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Diorites of the High-K Calc-Alkalic Association: Geochemistry and Sm-Nd Data and Implications for the Evolution of the Borborema Province, Northeast Brazil

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Abstract

Accretion of exotic terranes during the Cariris Velhos (late Mesoproterozoic to early Neoproterozoic) and Brasiliano (late Neoproterozoic) events has been proposed as an important process of continental growth in Borborema province, northeastern Brazil. If this hypothesis holds true, it is reasonable to assume that the roots of these accreted blocks have variable chemical and isotopic compositions. Here, we investigate this possibility using lithospheric-derived high-K calc-alkalic diorites. These rocks are widespread throughout the province and occur in areas proposed to represent distinct tectonic terranes. The similar geochemical and Sm-Nd isotopic signatures of the diorites (T_{DM} from 1.7 to 2.0 Ga), except for one pluton, impose serious limitations to the terrane accretion model in Borborema province. On the contrary, these data strongly suggest that a large portion of the province is underlain by an LILE-enriched metasomatized lithospheric mantle formed around 2.0 Ga.

Introduction

DURING THE LAST 20 years, growth of major Phanerozoic, Mesozoic, and Cenozoic continental areas has been attributed to accretion of tectonic stratigraphic terranes. Examples include the Appalachian orogen in Canada (Keppie, 1993; Curie and Parish, 1997), the northern portion of China (Zhang et al., 1997), and the southern Ural Mountains (Brown and Spadea, 1999). Limits of terranes are characterized by important discontinuities in stratigraphy or lithology, and are commonly marked by major shear zones (Coney, 1989). Identification of exotic terranes involves studies of the magmatism, of the sedimentary record and associated fossil content, and of the tectonic environment where they were formed. Difficulties applying these studies to Precambrian areas places constraints on the use of the terrane concept in old orogens. Despite these limitations, continental growth by accretion of tectonic terranes in Precambrian shields has been proposed for several regions, including the Grenville orogen in central Texas (Roback, 1996) and eastern Canada (Smith and Harris, 1996), and the Chinese (Zhao et al., 1999) and Siberian cratons (Griffin et al., 1999).

The mechanisms responsible for continental growth in Precambrian shields are still under debate. However, recent works (Wyman and Hollings, 1998; Hanmer et al., 2000) demonstrate that large orogenic systems may have developed without the need of accretion of tectonic terranes. In this work we evaluate the terrane accretion model proposed for Borborema province, northeastern Brazil, using diorites of the high-K calc-alkalic association to probe its lithospheric mantle.

Geology of the Borborema Province

Borborema province (BP) consists of gneissic and migmatitic basement complexes, mostly formed during the Transamazonian tectonic cycle (~2.0 – 2.2 Ga), partially covered by Paleoproterozoic to Neoproterozoic metasedimentary and metavolcanic rocks (Van Schmus et al., 1995; Dantas et al., 1998; Fetter et al., 2000) (Fig. 1). In addition to the Transamazonian tectonic cycle, BP was affected by the Cariris Velhos (~1.0 Ga) and Brasiliano(~0.6Ga) events. The Cariris Velhos event is represented by orthogneisses, muscovite-bearing migmatites, and metavolcanic rocks, mainly distributed in the central portion of the province (Brito Neves et al., 1995, 2000; Santos and Medeiros, 1999). The Brasiliano event affected the entire province, and was respon-

