Enriched-mantle contributions to the Itu Granitoid Belt, Southeastern Brazil: evidence from K-rich diorites and Syenites

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ABSTRACT

Geochemical comparisons between basic and intermediate rocks of the late Brasiliano Itu granitoid belt, state of São Paulo, southeastern Brazil, indicate that at least two different mantle-derived primitive melts contributed to this magmatism.

K-diorites and their fractionates that make up the Piracaia massif, and quartz diorites that occur as dikes and enclaves within the Morungaba granitoids, derive from K-rich basic magmas with close affinities to shoshonites, although their Ti contents are slightly higher than those usually found in these lavas.

The absence of Sr and Eu negative anomalies in mantle-normalized incompatible-element and REE patterns, and the comparatively low Al/(Na+K) ratios shown by the K-syenites that make up the bulk of the Capituva and Pedra Branca massifs, suggest that they derive from oxidized K-feldspar-phlogopite-rich magmas akin to minettes.

The LILE-rich nature of both lineages of basic magmas is difficult to reconcile with crustal contamination, since they are far richer in these elements than the potential contaminants. It must therefore reflect the incorporation of melts produced in the subcontinental lithosphere, where "metasomatic" horizons can be formed by percolation of LILE-rich melts and/or fluids, and become isotopically evolved over time. The basalt component present in the "shoshonitic" magmas might reflect more advanced melting of hydrated lithospheric peridotite. Alternatively, it could represent an asthenospheric component, which would respond for the "within-plate" trace-element signatures shown by the K-diorites.

Key words: potassic igneous rocks; diorite; syenite; geochemistry.

INTRODUCTION

Basic to intermediate plutonic rocks occur in the late Brasiliano (620-580 Ma) Itu granitoid belt (Vlach et al., 1990), state of São Paulo, southeastern Brazil, as scarce individual occurrences of broadly monzodioritic to syenitic composition and as a series of small dioritic bodies, syn-plutonic dikes and enclaves present within granitic massifs, mostly those with calc-alkalic affinities. All known occurrences are characterized by remarkably high (although variable) contents of large-ion lithophile elements (e.g. K, Ba, LREE), a feature which is by no means exclusive of the Itu belt; rather, it seems to be very typical of the late Brasiliano magmatism in several east Brazilian granitic provinces (e.g. Ferreira & Sial, 1991; Lima & Nardi, 1991). In the case of small dioritic bodies intimately associated with granites (as enclaves, dikes, etc), an obvious question can be raised as to whether these chemical fingerprints are related to some contamination by the coeval granitic magmas. While detailed petrological studies in some of these granitoid massifs present evidence that the most prominent geochemical features of these diorites are primary, and not related to hybridization (e.g. Vlach, 1993), the volumetrically larger basic-intermediate occurrences forming independent massifs not spatially related to granites would certainly be more informative concerning the nature and origin of these magmas.

In this article, we bring together the data (mostly elemental geochemistry) obtained in detailed studies recently concluded in some massifs of the Itu belt, namely the Piracaia monzodioritic-monzonitic massif (Janasi, 1986; Janasi & Ulbrich, 1987), the Capituva syenitic massif (Janasi, 1992; 1993), and the Morungaba granitoids (Vlach, 1985, 1993). Chemical data are used to identify and compare the parental magmas from which these rocks may have derived and to evaluate the characteristics of their (mantelic) source areas.

THE LATE BRASILIANO ITU BELT: AN OUTLINE

The greater volume of granitoid rocks outcropping in the State of São Paulo and vicinities appear as "syn-orogenic" massifs and batholiths, mostly of calc-alkalic (generally high-K) or peraluminous affinities (Janasi & Ulbrich, 1991). These granitoids occur in almost all the different geologic domains recognized in the region, but their emplacement preceded the final juxtaposition of these domains. In contrast to them, a series of massifs made up predominantly of massive granitoids occur in two major belts that truncate limits between the geologic domains.

The northernmost portion of Serra do Mar belt (Kaul et al., 1982), which intrudes mainly paleoproterozoic to older high-grade metamorphic rocks, crops out in the south of the State of São Paulo, and is mostly made up of post-orogenic A-type granites of meta-luminous or peralkalic character.

The Itu belt extends from north Paraná to south Minas Gerais, accompanying the present erosive border of the Phanerozoic Paraná basin, and intruding principally low- to high-grade metamorphic rocks strongly reworked in the Brasiliano cycle. Four major granitoid associations were recognized in this belt (Vlach et al., 1990): (1) high-K calc-alkalic (dominated by usually porphyritic monzogranites with biotite hornblende + titanite + allanite); (2) "alkalic" (with predominant pink syenogranites locally exhibiting wiborgitic textures); (3) inequigranular monzogranites partly transitional between the previous associations; and (4) muscovite and fluorite-bearing fractionated monzo- and syenogranites.

Basic and intermediate (dioritic) rocks occur as enclaves and syn-plutonic dikes emplaced contemporaneously with granitoids from all the above associations, but are far more abundant within the calc-alkalic occurrences. Additionally, some individual occurrences made up exclusively of basic and intermediate rocks appear in the belt, and define two different associations: K-syenites comprise the bulk of two quite large massifs occurring in the northern end of the belt, in south Minas Gerais (the Capituva and Pedra Branca massifs), while K-diorites and their fractionates constitute the Piracaia massif and minor related intrusions.

