Brasiliano age peralkaline plutonic rocks of the Central structural domain, Northeast Brazil

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ABSTRACT. — The Precambrian SW-NE trending central structural domain of Northeast Brazil is comprised of three segments: the Seridò Fold Belt (SFB); the Cachoeirinha - Salgueiro Fold Belt (CSF); and the Riacho do Pontal Fold Belt (RFB). Peralkaline plutonic rocks are widespread in the CSF, where they were emplaced between 450 and 510 Ma and around 660 Ma. They constitute two syenite groups. One group is sodic to potassic, quartz-normative syenites that form ring-dikes, dike sets, and small stocks. The second group is potassic to ultrapotassic, nepheline-normative syenites aligned along the southern boundary of the CSF, forming the syenitoid line, and two dike swarms with about 50 dikes each; they are sphene and magnetite-bearing and aegirine-augite and riebeckite - arfvedsonite - rich. In its northern extension, the syenitoid line changes into quartz monzonites with shoshonitic affinities.

The silica-saturated group in the CSF is very high in K, Sr and Ba, high in P and Ti and low in Zr and Nb. MORB-normalized spidergrams show Ce, Y and Sm positive anomalies and Nb and Ti negative anomalies. The oversaturated group displays negative P and positive Zr anomalies. The possibility of an anomalously enriched mantle is suggested by high K, P, Ba, Sr and REE contents of alkali-pyroxenite inclusions in the first group. Both groups show similar REE patterns, LREE-enriched and HREE-depleted, with discrete or absent Eu anomalies, due either to the high fO_2 during crystallization or to a possible cumulate origin for these rocks. Alkali-pyroxenite inclusions display LREE-enriched and HREE-depleted patterns. MORB-normalized spidergrams for rocks with shoshonitic affinities show P, Ti and Nb negative anomalies, and Zr and Rb positive anomalies. REE patterns are LREE-enriched and approximately flat in HREE.

W.R. $\delta^{18}O$ for the saturated group (+ 6 to + 8 permil Smow), suggest differentiation from a mafic magma with minor, if any, post-magmatic alteration, or straight mantle derivation with minor crustal assimilation. The $\delta^{18}O$ values for the oversaturated group, (+ 8 to + 10 permil Smow) suggest interaction with meteoric water and more significant crustal contamination.

The regional geographic patterns displayed by the peralkaline plutons in the central structural domain seem to follow major sigmoidal fault zones, and are perhaps related to pull-apart processes along these zones, associated with the Patos-Aurora and Pernambuco transcurrent lineaments.

Introduction

The Proterozoic central structural domain (CSD) in central Northeast Brazil extends for 900 km and occupies about 90.000 km^2 with SW-NE trending metamorphic rocks. It contains the largest number of granitoids in Northeast Brazil and is comprised of three fold belt segments: the Seridò (SFB, 3a, in Fig. 1), the Cachoeirinha-Salgueiro (CSF, 3b, in Fig. 1); and the Riacho do Pontal (RPF, 3c, in Fig. 1).

Based on petrography and textural relationships, ALMEIDA et al. (1967) recognized four granite-types in the CSF and proposed a tectonic classification: a) *Conceição* and *Itaporanga*-types, syntectonic at 650 ± 30 Ma, represented respectively by epidote-bearing granodiorite and porphyritic granodiorite to granite; b) *Itapetim*-type, late tectonic at 540 ± 25 Ma, and composed of slightly porphyritic dike rocks of composition similar to the Itaporanga-type; and c) *Catingueira*-type, post-tectonic at 460-510 Ma and comprised of peralkaline aegirine-bearing quartz-syenite to granite. Later, it was noted that the Itaporanga-type has potassic-calc-
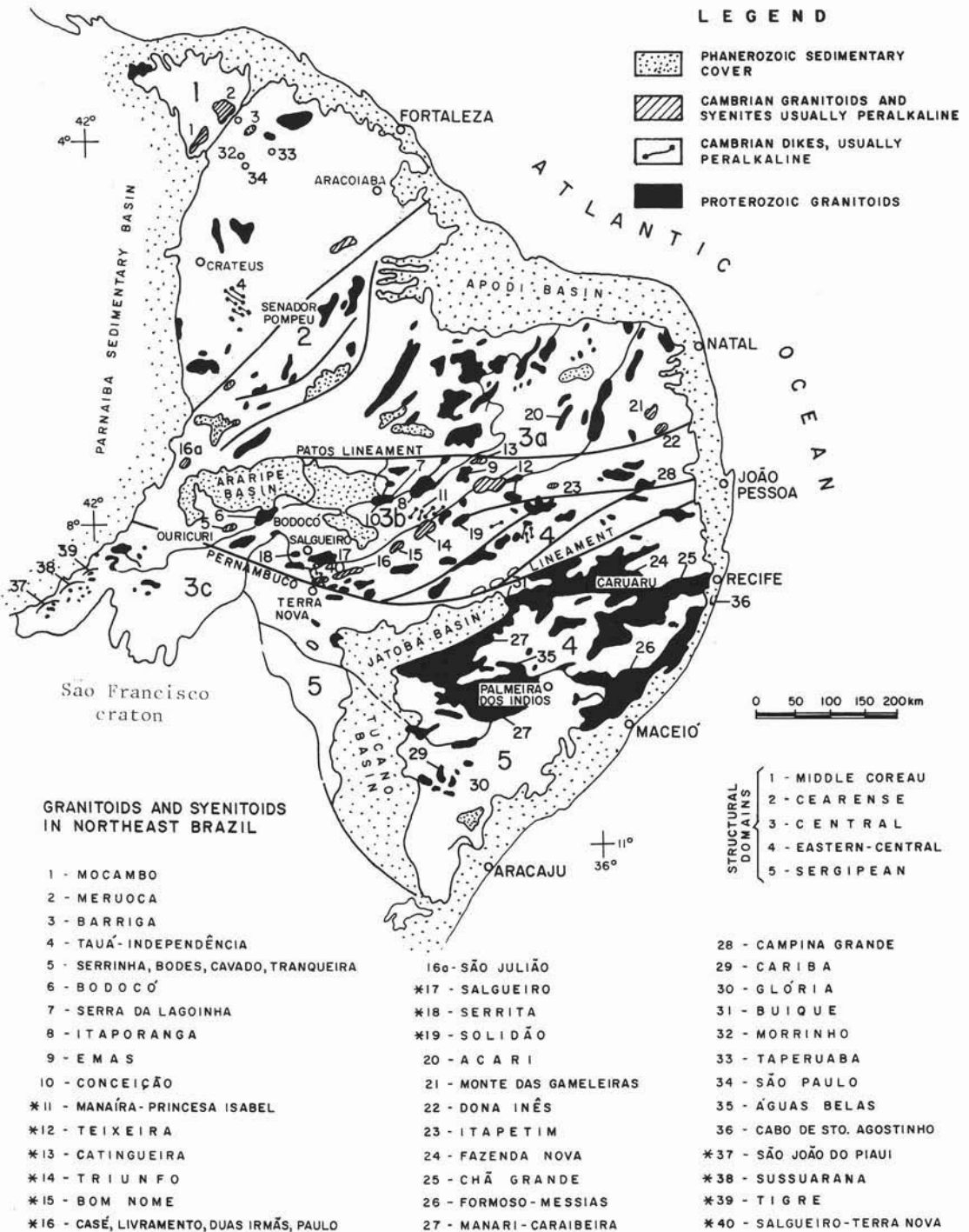
Fig. 1. — Distribution of the main granitic bodies within structural domains in Northeast Brazil (modified from SANTOS et al., 1984 and SIAL, 1987). Main peralkaline and shoshonitic granitoids in central structural domain, are marked with asterisk.
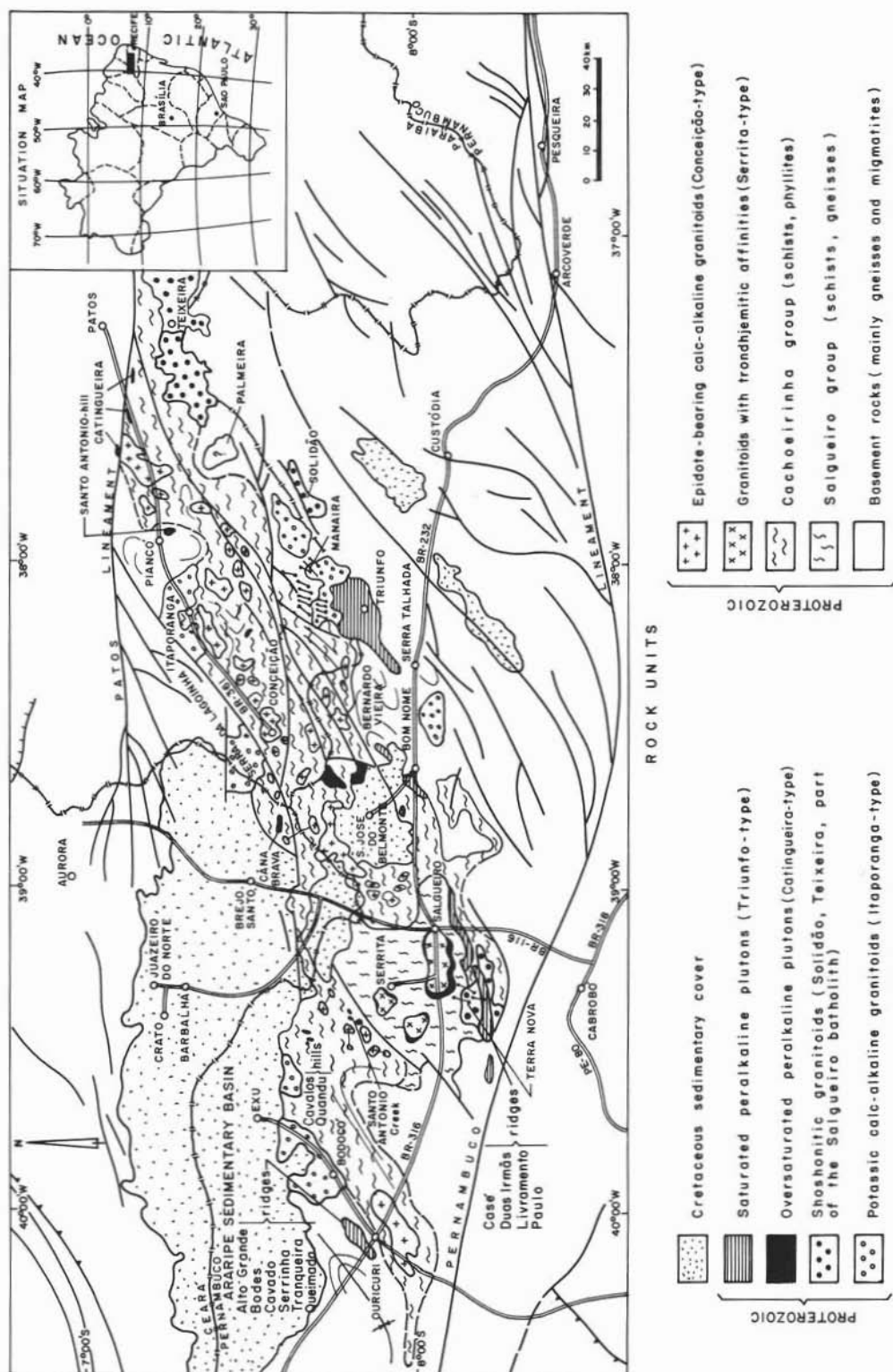
Fig. 2. — Geological sketch of the Cachoeirinha-Salgueiro Fold Belt, Northeast Brazil, where five identified granite groups are shown (modified from SIAL et al., 1987).

alkaline affinities, while the Conceição and Itapetim-types are typically calc-alkaline rocks (SIAL et al., 1981a, 1981b; SIAL, 1986). In addition, plutons with trondhjemitic affinities (Serrita-type) and a saturated peralkaline association (*Triunfo*-type) were recorded (SIAL et al., 1981a, 1981b; FERREIRA, 1986; FERREIRA and SIAL, 1986). Each group shows distinctive oxygen isotope and REE patterns (SIAL, 1984a, 1984b), and each has a clearly defined geographic distribution (Fig. 2).

The peralkaline group is widespread in the CSF and includes the oversaturated Catingueira-type (ALMEIDA et al., 1967). This is commonly associated with fault zones and intruded into Cachoeirinha metasediments (e.g. Quandu, Cavalos, Bernardo Vieira, Cana Brava), or constitutes a syenitoid line (Triunfo-type, FERREIRA and SIAL, 1986; FERREIRA, 1986; SIAL, 1986), defined by intrusions into the basement that roughly follow the southern boundary of the CSF, or discontinuously along the northern boundary (e.g. Ouricuri) of the CSF.

The knowledge of peralkaline bodies in the SFB is limited. Dike rocks such as those forming the Santa Luzia hill, near Dona Inês, Paraíba state, reported as aegirine-bearing (BARBOSA et al., 1974) are possibly equivalent to the Catingueira-type. Also, rocks with possible peralkaline affinities were mentioned for several other places (e.g. Equador, Rio Grande do Norte; SOUZA, 1987; Açu, SANTOS, 1968).

Little is known about granitoids in the RPF, located marginally to the Sao Francisco craton and south of the Pernambuco lineament (Fig. 1). The geological history of these granitoids seems to be similar to those at the CSF, although no systematic study has been carried out and only preliminary geochemical data are available.

SANTOS and CALDASSO (1978) recognized in this region syn- to late-tectonic granitic rocks of calc-alkaline to slightly alkaline nature. They also identified syn-kinematic granodiorites of diffuse contacts intruding schists and gneisses, as well as granites to syenites which intruded phyllites. This granite-syenite association is probably equivalent to the peralkaline rocks of the CSF.

GAVA et al. (1984) recognized a late to post-kinematic suite of alkaline granitoids named Serra da Aldeia, geographically distributed in three groups of plutons (Tigre, Sussuarana and São João do Piauí, Piauí state), without apparent chemical distinction among them.

Occurrence and petrography

1. The Cachoeirinha-Salgueiro Fold Belt (CSF)

(a) THE OVERSATURATED PERALKALINE GROUP OF ROCKS

Rocks in this group form stocks of variable size, dikes and ring-dikes, usually in topographic relief, intruding rather low - grade metamorphics of the Precambrian Cachoeirinha Group in the CSF (e.g. Quandu, Cavalos, Cana Brava and Campo Grande stocks, Santo Antônio dike, all in Pernambuco state), metasediments of the Salgueiro Group (ring-dikes at Serrita stock, Pernambuco), or are found near the contact of the Cachoeirinha and Seridò Group metasediments (e.g. Catingueira dike set, Paraíba state) (Fig. 2). Petrographically, they are mostly aegirine-bearing quartz-syenites to granites.

The E-W trending Catingueira dike set, with five dikes, (the longest of which is 12 km long), is composed of medium to coarse-grained leucocratic quartz syenite to granite. Modal mineralogy is essentially microcline, albite, quartz, with accessory aegirine, sphene, blue amphibole, minor biotite, magnetite, apatite and ferroaugite. Aegirine, up to 15%, is partially replaced by a blue amphibole, which, with sphene and magnetite, indicates high oxygen fugacity prevailing during crystallization. Minor fluorite was detected in two of these dikes.

Peralkaline ring-dikes are found in two small stocks near Serrita town (Fig. 2). Topographically, the cores of these stocks are at ground level, while the ring-dikes are in relief (e.g. Vassouras, Macacos, Boqueirão and Serrita hills). The cores are composed of biotite tonalite to granodiorite with trondhjemitic affinities (SIAL, 1986; FERREIRA

and SIAL, 1986). Ring-dikes are mainly aegirine-bearing quartz-alkali-feldspar syenite to alkali-feldspar granite. Mineralogically, they are similar to the Catingueira-type, except they do not contain fluorite. Instead, minor, zoned cassiterite associated with pyroxene is present. Albitization was locally important and chess-board textures in microcline are sometimes present. Cumulate textures in thin, alternating pyroxene and microcline layers (photo 1) (e.g. Boqueirão hill), sometimes offset by microfractures, forming «en echelon» structures are recorded. Narrow

An E-W trending subvolcanic dike set at about 30 km north of Serrita, along Santo Antônio Creek, encompasses aegirine-bearing trachytes. Mineralogically, they contain microcline, aegirine, and magnetite phenocrysts in a quenched, blue amphibole-rich groundmass. Microcline, sometimes mantled by albite, forms agglomerates (glomeroporphyric textures) and includes aegirine and blue amphibole. Aegirine shows discontinuous zoning with a pale green core. A brown amphibole with blue margins is also present.