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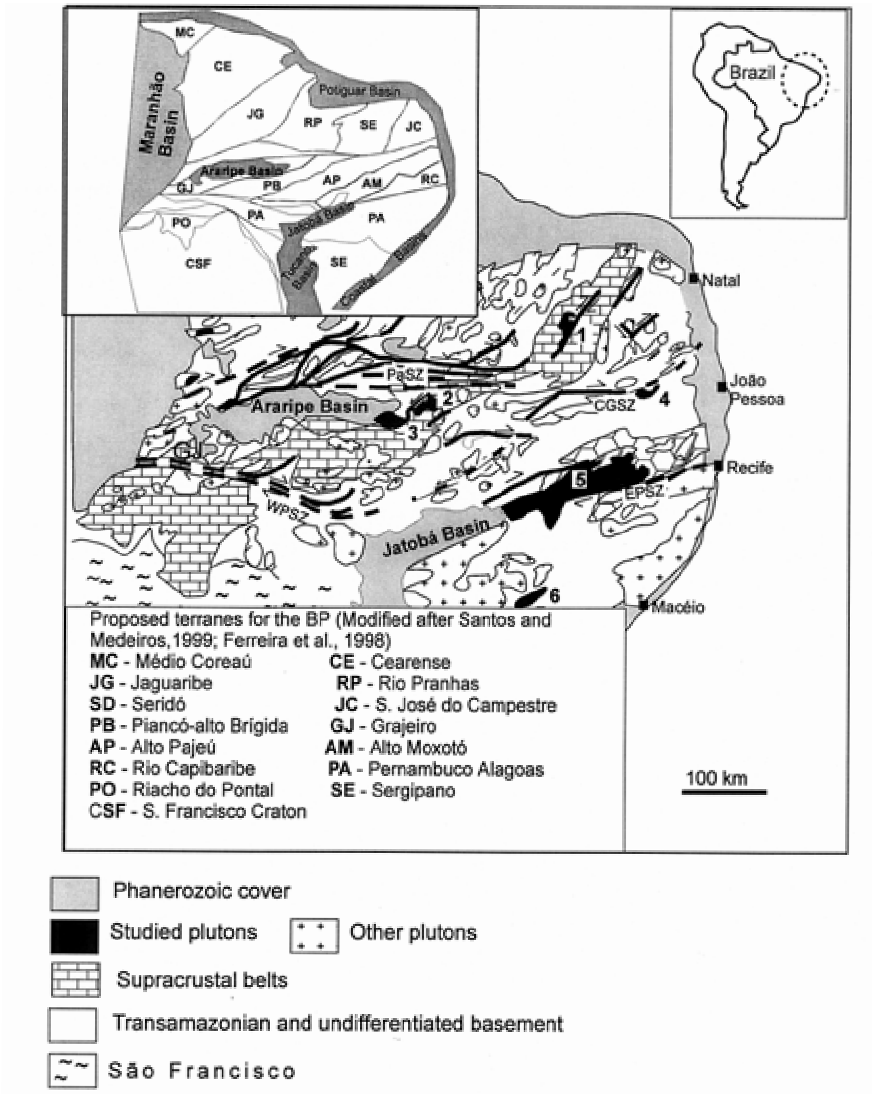

FIG. 1. Generalized geologic map of the Borborema province, Northeast Brazil.Tectonic terranes: CE = Cearense; OJ = Orós-Jaguaibe; SE = Seridó; JC = São José do Campestre; GJ = Granjeiro; PB = Piancó-Alto Brígida; AP = Alto-Pajeú; AM = Alto Moxotó; CA = Capibaribe; RP = Riacho do Pontal; PA = Pernambuco-Alagoas; SE = Sergipano. Shear zones: SPSZ = Senador Pompeu; PASZ = Patos; WPSZ = West Pernambuco; EPSZ = East Pernambuco. High-K calc-alkalic studied plutons: 1= Acari; 2 = Itaporanga; 3 = Serra da Lagoinha; 4 = Campina Grande; 5 = Caruaru-Arcoverde; 6 = Sítio Novos.

sible for low- to high-grade metamorphism, abundant and varied magmatism, and for the development of an intricate system of E-W– and NE-SW–trending, continental-scale transcurrent shear zones (Santos et al., 1984; Caby et al., 1991). The most important E-W shear zones are represented by the Patos-Campina Grande and Pernambuco systems (Vauchez et al., 1995) (Fig. 1).