A geological sketch map of a portion of the crystalline basement in NE São Paulo and SW Minas Gerais is presented in Fig. 1, and shows the location of the studied occurrences, as well as the main "syn-orogenic" batholiths and the (tectonic) limits between the different geological domains in which they appear.

THE CAPITUVA AND PEDRA BRANCA MASSIFS: K-SYENITIC MAGMAS

The Capituva and Pedra Branca massifs are the northeasternmost occurrences of the Itu belt, intruding migmatites and syn-tectonic granitoids of the allochtonous Guaxupé Domain. The predominant facies in both massifs are medium- to coarse-grained laminated K-rich syenites (color indices 20-25). Fine-grained syenites found in the Capituva massif are chemically similar to those facies, indicating that the more important chemical features of these rocks reflect the nature of the parent magmas and cannot be attributed to cumulative processes (Janasi, 1993). More basic rocks are restricted to biotite-rich mela-syenites (color indices over 35) present in the core of the Capituva massif; they share most of the chemical fingerprints of the predominant facies, but do not seem to be related to them through simple fractionation processes (Janasi, 1993).

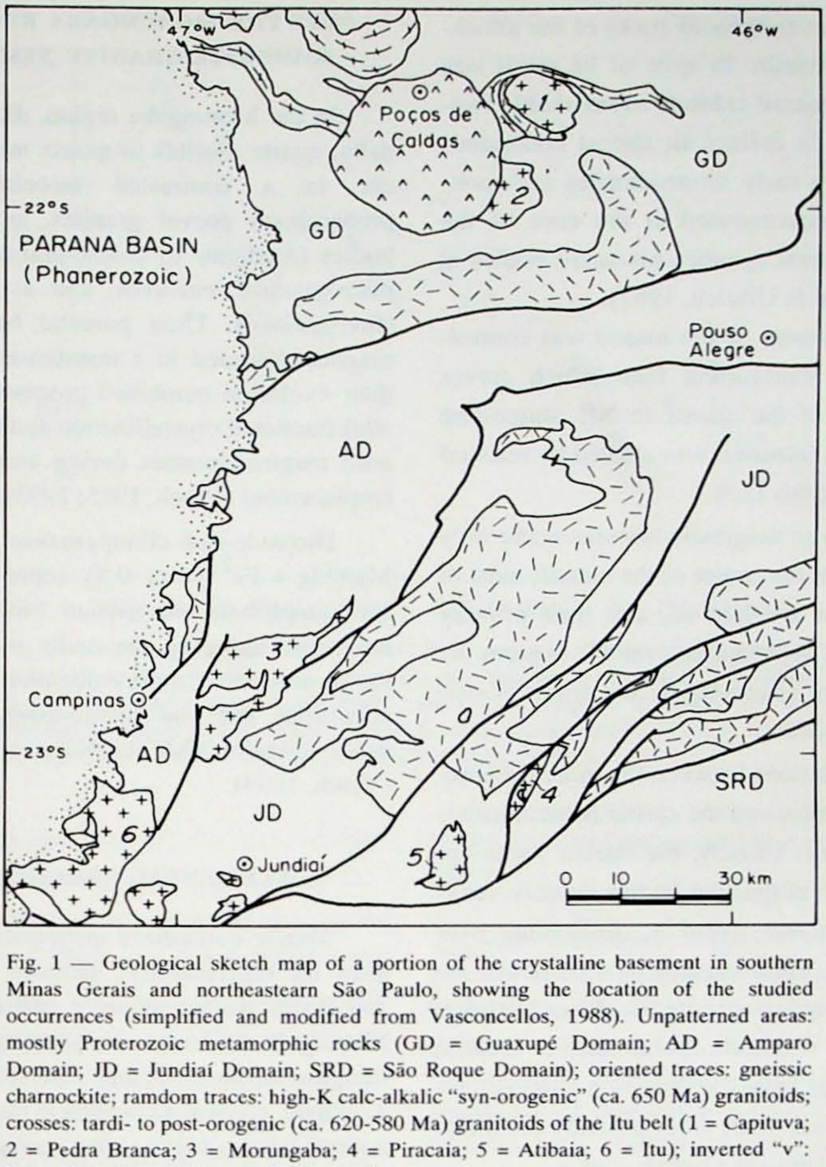

Fig. 1 — Geological sketch map of a portion of the crystalline basement in southern Minas Gerais and northeastearn São Paulo, showing the location of the studied occurrences (simplified and modified from Vasconcellos, 1988). Unpatterned areas: mostly Proterozoic metamorphic rocks (GD = Guaxupé Domain; AD = Amparo Domain; JD = Jundiaí Domain; SRD = São Roque Domain); oriented traces: gneissic charnockite; ramdom traces: high-K calc-alkalic "syn-orogenic" (ca. 650 Ma) granitoids; crosses: tardi- to post-orogenic (ca. 620-580 Ma) granitoids of the Itu belt (1 = Capituva; 2 = Pedra Branca; 3 = Morungaba; 4 = Piracaia; 5 = Atibaia; 6 = Itu); inverted "v": Poços de Caldas alkalic massif (Cretacic).