Photo 1. — Cumulate textures in thin, alternate pyroxene and microcline layers, offset by microfractures in «en echelon» structure. Boqueirão hill, ring-dike at Serrita stock.

peralkaline to calc-alkaline dikes, up to one-meter wide, cut the tonalites and granodiorites of the core of the stock. The rounded Quandu and Cavalos quartz syenite stocks, Sítio dos Moreiras, Pernambuco, mineralogically resemble the Serra dos Macacos ring-dike at Serrita. Zoned microcline shows flake perthite and includes early crystallized albite and pyroxene. Aegirine shows discontinuous zoning and, as in most peralkaline rocks in the CSF, was partially converted to blue amphibole. Biotite, as in most of these peralkaline bodies, associates with pyroxene and includes zircon grains.

(b) THE SATURATED GROUP OF ROCKS AND THE SYENITOID LINE

Peralkaline rocks along syenitoid line are usually pink, aegirine-bearing, alkali-feldspar syenites, with some clots of aegirine and locally with dark, silica-enriched material (FERREIRA, 1986; FERREIRA and SIAL, 1986; SIAL, 1986).

The syenitoid line extends for about 150 km from Terra Nova, through Bom Nome to Triunfo towns. Next to Terra Nova, a discontinuous quartz alkali-feldspar syenite dike, forms the Casé, Livramento, Duas

Irmãs, and Paulo ridges, up to 4 km wide and 600 m above sea-level. It intruded biotite-schists of the Salgueiro Group and the porphyritic hornblende syenite of the Terra Nova batholith. At the Casé ridge, hornblende syenite xenoliths are abundant and reacted with the host peralkaline syenite liquid, showing rounded to diffuse contacts. Microcline shows cross-hatched twinning overprinting earlier Carlsbad twins and exhibits rows of elongate to needle-like pyroxene inclusions. Less often, it poikilitically encloses aegirine grains, blue amphibole and apatite. Aegirine phenocrysts show discontinuous zoning, gradation into blue amphibole and magnetite, and often include sphene and apatite. Biotite, usually associated with aegirine and interstitial quartz with wavy extinction, is rare.

Dark, narrow peralkaline dikes, a few meters long, related to the Terra Nova dike swarm, cut across the Casé dike, often with «en echelon» structure (photo 2) and trending N-S or E-W. They are composed of aegirine-bearing alkali-feldspar syenite.

Next to Bom Nome town, Pernambuco, a peralkaline syenite dike about 10 km long and 1.5 km wide intruded the contact zone between Cachoeirinha metamorphics and basement rocks. It is partially covered by Cretaceous sediments of the São José do Belmonte Basin. This dike is sheared and exhibits irregularly shaped, flintlike, dark portions which break conchoidally, giving the dike a composite appearance. These dark rocks are quartz-enriched, with aegirine weathered and partially transformed into blue amphibole, and hematite filling parallel fractures.

The Triunfo batholith, the most voluminous peralkaline pluton in Northeast Brazil (about 600 km^2), is elongate in the SW-NE direction, parallels the regional metamorphic trend, and is in contact with migmatites of the basement and in fault contacts with Cachoeirinha and Salgueiro Group metamorphics. In this nearly flat-topped batholith, biotite-schist xenoliths are widespread, indicating that the present level of exposure is not far from the original top of the pluton. Three faults cut across the batholith, locally generating shear fabrics and

Photo 2. — Peralkaline syenitic dike related to the Terra Nova dike swarm, cutting across the peralkaline Casé syenitic dike (part of the syenitoid line) with «en echelon» structure.

stretching lineation. Flow textures are associated with primary planar structure, and where aligned, flat, baked biotite-schist and pyroxenite xenoliths are found. Cumulate textures are shown by alternating microcline and pyroxenite layers, which are also recorded in some autoliths. Sulphides are associated with late pyroxenite or syenite veins.

Oval-shaped, globular or streaky pyroxenite inclusions (photo 3) throughout the batholith, varying from a few cm to one-meter long, are usually aligned with the flow foliation of the host syenite. These inclusions are composed of aegirine (90%), sphene, blue amphibole, and microcline. Narrow pyroxenite dikes show «boudins» (photo 4) and are regarded as syn-plutonic dikes, according to PITCHER (1979), intruded during the last stages of emplacement of the Triunfo batholith.

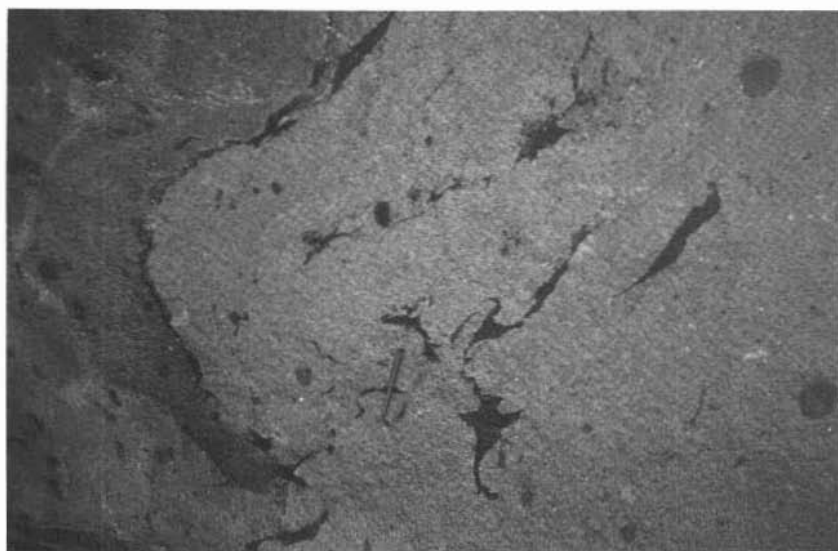Disk-like, biotite-schist xenoliths (hornfels),

Photo 3. — Clinopyroxenite inclusions of different shape and size in the Triunfo batholith.

Photo 4. — Syn-plutonic pyroxenite dike in the Triunfo batholith.

are oriented according to flow foliation of the host syenite. Some small xenoliths show coarse, recrystallized biotite, sometimes surrounded by a thin layer of fine-grained pyroxene.

Aegirine is typically oriented according to the magmatic flow and shows discontinuous zoning and pale green cores (ferroaugite?)

(photo 5). Locally, it forms aggregates in a typical cumulate texture. Aegirine often contains sphene and apatite, and when partially transformed into blue amphibole, magnetite grains are present in fractures and cleavage planes. Biotite is also seen associated with pyroxene, as in the other peralkaline plutons in the CSF. Sphene is the most
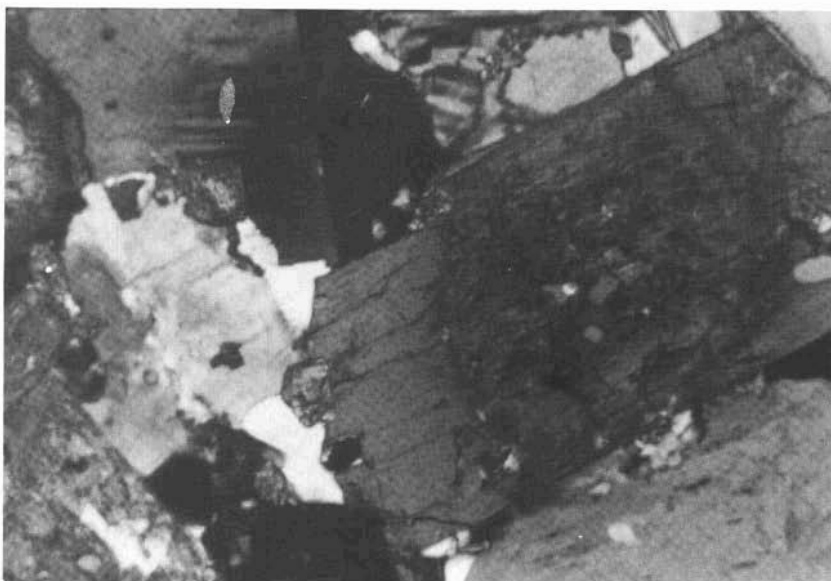
Photo 5. — Euhedral aegirine showing discontinuous zoning and partially transformed into blue amphibole, in Triunfo batholith.
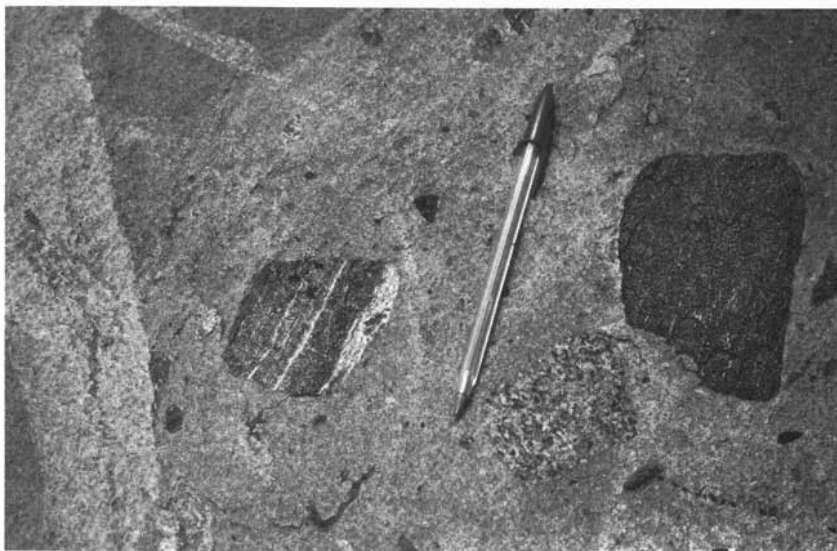

Photo 6. — Breccia structure, with fragments of meta-mafic, gabbroic and metasedimentary rocks, in a peralkaline dike of the Manaíra-Princesa Izabel dike swarm.

abundant accessory phase, often found in aegirine or microcline, and apatite is also seen in almost all other phases. Textural relationships suggest that sphene and apatite were the first phases to crystallize, followed by aegirine and microcline. Magmatic hydrothermal activity (autometasomatism) is indicated by albitization at the microcline borders, and by blue amphibole formed from aegirine. Quartz, the last phase to crystallize, is preferentially found next to fault zones, suggesting that it did not crystallize primarily

from the magma.

In the Terra Nova region of Pernambuco, over 50 peralkaline dikes, often 15-20 cm wide and up to 6 km long, intruded the Terra Nova batholith, biotite-schists of the Salgueiro Group, and the western portion of the Salgueiro batholith. These dikes show multiple trends, but are N-S where cutting the Salgueiro batholith. Another dike swarm of this kind is next to Manaíra and Princesa Izabel towns, Paraíba, north of the Triunfo batholith, with subparallel dikes intruding low grade metamorphics of the CSF and basement rocks. Narrow dikes, NE-SW-trending, 10 m wide and up to 2 km long, are in topographic relief where intruding granitic rocks. When intruding metavolcanics of the CSF, they show chilled contacts and one-meter wide hornfels aureole. Breccia structures with fragments of meta-mafic, gabbroic, and metasedimentary rocks are present (photo 6).

The rocks in these two swarms are mostly subvolcanic, varying from aegirine-bearing trachytes to syenites. Less often, quartz-alkali-feldspar syenites and alkali-feldspar granites are present.

At Terra Nova, the dikes are grey to green or brown, with predominantly aphanitic textures, and are essentially composed of aegirine, blue amphibole, orthoclase, sphene, apatite, magnetite and quartz. Similar composition is observed in the dikes of Princesa Izabel-Manaíra, except they are microscopically more similar to the Triunfo syenites.

Orthoclase is often zoned and pyroxene needle-inclusions grew according to its zones or cleavages in epitaxial growth (photo 7). Flake perthites are common, and albite is also seen as isolated grains. Pyroxene is represented by aegirine or ferroaugite with aegirinic borders, partially transformed into blue amphibole plus magnetite, forming glomeroporphyric textures. Ferroaugite, less abundant, includes apatite and sphene. Green biotite is rare, usually associated with the pale green pyroxene, and often has zircon inclusions.

In the northern boundary of the CSF, at its southwest extremity, 5 km west of Ouricuri town, Pernambuco, there is a series of aligned, elongate SW-NE trending aegirine-bearing syenite stocks. They form the Alto Grande, Bodes, Covado, Serrinha, Pelado, Tranqueira, Quixaba and Queimada hills (Fig. 2), extending for about 30 km. These rocks exhibit a metamorphic banding, dipping 30° east, overprinting an igneous layering (microcline and pyroxenite alternate layers, 5 to 10 cm thick). These structures are locally cut by orthoamphibolite dikes.

At the Serrinha hill, the meta-syenite is interlayered with meta-gabbro, locally tightly folded (photo 8) and with «boudins». Biotite-schist megaxenoliths partially baked are sometimes found. Small, angular pieces of such baked rocks are found in pegmatite dikes which lack signs of deformation and whose vugs are filled with black to white calcite or show a yellowish non-identified material.

In the syenite, aegirine grains show preferential orientation forming bands with which recrystallized quartz may be associated, and forming sub-grains in poikiloblastic textures. Some aegirine was transformed into blue amphibole along its cleavage planes and fractures, in which magnetite is associated. Biotite shows wavy extinction and kink bands, and apatite and sphene are the main accessory phases.

The meta-gabbros are composed of albite and amphibole which form agglomerates, or are disposed in parallel bands where the amphibole is preferentially euhedral.

(c) ROCKS WITH SHOSHONITIC AFFINITIES

Among the rocks in this group, those which form the Solidão and Teixeira batholiths, in the prolongation of the syenitoid line (Fig. 2), are the most important ones. At Solidão, the rocks are essentially quartz-monzonites, while at Teixeira they tend to be mostly quartz-syenites. Besides these two plutons, the eastern portion of the Salgueiro batholith, Pernambuco, bears some shoshonitic tendencies.

The Solidão batholith, next to Solidão village, is elongate NE-SW, occupies 140 km, forms the Solidão and Queimada hills and intrudes gneisses and migmatites of the
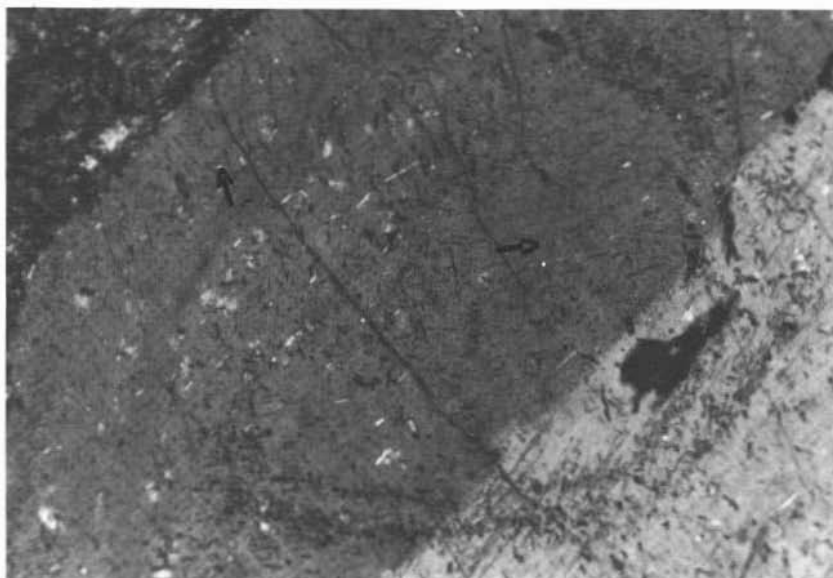
Photo 7. — Zoned orthoclase showing pyroxene needle-inclusions, grown according to its zones or cleavages, in a dike of the Manaíra-Princesa Izabel dike swarm.

Photo 8. — Meta-syenite interlayered with meta-gabbro, tightly folded, near Ouricuri town, Pernambuco.

basement. The Teixeira batholith is elongate in the E-W direction, 60 km long and about 10 km wide, and forms the Borborema and Teixeira hills. This pluton intruded quartzites and biotite-schists to the north and gneisses and quartzites to the south.

