THE ITU BELT: ASSOCIATED CALC-ALKALINE AND ALUMINOUS A-TYPE LATE BRASILIANO GRANITOIDS IN THE STATES OF SÃO PAULO AND PARANÁ, SOUTHERN BRAZIL

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RESUMO

O cinturão Itu é formado por dezenas de plutons e complexos granitóides tardi- a pós-orogênicos ao ciclo brasiliano (ca. 640-580 Ma) e acompanha grosseiramente a borda atual da Bacia do Paraná, truncando os limites entre domínios tectonoestratigráficos definidos durante esse ciclo.

Quatro associações granitóides geograficamente superpostas podem ser reconhecidas no cinturão, com base em contrastes estruturais, petrográficos e geoquímicos.

Granitóides porfiríticos cálcio-alcalinos (comparáveis aos de tipo I Caledoniano) possuem biotita e eventual hornblenda como minerais máficos; titanita e allanita são acessórios comuns. Um conjunto de rochas intermediárias a básicas possivelmente não comagmático ocorre como pequenos corpos, diques sin-plutônicos e enclaves.

Uma associação de granitos róseos grossos, na qual alguns facies mostram texturas viborgíticas, é sob alguns aspectos comparável aos granitóides de tipo A, característicos de ambientes distensivos. A composição é tipicamente sienogranítica; biotita é raramente acompanhada de um anfibólio ferro-edenítico (?). Acessórios típicos são titanita, allanita e fluorita.

As outras duas associações incluem biotita monzogranitos inequigranulares sob certos aspectos intermediários entre as duas anteriores, e granitos róseos muito diferenciados com muscovita e fluorita, aos quais localmente se associam fenômenos de alteração pós-magmática e mineralizações de Sn, W, Mo e outras.

Embora se possa admitir uma gênese independente para as associações cálcio-alcalina e de "tipo A", a superposição geográfica, temporal, e em parte geoquímica entre elas sugere uma possível relação com um mesmo processo tectônico que provoca a fusão em graus variados de diferentes segmentos da crosta inferior, possivelmente através de magmatismo básico infracrustal.

INTRODUCTION

During the late- to post-orogenic Brasiliano period (ca. 640-580 Ma), several mesozonal to epizonal granitoid complexes and plutons were emplaced in a wide area which follows approximately the present border of the Paraná intracratonic basin in the States of São Paulo and Paraná (Southeastern Brazil). This area defines an arcuated belt with a NE-SW trend, here named "Itu belt", which cuts across the boundaries between geologic domains established in the Brasiliano

The body of information presently available for these granitoid occurrences is still unsatisfactory and unevenly distributed. For some massifs mapped in detail in the last years, a large body of petrographic description is available, but appropriate geochemical data are still required (e.g., the granitoids from the Morungaba region; Vlach, 1989). For others, chemical analyses, although plentiful, need to be revised, and geological-petrographic information is scant (e.g., Itaoca massif; Gomes et al., 1974a, b).

In spite of these problems, with the data that has come out in the last years, it has become evident that very contrasted granitoid associations appear in the belt. Among them, can be recognized high-K porphyritic "calc-alkaline" (biotite+titanite±hornblende) granitoids, coarse-grained to wiborgitic "A-type" (biotite+allanite+fluorite±Fe-edenite) syenogranites, and strongly differentiated pink equigranular biotite (±muscovite, fluorite) granites, the latter occasionally showing Sn-W (Mo) ore occurrences. Moreover, some inequigranular monzogranites (biotite+titanite) occur that are difficult to compare with granite types and series proposed in the literature and are in some respects intermediate between the two first associations mentioned above.

Apart from the petrographic, textural and chemical contrasts, the granitoid associations were emplaced through different mechanisms, partly reflected in the characteristic shape of each occurrence. This feature could therefore be explored to correlate timing and emplacement mechanisms with the evolution of the granitoid magmatism throughout the belt.