The shear zones divide the province into separate segments, providing an ideal scenario for the hypothesis of continental growth controlled by accretion of exotic terranes. In the past five years, several authors (Brito Neves et al., 1995, 2000; Ferreira et al., 1998; Santos and Medeiros, 1999) suggested that the tectonic evolution of BP was controlled by this mechanism. They divided BP into three major domains, individually segmented into several terranes (Fig. 1): (1) the Pajeú River or Transversal domain, located between the Patos-Campina Grande and Pernambuco shear zone systems, encompassing the Alto Moxotó, Alto Pajeú, Piancó-Alto-Brigida, Granjeiro, and Rio Capibaribe terranes; (2) the domain south of the Pernambuco shear zone, involving the Riacho do Pontal, Sergipano, and Pernambuco-Alagoas terranes; and (3) the domain north of the Patos–Campina Grande shear zone system, including the São José do Campestre, Rio Piranhas, Seridó, Jaquaribe, Cearense, and Médio-Coreaú terranes. If the terrane model holds true, the accreted microplates should have had independent origins and tectonic histories prior to the accretionary events, and underlying lithospheric mantle blocks with distinct geochemical and isotopic signatures.

The High-K Calc-Alkalic Association

General age relations

The Brasiliano plutonic magmatism consists of several associations (Sial, 1986; Ferreira et al, 1998), of which the high-K calc-alkalic one is the most voluminous. Plutons of this association vary in size from 100 km^2 to 2000 km^2 in outcrop area, and are intrusive in distinct portions of BP where several different tectonic terranes have been proposed to exist. Despite their wide separation, up to hundreds of kilometers apart, these plutons have similar mineralogic compositions, magmatic associations, and geochemical and isotopic characteristics (Neves and Mariano, 1997). They are composed of coarse-grained to porphyritic quartz monzonites to granites, with K-feldspar megacrysts up to 10 cm in length, intimately associated with biotite diorites to quartz monzodiorites. Field evidence (contorted, diffuse, and cuspate contacts; K-feldspar megacrystals cross-cutting contacts; net-veined complexes, etc.) clearly shows the coexistence of felsic and mafic facies. The major phases of the felsic rocks are plagioclase, K-feldspar, quartz, biotite, and amphibole. Apatite, sphene, allanite, and zircon are common accessory phases. The mineralogical composition of the diorites is essentially the same as observed for the granitoids, but with greater modal abundances of biotite and amphibole, the latter in some cases showing clinopyroxene cores.

Diorites belonging to six plutons located in proposed distinct terranes in the eastern portion of BP were studied (Fig. 1): the Acarí batholith in the Serido terrane; the Itaporanga and Serra da Lagoinha batholiths along the boundary of the Granjeiro and Piancó-Alto-Brígida terranes; the Campina Grande complex in the Alto-Pajeú terrane; the Caruaru-Arcoverde batholith in the Rio Capibaribe terrane; and the Sítio Novos pluton in the Sergipano terrane.

The Acarí pluton intrudes late Neoproterozoic amphibolite-facies biotite schists. U-Pb SHRIMP ages obtained from detrital zircons show that these metasedimentary rocks are younger than 650 Ma, and Sm-Nd T_{DM} ages indicate that their protoliths are younger than 1.2 Ga (Van Schmus et al., 2000). One diorite sample dated by the zircon U-Pb method gave an age of 580 Ma (Leterrier et al., 1994), which is considered the age of crystallization of the pluton.

The Itaporanga and Serra da Lagoinha plutons intrude low- to medium-grade biotite schists. To the south and east of these plutons, the country rocks grade into a sequence of metapelithic and metavolcanic rocks. A metarhyolite yielded a zircon U-Pb age of 730 Ma and a Sm-Nd T_{DM} age of 1.3 Ga (Kozuch et al., 1997). Samples of the felsic porphyritic facies of the Itaporanga pluton dated by the whole-rock Rb-Sr method gave an isochron age of 620 ± 20 Ma (Mariano, 1989), and those dated by the ^{40}Ar-^{39}Ar method gave an age of 584 Ma in amphibole (Dallmeyer et al., 1987). The Serra da Lagoinha pluton has not yet been dated.