The oxidized nature (fO_2 above the NNO buffer) of the syenites from both massifs is revealed by the occurrence of hematite-rich ilmenite as the sole opaque oxide, and by the Mg-rich chemistry of the mafic phases (mainly biotite and diopside). A particular facies association present in the Pedra Branca massif crystallized under even higher fO_2 (near the HM buffer) and bears a mafic assemblage of (soda)-diopside, phlogopite, titanohematite, magnetite and titanite.

No reliable geochronological ages are available for these massifs; the very high Sr contents of all rock types frustrated attempts at obtaining a Rb-Sr isochron for the Pedra Branca massif (Winters, 1981). They are correlated to the Itu belt on the basis of several stratigraphic evidences, such as their late orogenic character, and their level of emplacement (P ≅ 3 kb; Janasi, 1992).

THE PIRACAIA MASSIF: K-DIORITES AND THEIR FRACTIONATES

The Piracaia massif is an oval-shaped, northeast-striking pluton intruding high-grade metasedimentary and meta-igneous rocks of the allochtonous Jundiaí Domain. In spite of its small size (ca. 32 km^2), the massif exhibits a remarkable variety of facies which defines an almost continuous modal trend, from early monzodiorites and monzonites (mostly concentrated at the core of the massif) to late quartz syenites (as small bodies at the borders; Janasi & Ulbrich, 1987).

The emplacement of the massif was controlled by a major transcurrent fault which curves from N-S south of the massif to NE, suggesting that space for the intrusion was created by sinistral movements along this fault.

Well-preserved magmatic textures occur only in rocks located at the center of the massif; most of the border facies are foliated, and their primary mineralogy was replaced to varied degrees by lower temperature assemblages, as a result of synplutonic deformation.

The field relations between the more differentiated quartz syenites and the earlier monzodiorites are quite complex. Usually, the darker rocks appear as elongated ellipsoidal bodies densely venulated by the quartz syenites, indicating near contemporaneous emplacement. In a particular facies association, quartz syenite occelli and veinlets occur within a monzodiorite-monzonite matrix, probably resulting from (deformation-induced) extraction of residual melts from partially solidified crystal mushes (Janasi & Ulbrich, 1987).

Geochemical data (Janasi, 1986, and unpublished data) show that most of the variation observed in the Piracaia massif can be modeled by *in situ* crystal fractionation, which involved the extraction of early crystallizing phases (calcic plagioclase, clinopyroxene, biotite, apatite and Fe-Ti oxides) from a parental monzodioritic magma.

Recalculation of the available Rb-Sr isotope data (Janasi, 1986) point to an emplacement age of 600 13 Ma; Sr initial ratios are in the 0.704-0.705 range for all facies, emphasizing their consanguineous nature.

THE MORUNGABA REGION: K-DIORITE/GRANITE ASSOCIATION

In the Morungaba region, dioritic rocks (modally, quartz diorites to quartz monzodiorites) occur in a contrasted association with the predominant coeval granites, as small irregular bodies (medium- to coarse-grained), as abundant microgranular enclaves, and as disrupted dikes (fine-grained). Their parental basic-intermediate magmas intruded in a transtensional regime, and their evolution combined processes of (largely *in situ*) fractional crystallization and mixing with granitic magmas/mushes during ascension and final emplacement (Vlach, 1985; 1993).

Diopside-rich clinopyroxene (mg# = cationic $Mg/(Mg + Fe^{2+})$= ca. 0.8), actinolitic and magnesian amphibole, magnesian biotite, titanite and magnetite make up the mafic mineralogy of the rocks, and point to crystallization under oxidizing conditions, near the titanite-magnetite-quartz-actinolite-ilmenite (TMQAI; Noyes et al., 1983) buffer (Vlach, 1993).

ELEMENTAL GEOCHEMISTRY

Mantle-normalized incompatible-element patterns for representative samples of the Capituva and Pedra Branca syenites and the Piracaia and Morungaba K-diorites are presented in Fig. 2. The samples, whose complete analyses appear in Table 1, where chosen to represent fine-grained, phenocryst-poor varieties (less prone to cumulative processes), except for the Pedra Branca syenite, where all collected samples are coarse-grained. The Morungaba sample is that showing less textural evidences of contamination by the country granites.

Apart from some small differences (discussed later), both syenites have very similar enrichment patterns, which show important contrasts with those of the K-diorites, the most outstanding being the deeper trough in Nb and the absence of a negative Sr anomaly, well displayed in the Morungaba sample, and less significant but still perceptible in the Piracaia monzodiorite. Moreover, the syenite patterns are more fractionated (less enriched in ele-