The petrological relationship between the high-K calc-alkaline and the (usually somewhat younger) "A-type" granitoid magmatism during the late- to post-orogenic evolution of folded belts is a matter of considerable debate in the current literature (Ba et al., 1985; Bonin, 1987). This sinoptic article tries to characterize the different granitoid associations recognizable in the Itu belt and to address some general petrological problems to be assessed through more detailed studies and which seem to be of prime significance for the tectonic modelling of the late-Brasiliano evolution of the region.

GRANITOID ASSOCIATIONS IN THE ITU BELT

CALC-ALKALINE GRANITOIDS (Table 1, Figure 1)

The calc-alkaline granitoids occur in the Itu belt as various complexes and plutons emplaced through different mechanisms at mesozonal and epizonal levels.

In the Morungaba region (Vlach, 1989), the elliptical Jaguari pluton shows a complex zoning pattern partly due to its poli-intrusive character; the irregularly-shaped Ouro Verde complex, by contrast, is made up of a series of granitoid sheets which enclose considerable volumes of country rocks. The Sorocaba (Godoy, 1989) and Serra da Batéia (Stein, 1984; Janasi et al., 1990) massifs are remarkably elongated intrusions whose emplacement must have been controlled by linear (fault?) zones.

Preliminary Rb/Sr radiometric data (Vlach, 1985 and unpublished data) suggest ages of emplacement for the northern Morungaba occurrences in the 640-600 Ma range.

The main petrographic facies are porphyritic monzogranites and quartz monzonites, usually massive (Itaoca, Sorocaba massifs), but in some occurrences (Ouro Verde complex, Serra da Batéia massif) a remarkable flow foliation is observed. Idiomorphic plagioclase (sodic andesine to intermediate oligoclase) often shows normal and/or oscillatory zoning; K feldspar megacrysts are strongly perthitic and also zoned when not recrystallized. Main mafic minerals are biotite and edenitic hornblende in more mafic facies (colour indices, 9-12) and biotite alone in more differentiated (colour indices, 4-9) varieties. Typical accessories are titanite, allanite and magnetite, accompanied by apatite, zircon, ilmenite, chalcopyrite and pyrite. Zircon morphology data (Wernick & Galembeck, 1985; Godoy, 1989) place these rocks in the field of "deep calc-alkaline granitods", with some overlapping with the "subalkaline" field, according to the nomenclature of Pupin (1980).

The chemical data currently available is restrict (Gomes et al., 1975a,b; Chiodi Fº et al., 1987; Godoy, 1989; S.R.F. Vlach, unpublished data). Silica contents are in the 65-68 wt% range for the more voluminous facies, but may reach values over 72 wt% in more differentiated varieties. K_2O (4.5-6.5 wt%), Ba (1,000-3,500 ppm) and F (700-1,500 ppm) are comparatively high. The rocks are usually marginally peraluminous (A/CNK = 0.9-1.2), and mg indices (molecular Mg/Mg+Fe) fall normally in the 0.3-0.4 range. Isotopic data for the Morungaba occurrences yield Sr initial ratios of 0.706-0.707 (Vlach, 1985 and unpublished data).

A remarkable feature in most of these calc-alkaline granitoid occurrences is the presence of several generations of syn-intrusive dikes (often deformed and disrupted) and microgranular enclaves of various sizes and shapes. Both dikes and enclaves show a wide range of compositions (from quartz dioritic to granitic) and may exhibit similar fine-grained textures. Small mappable occurrences of fine-grained ring-dikes and subcircular bodies of porphyritic to equigranular hornblende-biotite granodiorites and quartz monzodiorites were reported in the Morungaba (S.R.F. Vlach, unpublished), Sorocaba (Godoy, 1989) and Morro Grande granitoids. Evidence of limited mixing between syn-intrusive magmas and the enclosing coarse-grained granitoids (mantled ocelli, xenocrysts, mafic glomerules) are seen in several outcrops.