The Campina Grande complex and the Caruaru-Arcoverde batholith are dominantly intrusive in gneisses and migmatites, which have yielded Paleoproterozic ages ranging from 2.0 to 2.15 Ga (Van Schmus et al., 1995; Sá et al., 1997; Melo et al., 2000). Zircon U-Pb ages of 581 and 588 Ma were obtained in the felsic porphyritic facies of the Campina Grande complex (Almeida et al., 1997) and Caruaru-Arcoverde batholith (Guimarães et al., 1998), respectively. For the latter, Pb-Pb zircon ages of 588 and 591 Ma are also available (Melo et al., 2000).

The Sítios Novos pluton intrudes migmatites and older granitoids. Metarhyolites and metasediments in the vicinity of the Sitio Novos pluton have Sm-Nd T_{DM} and εNd values varying from 1.2 Ga to 1.4 Ga and –3.9 to +0.6, respectively (Silva Filho et al., 1997). A whole-rock Rb-Sr isochron, including

TABLE 1. Selected Major- and Trace-Element Chemical Data Range for the Studied Plutons[1]

Sample	SiO_2	TiO	Al_2O_3	FeO_{total}	MgO	CaO	Na_2O	K_2O	Ba	Rb	Sr
ITA	52–60.5	0.9–2.1	14.5–17.8	5.3–8.9	1.9–4.6	3.0–6.6	2.9–5.2	2.9–5.4	920–2310	89–130	650–1200
SL	53.8–58.4	1.4–2.0	16.1–17.4	7.3–8.3	1.9–3.2	4.0–6.0	3.7–4.0	3.4–4.1	1780–2120	92–110	880–960
CA	52.6–61.0	0.8–1.4	13.9–16.7	6.5–9.9	2.69–4.39	3.9–6.4	2.9–3.9	2.7–4.5	1452–1694	100–229	384–792
AC	52.4–59.4	0.9–1.6	13.8–17.8	6.5–9.9	2.6–4.5	3.9–6.4	2.9–3.9	2.7–5.8	1113–2788	64–140	665–981
CG	48.6–54.4	1.1–18	18.3–19.8	7.2–9.2	2.9–4.1	4.7–7.6	3.0–4.3	2.6–4.4	1753–4146	64–167	849–1012
SN	52.4–56.9	1.0–1.4	15.5–15.9	7.4–9.7	4.7–6.4	4.8–5.0	4.0–4.3	3.6–4.1	672–1461	193–676	737

[1]ITA = Itaporanga; SL = Serra da Lagoinha; CA = Caruaru-Arcoverde; AC = Acari; CG = Campina Grande; SN = Sítio Novos plutons.

Sources: Campina Grande pluton (Almeida, 1999); Caruaru-Arcoverde (Neves et al., 2000); Sítio Novos pluton (Silva Filho et al. 1997); Serra da Lagoinha batholith (Mariano and Sobreira, 1999); Acari (Jardim de Sá, 1994); Itaporanga batholith (Mariano, 1989; Mariano and Sial, 1990).

diorite and granite samples, gave an age of 595 Ma (ibid.).

Geochemical (major, trace, and rare-earth elements) and Sm-Nd data are available for the Acarí (Jardim de Sá, 1994), Itaporanga (Mariano, 1989; Mariano and Sial, 1990; Neves and Mariano, 1997), Serra da Lagoinha (Mariano and Sobreira, 1999), Campina Grande (Almeida, 1999), Caruaru-Arcoverde (Neves and Vauchez, 1995; Neves and Mariano, 1997; Neves et al., 2000) and Sítio Novos plutons (Silva Filho et al., 1997).