Both batholiths are predominantly equigranular, leucocratic rocks. In the Solidão batholith, albite and microcline predominate over quartz, which often shows wavy extinction and forms sub-grains. Bluish-green amphibole (probably ferroedenite) is the main

mafic mineral, with pale green pyroxene cores. Minor biotite, associated with amphibole, partially altered to chlorite, includes zoned zircon grains and apatite. Ferroaugite is relatively rare in the Solidão batholith and usually exhibits borders transformed into amphibole. Sphene is the main accessory phase, included in all major phases.

In the Teixeira batholith, perthitic microcline (flake and veined perthite) predominates over plagioclase and quartz. Plagioclase in contact with microcline, usually exhibits drop-like quartz inclusions, mymerkites, and is often deformed with bent twinning planes and wavy extinction. Quartz forms subgrains and equilibrium textures with grains boundaries meeting at 120° angles.

Among the mafic phases, bluish-green amphibole (probably ferroedenite) is the main phase, sometimes forming agglomerates. It shows simple twinning and inclusions of zircon, apatite and sphene. Biotite is found included in amphibole and also shows inclusions of zircon. Primary epidote is found as euhedral to subeuhedral grains, included in biotite or the border of the amphibole, in textural relationships similar to those described by ZEN and HAMMARSTROM (1984). Some epidote grains have allanite cores.

The eastern portion of the composite Salgueiro batholith, one of the largest plutons in the west of Pernambuco, next to Salgueiro town, petrographically resembles the Solidão batholith. It is composed of rather homogeneous, coarse-grained porphyritic quartz-monzonite to quartz-syenite. This pluton was late to posttectonic emplaced and pierced the Precambrian biotite-schists of the Salgueiro Group.

Mafic minerals usually occupy less that 10 percent of the volume of the rocks. Pyroxene (ferrosalite to ferroaugite), as elongate grains, was partially transformed into a bluish-green amphibole. Ferroedenite often forms clots, and biotite flakes, strongly pleochroic within amphibole or replacing this mineral, are also present. Flame perthite and, less often, patch perthite, seems to have partially replaced plagioclase, which in turn appears to assimilate and corrode microcline. Oscillatory zoned microcline, although not common, is also present. Quartz grains are sub-plates and often include pyroxene or amphiboles. Zoned zircons are in almost all phases. Zoned allanite is surrounded by epidote and apatite needles are often found within amphibole and biotite. Iron oxide minerals are usually absent.

Slightly porphyritic fine-grained dikes, dark green to black, one meter-wide at most, cut the Salgueiro batholith. In a few places, white or pink feldspar phenocrysts of microcline, up to 0.5 cm long are observed. Their mineralogy includes microcline, amphibole, magnetite, chlorite, quartz and epidote. Microcline often has magnetite inclusions, oscillatory zoning, fractures filled by quartz, and plagioclase mantles. Quartz in small amounts, usually interstitial, shows wavy extinction, and alkali-amphibole exhibits strong pleochroism from blue to violet.

2. *The Seridò Fold Belt*

At this belt, BARBOSA et al. (1974) referred to the Santa Luzia pluton near Dona Inês town, Paraíba, and to elongate plutons trending SW-NE and roughly paralleling the Cacerengo Fault zone, as hedenbergite or aegirine-bearing granitoids.

Between Picuí and Barra de Santa Rosa, Paraíba, a large elongate pluton, slightly porphyritic, with brownish feldspar, exhibits quartz-monzonitic composition. Similar to the rocks in the Teixeira batholith, it perhaps represents its northern prolongation, beyond the Patos lineament. Among the three groups of granitoids recognized by SANTOS (1968) in Açu region, Rio Grande do Norte, he recognized a late-orogenic one, composed of monzonite-adamellite and alkali-syenite-granite associations, the latter being probably equivalent to the Catingueira-type of ALMEIDA et al. (1967).

Next to Equador, not far from the Patos lineament, Rio Grande do Norte, sheets of biotite-monzosyenitic to clinopyroxene-monzosyenitic gneisses are interpreted as having shoshonitic character, and having intruded rocks of the Archean basement (Caicò complex) and Jucurutu and Equador Proterozoic supracrustal (SOUZA, 1987). They do not pierce, however, metamorphics of the

TABLE 1

Representative chemical analyses of the main peralkaline plutons along the syenitoid line (from SW to NE), peralkaline dike swarms and of rocks with shoshonitic affinities

a) Major elements (wt %)

	SATURATED PERALKALINE PLUTONS									SHOSHONITIC PLUTONS				
	SL-1	SD1-1	TN-2	BN-1	TRF-3	TRF-11	TRF-14	PI-02	PI-1	SOL-1	SOL-2	TX-2	TX-3	AS-119A*
SiO2	61.20	62.60	59.10	62.10	58.80	59.90	61.00	60.60	60.10	70.50	69.30	66.70	68.00	64.52
TiO2	0.24	0.48	0.86	0.08	0.71	0.46	0.56	0.62	1.10	0.19	0.17	0.29	0.18	0.38
Al2O3	13.10	10.70	13.80	15.80	13.50	14.90	15.20	13.00	13.00	13.20	14.30	14.30	14.20	16.54
Fe2O3	2.60	3.70	1.80	1.40	3.60	3.10	2.40	5.80	6.20	0.42	0.42	1.10	0.56	0.87
FeO	1.18	1.33	4.58	9.74	2.30	1.15	0.86	1.01	0.54	1.33	1.33	1.62	1.48	1.15
MnO	0.05	0.11	0.13	0.04	n.d.	n.d.	n.d.	n.d.	n.d.	0.04	0.04	0.07	0.05	0.12
MgO	2.40	2.80	3.40	1.40	2.30	1.10	1.00	1.50	1.30	0.56	0.79	1.70	1.30	0.28
CaO	4.10	4.00	5.20	2.30	4.10	2.60	2.50	0.77	1.80	1.30	1.10	2.50	2.40	2.67
Na2O	2.70	2.30	3.60	1.40	3.50	3.80	2.70	2.30	3.80	5.00	5.50	4.90	5.50	4.85
K2O	10.40	9.90	5.60	12.40	9.70	11.60	12.20	12.10	10.80	6.00	5.90	4.90	4.70	5.84
P2O5	0.72	0.68	0.53	0.29	0.33	0.28	0.26	0.43	0.25	0.10	0.11	0.15	0.11	0.19
CO2	0.25	0.41	0.41	0.88	0.05	0.05	0.07	0.78	0.50	0.25	0.40	0.23	0.25	n.d.
H2O+	0.66	0.26	0.50	0.25	0.13	0.15	0.18	0.06	0.19	0.26	0.26	0.58	0.47	0.08
H2O-	0.34	0.03	0.22	0.29	0.20	0.18	0.00	0.10	0.10	0.16	0.16	0.16	0.13	1.26
Total	100.04	99.30	99.73	99.37	99.22	99.27	98.93	99.27	99.68	99.51	99.48	99.20	99.33	98.75
K2O/Na2O	3.85	4.30	1.56	8.86	2.77	3.05	4.52	5.26	2.84	1.20	1.13	1.00	0.85	1.20
a.i.	1.17	1.35	0.87	0.99	1.20	1.26	1.16	1.30	1.38	1.11	1.04	0.93	0.99	0.86

b) CIPW norms

	SL-1	SD1-1	TN-2	BN-1	TRF-3	TRF-11	TRF-14	PI-02	PI-1	SOL-1	SOL-2	TX-2	TX-3	AS-119A*
q	2.84	10.56	3.70	3.44	0.00	0.00	0.00	3.03	0.71	19.70	15.21	13.42	13.03	9.42
or	61.46	58.42	33.09	73.28	58.00	69.32	73.06	72.30	64.54	35.46	34.87	28.96	27.78	35.43
ab	9.48	0.00	30.46	11.85	9.16	5.05	8.19	0.00	6.82	34.49	40.71	41.46	46.54	42.13
an	0.00	0.00	4.96	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.55	0.18	6.28
ne	0.00	0.00	0.00	0.00	3.50	3.87	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ac	7.52	10.71	0.00	0.00	10.54	7.07	7.04	17.09	18.14	1.22	1.22	0.00	0.00	0.00
ns	1.12	1.70	0.00	0.00	0.55	2.33	1.11	0.10	1.17	1.50	0.45	0.00	0.00	0.00
ks	0.08	0.02	0.00	0.00	0.00	0.00	0.58	0.15	0.00	0.00	0.00	0.00	0.00	0.00
wo	0.00	0.00	7.59	0.10	10.19	5.98	5.45	0.70	4.38	1.49	0.91	4.41	4.95	0.80
di	9.16	8.30	4.49	2.93	4.73	2.57	1.25	0.12	0.00	2.05	0.91	1.56	2.73	1.54
hd	2.49	1.92	4.95	2.18	0.00	0.00	0.00	3.48	1.25	0.70	1.54	2.19	0.94	1.91
en	1.73	3.13	3.36	0.09	0.00	0.00	0.00	0.70	0.89	1.11	1.70	0.89	0.60	0.00
fs	0.54	0.83	2.61	2.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	0.81	1.29
mt	0.00	0.00	1.63	0.15	1.36	0.88	1.08	1.30	1.15	0.36	0.32	0.55	0.34	0.74
il	0.00	0.91	1.26	0.69	0.79	0.67	0.62	1.04	1.15	0.24	0.26	0.36	0.26	0.46
ap	1.71	1.61	0.93	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.52	0.55	0.00
cc	0.57	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00
tn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 1 (Continued)

Representative chemical analyses of the main peralkaline plutons along the syenitoid line (from SW to NE), peralkaline dike swarms and of rocks with shoshonitic affinities

c) Trace elements (ppm)

	SL-1	SDI-1	TN-2	BN-1	TRF-3	TRF-11	TRF-14	P1-02	P1-11	SOL-1	SOL-2	TX-2	TX-3	AS-119A*
Rb	330	270	160	310	210	240	310	330	350	140	130	94	90	110
Sr	680	1090	1050	670	650	750	550	310	520	1840	1740	2290	1940	2710
Ba	2300	6200	1510	7000	5600	4600	5540	4900	4500	5200	4230	4460	3600	6800
Th	< 15	< 15	< 15	< 15	n.d.	n.d.	< 25	< 25	n.d.	< 15	< 15	< 15	< 15	n.d.
Ta	< 15	< 15	< 15	< 15	n.d.	n.d.	< 25	< 25	n.d.	< 15	< 15	< 15	< 15	n.d.
Zr	290	510	430	160	48	27	14	300	600	450	340	480	410	112
Nb	< 20	< 20	22	< 10	< 20	< 20	< 20	28	22	< 20	< 20	< 20	n.d.	20
Hf	< 200	< 200	< 200	< 200	n.d.	n.d.	< 200	n.d.	n.d.	< 200	< 200	< 200	n.d.	n.d.
Y	50	32	30	< 10	36	< 10	14	44	66	< 10	< 10	< 10	n.d.	n.d.

d) Rare-earth elements (ppm)

	Si-1	SDI-1	TN-2	BN-1	TRF-3	TRF-11	TRF-14	P1-02	P1-11	SOL-2	TX-2	TX-3	AS-119A*
La	n.d.	n.d.	75.70	21.30	67.62	33.29	19.03	94.50	118.60	28.80	25.10	32.40	43.55
Ce	n.d.	n.d.	134.30	35.80	123.10	56.50	40.00	168.10	190.40	47.30	42.30	56.20	83.65
Nd	n.d.	n.d.	65.30	19.20	60.77	27.85	18.02	73.10	74.20	29.90	26.50	27.30	30.30
Sm	n.d.	n.d.	13.10	3.80	15.65	6.64	5.05	18.50	17.60	3.60	3.50	4.90	5.62
Eu	n.d.	n.d.	3.10	0.98	3.04	1.18	0.97	3.20	3.40	1.06	1.04	1.38	1.84
Gd	n.d.	n.d.	7.99	3.20	10.42	3.68	2.90	11.70	11.20	2.80	2.61	3.30	3.78
Dy	n.d.	n.d.	6.50	2.40	6.98	1.83	1.76	7.90	9.10	1.85	1.66	2.20	1.87
Ho	n.d.	n.d.	1.16	0.38	1.64	0.36	0.24	1.40	1.80	0.27	0.26	0.33	0.00
Er	n.d.	n.d.	3.20	1.29	3.54	0.85	0.56	3.80	4.90	0.81	0.76	1.00	0.58
Tm	n.d.	n.d.	n.d.	n.d.	0.42	0.13	0.10	0.42	0.77	n.d.	n.d.	n.d.	n.d.
Yb	n.d.	n.d.	2.50	1.14	2.54	0.59	0.50	2.90	4.90	0.71	0.76	0.86	0.00
Lu	n.d.	n.d.	0.33	0.19	0.39	0.16	0.07	0.37	0.64	0.09	0.13	0.13	n.d.
T.REE	n.d.	n.d.	315.19	89.68	296.01	133.06	89.20	385.89	437.51	108.19	98.52	130.66	179.12
LaN/SmN	n.d.	n.d.	3.63	3.52	2.72	3.78	2.37	3.21	4.24	5.02	4.51	4.16	4.85
CeN/YbN	n.d.	n.d.	13.94	8.13	12.55	24.81	20.69	15.00	10.05	17.20	14.41	16.94	37.55**
Eu/EuN	n.d.	n.d.	0.79	0.83	0.66	0.66	0.71	0.62	0.69	0.98	1.01	0.99	1.18

Aegirine-augite syenites: SL= Livramento dike; SD1= Duas Irmãs dike; TN= Casé dike; BN= Bom Nome dike; TRF= Triunfo batholith; P1= Princesa Isabel-Manaíra dike swarm; DTN= Terra Nova dike swarm. Quartz-monzonite; SOL= Solidão batholith. Quartz syenite; TX= Teixeira batholith; AS= Salgueiro batholith. * Silva Filho, 1982.
** = CeN/ErN.

TABLE 2

Representative chemical analyses of oversaturated peralkaline bodies within the Cachoeirinha-Salgueiro Fold Belt

OVERSATURATED PERALKALINE PLUTONS

a) Major elements (wt %)

	SM-2	SM-3	DC-5	CAT-1	DCG-1	DU-1	SSA-2	SG-1
SiO_2	71.10	66.00	66.10	68.90	67.70	62.50	66.70	69.92
TiO_2	0.30	0.31	0.14	n.d.	0.15	0.35	0.12	0.14
Al_2O_3	14.60	16.60	16.80	14.90	15.00	15.80	15.00	16.20
Fe_2O_3	1.40	1.50	1.20	1.10	0.90	2.60	0.74	0.79
FeO	0.64	0.57	0.43	1.28•	0.72	0.78	0.86	0.28
MgO	0.27	0.18	0.17	1.40	0.43	0.57	0.14	0.27
CaO	1.20	0.91	0.57	1.40	1.10	2.40	0.53	0.37
Na_2O	6.20	6.40	6.40	5.00	5.30	4.30	6.40	4.30
K_2O	3.40	5.80	6.20	6.40	7.10	8.80	8.10	6.70
P_2O_5	0.07	0.08	0.06	0.10	0.10	0.23	0.05	0.06
H_2O+	0.15	0.16	0.09	0.28	0.18	0.52	0.13	0.23
H_2O-	0.10	--	0.27	0.18	0.20	0.05	0.12	0.26
CO_2	n.d.	n.d.	0.22	n.d.	<0.55	0.36	--	0.40
Total	99.33	98.51	98.65	99.88	98.93	99.26	98.94	99.92
K_2O/Na_2O	0.55	0.91	0.97	1.28	1.34	2.05	1.27	1.56
a.i.	0.95	1.01	1.03	1.02	1.09	1.05	1.28	0.88

b) CIPW norms

	SM-2	SM-3	DC-5	CAT-1	DCG-1	DU-1	SSA-2	SG-1
q	20.43	5.78	5.49	12.63	10.81	1.68	9.08	21.62
c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28
or	34.17	34.85	37.13	37.81	42.60	51.89	48.30	39.82
ab	49.16	53.99	52.60	41.02	38.20	32.83	32.50	31.80
ac	0.00	0.00	2.02	1.14	2.64	3.68	2.17	0.00
ns	0.00	0.00	0.00	0.00	1.01	0.00	4.64	0.00
ks	0.00	0.00	0.00	2.57	0.00	2.75	0.00	0.00
wo	1.14	0.94	0.93	1.07	2.15	3.12	0.45	0.68
di	0.65	0.49	0.26	1.51	1.88	0.00	1.56	0.00
hd	0.49	0.45	0.00	0.00	0.09	0.00	0.14	0.68
en	0.04	0.00	0.00	0.00	0.09	0.00	0.57	0.57
fs	0.03	0.00	0.75	1.02	0.29	1.52	0.23	0.27
mt	0.78	0.67	0.27	0.40	0.00	0.68	0.00	0.40
il	0.36	0.43	0.00	0.00	0.24	0.32	0.00	0.97
hm	0.21	0.37	0.00	0.00	0.00	0.55	0.12	0.14
nc	0.00	0.00	0.14	0.24	0.00	0.00	0.00	0.00
ap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97
tn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

younger Seridò Group. Although Souza (1987) proposed that those gneisses were anorogenic plutons equivalent to alkaline orthogneisses of the west Pan-African chain described by Caby (1984), their relative time of emplacement is not clear. They are composed of ferrosalite to ferrohedenbergite, ferrohastingsite, magnetite, sphene, microcline and plagioclase.