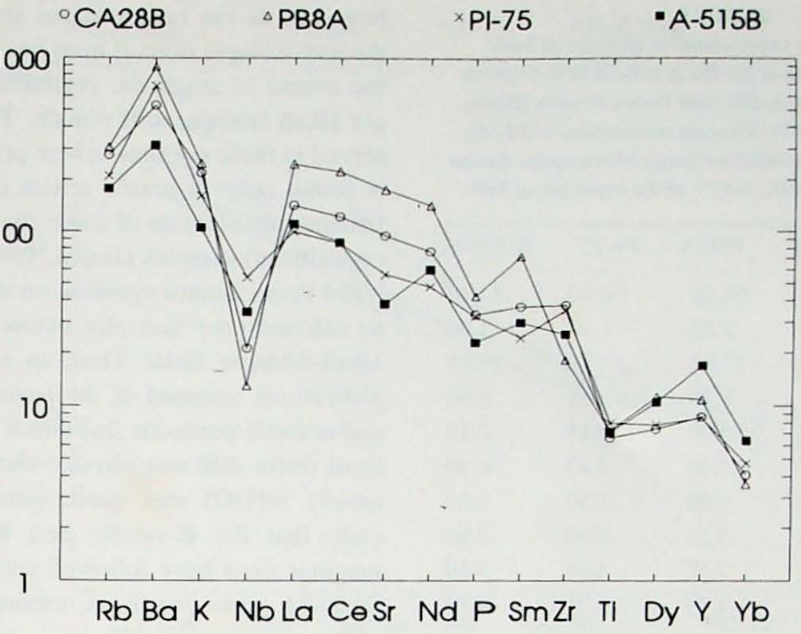

Fig. 2 — Mantle-normalized incompatible-element patterns for K-diorites and syenites from the Itu belt. Open circle, fine-grained syenite, Capituva massif (Janasi, 1992); open triangle, laminated syenite, Pedra Branca massif; closed square, K-diorite from the Morungaba region (Vlach, 1993); "x", fine-grained monzodiorite, Piracaia massif. Normalization factor: Sun & McDonough (1989) depleted mantle.

ments less incompatible than Ti; Fig. 2), a feature more evident in normalized REE patterns (Fig. 3).

The geochemical data available for these rocks (Janasi, 1986, 1992, and unpublished data; Vlach, 1993) suggest that none of them could represent primary mantle magmas. That is particularly evident for the least differentiated rocks from the Piracaia massif, whose Ni (<40 ppm) and Cr (<10 ppm) contents and mg# are extremely low, showing that these magmas could not have been in equilibrium with typical (olivine-bearing) mantle rocks. The Capituva syenites and the Morungaba K-diorites have higher values (Ni <70 ppm; Cr <90 ppm; mg# around 50), which are however lower than those accepted even for magmas generated from olivine-free (phlogopite-clinopyroxenite) mantle sources (e.g. Foley, 1992a). The interpretation of the incompatible-element patterns must therefore distinguish, as far as possible, those features inherited from the source and those which result from fractionation.

Evidence for Different Primary Mantle Melts

The contrasted behavior of Sr in the K-syenites and K-diorites must reflect different crystallization paths. The Sr troughs in the K-diorite patterns can be easily attributed to plagioclase fractionation, which indeed is expected from the abundance of plagioclase phenocrysts in some of these rocks. In contrast, plagioclase was *not* a primary magmatic phase in the Capituva syenites; the absence of Sr troughs suggests that only mafic mineral phases participated in the previous fractionation history of these magmas, pointing to the very peculiar nature of the primitive mantle magmas.

The situation of samples from the studied basic-intermediate rocks in the normative feldspar diagram (Fig. 4) further emphasizes the mentioned differences. Whereas the K-diorites clearly plot within the feldspar *solvus* (above the LKS line), implying that plagioclase was the first feldspar to crystallize in these rocks and that two feldspars must appear in their groundmass, the syenites from

TABLE I

Chemical data for representative samples of basic to intermediate rocks of the Itu granitoid belt. Sources of data: Capituva (CA-28b) and Pedra Branca (PB8a) syenites, Janasi (1992); Piracaia monzodiorite (PI-75), Janasi (1986, and unpublished data); Morungaba diorite (A-515b), Vlach (1993). FeO*: all Fe reported as FeO.

sample	CA28B	PB8A	PI-75	A-515-B
SiO_2	60.54	56.25	50.60	54.40
TiO_2	1.42	1.53	1.70	1.50
Al_2O_3	13.81	13.61	18.80	14.55
FeO*	5.12	5.70	8.15	8.00
MnO	0.09	0.09	0.16	0.13
MgO	3.02	3.00	3.40	6.40
CaO	4.39	5.80	5.50	5.80
Na_2O	3.04	3.15	4.00	2.90
K_2O	6.53	7.32	4.80	3.10
P_2O_5	0.94	1.18	0.91	0.64
Cr	85	45	5	nd
Ni	55	15	18	72
V	95	100	130	160
Rb	175	190	131	110
Ba	3660	6060	4700	2150
Sr	1986	3633	1170	790
Nb	15	9	38	24
Zr	420	200	390	280
Y	39	48	38	75
La	96.98	165.40	67.42	74.69
Ce	215.10	388.50	149.60	150.10
Nd	102.90	188.70	63.96	79.53
Sm	16.27	31.36	10.70	13.03
Eu	3.48	6.28	2.39	2.81
Gd	9.18	15.70	6.93	8.70
Dy	5.41	8.06	5.61	7.49
Ho	1.04	1.42	1.09	1.30
Er	2.60	2.86	2.75	3.76
Yb	1.98	1.74	2.30	3.05
Lu	0.27	0.22	0.30	0.38