Diorites

The diorites have intermediate SiO_2 contents (51 to 61 wt%); relatively high MgO (1.9 to 6.4 wt%), CaO (3.0 to 8.0 wt%), and K_2O (2.4 to 5.8 wt%) contents (Table 1); and a K_2O/Na_2O ratio usually greater than 1.0. They are metaluminous, and transitional from subalkaline to alkaline (Fig. 2). Moderate to high Ba (670 to 4000 ppm) and Sr (400 to 1200 ppm) and low to intermediate Rb (60 to 670 ppm) contents are the main trace-element features. Rare-earth element (REE) patterns are fractionated, with ($(La/Yb)_N$ varying from 11.3 to 61.4), and with heavy REE (HREE) around 10 times chondritic values (Fig. 3). Primitive mantle-normalized multielemental diagrams show very consistent patterns, characterized by Nb and Ti negative anomalies (Fig. 4). The REE and trace-element spiderdiagrams highlight the similar geochemical signatures of the diorites in plutons tens to hundreds of kilometers apart, and support the hypothesis of a similar source.

Except for the Sitio Novos pluton, diorites have negative ε_{Nd} (600 Ma) values varying from –6.94 to –14.8, and Sm-Nd model ages from 1.5 to 2.0 Ga. (Table 2). Diorites of the Sítio Novos pluton have ε_{Nd} (600 Ma) values varying from –2.5 to –3.5 and Sm-Nd model ages from 1.2 to 1.4 Ga (Table 2). The Acari (1.7 Ga), Itaporanga (1.5 and 1.7 Ga), and Serra da Lagoinha (1.7 Ga) plutons, which are total or partially intruded into Neoproterozoic metasedimentary rocks have lower Sm-Nd model ages compared to the Caruaru-Arcoverde (1.9 to 2.0 Ga) and Campina Grande (2.0 Ga) batoliths, which intrude gneisses and migmatites of the Paleoproterozoic basement.

Diorites and felsic porphyritic rocks have similar Sm-Nd isotopic signatures (Neves and Mariano, 1997; Silva Filho et al., 1997; Almeida, 1999; Mariano and Sobreira, 1999; Neves et al., 2000). An exception is the Acari pluton, where the porphyritic granitoids have an older T_{DM} (2.0 Ga) age (Jardim de Sá, 1994).

Discussion

The geochemical signature of the diorites precludes their derivation from crustal sources or from a source with normal mantle composition. If they were derived from crustal sources, their high K_2O content should also be associated with higher SiO_2 and Al_2O_3 and lower MgO and CaO contents. On the other hand, if they were derived from a source with normal mantle composition, their high K_2O content and strongly negative ε_{Nd} values could only be

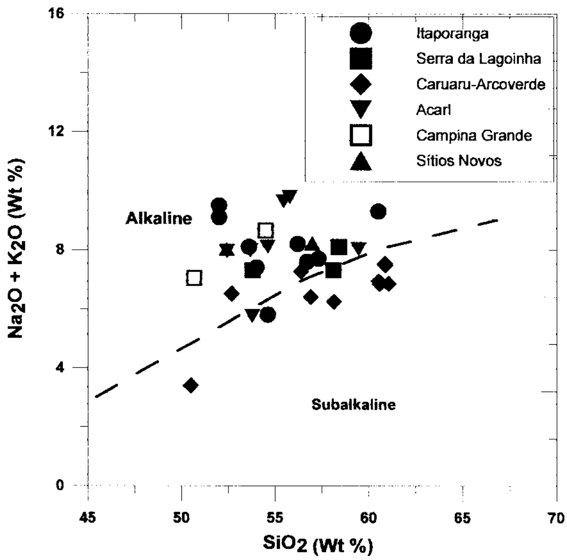

FIG. 2. Total alkali versus SiO_2 diagram. *Sources:* Itaporanga batholith (Mariano, 1989); Campina Grande pluton (Almeida, 1999); Caruaru-Arcoverde (Neves et al., 2000); Sítio Novos pluton (Silva Filho et al. 1997); Serra da Lagoinha batholith (Mariano and Sobreira, 1999); Acari (Jardim de Sá, 1994). Line separating fields from Irvine and Baragar (1971).