Also striking is the development of thermal metamorphic aureoles around those calc-alkaline plutons which intruded low-grade metamorphic sequences. Godoy (1989) reports the presence of cordierite and andaluzite in the Sorocaba massif aureole; the last mineral was also formed near the Serra da Batéia massif (Stein, 1984). Garnet-wollastonite-diopside metasomatic tactites, in part with W (scheelite) and Cu-Au (chalcopyrite, bornite) ore, occur as inclusions within the Itaoca massif (Mello et al., 1981).

WIBORGITIC AND ASSOCIATED SYENOGRANITES (Table 1, Figure 1)

These granitoids occur as epizonal sub-circular to elongated plutons af varied sizes. The only occurrence mapped in detail up to now is the São Francisco massif (Godoy, 1989), where facies with predominant ovoidal K feldspar megacrysts mantled by plagioclase ("wiborgites") constitute small (4-8 km^2) sub-circular bodies enclosed in coarse-grained syenogranites compositionally similar, but lacking the wiborgite texture. The picture must be similar in the southern Itu batholith (Pascholatti et al., 1987) and in the Sguario and Campina do Veado massifs (Theodorovicz et al., 1986), where wiborgitic facies were reported but not mapped.

No isotopic data are available for wiborgites , but associated syenogranites in south Itu were dated at 586 $\pm$ 10 Ma (Sr initial ratio, 0.7066) by Tassinari (1988).

The compositions are usually restricted to the syenogranite field; colour indices are low (5-6). K-feldspar megacrysts are zoned and strongly perthitic; plagioclase is zoned in the calcic-oligoclase albite range. Biotite is always the main mafic phase, occasionally accompanied by a hastingsitic (Fe-edenitic?) amphibole. Typical accessories are titanite, allanite and fluorite, along with some apatite , zircon, magnetite, ilmenite and pyrite.

The wiborgitic facies in south Itu shows a two-phased texture: abundant K-feldspar (1-3 cm) and quartz (0.5-1.5 cm) occur as ovoidal megacrysts, the former usually irregularly mantled by sodic oligoclase-albite. The mantles (1-4 mm) may show quartz as micrographic intergrowths. The matrix, often granophyric, contains sodic plagioclase, microcline and quartz.

Chemical analyses (Theodorovicz et al., 1986; Godoy, 1989) indicate rather restricted compositional ranges (SiO_2= 72-74 wt%; K_2O= 5.0-5.6 wt%; Na_2O= 3.5-4.0 wt%), <u>not</u> allowing a distinction between wiborgitic and coarse-grained porphyroid syenogranites. A/CNK values point to a marginally peraluminous character (0.95-1.2); <u>mg</u> indices are around 0.20-0.25. F contents are high (1,000-2,000 ppm), Ba is medium (200-400 ppm, and Sr lower than 100 ppm.

INEQUIGRANULAR BIOTITE MONZOGRANITES (Table 1, Figure 1)

The mesozonal to epizonal, poli-intrusive south Morungaba centered pluton (40-60 km^2) is made up of inequigranular medium-grained biotite monzogranites intruded by differentiated pink equigranular granites (described in the following section). Similar rock-types seem to predominate in the northeastern half of the Itu batholith (Pascholatti et al., 1987). Rb-Sr isotopic data suggest ages of emplacement around 580-590 Ma for the south Morungaba pluton (Vlach & Kawashita , 1984; Vlach & Cordani, 1986), similar to those obtained for the above-cited wiborgitic granites.

The main facies are medium- to coarse-grained inequigranular, massive monzogranites; colour indices are between 3 and 7. Reddish-pink tabular K-feldspar is usually somewhat larger than white plagioclase; rarely, ovoidal K-feldspars mantled by plagioclase are found.