the Capituva and Pedra Branca massifs plot *below* that line. The Capituva syenites are situated above the plagioclase-alkali feldspar cotectic-peritectic line (PAL), so that also in these rocks plagioclase must have been the first feldspar to crystallize; however, as the compositions are situated within the one-feldspar field, it must be totally resorbed in the course of magmatic crystallization, and a single alkali feldspar will remain. That is indeed observed in these syenites, where primary plagioclase is found only as scarce relicts in cores of alkali feldspar phenocrysts of some fine-grained (rapidly crystallized) samples (Janasi, 1992). The two analyzed Pedra Branca syenites, on the other hand, are so calcium-poor that plot below PAL, within the alkali-feldspar field. Thus, in spite of the simplifications assumed in the position of the *solvus* and cotectic-peritectic line (since the rocks crystallized under different physico-chemical conditions, mostly a(H_2O) and quartz-saturation), it seems clear that the K-syenite and K-diorite parental magmas must have followed very contrasted fractionation paths, mostly in response to different initial compositions.

These very contrasted fractionation paths are also illustrated in Fig. 5, where rock compositions are plotted in the A/CNK *vs.* A/NK[1] Shand's indices diagram (after Maniar & Piccoli, 1989): while the Piracaia compositions evolve towards the peralkalic field as a result of decreasing A/NK and increasing A/CNK (reflecting the rapid Ca decrease), the K-syenites follow a tendency of reduction of *both* indices.

The above discussion highlights the fact that the K-syenitic magmas from the Capituva and Pedra Branca massifs were primarily poor in a "basalt component" when compared to the K-diorites. The more primitive magmas from which they derived cannot therefore be comparable to shoshonites; in fact, studies of similar rocks (e.g. Thompson & Fowler, 1986; Leat et al., 1988) point to parental magmas akin to minettes, i.e. alkali-feldspar-phlogopite-rich lamprophyres (Velde, 1971; Rock, 1991). The petrological status of minettes is not yet clearly established, but some authors classify them as ultrapotassic rocks, in some respects intermediate between plagioclase-bearing rocks (e.g. leucite-basalts from the Roman Province) and lamproites (Foley et al., 1987). In

[1] A = Al_2O_3: C = CaO: N = Na_2O: K = K_2O, molecular proportions.

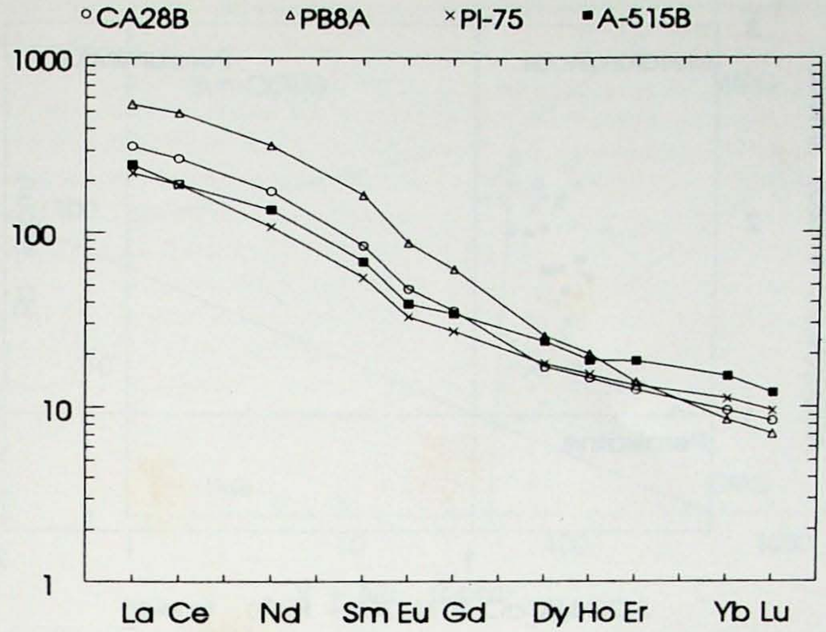

Fig. 3 — Chondrite-normalized (Boynton, 1984) REE patterns for K-diorites and syenites from the Itu belt. Symbols as in Fig. 2.