3. The Riacho do Pontal Fold Belt

At the northwest portion of this belt, Piauí state, a number of late to posttectonic granitoids, the so-called «Serra da Aldeia suite», forms round to elongate stocks and dikes which pierce low-grade metamorphics, the Phanerozoic Paraíba sedimentary basin. They are in topographic relief, as in Aldeia hill, or partially eroded to ground level, as near

TABLE 2 (Continued)
Representative chemical analyses of oversaturated peralkaline bodies within the Cachoeirinha-Salgueiro Fold Belt

c) Trace elements (ppm)

	SM-2	SM-3	DC-5	CAT-1	DCG-1	DU-1	SSA-2	SO-1
Rb	75	71	140	150	140	150	180	220
Sr	1660	1870	1170	1320	1080	1500	470	240
Th	n.d.	n.d.	n.d.	n.d.	n.d.	<25	n.d.	<15
Ta	n.d.	n.d.	n.d.	n.d.	n.d.	<25	n.d.	<15
Nb	52	29	30	10	24	28	24	16
Hf	n.d.	n.d.	n.d.	n.d.	n.d.	<200	n.d.	<100
Y	<10	<10	<10	11	16	28	<10	8
Zr	360	74	106	70	220	92	139	100
Ba	3700	6800	3900	5210	3600	4000	6700	3700
Zn	88	83	72	n.d.	49	n.d.	46	n.d.
Ga	14	12	12	n.d.	n.d.	n.d.	9	n.d.

d) Rare-earth elements (ppm)

	SM-2	SM-3	DC-5	CAT-1	DCG-1	DU-1	SSA-2	SO-1
La	80.37	60.03	14.61	28.72	30.59	23.20	16.44	21.12
Ce	139.80	120.90	28.10	74.68	47.60	50.50	32.60	33.70
Nd	59.87	60.63	14.43	36.83	20.38	32.90	14.71	13.57
Sm	12.48	12.63	3.58	8.53	4.38	7.50	3.43	2.01
Eu	2.91	1.92	0.91	2.57	1.05	1.90	0.89	0.678
Gd	6.75	6.68	2.54	6.69	2.73	4.90	2.28	1.60
Dy	3.86	3.31	2.02	4.41	1.85	4.00	1.94	1.41
Ho	0.57	0.46	0.17	0.74	0.18	0.82	0.18	0.238
Er	1.34	0.85	0.37	1.88	0.33	1.90	0.64	0.455
Im	0.18	0.14	0.06	n.d.	n.d.	0.21	0.10	n.d.
Yb	1.45	0.83	0.79	1.33	0.69	1.70	0.96	0.564
Lu	0.21	0.11	0.14	n.d.	0.09	0.20	0.16	0.090
T.REE	309.79	269.48	67.72	166.38	109.44	129.73	74.33	75.435
LaN/SmN	4.05	2.99	2.57	2.10	4.39	1.94	3.02	6.615
CeN/YbN	24.96	37.68	9.21	12.35	17.85	7.62	8.79	15.465
Eu/Eu*	0.88	0.87	0.91	1.02	0.86	0.90	0.92	

Quartz-alkali-feldspar syenite: STM= Serrote dos Cavalos; SM= Serra dos Macacos ring dike; DC; CAT= Catingueira dike; DCG= Campo Grande dike; DU= Urtiga, quartz-alkali trachyte; SSA= Serra de Santo Antônio dike.

Tigre and Sussuarana villages or São João do Piauí town. The plutons at Tigre petrographically resemble the rocks at the ring-structure in Serrita and locally crosscut granitoids similar to the calc-alkaline Conceição-type granitoids in the CSF.

GAVA et al. (1984) used textural relationships and WRIGHT's plot (1969) to identify several types of granitoids bearing alkaline to peralkaline affinities. Among them are fluorite-bearing alkali-pyroxene granodiorites, granites and syenites, and porphyritic, amphibole quartz monzonites and biotite granite. Hastingsite granites with biotite and ilmenite form plutons, diapirically emplaced, with incipient foliation next to their margins.

Geochronology

ALMEIDA et al., (1967) suggested that the

synorogenic granodiorites, tonalites and calc-alkaline granites in the CSF were emplaced between 650-520 Ma, and that the peralkaline granites and syenites are younger (Cambro-Ordovician).

HURLEY et al. (1967) determined a K-Ar age of 530 ± 30 Ma for the Serrita stock, which is probably its cooling age. Rb-Sr dating of the stock was not successful because of its high Sr and low Rb (SIAL and FERREIRA, 1985), similar to the Salgueiro batholith. A low initial Sr ratio of around 0.7040, however, was identified.

Recently, $^{40}Ar/^{39}$ Ar (R.D. Dallmeyer, unpublished data) and Rb-Sr (L.E. Long, unpublished data) determinations have been carried out. $^{40}Ar/^{39}$ Ar ages range from 625 Ma (hb) to 605 Ma (bi) for Conceição-type calc-alkaline plutons, and a value 620 Ma was found by Rb-Sr for the Itaporanga plutons. As one of the peralkaline dikes in the Catingueira dike set cuts the calc-alkaline Emas batholith of the Conceição-type, a younger age for the Catingueira dike set is expected. For the Triunfo batholith in the syenitoid line, W. Teixeira (in BRITO NEVES, 1982) determined a Rb-Sr isochron around 660 ± 60 Ma with an initial ratio of 0.7076. Crosscut relationships indicate two Brasiliano (= Pan-African) age peralkaline magmatisms in the CSF and surrounding regions. The older one is represented by syenites in the syenitoid line that are crosscut by the Terra Nova dike swarm, which also cuts the Salgueiro batholith. Possibly the Ouricuri peralkaline syenite represents an older event, considering its gneissic fabric.

Geochemistry

1. *The Cachoeirinha-Salgueiro Fold Belt*

Major and trace elements

(a) PERALKALINE ROCKS AND THE SYENITOID LINE

Representative chemical analyses of the main peralkaline rocks and those with shoshonitic affinities in the syenitoid line and within the CSF are in Tables 1 and 2, including major, trace, rare-earth elements (REE) and CIPW norms.

The syenites in the Livramento, Duas Irmãs and Casé ridges are quartz normative, while the Triunfo, the largest pluton, is nepheline-normative. Except for the Casé and Bom Nome bodies, all are acmite and Na-metasilicate-normative rocks. With one exception, all of them are very K-enriched (K_2O up to 12.80%), which lends to these rocks a potassic to ultrapotassic character, with $K_2O/Na_2O > 3.0$.

The oversaturated peralkaline rocks show a broader SiO_2 variation than those at the syenitoid line (60 to 71%), and K_2O/Na_2O varies from 0.54 to 2.84, lower than in the saturated peralkaline group of rocks. They are sodic to potassic according to the DEBON and LEFORT (1983) classification, and also quartz, acmite and Na-metasilicate-normative rocks.

In the QAP diagram (Fig. 3), modal compositions of the saturated peralkaline group follow the alkaline-peralkaline trend of LAMEYRE and BOWDEN (1982), while the oversaturated peralkaline group and rocks with shoshonitic affinities follow the monzonite (high K) trend.

The type of granitic magmatism can be identified using the R1-R2 diagram (DE LA ROCHE et al., 1980), where the milicationic parameter R1 = 4Si-11 (Na + K)-2 (Fe + Ti) opposes quartz to alkali feldspars and Fe-Ti minerals, and R2 = Al + 2Mg + Ca expresses anorthite and mafic minerals. In Fig. 4a the syenites in the syenitoid line show a positive trend, which seems to follow the source trend visualized by BATCHELOR and BOWDEN (1985), mostly, however, in the undersaturated field of the diagram. This trend reflects the constant increase in alkalis, especially K, and the decrease in Ca + Mg + Al, generating the ultrapotassic character of these rocks. Two samples lie in the late-orogenic field of the diagram, in agreement with field observations. Two pyroxenite samples also plot in the undersaturated field, corresponding approximately to an alkali-gabbro composition in the DE LA ROCHE et al. classification (1980), at the extension of the saturated peralkaline trend.

The oversaturated plutons exhibit a trend

distinct from the saturated peralkaline trend, with R2 approximately constant and a broad range of R1, a result of major variation of total alkalis.

In the AFM plot (Fig. 5c), the saturated peralkaline group shows a trend which suggests little enrichment in Fe during differentiation, compatible with a high oxygen fugacity during crystallization. This contention is supported by the presence of sphene and magnetite in most rocks of this group.

Rocks of the saturated peralkaline group cluster in the alkaline field in the alkalis versus SiO_2 plot (Fig. 6a), while those in the oversaturated group cluster along the shoshonitic group of granitoids. Besides the remarkable K-enrichment in the saturated group, it is also extremely enriched in Sr and Ba, low in P, Ti, Zr and Nb. MORB-normalized spidergrams (Fig. 7) enhance the strong enrichment in Sr, K and Rb relative to Yb, and show slightly positive anomalies in Sm and Y, and marked troughs in P and Ti. When normalized to primordial mantle (Fig. 8), the strong enrichment in Rb, Ba, K and Sr besides Nd and Sm, is confirmed. The oversaturated peralkaline group in MORB-normalized spidergrams (Fig. 10) shows a strong enrichment in K, Rb and Sr in relation to Yb, but has less Rb, P and Ti than the saturated group, showing pronounced troughs in these elements.

(b) THE SHOSHONITIC ASSOCIATION

Since shoshonites were first described (IDDINGS, 1895) and their concept broadened and modified by JOPLIN (1968) who proposed a shoshonitic series, there have been imprecisions in their characterization. The main reason is that this series shares some characteristics with the calc-alkaline and alkaline series. The most complete summary on shoshonites was presented by MORRISON (1980) and after that, a number of workers mentioned shoshonitic granitoids, known also as the monzonitic series (NARDI, 1986), whose knowledge is still limited. Some of the main characteristics of shoshonitic granitoids, compiled from several authors with few
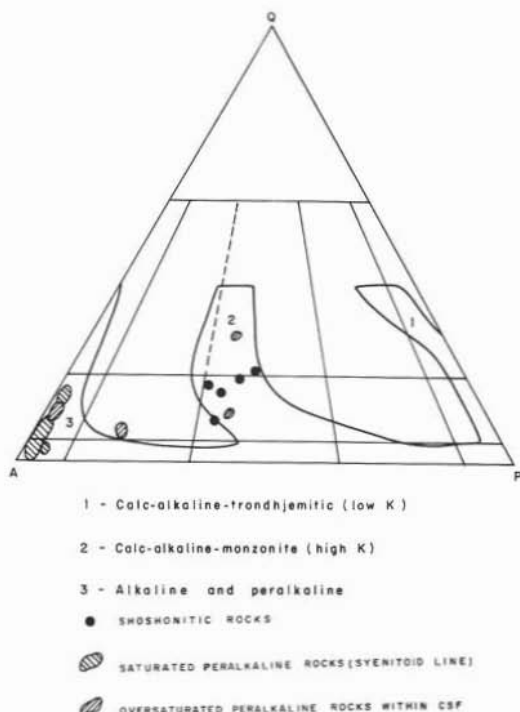

Fig. 3. — Q-A-P ternary plot for the peralkaline and shoshonitic granitoids of the Cachoeirinha-Salgueiro Fold Belt. Trends (1) calc-alkaline trondhjemitic (low K), (2) calc-alkaline monzonitic (high K) and (3) alkaline and peralkaline, are from LAMEYRE and BOWDEN (1982).

modifications, are shown in Table 3, as well as the main characteristics of the Solidão, Teixeira and Salgueiro batholiths.

The rocks in the CSF which are probable representative of the shoshonitic or monzonitic series are all quartz-normative and those from Solidão batholith show acmite and Na-metasilicate in their norms. Although they are sodic rocks according to the DEBON and LE FORT (1983) classification, with K/K (K + Na) > 0.45, this does not eliminate the possibility that they belong to the shoshonitic trend. Riebeckite-bearing sodic rocks belonging to the more evolved stages of the shoshonitic series were observed in Papua by SMITH (1972). In addition, arfvedsonite-bearing peralkaline rhyolites are associated with shoshonitic volcanics in andesitic arcs of the southwest Pacific (SMITH et al., 1977).

Modal compositions in the QAP diagram (Fig. 3) plot along the monzonite (high K) trend of LAMEYRE and BOWDEN (1982), and
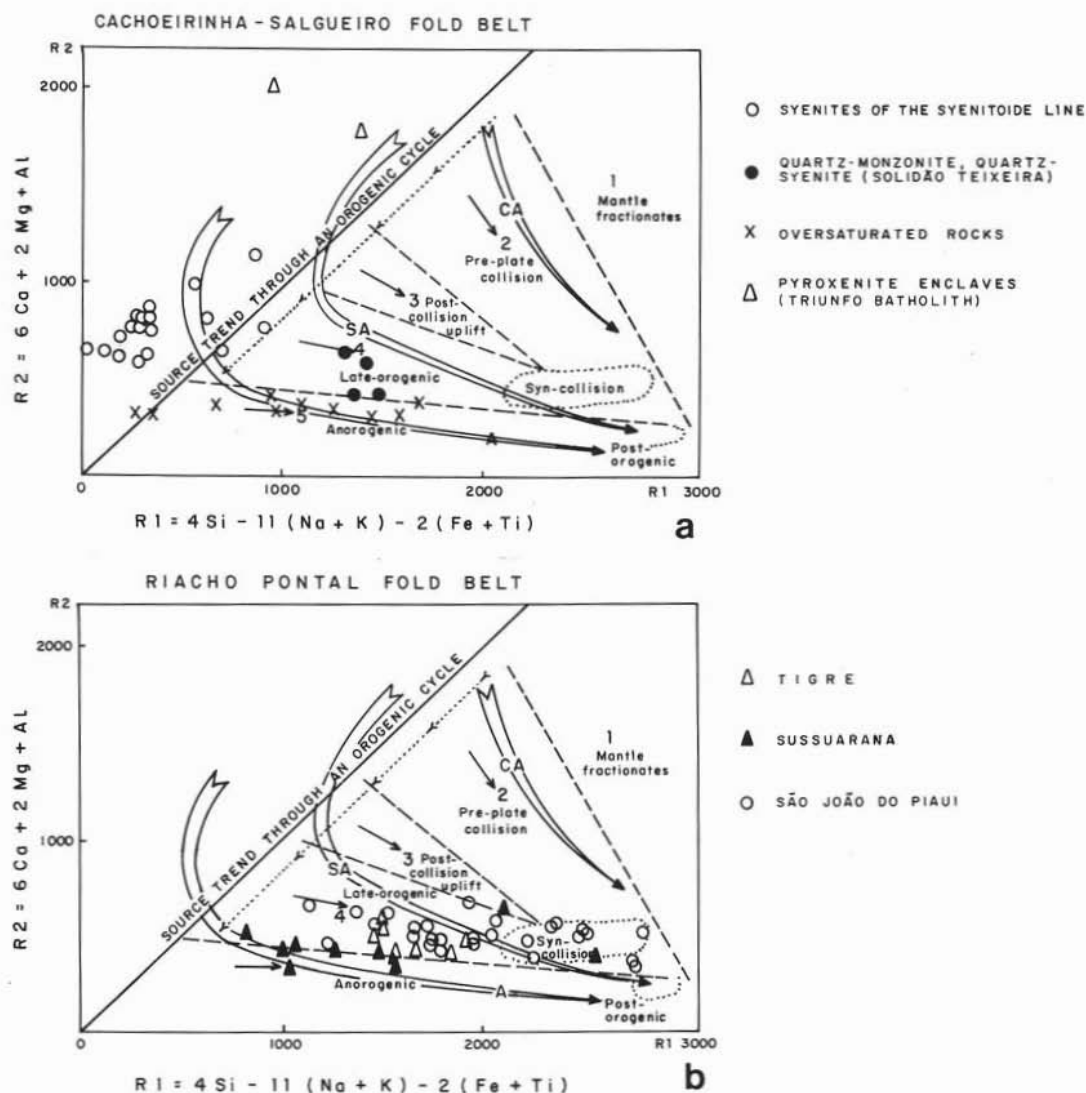
Fig. 4. — R1-R2 diagram (DE LA ROCHE et al., 1980; BATCHELOR and BOWDEN, 1985) for the peralkaline group and shoshonitic granitoids of the Cachoeirinha-Salgueiro Fold Belt (a) and for granitoids of the Riacho do Pontal Fold Belt (b). CA = Calc-alkaline, SA = subalkaline and A = alkaline (trends from MAREYVOL et al., 1987).

oversaturated peralkaline bodies plot next to the minimum of the granite system, suggesting that they differentiated from shoshonitic liquids.