Plagioclase shows normal and oscillatory zoning from sodic andesine to sodic oligoclase; K-feldspar, at times also zoned, is strongly perthitic. The main mafic mineral is a relatively Mg-rich biotite (e.g., mg around 0.35, S.Vlach, unpublished data). Typical accessories are titanite, allanite and magnetite, besides some apatite, zircon, ilmenite and pyrite.

Unpublished chemical data (S.Vlach, thesis in preparation) indicate a marginally peraluminous character (A/CNK= 0.95-1.2) and mg indices around 0.3-0.4 for these rocks. Typical SiO_2 contents are 69-72 wt%, but they reach 75 wt% in more differentiated varieties. K_2O (4.5-5.5 wt%), Sr (300-700 ppm) and Ba (1,500-3,000 ppm) contents are high; F (lower than 600 ppm) is characteristically low. Initial Sr ratios vary in the 0.705-0.707 range (Vlach, 1985; Vlach & Cordani, 1986).

Small quartz diorite and quartz monzodiorite bodies (biotite +hornblende+titanite) occur in south Morungaba, besides a suite of microgranular enclaves which includes dark quartz diorites and light microgranites (Vlach, 1985).

DIFFERENTIATED EQUIGRANULAR PINK GRANITES (Table 1, Figure 1)

These differentiated granites are widely distributed along the Itu belt, either as isolated epizonal stocks (e.g., Pilar do Sul massif, eastern Morungaba pluton) or intimately associated with wiborgitic (São Francisco) and inequigranular (south Morungaba) granitoids. Preliminary Rb/Sr isotopic data for the Morungaba occurrences indicate ages around 580-600 Ma (Vlach & Cordani, 1986), similar to those obtained for wiborgitic and "inequigranular" granitoids.

Predominant rock-types are reddish-pink, homogeneous, massive and equigranular; inequigranular varieties with larger globular quartz appear locally. More differentiated facies may show miarolitic cavities, and may pass into microgranites.

Compositionally, these rocks are mainly hololeucocratic (colour indices lower than 5) monzo- and syenogranites. Plagioclase is slightly zoned (intermediate oligoclase to calcic albite); microcline is commonly homogeneous and weakly perthitic. Quartz is abundant (30-35%). Biotite is commonly the main mafic mineral, often accompanied by (in part secondary) muscovite and fluorite. Other accessories are rare, but some syenogranite occurrences (São Francisco and Morro Grande) show topaz ± tourmaline (Godoy, 1989; Chiodi Fº et al., 1987).

The strongly differentiated character of these granites is stressed in the few chemical analyses presently published: they are Ba and Sr-poor, silica-rich (SiO_2 over 74 wt%), and show low mg indices (lower than 0.3) and a peraluminous character (A/CNK = 1.0-1.3). Relative to the former associations, these granites have higher Na_2O/K_2O ratios.

Some of these late granites are locally affected by post-magmatic metasomatic processes, to which some interesting ore occurrences are associated. Wolframite and cassiterite (± molibdenite and some galena and pyrite) ores were reported in quartz veins and greisens in the São Francisco, Bairro dos Correias and Morro Grande massifs (Knecht, 1946; Goraieb et al., 1987; Chiodi Fº et al., 1987).

PETROLOGIC AND TECTONIC ASPECTS

Some of the granitoid associations present in the Itu belt can be compared with granitoid series and types proposed in the current literature. There are however some important differences that might reflect source-area peculiarities or, else, different genetic mechanisms.

The granitoids of the high-K calc-alkaline association are comparable to the I-type Caledonian granitoids of Pitcher (1982, 1986), on the basis of their composition (mostly restricted to the granite-granodiorite fields), mineralogy (biotite as the main mafic phase), geochemistry, mode of occurrence, late- to post-orogenic character, etc. This granitoid type is not universally acknowledged, however, and its tectonic significance is still disputed in its very type-area (e.g., Brown et al., 1984).