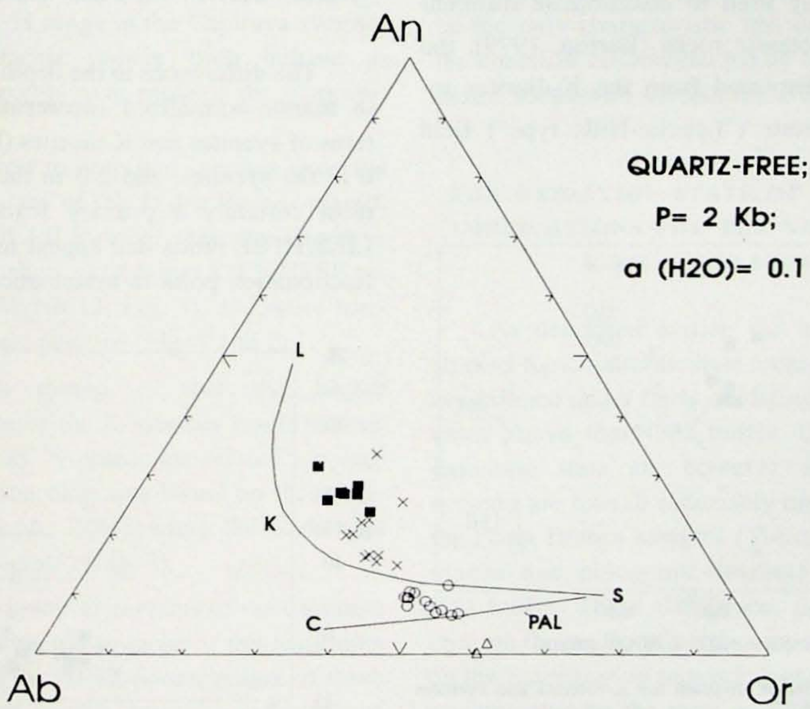

Fig. 4 — Albite-Ortoclase-Anortite CIPW normative compositions (wt%) of K-diorites and syenites from the Itu belt. Symbols as in Fig. 2. Plagioclase-alkali feldspar cotectic-peritectic line (PAL) and solvus (LKS) for the quartz-free system, at P (total) = 2 kb and $a(H_2O) = 0.1$, from Nekvasil (1990). $Fe^{2+} + Fe^{3+}$) set at 0.7 for all rocks.

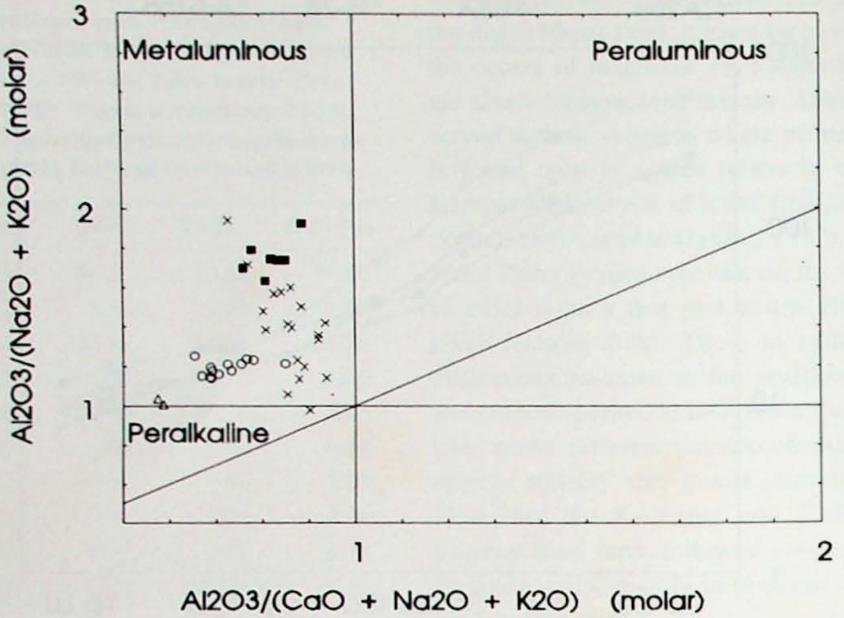

Fig. 5 — Shand's A/NK vs. A/CNK diagram (after Maniar & Piccoli, 1989) for K-diorites and syenites from the Itu belt. Symbols as in Fig. 2.

fact, in a ($K_2O + Na_2O / Al_2O_3$) (molar) *vs.* SiO_2 diagram, normally used to discriminate different groups of ultrapotassic rocks (Barton, 1979), the K-syenites are displaced from the K-diorites towards the lamproite ("Leucite-Hills type") field (Fig. 6).

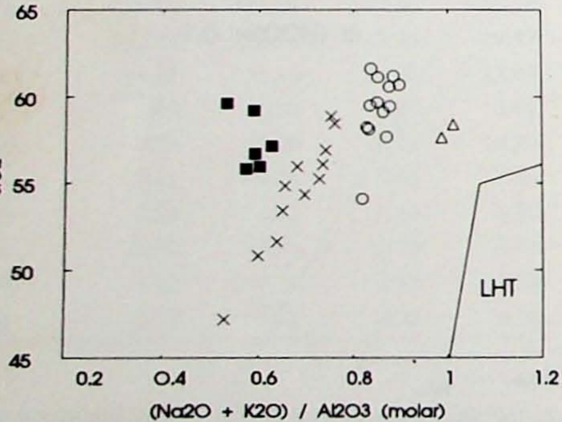

Fig. 6 — SiO_2 vs. NK/A diagram for K-diorites and syenites from the Itu belt. Symbols as in Fig. 2. Compositions are situated to the left of the Barton's (1979) LHT (leucite-Hills type = lamproite) field of ultrapotassic rocks, falling mostly within the field of (plagioclase-bearing) Roman-Province-type lavas.