These granitoids do not show a trend in the R1-R2 plot (Fig. 4a) probably due to the limited data. They plot in the late orogenic field, in consonance with field observations which indicate late to posttectonic emplacement. The trend of the main magmatic associations are shown in that

Figure: calc-alkaline (CA), subalkaline (SA) and alkaline (A), with the term subalkaline defining plutonic rocks with chemical composition lying between the fields for alkaline and calc-alkaline rocks (French nomenclature). Teixeira and Solidão samples in the R1-R2 diagram lie between the SA and A trends, interpreted here as an indication of a transition between shoshonitic to peralkaline affinities.

Compared with the shoshonitic granitoids

TABLE 3

Main characteristics of Cachoeirinha-Salgueiro Fold Belt granitoids with shoshonitic affinities as compared to shoshonitic granitoids (compiled from TAUSON, 1983; NARDI, 1986; TSVETKOV, 1984; PEARCE, 1983, *with some modifications)*

SHOSHONITIC SERIES GRANITOIDS	SHOSHONITIC GRANITOIDS IN THE CSF, NORTHEAST BRAZIL
1. Mainly monzonites, granodiorites and monzogranites, corresponding to I-type or magnetite granitoids	1. Quartz syenites to quartz monzonites
2. Abundance Ca-Mg-biotite, reflecting high K volatiles (H_2O, F, Cl, B, CO_2, S). Ca-Mg-amphibole (ferro-edenite), with Fe/(Fe + Mg) > 0.75; augitic pyroxene (ferroaugite). Arfvedsonite, aenigmatite and ferro-hedenbergite found in Papua. Magnetite and sphene, usually present (high oxygen fugacity).	2. Ca-Mg-biotites; Ca-Mg-amphibole (ferroedenite with Fe/Fe + Mg < 0.75). Sphene and some magnetite. Pass to rocks with aegirinic pyroxene and blue amphibole. Solidão batholith is locally acmite-normative.
3. Transitional between calc-alkaline and alkaline series (subalkaline series). More differentiated members may lie in the alkaline field.	3. In Q-A-P diagram plot along the monzogranite calc-alkaline series of Lameyre and Bowden (1982).
4. High K_2O/Na_2O (> 1.0) in basic to intermediate shoshonitic rocks is not verified in more differentiated members, which could show values below 1.0. MgO, CaO, total Fe and Al_2O_3 decrease with differentiation. Low FeO contents with FeO/Fe_2O_3 > 0.5. Metaluminous.	4. High K_2O/Na_2O (usually greater than 1.0); $FeO/Fe_2O_3 > 1.0$. Metaluminous to peralkaline. Total FeO lower than in the associated ultrapotassic rocks.
5. High LILE (Ba, Sr), intermediate Rb. Sharp decrease in Sr and Ba in differentiated members (SiO_2 = 73%). Distinguished from the calc-alkaline series by its higher Ba and Sr and from granitoids formed by ultrametamorphism by its higher Zr, Nb and Y. Zr and Nb in shoshonites, however, are usually lower than in the alkaline series.	5. High to extremely high Ba (up to 5200ppm); Sr (up to 2290 ppm); moderate Rb (up to 140 ppm); Zr up to 480 ppm; Nb < 20 ppm.
6. Moderate Σ REE. Moderate to high fractionation.	6. Moderate ΣREE (up to 130 ppm), highly fractionated (Ce_N/Y_N up to 16.94).
7. Produced by mantle-derived magma contamined by granitic or pelitic rocks of the overlying granitic-metamorphic crust.	7. Probably mantled derived, with some crustal contribution.
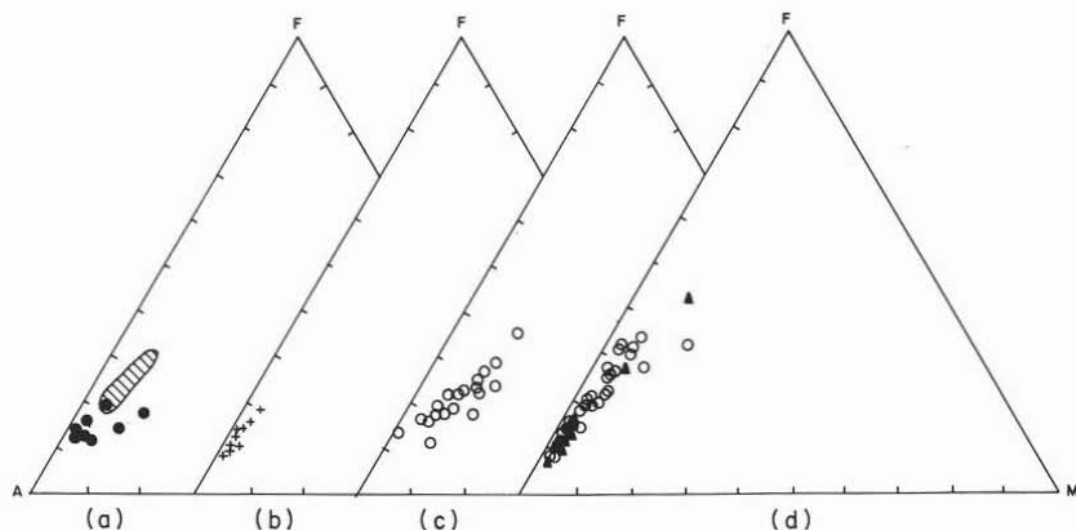
CACHOEIRINHA-SALGUEIRO FOLD BELT (a,b,c)

- ● Shoshonitic granitoid
- + Oversaturated peralkaline rocks
- ○ Saturated peralkaline rocks (syenitoid line)
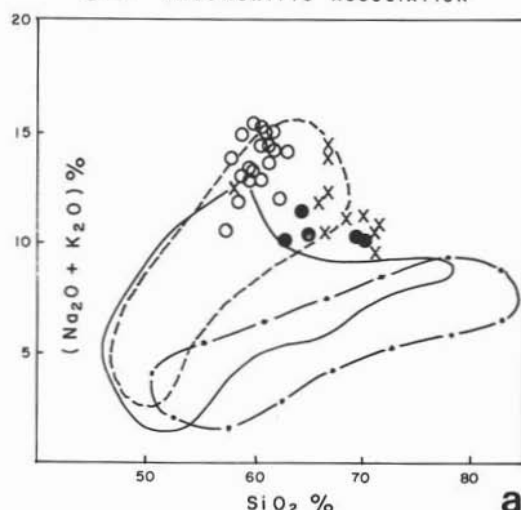- ▨ Shoshonitic granitoids from Lavras do Sul, Rio Grande do Sul, Brazil

RIACHO DO PONTAL FOLD BELT (d)

- △ Tigre
- ○ São João do Piaui
- ▲ Sussuarana

Fig. 5. — Alkalis - FeO(t) - MgO ternary plot for peralkaline and shoshonitic rocks of the Cachoeirinha-Salgueiro Fold Belt (a-c) and granitoids of the Riacho do Pontal Fold Belt (d).
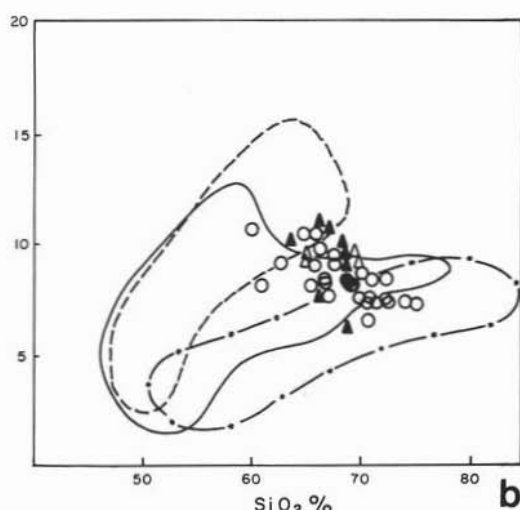
MORRISON 1980

Fig. 6. — Alkalis versus SiO_2 plot for peralkaline and shoshonitic rocks of the Cachoeirinha-Salgueiro Fold Belt (a) and granitoids of the Riacho do Pontal Fold Belt (b).

ALKALINE SERIES

CALC-ALKALINE SERIES

SHOSHONITIC ASSOCIATION

CACHOEIRINHA-SALGUEIRO FOLD BELT

O   Saturated peralkaline rocks (syenitoid line)

●   Shoshonitic granitoids

X   Oversaturated peralkaline rocks

RIACHO DO PONTAL FOLD BELT

O   São João do Piaui

Δ   Tigre

▲   Sussuarana

from Lavras do Sul, Rio Grande do Sul, Brazil (NARDI, 1986) shown in the AFM diagram (Fig. 5a), they seem to represent more evolved rocks. In the total alkali versus SiO_2 diagram (Fig. 6b), the shoshonitic group makes a cluster distinct from the peralkaline saturated one, plotting along the oversaturated peralkaline rocks. In Fig. 9a, where log $CaO/(Na_2O + K_2O)$ is plotted against SiO_2, they fall between the area of the diagram reserved for the calc-alkaline rocks (BROWN, 1982) and the peralkaline rocks under consideration. In other words, they seem to belong to the alkali-calcic series, a characteristic of the shoshonitic series.

These granitoids in MORB-normalized spidergrams (Fig. 10) show strong enrichment in K, Rb, Sr and Sm and marked troughs in

P and Ti. They are slightly more enriched in Zr and Ce than the saturated group of peralkaline rocks. In primordial mantle-normalized spidergrams (Fig. 11), these rocks differ from the saturated peralkaline group of rocks in relation to Zr which is slightly more abundant in the shoshonitic granitoids and in Ce which is slightly less abundant in this group.

Mineral chemistry

No systematic mineral chemistry study was carried out on the rocks under consideration. There are, however, a few mineral analyses available on the Salgueiro batholith (SIAL et al., 1983), on the Serra dos Macacos ring-dike and on the Catingueira dike. These analyses, obtained through electron microprobe at the

TABLE 4

Representative mineral chemical analyses for peralkaline rocks and for those with shoshonitic affinities of bodies within the Cachoeirinha-Salgueiro Fold Belt, Northeast Brazil

a) Pyroxenes

	Catingueira dike				Serra dos Macacos ring-dike				Salgueiro batholith				Triunfo batholith
	1*	2	3*	4*	1	2*	4	4*	1*	3*	1-A*	2*	P1RF-53
SiO2	50.71	52.06	51.74	52.22	47.12	46.74	47.79	48.04	53.98	52.59	49.66	49.15	48.40
Al2O3	2.01	0.40	0.33	0.48	0.83	0.76	0.69	0.90	0.50	0.86	0.35	0.58	2.00
Na2O	2.93	2.43	2.68	2.69	5.15	5.03	4.59	4.77	0.00	0.00	0.59	0.59	4.30
K2O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.74
FeOt	20.88	21.29	21.70	21.22	18.49	18.96	20.48	20.05	19.98	20.94	22.00	21.75	15.39
CaO	13.36	13.90	13.28	12.66	13.28	13.51	14.76	13.67	20.55	19.77	19.61	20.05	15.50
MgO	8.62	8.44	7.23	6.88	15.73	10.88	12.27	11.18	6.71	6.09	5.76	5.82	6.00
MnO	0.73	0.81	0.78	0.91	0.59	0.57	0.58	0.66	0.83	0.90	0.83	0.77	0.36
NiO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.48	0.49	0.48	0.49	n.d.
TiO2	0.45	0.33	0.32	0.39	0.49	0.33	0.32	0.40	0.00	0.00	0.00	0.00	3.10
P2O5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.20
Total	99.70	99.65	98.12	97.45	101.72	96.77	101.48	99.66	103.03	101.64	99.28	99.20	97.89
EN	24.54	23.65	21.09	20.83	38.94	30.15	30.94	29.95	20.65	18.92	17.11	18.04	19.85
FS	43.82	43.96	46.68	47.31	33.72	28.72	28.06	39.59	34.24	36.76	38.54	37.63	37.51
WO	31.63	32.98	32.23	31.86	27.34	31.13	30.00	30.46	45.11	44.32	43.75	44.33	42.64

* margin of the grain

b) Amphiboles

	Santo Antônio Creek dike				Salgueiro batholith**				Serrita stock (ring structure)			
	1	2*	2-3	1-2	1	2*	1-1*	2-1	1	1*	2*	4
SiO2	56.80	54.70	54.91	54.58	43.99	44.38	44.48	44.25	45.93	45.82	46.00	46.32
Al2O3	1.20	1.33	1.61	1.76	8.79	8.13	8.37	8.44	8.62	8.55	8.59	8.70
Na2O	6.04	5.70	6.40	6.23	1.62	1.64	1.67	1.53	1.00	0.48	1.22	0.80
K2O	0.14	0.19	0.32	0.25	n.d.	n.d.	n.d.	n.d.	1.60	1.43	1.56	1.52
FeOt	26.80	27.59	26.10	25.59	21.67	20.46	19.76	20.46	24.65	24.87	24.06	23.71
CaO	0.89	1.13	1.28	1.14	11.42	11.10	10.96	11.33	12.59	12.38	12.21	12.80
MgO	6.02	6.33	7.60	7.52	5.60	5.47	6.57	5.61	7.38	6.91	7.46	7.88
MnO	n.d.	n.d.	n.d.	n.d.	0.67	0.56	0.62	0.62	n.d.	n.d.	n.d.	n.d.
NiO	n.d.	n.d.	n.d.	n.d.	0.03	0.02	0.03	0.06	n.d.	n.d.	n.d.	n.d.
TiO2	0.11	0.19	0.08	0.15	1.25	1.23	1.74	1.22	0.80	0.94	0.59	0.75
Total	98.01	97.16	98.29	98.17	94.04	93.07	94.20	93.52	102.65	101.27	101.68	102.47

* margin of the grain
** Sial et al, 1983

University of Georgia, Athens, USA, and at São Paulo University, Brazil, are in Table 4. A pyroxene analysis performed at the GEOSOL Laboratory, Belo Horizonte, Brazil, from the Triunfo batholith, is included for comparison.

The pyroxene compositions in these plutons differ slightly. At Salgueiro, SIAL et al. (1983) recognized a smooth chemical zoning with respect to Fe which increases toward the edge of grains, and atomic ratios Ca:Mg:Fe indicate a trend varying from ferrosalite to ferroaugite (Fig. 12). This trend might result from extensive fractionation of this mineral during magma ascent, an assumption confirmed by textural relationships.

The pyroxenes in the oversaturated peralkaline group (Catingueira and Serra dos Macacos) are predominantly ferroaugite (Fig. 12), with much less Ca contents than the pyroxene at Salgueiro. The Na of the pyroxenes at Catingueira is slightly lower than

at Serra dos Macacos, with Ca-Mg-Fe trends at an angle to that of aegirine-augite at the Morutu district (GOMES et al., 1970). In the Serra dos Macacos, the Mg/Fe ratios are higher than in the Catingueira pyroxenes.

The fractionation of pyroxenes in a granitic liquid with shoshonitic affinities (e.g. Salgueiro) could cause enrichment in alkalis, especially Na, in the residual liquid. Perhaps such a fractionation, associated with that of biotite and/or Ca-amphibole, partially provides a mechanism to generate oversaturated peralkaline rocks from shoshonitic liquids.