Also evident are some similarities between the Itu belt calc-alkaline association and the "calc-alkaline monzonitic granitoid series" (Bowden et al., 1984), also called "shoshonitic" by some authors (Morrinson, 1980; see also Nardi, 1986). Intermediate to basic associated occurrences are however volumetrically minor in the Itu belt massifs, and may not be comagmatic with the predominant granitoids (see below).

The wiborgitic and associated syenogranites show several features often taken as characteristic of A-type granitoids (White & Chappell, 1983; Pitcher, 1986). Compared to wiborgites of the type-area in Finland (Wiborg and Laitila massifs; Simonen & Vorma, 1969; Vorma, 1976), the Itu occurrences show important dissimilarities, though. The Finnish wiborgites are less differentiated (higher colour indices; SiO_2=68-72 wt% versus 72-74 wt% for the Itu occurrences), and have higher A/CNK and lower mg values. The presence of less differentiated fayalite (±clinopyroxene)-bearing granitoids ("tirilites") has not been reported in the Itu belt up to now. Additionally, titanite is a common accessory in the Itu occurrences and monazite is absent, the contrary happenning in the Finnish occurrences.

Ore occurrences in the Itu belt are characteristically associated with the late differentiated muscovite-fluorite-bearing granites, a feature which is common in the A-type granitoid provinces (Kinnaird et al. , 1985; Haapala, 1977). Worth mentioning is that the mineralized occurrences in the area appear in rocks of syenogranitic composition, some of them geographically related to wiborgite massifs (São Francisco and Bairro dos Correias). Late, differentiated pink monzogranites associated with rocks of calc-alkaline affinities (south Morungaba) or as isolated plutons (Pilar do Sul) are generally barren.

Available Rb/Sr isochronic data indicate slightly older ages for calc-alkaline occurrences (over 610 Ma for north Morungaba) relative to the wiborgitic syenogranite association (ca. 590 Ma for south Itu). The south Morungaba inequigranular biotite monzogranites, which might correspond to more differentiated calc-alkaline rocks, show about the same age as the last association, though. Thus, the two contrasted "calc-alkaline" and "A-type" associations may show some temporal overlapping, a thesis which demands a better geochronological coverage. Anyhow, the time span involved is very short, and the use of more precise geochronological methods (as U-Pb concordia in zircons) is clearly required.

Many authors (e.g., Bonin, 1987) maintain that these two associations result from fundamentally different tectonic processes and source areas. For some, the I-type Caledonian granitoids mark a survival of the subduction influence much after ocean closure (Brown et al., 1984; Harris et al., 1986); even in areas situated relatively far from the subduction edge granitoids could be generated as a reflex activity (Farmer & DePaolo, 1983). As for the A-type granitoids, they are characteristic of post-orogenic to anorogenic extensional environments; many authors favour models involving lower crustal melting driven by underplating of hot basic magmas (e. g. , Haapala & Rämö, 1988).

A mantelic contribution to the Itu belt magmatism is mostly evidenced in the calc-alkaline association, where basic to intermediate rocks are fairly common, though volumetrically of minor significance. Furthermore, none of these occurrences has yet proven to be comagmatic with the predominant more felsic calc-alkaline granitoids. The interaction between the two magmas resulted in very local mixing features, at least at the present level of exposure.

The few Sr-isotopic data presently available for the Itu belt "calc-alkaline" and "A-type" occurences are similar (initial ratios are, respectively, 0.7072 and 0.7066, Table 1). Moreover, the inequigranular biotite monzogranites, which show identical Sr initial ratios (Table 1), seem to be in some respects chemically transitional between these two associations. A question arises whether the major granitoid associations of the Itu belt can be products of a same tectonic cause, the differences among them reflecting contrast in intensive and extensive parameters (e.g., depth and degree of partial melting) during the magma genesis from roughly similar lower crustal sources.