THE BEHAVIOR OF THE HFS ELEMENTS: "WITHIN-PLATE" VS. "ARC" CHARACTERISTICS

The differences in the depth of the Nb troughs in mantle-normalized incompatible element patterns of syenites and K-diorites (Fig. 2; La/Nb= ca. 6 in the syenites, and 2-3 in the K-diorites) is almost certainly a primary feature. A few other LILE/HFSE ratios that appear to be unaffected by fractionation point to systematically higher values

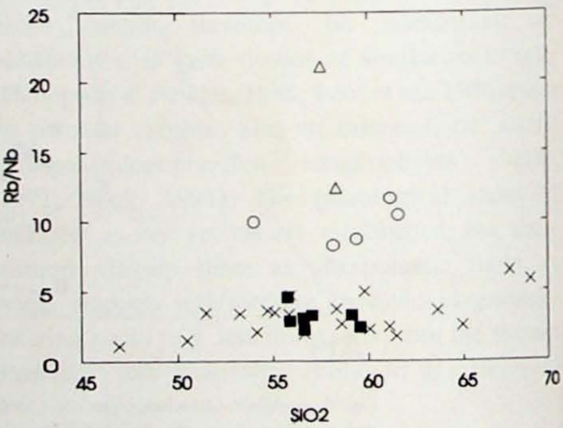

Fig. 7 — SiO_2 vs. Rb/Nb diagram for K-diorites and syenites from the Itu belt. Symbols as in Fig. 2.

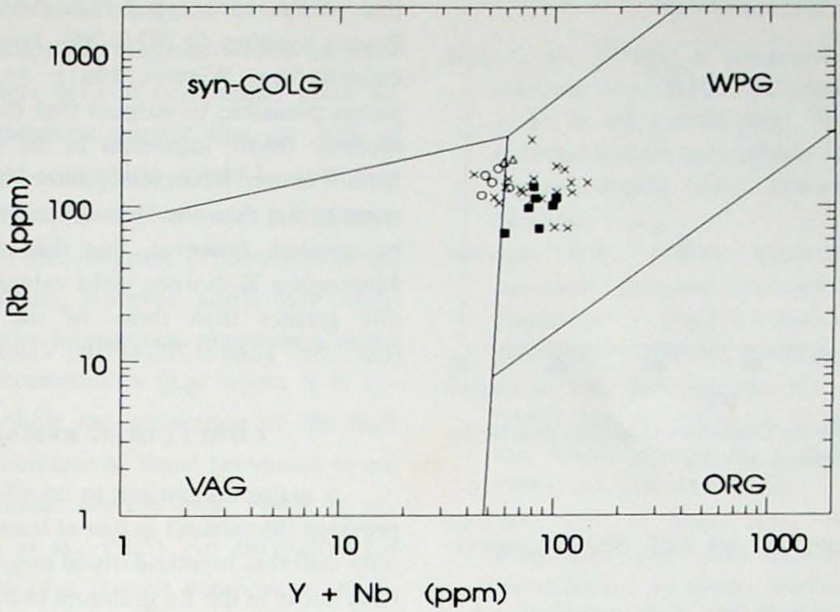

Fig. 8 — Rb vs. Y+Nb diagram for K-diorites and syenites from the Itu belt. Symbols as in Fig. 2. Fields (after Pearce et al., 1984) are indicated for granitoids from different tectonic environments (syn-COLG = syn-collisional; WPG = within-plate; VAG = volcanic arc; ORG = ocean-ridge).

in the syenites; one example is Rb/Nb (Fig. 7), which is in the 8-11 range in the Capituva syenites and 2-5 in Piracaia (where both behave as incompatible elements over most of the compositional range).

It is of interest to note that syenites from the more oxidized facies of the Pedra Branca massif, which are overall LILE-richer than the Capituva syenites (Fig. 2), show even larger LILE/HFSE ratios (La/Nb 11; Rb/Nb 12; Fig. 7), and more fractionated enrichment patterns (Fig. 1 and 2).

Also worth noting is that the higher LILE/HFSE ratios of the K-syenites result in their being classified as "volcanic-arc-related" in tectonic discrimination diagrams based on these elements (Pearce et al., 1984), while the K-diorites would be "within-plate" (Fig. 8).

The slightly lower Ti contents of the Capituva syenites when compared to those of the K-diorites could also reflect the HFSE-poorer nature of these magmas, although in this case the influence of opaque mineral fractionation is difficult to evaluate. Additionally, the comparatively high TiO_2 contents of the K-diorites from Piracaia and Morungaba (often higher than 1,5 wt%) seems to be the only characteristic that does not fit well to the chemical criteria elected by Morrison (1980) to define rocks with shoshonitic affinities.

THE OXIDATION STATE OF THE MAGMAS: IMPLICATIONS FOR THE NATURE OF THE K-RICH END-MEMBER

As described earlier, the mineralogy of the studied K-rich intermediate rocks indicate that they crystallized under fairly oxidizing conditions, in all cases above the NNO buffer. Differences in the oxidation state are however apparent: the K-syenites are overall noticeably more oxidized, with the Pedra Branca samples (Ti-hematite, magnetite, titanite and phlogopite-bearing) approaching the HM buffer. These differences have strong influence on the mafic mineral compositions and hence on the fractionation trends followed by these rocks, as illustrated by the mg# *vs.* SiO_2 diagram shown in Fig. 9. The Piracaia rocks have lower mg# than the K-syenites through all their compositional range, showing a discernible Fe-enrichment trend

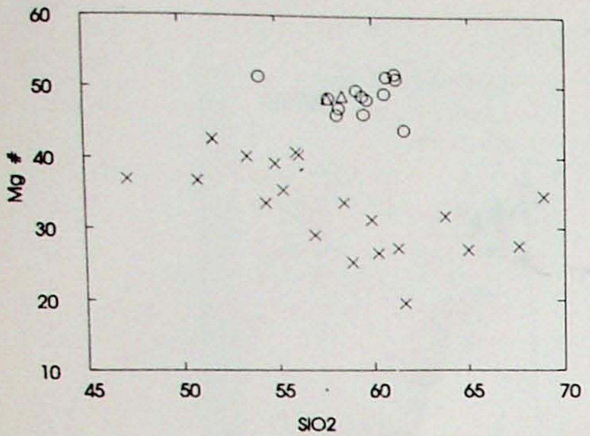

Fig. 9 — SiO_2 vs. mg# for K-diorites and syenites from the Itu belt. All Fe as Fe^{2+}. Symbols as in Fig. 2.

up to intermediate (ca. 60 wt% SiO_2) compositions.