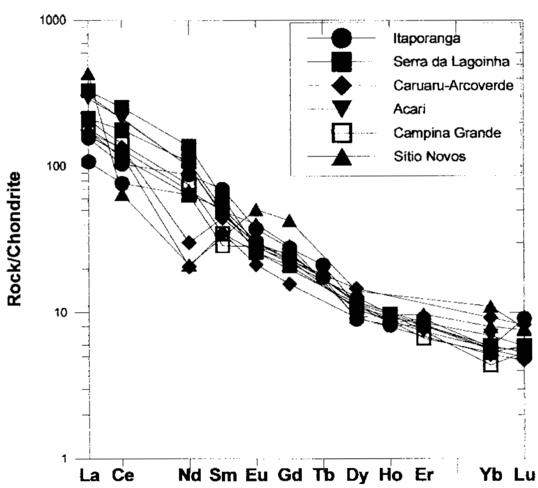

FIG. 3. Chondrite-normalized rare-earth elements. *Sources*: Itaporanga batholith (Mariano, 1989); Campina Grande pluton (Almeida, 1999); Caruaru-Arcoverde batholith (Neves et all. 2000); Sítio Novos pluton (Silva Filho et all., 1997); Serra da Lagoinha batholith (Mariano and Sobreira, 1999); Acari batholith (Jardim de Sá, 1994). Normalization factors Sun (1982).

acquired through a large proportion of assimilation of crustal rocks, which certainly would result in modified geochemical signatures (e.g., high aluminum and rubidium contents). Furthermore, the similar geochemistry of diorites from plutons hundreds of kilometers apart requires the same proportion of assimilation in all cases, which is very unlikely. The chemical signature of the diorites suggests their ori-

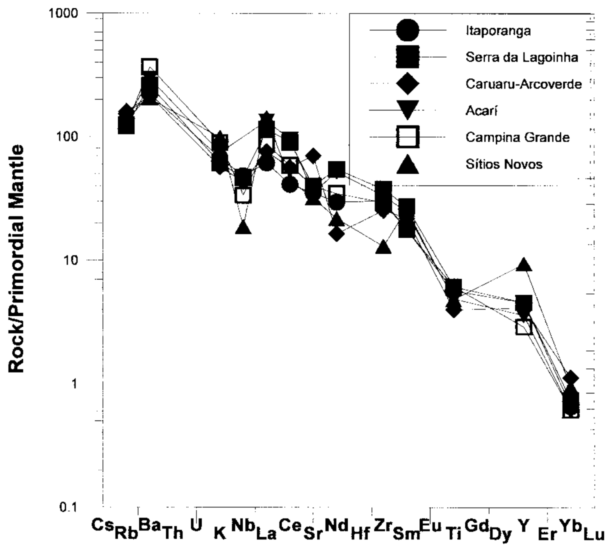

FIG. 4. Primordial mantle-normalized multi-element diagram. *Sources*: Itaporanga batholith (Mariano, 1989); Campina Grande pluton (Almeida, 1999); Caruaru-Arcoverde (Neves et al., 2000); Sítio Novos pluton (Silva Filho et al. 1997); Serra da Lagoinha batholith (Mariano and Sobreira, 1999); Acari (Jardim de Sá, 1994). Normalization factors are from Taylor and McLennan (1985).

gin from the partial melting of an anomalous, large-ion lithophile element (LILE)–enriched, metasomatized lithospheric mantle (Neves and Mariano, 1997).

Origin by partial melting of a metasomatized lithospheric mantle was proposed for other plutons in Borborema province. Examples include the ultrapotassic syenitic Triunfo pluton, located in the so-called Piancó Alto-Brigida terrane (Ferreira et al., 1997), and the shoshonitic Bom Jardim and Toritama plutons, emplaced along the southern border of the proposed Alto-Pajeú terrane (Silva Filho, et al., 1993; Guimarães and Silva Filho, 1998).

Sm-Nd model ages for the Caruaru-Arcoverde and Campina Grande plutons concentrated around 2.0 Ga (Table 1) suggest a major metasomatic event in the lithospheric mantle during the Transamazonian tectonic cycle (~2.0 Ga). The lower Sm-Nd model ages (1.5–1.7 Ga) for the Acari, Itaporanga, and Serra da Lagoinha plutons may reflect crustal contamination, inasmuch as they intrude Neoproterozoic metasediments (Van Schmus et al., 1995; Kozuch et al., 1997; Van Schmus et al., 2000). Nevertheless, their Sm-Nd model ages are closer to the Transamazonian cycle than to the latter tectonic events.