During the post-orogenic Brasiliano period in the States of São Paulo and Paraná and nearby regions, various other granitoid occurrences not included in the Itu belt were emplaced. The Serra do Mar belt (Kaul et al., 1982), located to the south, is a prominent feature, extending for some hundreds of kilometers towards southwest. In contrast to the Itu belt, which was implanted over fold belts largely reworked during Brasiliano cycle, the Serra do Mar belt is entirely located on old cratonic areas (the Luiz Alves craton). Realiable ages of emplacement for the granitoids of this belt are totally lacking at present, which renders comparisons with the Itu belt difficult. The rocks of the Serra do Mar belt are, anyhow, much more similar to those found in A-type post-orogenic provinces, featuring various occurrences of peralkaline granites and associated syenites (the "alkaline A-type series") and lacking occurrences with calc-alkaline affinities.

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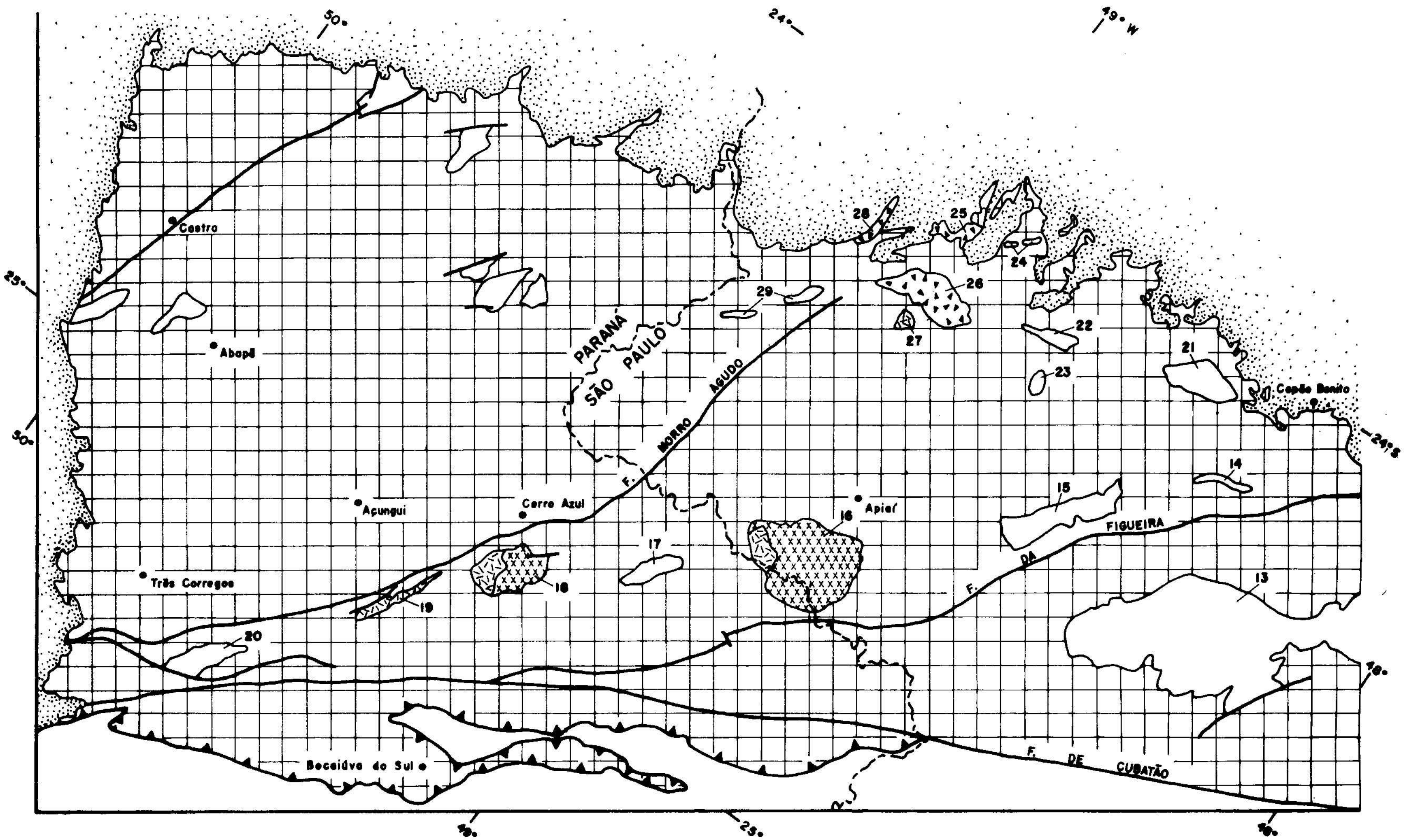

