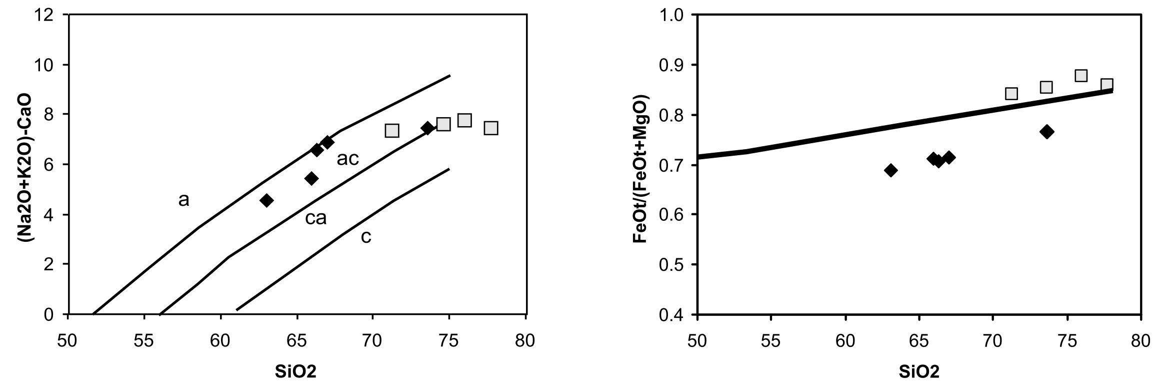

Fig. 6 – Geochemical parameters (Frost et al. 2001) for classification of the IAQM and enclosing charnockitic-granitic rocks: (a) (Na_2O+K_2O)-CaO × SiO_2 diagram; (b) (FeOt+MgO)/(FeOt) diagram.

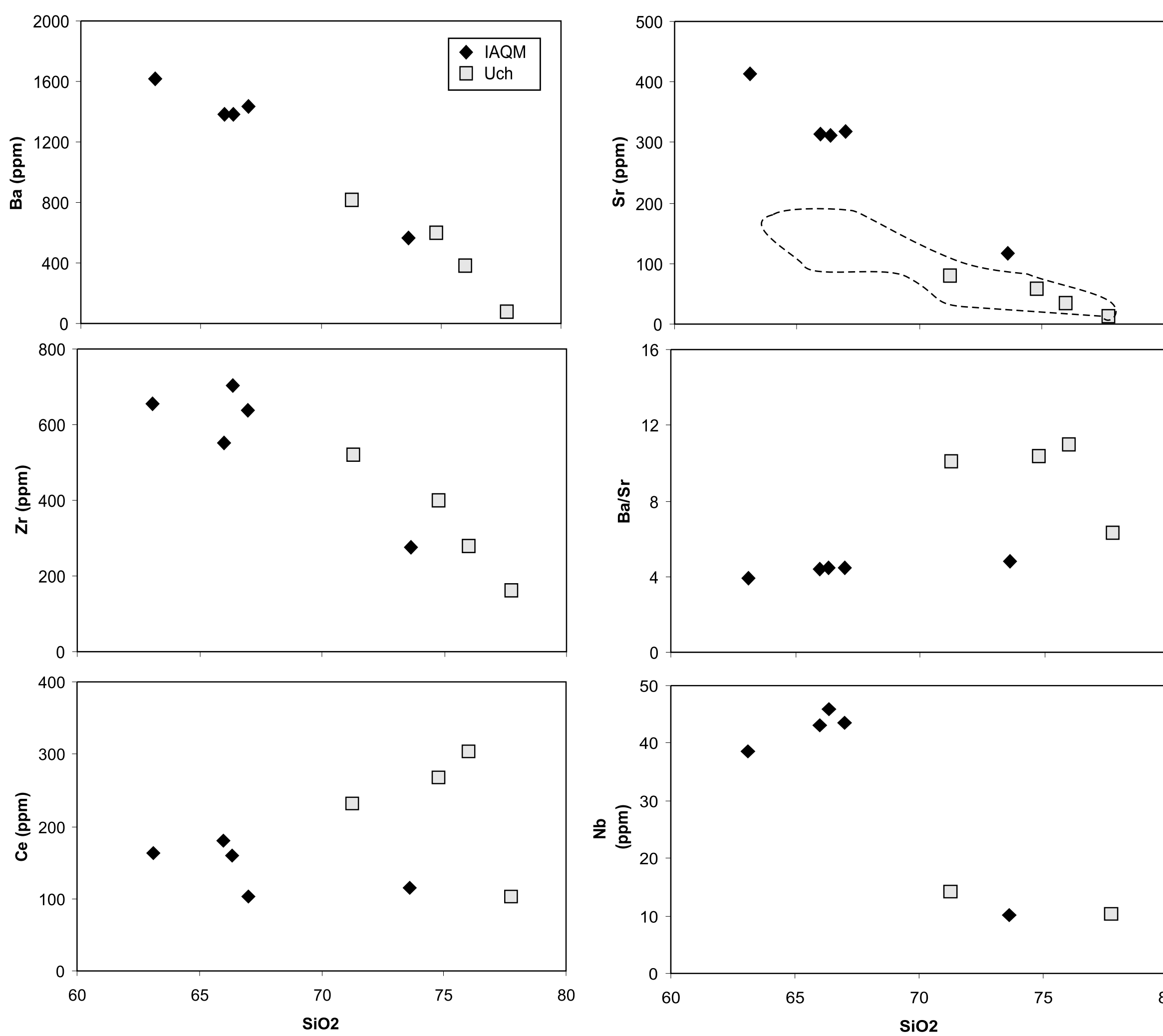

Fig. 7 – Major and minor element variation diagrams using SiO_2 as a differentiation index for IAQM and enclosing charnockitic-granitic rocks.