Even more remarkable is the correlation between the oxidation state and the LILE/HFSE ratios: the more oxidized the rocks, the higher their LILE/HFSE ratios (as illustrated by the depth of Nb troughs in Fig. 2 and by the Rb/Nb ratios in Fig. 7). This is strongly suggestive that both features are closely related (e.g. changes in the stability of Ti-bearing phases under variable fO_2), and merits further investigation. In this respect, it is now apparent that the "K-rich" end-member identified in these rocks would not be comparable to typical lamproites (known to be originated under reducing conditions; e.g. Foley, 1989), but to otherwise chemically similar more oxidized (and HFSE-depleted) magmas (e.g. Sheppard & Taylor, 1992).

COMMENTS ON ISOTOPE GEOCHEMISTRY

Data on radiogenic isotopes for the Itu belt basic-intermediate rocks are still very scarce: no Rb-Sr data are available for the Capituva syenites, and Nd data were only obtained in one Morungaba K-diorite (Vlach, 1993). The observed patterns deserve some preliminary comments.

Calculated at 600 Ma (the approximate Rb-Sr isochron age of the Piracaia and Morungaba occurrences, and also a reasonable estimate for the K-syenites), the Sr^{87}/Sr^{86} ratios of the rocks from the Piracaia massif are lower (0.704-0.705, irrespective of the rock type) than those of the Pedra Branca syenites (0.707-0.708; Janasi, 1992; recalculated from Winters, 1981). At first glance, it seems plausible to suspect that the "K-rich" end-member (more important in the syenites) derive from a source isotopically more evolved (with respect to Sr) than the "basalt" end-member. It must be pointed, however, that data obtained in the Morungaba K-diorites yield values that are generally greater than those of the Piracaia rocks ($(Sr^{87}/Sr^{86})_{600}$= 0.706-0.708; Vlach, 1993).

CONCLUDING REMARKS

A major conclusion to be advanced from the previous discussions is that at least two fundamentally different mantle-derived magmas, both LILE-rich, occur in the Itu granitoid belt. The K-syenites derive from strongly oxidized magmas, poor in a "basalt" component, and exhibiting very high LILE/HFSE ratios. The K-dioritic magmas present in the Piracaia and Morungaba occurrences have some "shoshonitic" affinities and less pronounced, although still remarkable, LILE/HFSE and fO_2.

A significant contribution from crustal materials to the Capituva and Pedra Branca syenites seems implausible, since they are LILE-richer than any potential contaminants known regionally (Janasi, 1993). In fact, many authors envisage the origin of very K-rich magmas in the subcontinental lithospheric mantle (more precisely in the mechanical boundary layer), where "metasomatic" horizons (formed by the percolation of "small-fraction melts" ascending from the convecting mantle or by fluids and/or melts released from subducting slabs) can be preserved and become isotopically evolved over geologic time (e.g. McKenzie, 1989; Rogers, 1992).

A major issue, however, is the extent to which the "cold" lithospheric mantle can be melted when reactivated by rifting or plume activity. Some geophysical evidence suggests that the temperatures usually attained under these circumstances would only allow the partial melting of the enriched veins (possibly of phlogopite-clinopyroxenite composition), giving rise to K-rich magmas poor in a "basalt component". In this case, "basaltic" magmas enriched in LILE and radiogenic isotopes could represent asthenospheric magmas which incorporated a lithosphere-derived component upon ascent; some calculations suggest that ca. 10% of this very enriched component would be sufficient to dominate the incompatible-element and isotope characteristics of the magmas (Thompson et al., 1993). Some authors, however, admit that extensive melting of the lithospheric mantle can occur under special circumstances (e.g. where it is hydrated), and attribute the generation of the high K/Ti basalts of continental flood provinces to essentially lithospheric sources (e.g. Hergt et al., 1991; Bradshaw et al., 1993). An alternative for the incorporation of a "basalt component" to lithospheric mantle magmas is offered by the "vein-plus-wall-rock melting" model (Foley, 1992b) which admits that solid-solution reactions in the veins and wall-rock dissolution allow material from the wall-rock peridotites to be progressively incorporated into the initial low-fraction, vein-derived magmas.

The presently available data for the mantle-derived magmas of the Itu belt do not yield elements to decide whether the "basalt component" present in the K-diorites is derived from the convecting mantle or from the mechanical boundary layer. Whatever the case, an old, possibly paleoproterozoic (Vlach, 1993) "K-rich" component derived from veined, oxidized horizons in the subcontinental lithospheric mantle strongly imprints the elemental and isotopic patterns of these magmas, and purely asthenospheric magmas seem to be absent or rare.

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