FIGURE 4 - SCHEMATIC GEOLOGICAL MAP SHOWING THE GRANITOID ASSOCIATIONS IN THE ITU BELT (WESTERN HALF). GEOLOGICAL BASE MAINLY FROM BISTRICHI ET AL. (1981) E BIONDI (1983)

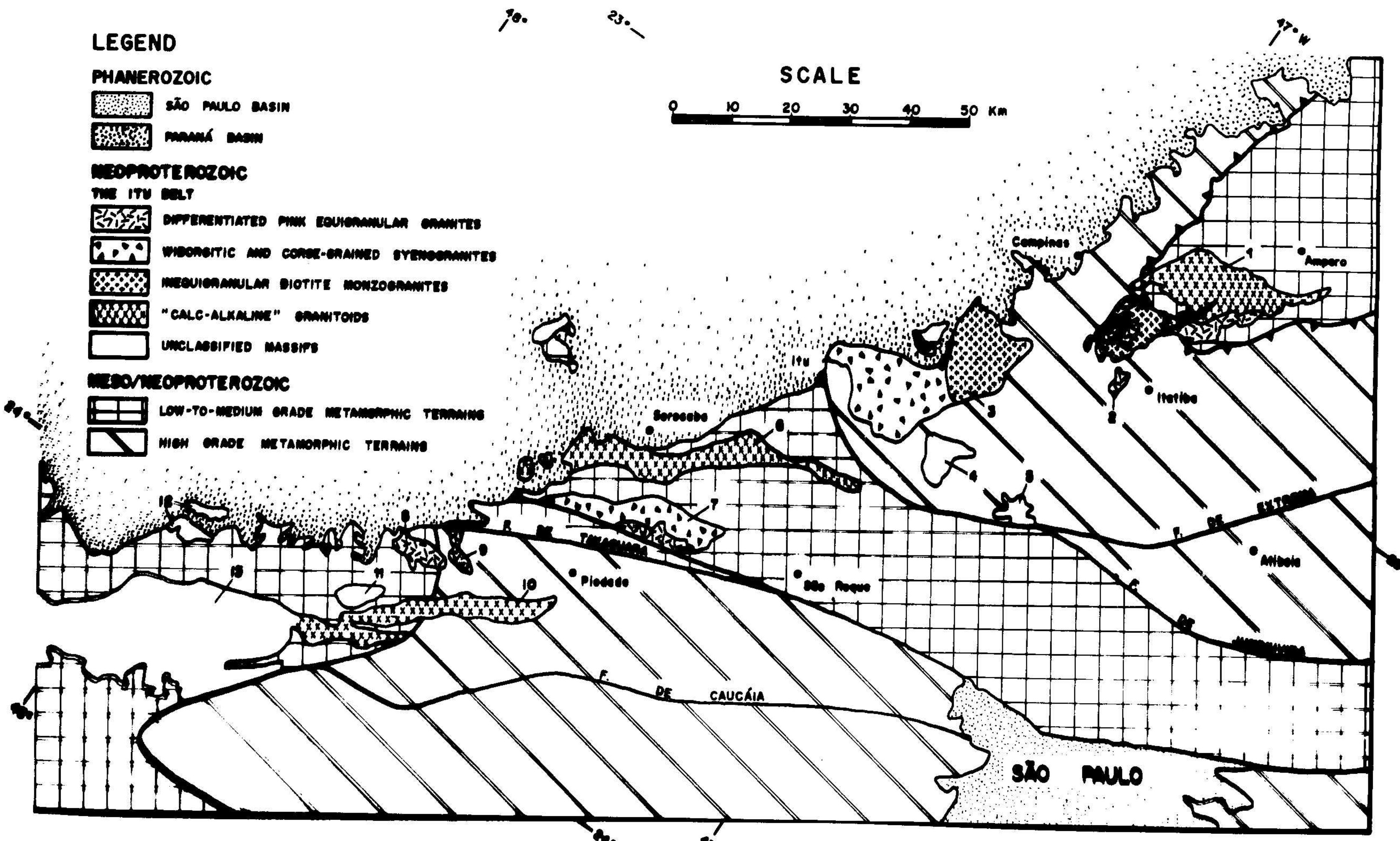

FIGURE 1 - CONTINUATION (EASTERN HALF)

Table 1 - Granitoid associations in the Itu belt, States of São Paulo and Paraná (SE Brazil)

Associations	Main occurences	Mode of occurrence	Composition and texture	Mineralogy	Chemistry	Remarks and isochronic Rb/Sr data
Porphyritic, "Calc-Alkaline"	Itaoca, Morro Grande, Sorocaba, north Morungaba, S.Batéia.	elongated intrusions, sheeted complexes	monzogranite to quartz monzonite; coarse-grained porphyritic to porphyroid	biotite (±hornblende); titanite, allanite, magnetite	av.SiO_2 = 65-68 wt %; high K, Ba,F; mg ~ 0.35	associated diorite to granite dikes and enclaves; 612 ± 18 Ma, IR=0.7072 (Morungaba)
Inequigranular monzogranites	south Morungaba, north Itu	centered complexes and plutons	monzogranite; medium- to coarse-grained inequigranular	biotite; titanite, allanite, magnetite	av.SiO_2 = 70-72 wt %; high Ba, Sr, medium F; mg ~ 0.35	590 ± 10 Ma, IR=0.7064 (Morungaba)