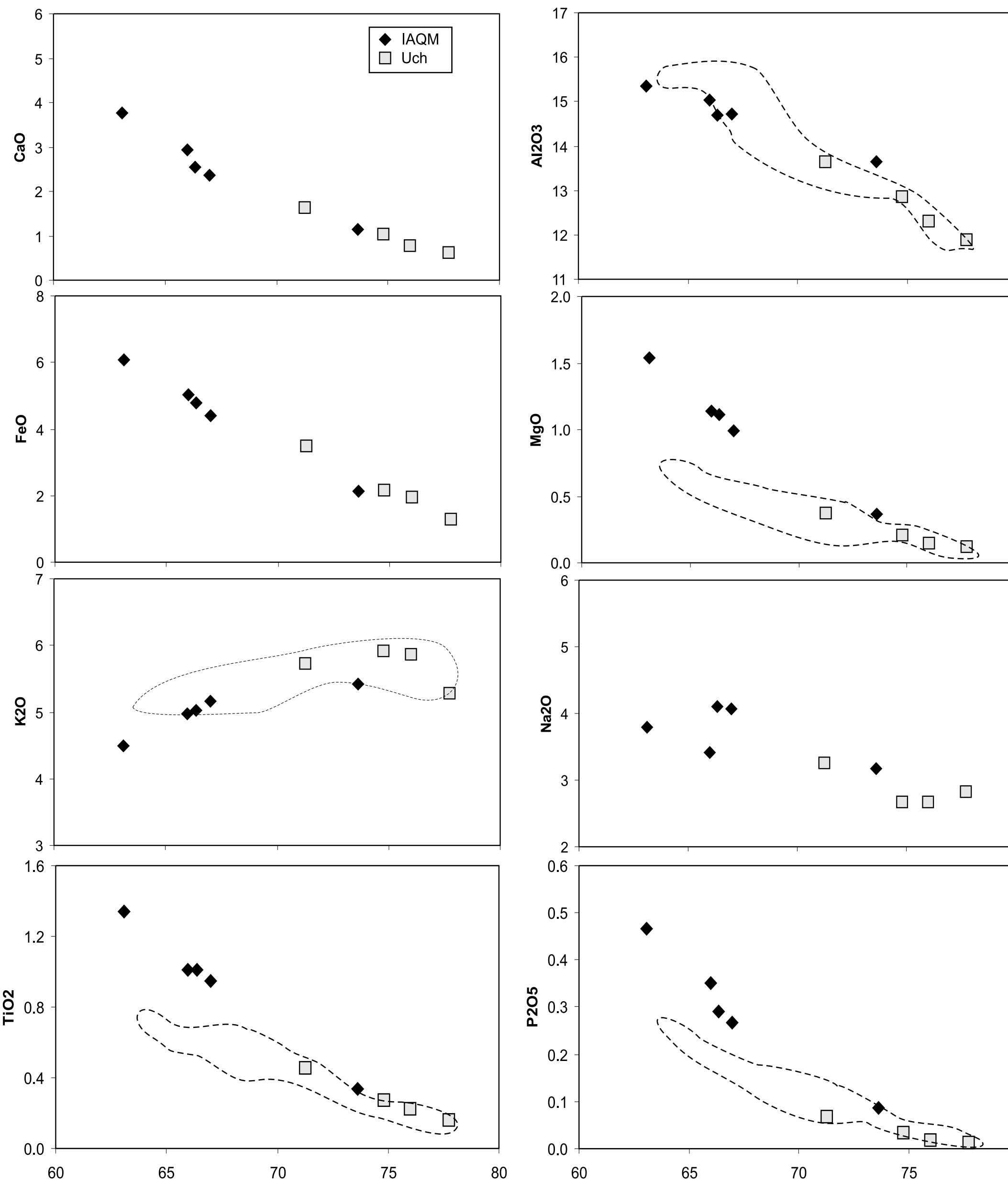

Fig. 8 – Trace-element variation diagrams using SiO_2 as a differentiation index for IAQM and enclosing charnockitic-granitic rocks.

tents, 35-80 ppm). High contents of HFSE as Nb (∼40 ppm) and Zr (550-700 ppm) are typical of the IAQM; this is also a feature of the least fractionated samples from the UCB. The Zr contents are suggestive of relatively high temperature magmas in both cases; zircon saturation temperatures calculated from the formulation of Watson and Harrison (1983) are 895-875°C for the IA quartz monzonites, and 885-875°C for the UB charnockites (Table I).