The pyroxene at Triunfo, from a pyroxenite enclave, shows Wo, En, Fe contents similar to pyroxene from the Salgueiro batholith. However, it shows lower Si, Fe, Ca contents, much higher Al, Na, Ti and P, while Mg is equivalent to the amounts in Salgueiro pyroxenes. Its chemistry approaches the Serra dos Macacos pyroxenes. Its high P content
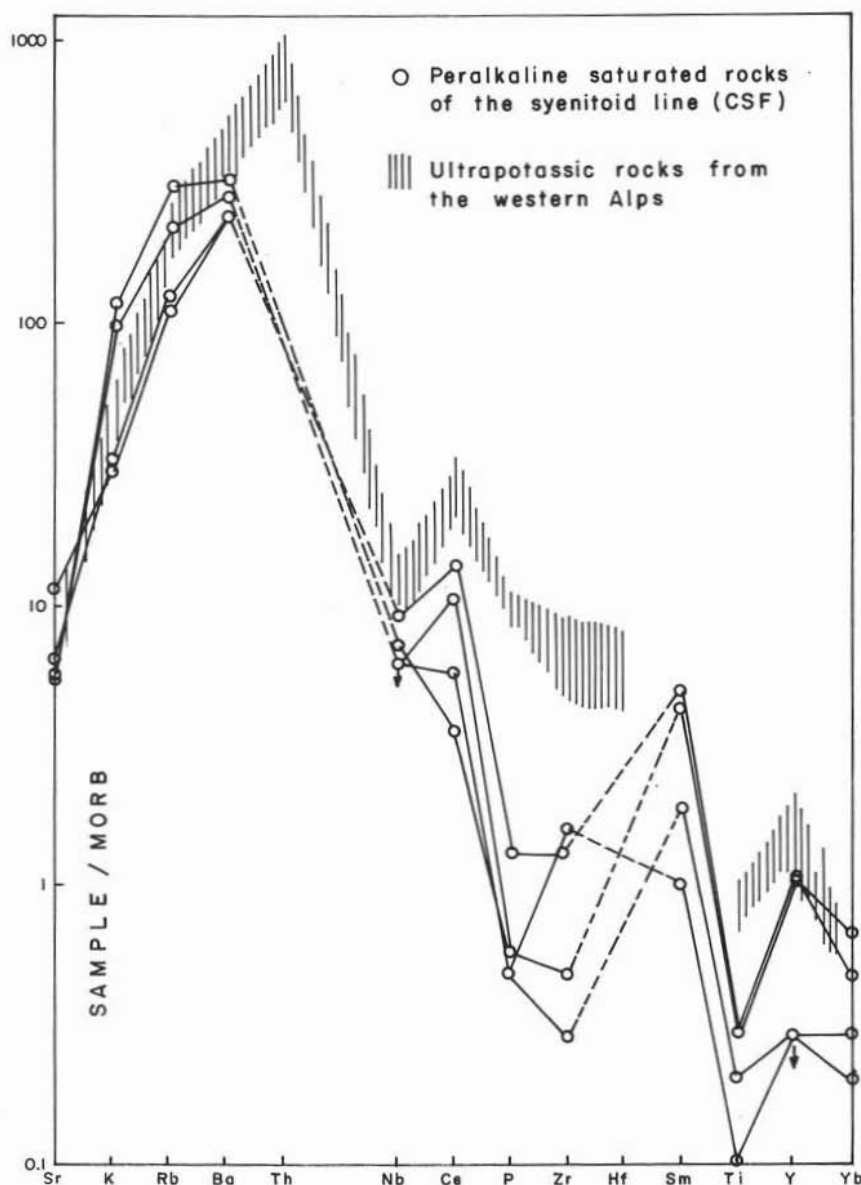
Fig. 7. — MORB-normalized spidergrams for the saturated peralkaline rocks of the Cachoeirinha-Salgueiro Fold Belt. Shaded pattern is from VENTURELLI et al. (1984), added for comparison.

(2.2% P_2O_5) is compatible with a high phosphorus fugacity during crystallization and suggests a P-enriched magma. Trace elements in this pyroxene show a signature which approaches that of shoshonitic rocks, with high Ba, Sr, low Nb and intermediate Zr. Its high Ti content ($TiO_2 = 3.10\%$) suggests a higher TiO_2-activity, which coupled with a high oxygen fugacity, favours formation of Mg-enriched aegirine (NIELSEN, 1979).

Amphiboles from the Salgueiro batholith and the Serrita stock are similar, corresponding to ferroedenite according to LEAKE's classification (1978). The amphiboles analysed in these two plutons are rather uniform in composition; those from the
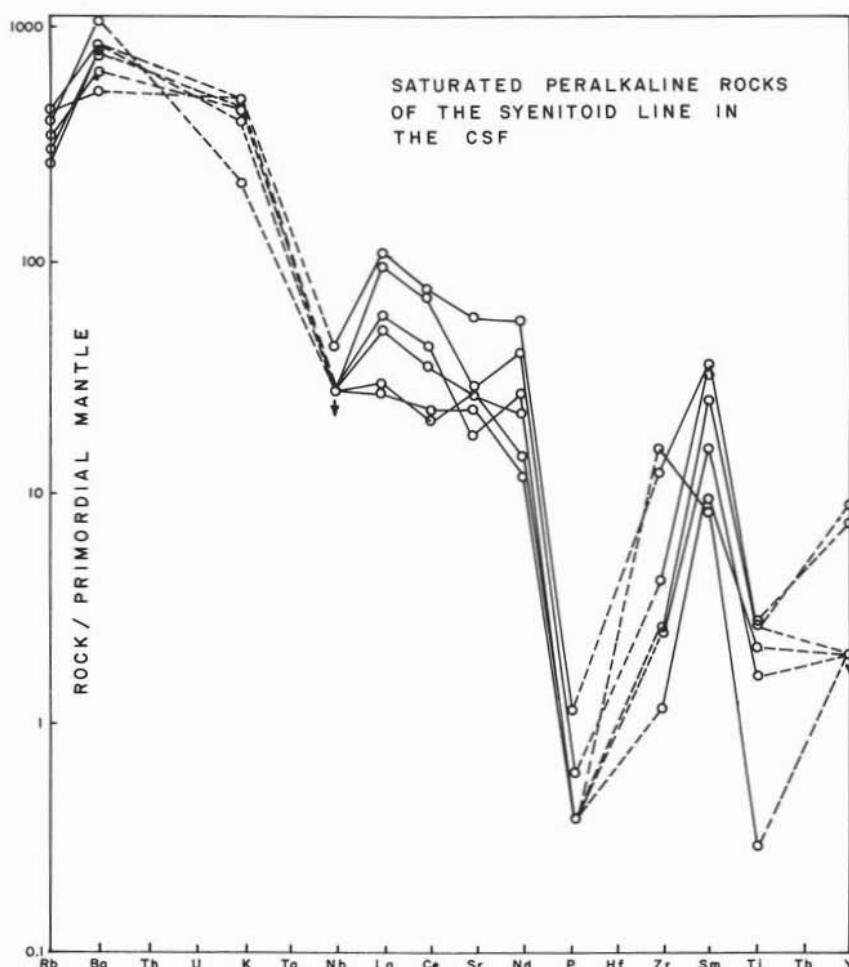
Fig. 8. — Primordial mantle-normalized spidergrams for the saturated peralkaline rocks of the Cachoeirinha-Salgueiro Fold Belt. Wood et al. (1979) normalizing values have been used.

Salgueiro batholith are slighty lower in Mg and Fe (Fe/(Fe + Mg) < 0.75), and higher in Ti than the Serrita amphibole. This behaviour perhaps indicates that they crystallized at relatively high temperature, according to Raase's (1974) suggestion. Sial et al., (1983) observe that Al^{IV} predominates over Al^{VI} at the Salgueiro amphiboles, a behaviour typical for minerals formed at high temperatures (Thompson, 1947).

Recently, Hammarstron and Zen (1986) proposed an empirical igneous geobarometer based on aluminum in hornblende. They assumed that Al content of hornblende is an indicator of pressures for crystallization of plutonic rocks of appropriate bulk composition, where the relation between Al in hornblende and pressures is expressed by $P = -3.92 + 5.03\ Al^T$. Preliminary estimates of pressure using this method for the Serrita and Salgueiro amphiboles (Table 5) indicate that the first one crystallized around 3.6 kbar and the second around 4.0 kbar pressure.

The Santo Antônio Creek amphibole is higher in Si and Na, and lower in Ca, Ti and Al. The problem of high Si in mineral formulae, with values greater than 8.0, can be explained by incomplete transformation of pyroxene into amphibole. Even so, they approach magnesian-arfvedsonite, according to Leake's classification (1978).
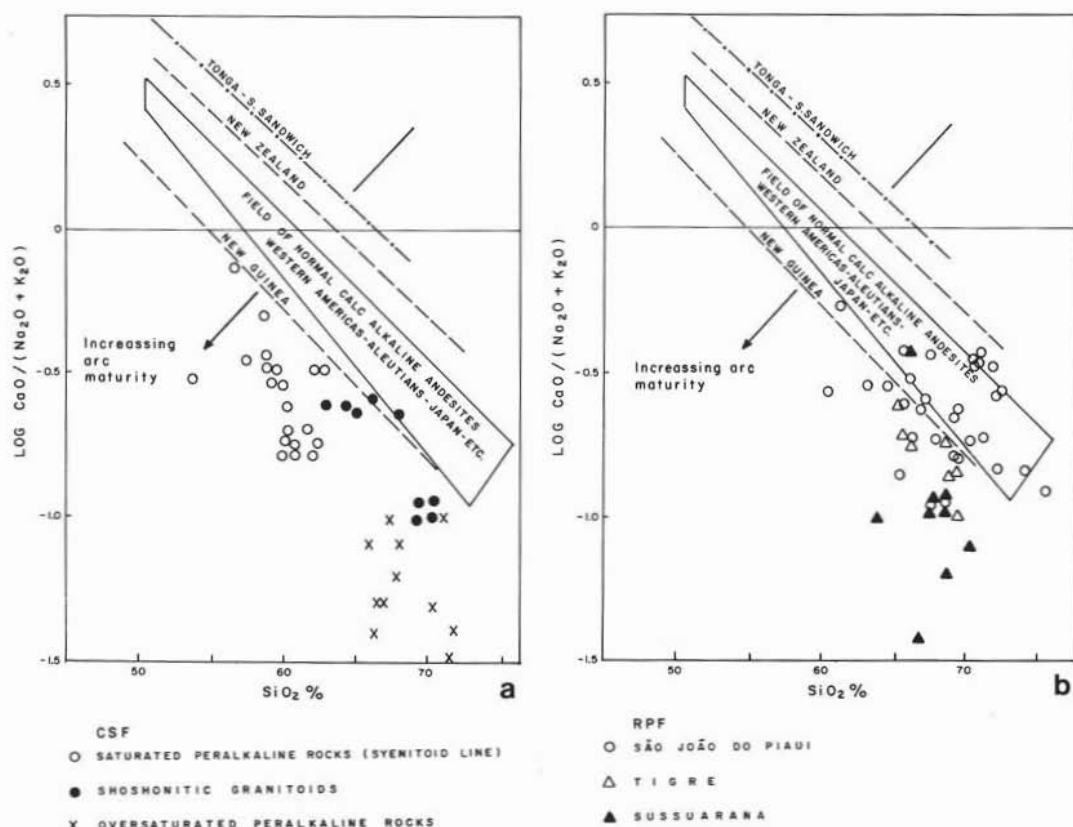
Fig. 9. — Calc-alkali ratio-silica trends for peralkaline and shoshonitic rocks of the Cachoeirinha-Salgueiro Fold Belt (a) and Riacho do Pontal Fold Belt (b). The trend for several volcanic magmatic arcs are from BROWN (1982).

TABLE 5

Pressure estimate for the crystallization of amphiboles from the Serrita and Salgueiro plutons

SAMPLE	Serrita (ring structure) SER-30				Salgueiro AS-82			AS-01
Phenocrysts	1	1*	2*	4	1	2*	1-1*	2-1
Pressure (Kbar)	3.6	3.6	3.6	3.7	4.2	3.8	3.8	4.0

* Rims of the grains .

Rare-earth elements

In the central structural domain, only rocks from the CSF were analysed for REE. Some were analysed by XRF in the Departement of Geology, Memorial University, Newfoundland, Canada and others by induced coupled plasma at the GEOSOL Laboratory, Belo Horizonte, Brazil.

The peralkaline saturated group (e.g. Triunfo batholith and Manaíra-Princesa Izabel dike swarm, Fig. 13a, b) has REE signatures characterized by strong enrichment of the LREE and depletion of HREE (FERREIRA and SIAL, 1987). The patterns for this group have discrete negative Eu anomalies (Eu/Eu* varies from 0.62 to 0.76) with the total REE from 89 to 437 ppm. There is an increase of the
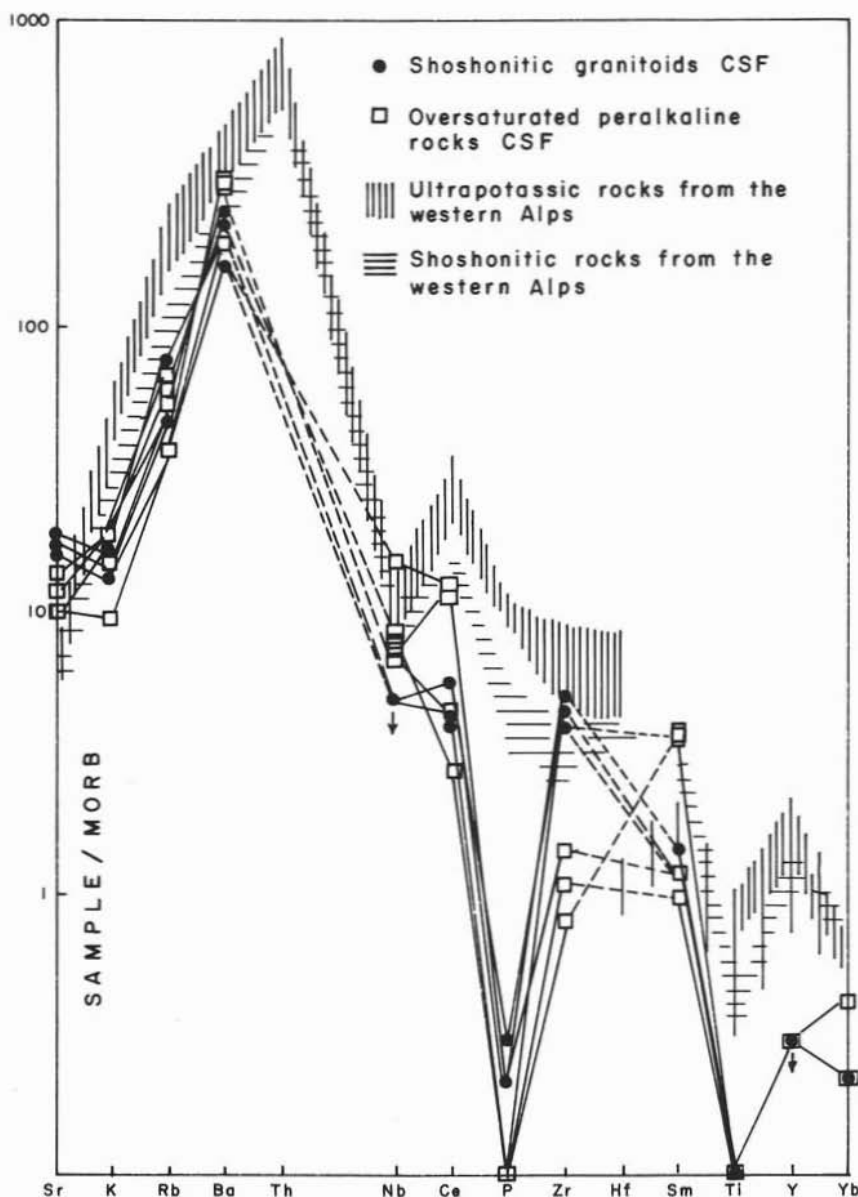
Fig. 10. — MORB-normalized spidergrams for oversaturated peralkaline rocks and shoshonitic granitoids of the Cachoeirinha-Salgueiro Fold Belt.

total REE with the decrease of SiO_2 and K_2O, with CaO showing opposite behaviour. The patterns for the oversaturated peralkaline group (Fig. 13c) depart from those usually observed for this kind of rock, lacking the typical negative Eu anomaly. In contrast, a Eu anomaly is either missing or slightly positive (Eu/Eu* varies from 0.86 to 1.89),

with total REE from 67 to 309 ppm.