wiborgitic and associated syenogranites	São Francisco, south Itu, Sguario, Campina do Veado	sub-circular plutons	syenogranite; wiborgitic or coarse-grained porphyroid	biotite; (±Fe-edenite ?) titanite, allanite, fluorite	av. SiO_2 = 72-74 wt %; medium Ba, mg ~ 0.20	586 ± 10 Ma, IR=0.7066 (Itu)
muscovite-bearing late granites	Pilar do Sul, B. Correias; parts of Itaoca, Morro Grande, Morungaba, São Francisco	small epizonal plutons and stocks	monzogranite and syenogranite; equigranular, locally granophyric	biotite, muscovite; fluorite (± tourmaline, topaz)	av. SiO_2 = 74 wt %; Na_2O/K_2O ~ 1; low Ba, Sr; mg generally low	associated greisens, albitites, quartz veins in part with Sn, W, Mo ore

Table 2 - Names of granitoid occurrences shown in Figure 2.

1. Morungaba	11. Córrego do Gázeo	21. Capão Bonito
2. Itatiba	12. São Miguel Arcanjo	22. Capote
3. Itu	13. Agudos Grandes	23. Serra Velha
4. Cachoeira	14. Freguesia Velha	24. Bairro dos Antunes
5. Terra Nova	15. Espírito Santo	25. Campina do Veado
6. Sorocaba	16. Itaoca	26. Sguario
7. São Francisco	17. Varginha	27. Bairro dos Correias
8. Pilar do Sul	18. Morro Grande	28. Rio Pirituba
9. Serra dos Lopes	19. Piedade	29. Bairro da Serrinha
10. Serra da Batéia	20. Passa Três	