CONCLUSIONS

This paper presents the first study devoted to the Ilha Anchieta Quartz Monzonite, which was known in the literature from a brief description in a regional mapping report (A.T.S.F. Silva et al. 1977, unpublished report). Field relationships demonstrate that the pluton is intrusive into foliated felsic charnockites and associated leucogranites that are part of the Ubatuba Charnockite

Batholith, thus far the youngest granitic rock dated in the state of São Paulo (∼565 Ma; Gasparini and Mantovani 1979, C. Tassinari, personal communication). LA-MC-ICPMS U-Pb zircon dating has shown that the IAQM is indeed very young (499.7±5.9 Ma), and can be interpreted as an extension of the "G5" belt of late-Brasiliano alkali-calcic granites and associated high-K mafic rocks described by Pedrosa-Soares et al. (2001) and Wiedemann et al. (2002).

A border facies with trachytoid structure present at the western contact of the IAQM is slightly more felsic (CI∼8-11) than samples of typical porphyritic quartz monzonite from the inner portions of the pluton. The latter appear to be at least in part cumulative, as evidenced by outcrop-scale structures, such as steep inward-dipping modal and grain-size layering. Recharge of the chamber by basic magmas is evidenced by elliptical mafic microgranular enclaves with textures indicative of interaction with the host granite; in one local, a larger (∼2 meter-thick) body of fine-grained mafic rock appears to have split up as concordant layers within the quartz monzonite. Differentiated granites are restricted, at the exposed portion of the pluton, to meter-sized intrusive pods found in several outcrops and to thin aplite dikes.

The IAQM chemical signature appears to be similar to those of coeval "G5" occurrences such as the Santa Angélica and Várzea Alegre plutons in Espírito Santo (Wiedemann et al. 2002), combining high HFSE contents (especially Nb and Zr) with some geochemical features that are not typical of within-plate granites, such as an alkali-calcic and magnesian character, as well as the relatively high contents of LILE (e.g., K, Ba, Sr), LREE and P_2O_5 shown by associated basic rocks. These features have been attributed to the involvement of distinct sources in the enriched mantle and a metaluminous lower crust (Ludka et al. 1998, Campos et al. 2004). The renewed influx of mantle-derived magmas in a post-collisional setting at 510-500 Ma appears to be connected with cessation of convergence and slab break off (Wiedemann et al. 2002, Campos et al. 2004).

The older Ubatuba Charnockite Batholith has a chemical signature that is clearly distinct from the IAQM, with major and trace-element signatures typical of within-plate, "A-type" granites (e.g., syenogranitic composition; low **mg#** and Sr; high Zr, Nb). However, these rocks are affected by a solid-state foliation, and their ∼565 Ma age is identical to "syn-collisional" granites elsewhere in the Oriental Terrane (Heilbron and Machado 2003, Campos et al. 2004, Heilbron et al. 2008). The significance of this high-temperature magmatism (anhydrous, with *liquidus* T up to 900°C) associated with mantle-derived mafic bodies has yet to be fully understood, since it is by no means typical of a "syn-collisional" environment and could imply a period of extensional tectonics preceding the last compressional events recorded in the Oriental Terrane at 530-510 Ma (Heilbron et al. 2008).

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RESUMO

O Quartzo Monzonito Ilha Anchieta (QMIA) ocupa a maior parte da ilha homônima na região costeira do Estado de São Paulo, e é intrusivo em rochas foliadas do Charnockito Ubatuba (∼565 Ma). A principal variedade petrográfica é um biotita-hornblenda quartzo monzonito porfirítico com foliação magmática e megacristais tabulares de microclínio com 2-4 cm em matriz de granulação média. Estruturas em afloramento indicam processos cumuláticos (bandamento modal e granulométrico) e interação com magmas básicos (enclaves microgranulares máficos). Dados geoquímicos indicam que a variedade principal é intermediária a ácida (SiO_2 = 63-67%), tem caráter álcali-cálcico, metaluminoso e magnesiano (**mg#** ∼30), conteúdos moderados de Sr (300-400 ppm) e Ba (∼1500 ppm) e conteúdos relativamente altos de HFSE (Nb = 40 ppm; Zr = 550-700 ppm). Os charnockitos encaixantes mais antigos são mais félsicos (SiO_2 = 71-78%), ferrosos (**mg#** = 12-16), e têm teores muito baixos de Sr (13-80 ppm), resultando em razões Ba/Sr notavelmente mais altas que o QMIA (10 *versus*

4). Datação de zircão do QMIA por LA-MC-ICPMS indicou 499.7 ± 5.9 Ma, a idade magmática mais jovem identificada até o momento no embasamento cristalino do Estado de São Paulo, e indica que o plúton marca a extensão meridional do magmatismo pós-colisional tardio ("G5") do Cinturão Ribeira.

Palavras-chave: granito, litogeoquímica, LA-ICPMS, datação U-Pb de zircão, Cinturão Ribeira.

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