The missing Eu anomaly perhaps reflects rather high oxygen fugacity during crystallization (DRAKE, 1975; HANSON, 1980). Alternatively, the Eu anomaly could have been inhibited by Ba and Sr contents in the magmas, in the way foreseen by BIRK et al. (1979).
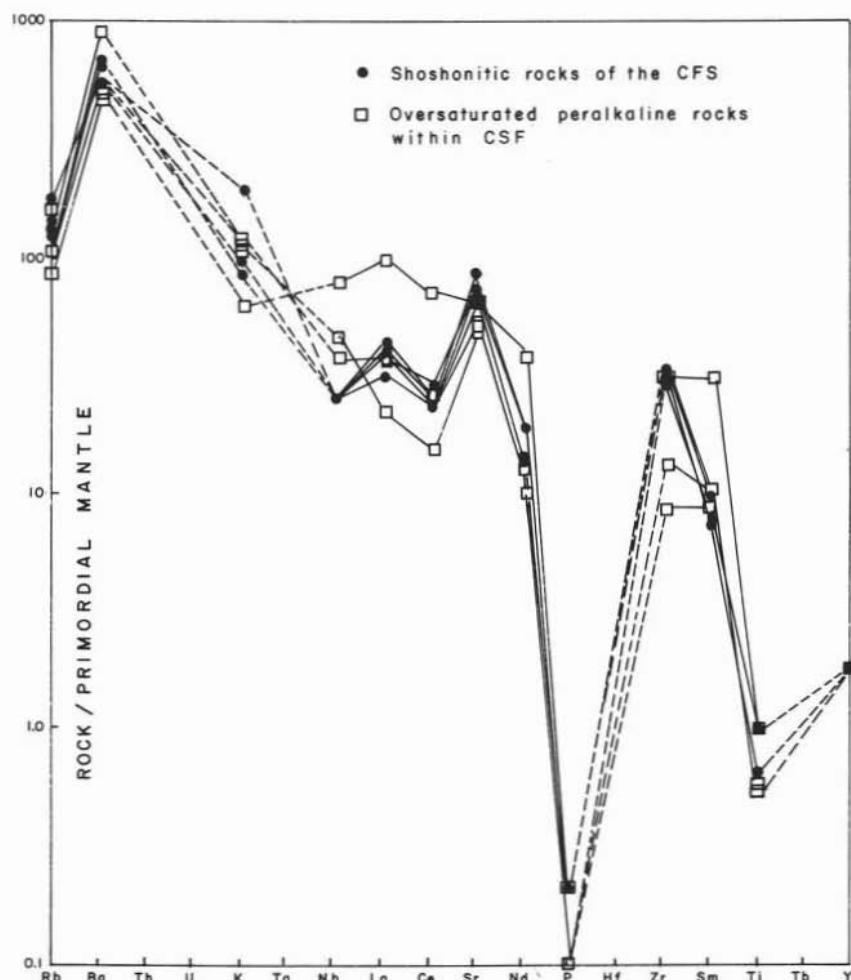
Fig. 11. — Primordial mantle normalized spidergrams for oversaturated peralkaline rocks and shoshonitic granitoids of the Cachoeirinha-Salgueiro Fold Belt.

The pyroxenite enclaves are REE-enriched, with LREE approximately 240-900 times chondritic abundances (Fig. 13d). The pattern for aegirine (Fig. 13d) resembles those for ferrohedenbergite (MAHOOD and HILDRETH, 1983). LREE are 100 times chondritic abundances and HREE are about 20 times, HREE showing upward concavity (FERREIRA and SIAL, 1987).

The REE patterns for the oversaturated peralkaline rocks from the ring dikes at Serrita stocks (Fig. 13f) are LREE-enriched and HREE-depleted with no Eu anomaly. One of the patterns, however, shows REE much lower than in the other samples, HREE below

the chondrite values, and a positive Eu anomaly. Similar to feldspar patterns, this one perhaps represents a feldspathic cumulate.

The granitoids with shoshonitic affinities (Solidão and Teixeira batholiths, Fig. 13f) display LREE-enriched patterns with HREE approximately flat. They show no Eu anomaly. Similar patterns were found by NARDI (1986) for the Lavras do Sul and Santa Rita shoshonitic granitoids in Rio Grande do Sul state, Brazil.

Stable isotopes

All oxygen isotope analyses were performed

by reaction with fluorine at the Department of Geology, University of Georgia, Athens, USA. Standard analytical procedure is found in WENNER (1981). Only rocks from the CSF were analyzed and results are in Table 6, where values for the basement and supracrustal rocks are included.

Most of the bodies analyzed exhibit an overall variation of about 2 permil and the data define three groups of peralkaline rocks. The Triunfo batholith, in the syenitoid line, shows $\delta^{18}O$ values rather low ($+6 < \delta^{18}O < +8$), suggesting either differentiation from mafic magma without post-magmatic alteration, or mantle derivation, with minor crustal contamination. Values for the oversaturated peralkaline Catingueira dike, the eastern portion of the Salgueiro batholith which bears shoshonitic affinities, and the ring dike of Serrita, are higher ($+8 < \delta^{18}O$

$< +10$). These divergences can be ascribed to differences in the isotope compositions of the protoliths, degree of differentiation, interaction with meteoric water, or more likely, to the nature and degree of assimilation of crustal rocks by mantle-derived magmas. Because Δ (Q-KF) for igneous rocks in isotope equilibrium ranges from 0.8 to 2.0 (TAYLOR and EPSTEIN, 1962; O'NEIL and TAYLOR, 1966), and numbers outside this range were recorded for the Catingueira dike and the Salgueiro batholith, there is slight isotope disequilibrium in these rocks, probably caused by exchange between feldspar and meteoric water at sub-solidus temperature.

The Santo Antônio dikes have the highest values, $\delta^{18}O > +10$. They penetrate high $\delta^{18}O$, low-grade metamorphic rocks of the CSF and perhaps the high values observed resulted from the interaction between those

TABLE 6

Oxygen isotope analyses of peralkaline rocks in the Cachoeirinha-Salgueiro Fold Belt, Northeast Brazil

SAMPLE	ROCK TYPE	W.R. $\delta^{18}O$(SMOW)	QUARTZ $\delta^{18}O$(SMOW)	FELDSPAR $\delta^{18}O$(SMOW)	Q-F	LOCALITY
SER-43	subvolcanic fine-grained	+ 12.21	---	---	---	Santo Antônio Creek, 30 Km north
SER-44	Mg-arfvedsonite-bearing trachytes	+ 10.60	---	---	---	of Serrita, Pernambuco
SER-63	aegirine-bearing granites	+ 9.66	---	---	---	Serra dos Macacos, Serrita, Pernambuco (ring-dike)
CAT-5	aegirine-bearing	+ 9.81	+ 8.67	+ 10.37	- 1.70	Catingueira, Paraíba (dike)
CAT-2	quartz-alkali-	+ 9.35	---	---	---	
CAT-1	feldspar syenites	+ 8.69	+ 8.80	+ 8.45	+ 0.35	
CAT-6		+ 8.12	---	---	---	
TRF-13	aegirine-bearing	+ 7.95	---	---	---	Triunfo, Pernambuco (batholith;
TRF-14	alkali-feldspar	+ 7.79	---	---	---	syenitoid line)
TRF-4	syenites	+ 6.79	---	---	---	
TRF-1		+ 6.79	---	---	---	
S-12	ferroaugite	+ 9.95	---	---	---	eastern portion of the Salgueiro
S-20	quartz monzonite	+ 9.93	+ 12.22	+ 9.92	+ 2.30	batholith, Pernambuco
S-30	of shoshonitic	+ 9.35	---	---	---	
S-7	affinities	+ 8.92	+ 11.75	+ 8.92	+ 2.83	
Host rocks						
Cachoeirinha supracrustal rocks	phyllites	+ 15.65	---	---	---	
Salgueiro Group	micaschists	+ 13.72	---	---	---	
Uauá Group	gneisses, migmatites	+ 12.63	---	---	---	

rocks.

The rocks with shoshonitic affinities display values equivalent to the Catingueira type. Probably they resulted from mantle derived magmas with some continental crust contribution.

2. *The Riacho do Pontal Fold Belt*

Fifty analyses of major and some trace elements for granitoids in the RPF are available in GAVA et al. (1984). Some of these analyses are in Table 7 with their respective CIPW norms. No stable isotopes or REE analyses are available for this segment of the CSD.

These rocks have an alkalinity index $(K/(Na + K))$ in the range of sodic to sodic-potassic, approaching a potassic composition, according to the DEBON and LE FORT (1983) classification, but no ultrapotassic rock was found. Although previously regarded as an

TABLE 7

Representative partial chemical analyses of granitoids in the Riacho do Pontal (GAVA et al., 1984) and Seridó (SOUZA, 1987) Fold Belts

| | RIACHO DO PONTAL FOLD BELT | | | | | | | | SERIDÓ FOLD BELT | | | | | | |
| | São João do Piauí granitoids | | | Sussuarana granitoids | | | Tigre granitoids | | Orthogn. | | Proter. metam. rocks | | | | Archean orthogn. |

a) major elements

	1	2	3	1	2	3	1	2	1	2	3	4	5	6	7
SiO2	69.10	71.60	67.20	64.00	68.80	68.50	69.50	65.50	64.10	70.30	65.80	51.30	75.80	59.80	70.60
TiO2	0.27	0.25	0.32	0.16	0.63	0.15	0.26	0.20	0.18	0.29	0.78	3.10	0.21	0.92	0.41
Al2O3	15.72	15.98	16.59	17.50	14.14	15.90	13.74	16.60	18.40	13.90	14.20	16.90	11.30	16.40	14.20
Fe2O3	0.99	0.98	1.96	0.57	4.62	0.62	1.13	1.19	1.50	1.20	1.50	11.00	1.50	1.70	1.40
FeO	0.14	0.90	1.58	1.40	1.42	0.03	0.63	0.53	0.50	1.16	4.00	8.60	0.72	5.83	1.31
MnO	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.02	0.10	0.30	0.05	0.12	0.05
MgO	0.23	0.21	0.41	0.27	1.33	0.18	0.35	0.21	0.44	0.56	2.40	3.10	0.60	3.70	1.10
CaO	1.55	1.57	2.22	1.42	0.74	0.93	1.38	1.72	2.10	1.20	2.40	2.20	3.00	3.00	2.00
Na2O	5.12	4.40	4.80	5.93	3.03	5.15	6.20	5.18	4.50	3.10	3.70	1.20	0.13	3.40	3.70
K2O	4.35	4.89	3.94	5.31	3.17	4.90	3.35	4.63	8.00	7.10	2.80	1.10	4.60	3.40	4.80
P2O5	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.09	0.20	0.24	0.11	0.22	0.11
K2O/Na2O	0.85	0.93	0.82	0.89	1.05	0.95	0.54	0.89	1.78	2.29	0.76	0.92	35.38	1.00	1.30
A.I.	0.83	0.73	0.73	0.89	0.59	0.80	1.01	0.81	0.87	0.92	--	--	--	--	--

b) CIPW norms

	1	2	3	1	2	3	1	2	1	2
q	19.28	26.63	18.83	5.48	36.45	21.58	18.81	15.40	3.09	22.14
c	0.01	1.70	0.64	0.00	4.71	1.71	0.00	0.18	0.00	0.00
or	25.71	24.13	23.47	32.43	29.20	24.51	19.80	28.22	47.28	41.96
ab	43.33	37.17	40.94	51.86	26.14	45.18	52.03	45.21	38.00	26.23
an	7.04	7.12	10.44	5.63	3.08	4.11	0.00	8.13	6.38	3.04
ac	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00
wo	0.00	0.00	0.00	0.00	0.00	0.00	1.58	0.00	0.00	0.00
di	0.00	0.00	0.00	0.23	0.00	0.00	1.88	0.00	2.36	1.33
hd	0.00	0.00	0.00	0.60	0.00	0.00	0.17	0.00	0.00	0.55
en	0.57	0.52	1.03	0.59	3.30	0.46	0.00	0.54	0.00	0.70
fs	0.00	0.62	0.95	1.77	0.00	0.99	0.00	0.00	0.00	0.37
hy	0.57	1.14	1.98	2.36	3.38	1.45	0.00	0.54	0.00	0.00
mt	0.00	1.42	2.86	0.85	3.14	0.93	1.44	1.50	1.35	1.74
il	0.51	0.47	0.61	0.31	1.22	0.30	0.49	0.39	0.34	0.55
hm	0.99	0.00	0.00	0.00	2.55	0.00	0.00	0.19	0.57	0.00
ap	0.24	0.24	0.24	0.24	0.24	0.25	0.24	0.24	0.12	0.21

c) trace elements

	1	2	3	1	2	3	1	2	1	2	3	4	5	6	7
Ba	2800	2760	2320	2200	800	2400	2200	2100	1033	1160	320	480	950	750	1250
Rb	122	107	100	140	163	140	114	120	290	280	160	44	120	110	200
Sr	1147	1350	1610	1310	70	1150	880	1130	430	130	180	92	115	180	290
Th	30	--	--	25	25	25	25	25	--	--	--	--	--	--	--
La	30	30	30	30	30	30	30	30	--	--	--	--	--	--	--
Ce	150	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nb	20	20	5	10	20	10	20	10	< 20	30	< 20	34	< 20	20	40
Y	10	10	10	10	26	10	10		--	--	--	--	--	--	--
Zr	144	130	176	130	212	145	124	130	--	--	--	--	--	--	--
Pb	30	56	46	87	10	67	70	67	--	--	--	--	--	--	--

Seridó Fold Belt: A unit (7= Archean orthogneisses); B unit - Proterozoic (1= Monzosyenite-gneiss (shoshonite), 2= biotite granodiorite, 3= micaschist, 4= cordierite-gneiss); C unit (5= quartzite); D unit (6= micaschist).
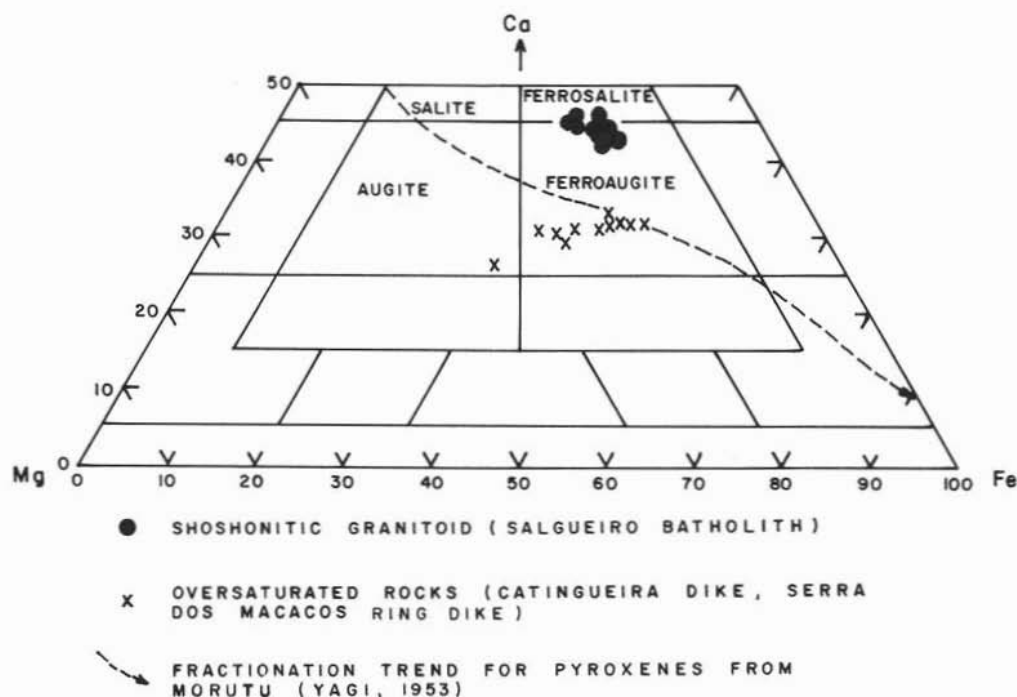
Fig. 12. — Compositional data for clinopyroxenes from the oversaturated peralkaline Catingueira dike, Serra dos Macacos ring-dike and Salgueiro batholith plotted in the pyroxene quadrilateral. Morutu trend (YAGI, 1953) is added for comparison.

alkaline province, most of these rocks bear some corundum in the norms and only one sample among the fifty analyzed has acmite. However, a few analyses show peralkalinity index around 1.0.