The very restricted geochemical and isotopic variation of diorites from plutons 40–600 kilometers apart suggests that the lithospheric mantle beneath much of the studied area resulted from the establishment of a large continental tract during the Transamazonian cycle, which remained as a coherent entity afterward. In this context, deposition of volcano-sedimentary successions of variable ages would have occurred in an intracratonic setting, with the Cariris Velhos event representing a major rifting episode, during which partial melting of the crust took place to generate granitic rocks.

The Sitios Novos pluton, located in the southern portion of BP, exhibits T_{DM} Sm-Nd model ages varying from 1.2 to 1.4 Ga. These model ages suggest that this portion of the Sergipano domain may represent an independent lithospheric block. Sm-Nd T_{DM} (1.2–1.4 Ga) and ε_{Nd} values (–3.9 to +0.6) from metarhyolites and metasediments in the vicinity of the Sitio Novos pluton (Silva Filho et al., 1997) corroborate this hypothesis. Another possibility is that these T_{DM} Sm-Nd model ages may have resulted from interaction between Transamazonian and juvenile material added to the lithosphere during the Brasiliano event. Diorites formed in this environ-

TABLE 2. Sm-Nd Data for the Studied Potassic Calc-Alkalic Diorites

Pluton	T_{DM}	ε_{Nd} (600 Ma)
Acarí	1.6 Ga	–11.8
Itaporanga	1.5 and 1.7 Ga	–8.8 and –6.9
Serra da Lagoinha	1.7 Ga	–11.1
Campina Grande	2.0 Ga	–9.2
Caruaru-Arcoverde	1.9 to 2.0 Ga	–14.8 to –12.1
Sítio Novos	1.2 and 1.4 Ga	–3.5 and –2.5

Sources: Campina Grande pluton (Almeida, 1999); Caruaru-Arcoverde (Neves et al., 2000); Sítio Novos pluton (Silva Filho et al. 1997); Serra da Lagoinha batholith (Mariano and Sobreira, 1999); Acari (Jardim de Sá, 1994); Itaporanga batholith (this work).

ment thus would have a mixed source composed of Transamazonian and Brasiliano lithospheres.

In addition to the geochemical arguments presented here, recent works dealing with shear-zone systems of Borborema province showed that they are not the main terrane boundaries. For instance, the Pernambuco lineament, a major dextral transcurrent E-W shear zone considered as the limit between the Rio Capibaribe and Pernambuco-Alagoas terranes (Ferreira et al., 1998; Santos and Medeiros, 1999), was recently reappraised based on field-oriented structural work (Neves and Mariano, 1999). It was concluded that the lineament is segmented into two disconnected branches—the west and east Pernambuco shear zones—as earlier proposed by Vauchez and Egydio-Silva (1992), and that its eastern portion is divided into low- and high-T, laterally and transversally discontinuous, mylonitic belts. The high-T mylonitic belt is restricted to border zones of the Caruaru-Arcoverde batholith. Based on these observations, the Pernambuco lineament is discounted as a tectonic structure responsible for the suture between distinct tectonic terranes.

Conclusions

The enrichment in LREE associated with a moderate to strongly fractionated REE pattern (although still enriched in HREE) and extremely negative ε_{Nd} (0.6 Ga) values suggests a very unusual source for high-K calc-alkalic diorites, which is likely to have been a metasomatized lithospheric mantle enriched in LILE. The requirement of an unusual source for mantle-derived rocks, which are widely distributed in Borborema province, favors the establishment of a large lithospheric tract during the Transamazonian cycle, and represents a strong argument against the model of accreted terranes.

This work demonstrates the utility of the study of mantle-derived rocks for the characterization of major Precambrian areas and emphasizes that the establishment of tectonic terranes must take into consideration their lithospheric roots, rather than only being based on the geochemical and isotopic signature of supracrustal rocks.

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