The R1-R2 plot (Fig. 4b) defines two subparallel trends. One of them (sample from Sussuarana granitoids) seems to follow the boundary between late-orogenic and anorogenic granitoids, a contention which matches field observations. The second one (samples from Tigre and São João do Piauí granitoids) follows the boundary between the fields reserved for late-orogenic and post-collision uplift granitoids and penetrates into the syn-collision granitoid field.

In the AFM triangular plot (Fig. 5d) these granitoids show two trends, which suggest that magmas evolved independently, under different oxygen fugacity conditions.

The analyzed granitoids of this belt cluster in the shoshonitic field of the alkalis vs. silica diagram (Fig. 6b) slightly grading into the calc-alkaline and alkaline fields.

In Fig. 9b, the granitoids from the RPF lie in part in the area reserved for the calc-alkaline granitoids, and like the granitoids of the CSF, they grade into the area of alkaline rocks (Fig. 9a). MORB-normalized spidergrams (Fig. 15) show a marked enrichment in K, Rb, Ba, and Th, and a depletion in Ti, with Zr equal or twice as high as the corresponding MORB value. Strontium varies from below MORB values up to values 7 times greater. Early plagioclase fractionation perhaps explains the depletion in Sr in some of these rocks. Their high Ba and Sr contents associated with low Nb, Ti and Zr in addition to their MORB-normalized trace element signatures suggest that they belong to the shoshonitic association.

Petrogenesis: a LILE-enriched mantle source?

Hypotheses on ultrapotassic magma generation require (THOMPSON, 1985; NELSON et al., 1986): (a) partial melting in the lithospheric mantle, previously enriched in
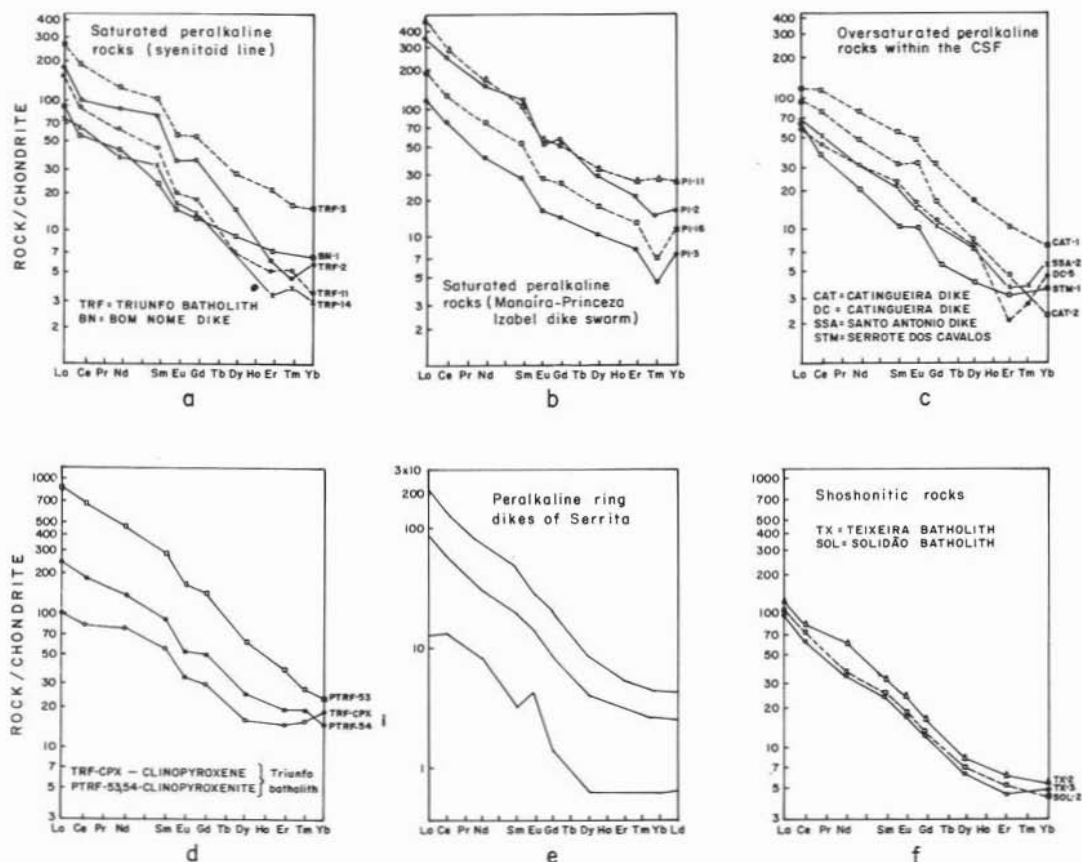
Fig. 13. — Chondrite-normalized REE-patterns for saturated peralkaline rocks of the syenitoid line (a), Manaíra-Princesa Izabel dike swarm (b), oversaturated peralkaline rocks (c), pyroxenite and aegirine of the Triunfo batholith (d), oversaturated peralkaline ring-dike at Serrita stock (e), shoshonitic granitoids (f), (FERREIRA and SIAL, 1986; NEVES, 1986; FERREIRA and SIAL, 1987; SIAL, 1987).

incompatible elements; (b) generation in the asthenosphere with contamination in the lithospheric mantle during magma ascent; or (c) enrichment through crustal sediments or megaliths recycled by subduction.

The petrological and geochemical characteristics of the shoshonitic series suggest a generation by partial fusion of a previously large-ion lithophile elements (LILE)-enriched mantle (GIROD, 1978; BARKER, 1978; CARR and FARDY, 1984). Alternatively a genesis by mantle melting and crustal contamination has been proposed.

Alkali enrichment in the mantle has been suggested by different processes and the influence of metasomatizing fluids has been emphasized by several authors (ERLANK, 1976; MENZIES and MURTHY, 1980, ERLANK et al.,

1982; MENZIES and WASS, 1983; RODEN et al., 1984; ROGERS et al., 1985; COMIN-CHIARAMONTI et al., 1986; FODOR and MCKEE, 1986; DUDAS et al., 1987).

Shoshonitic associations characterize the transition of orogenic to alkaline magmatism. They are usually associated with processes leading to the formation of rifts in areas of crustal thickening, or are related to subduction of oceanic crust or ensialic orogenesis (MARTIN, 1983).

The geochemical patterns observed in the peralkaline and shoshonitic granitoids in the Central Structural Domain lead to the assumption of possible mantle LILE-enrichment prior to or during the Late Brasiliano cycle, or alternatively, to systematic crustal contamination with rocks of
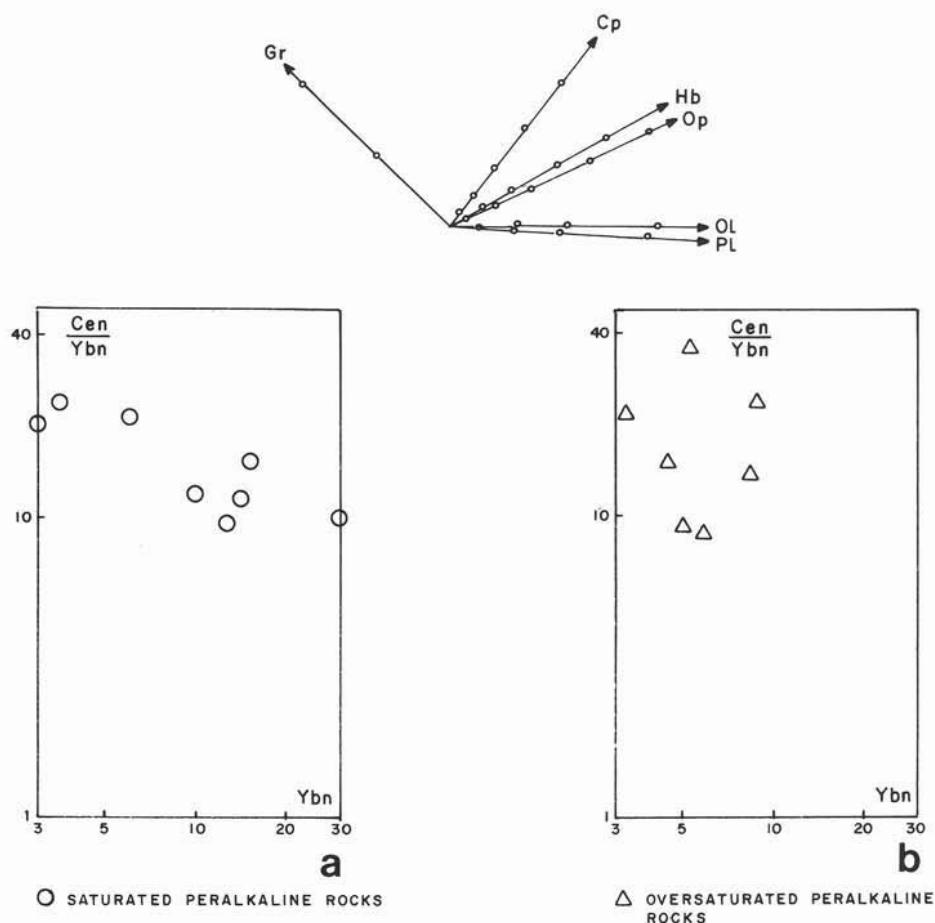
Fig. 14. — Ce_N/Yb_N versus Yb_N plot for saturated (a) and oversaturated (b) peralkaline group of rocks. At the top, the vectors indicate the fractional crystallization paths for the indicated minerals: GR, garnet; CP, clinopyroxene; HB, horblende, OP, orthopyroxene; OL, olivine and PL, plagioclase (VENTURELLI et al., 1984).

appropriate compósition.

Metamorphic rocks of the Seridò Fold Belt (Table 3), including orthogneisses of the Archean Caicò complex and supracrustals (biotite-schist, quartzite and cordierite gneisses), show high Ba and Sr and low Ti and Nb, conforming to geochemical patterns observed for the ultrapotassic and shoshonitic groups under consideration. However, as all groups of granitoids recognized in the CSF and surroundings by ALMEIDA et al. (1967) and SIAL (1984a, 1984b, 1986) systematically exhibit high to extremely high K, Ba, and Sr, and LREE-enrichment, it is difficult to accept assimilation as the major process leading to ultrapotassic or shoshonitic compositions.

There is no doubt that crustal assimilation took place, as recorded by schist xenoliths and by oxygen isotopes, but this would not systematically raise the LILE to values as high as those observed in the peralkaline or shoshonitic rocks in the CSF. These conclusions imply in that magmas were probably generated in a REE- and LILE-enriched mantle and underwent some crustal contamination in variable amounts. Those which filled the fractures in the syenitoid line (Triunfo-type syenites) were less contaminated, as indicated by lower $\delta^{18}O$ values.

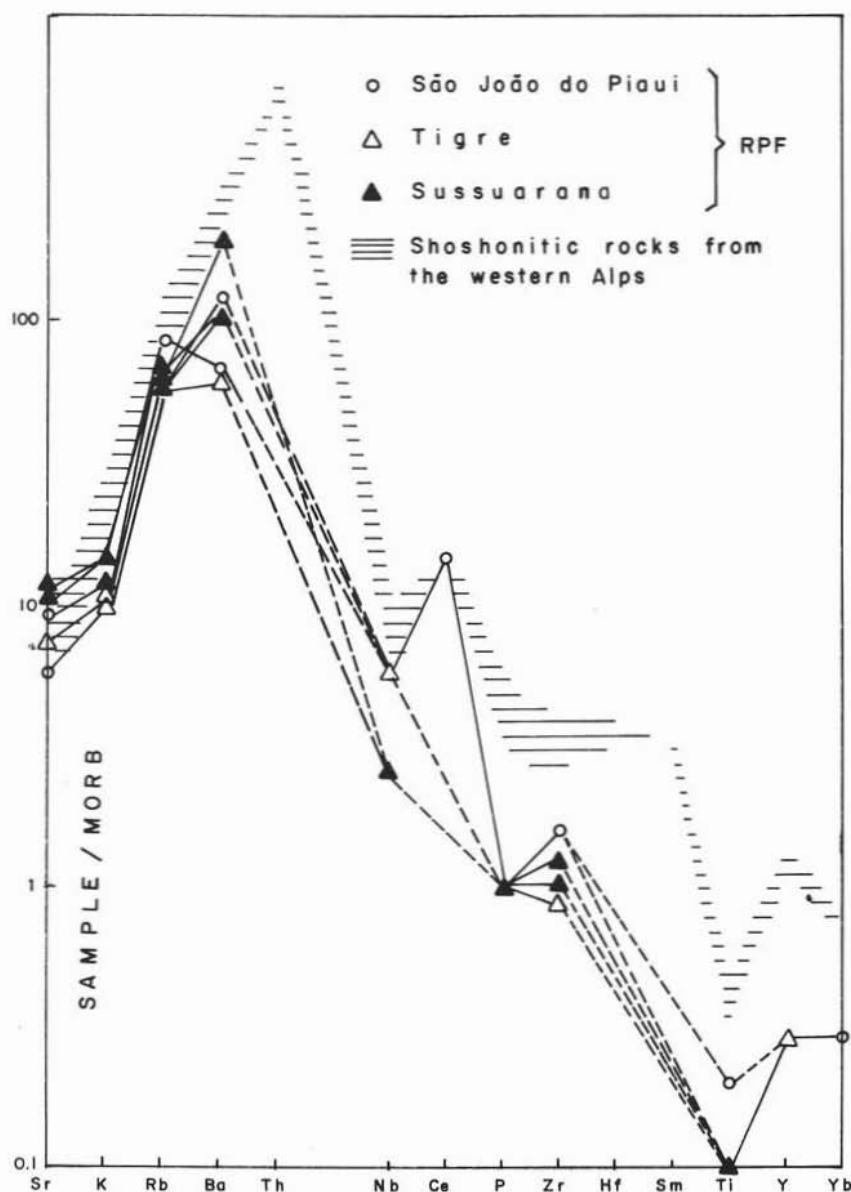A metasomatized mantle beneath Northeast Brazil has been proposed before. Areas of

Fig. 15. — MORB-normalized spidergrams for granitoids of the Riacho do Pontal Fold Belt.

veined or metasomatized mantle like those proposed for South Atlantic Ocean (e.g. Walvis ridge, Bouvet) have been recognized in the mantle beneath the Mesozoic Potiguar basin, Rio Grande do Norte state (FODOR and McKEE, 1986). Mesozoic tholeiitic diabases and Tertiary alkali basalts in Rio Grande do Norte and Paraíba states show very high K, Ba, Sr, P (SIAL, 1974) which reflect a LILE-

enriched mantle-source. These observations imply that the mantle beneath Northeast Brazil has undergone successive enrichment events or a major late Precambrian enrichment, or the existence of an anomalously LILE-enriched area in the mantle since Archean or primordial times.

The syenitoid line of probable Brasiliano (= Pan-African) age may find in the

peralkaline, lineary Itiúba syenite dike (120 km long, 12 km wide in northern Bahia, which seems to meet the syenitoid line at 120° angle) a Transamazonian (= Eburnean) to Archean analogue. This syenite also exhibits high Ba and Sr (Conceição et al., 1987) and REE patterns (Figueiredo, 1985) similar to those shown here, and this leads to the conclusion that the LILE-enrichment happened whenever magmas bearing some alkaline or shoshonitic affinities were formed, or that the mantle was enriched since Archean times.

The chemistry of pyroxenite enclaves (LREE-enriched) in the peralkaline syenite (of the syenitoid line) regarded as early fractionated material reinforces the concept of mantle derived magma already LILE-enriched. Because the pyroxene contains a high amount of phosphorus (around 2%), its fractionation caused the depletion of P observed in the spidergrams.

More structural and Sr, Pb and Nd isotope data are necessary to precisely describe the nature of the mantle source, the crustal contribution, and the time of LILE-enrichment in the mantle.

Probably subalkaline or moderate alkaline magmas formed in the upper mantle through partial melting of a garnet-peridotite source. These magmas intruded well-developed fractures to form the peralkaline saturated group of rocks of the syenitoid line, or interacted intensely with the crust to produce shoshonitic granitoids and peralkaline oversaturated rocks. The mechanism through which the shoshonitic liquid passed into oversaturated peralkaline ones is not clear. Biotite in amphibole in the shoshonitic granitoids suggests its early fractionation and this could explain the decrease in Mg, Fe, Ca and subsequent enrichment in Na in the residual liquid.

The lower $\delta^{18}O$ for the saturated group of peralkaline rocks (e.g. Triunfo batholith) is compatible with mantle derivation, followed by minor crustal contamination. The oversaturated peralkaline group shows higher $\delta^{18}O$, not much different from the shoshonitic granitoids. In a preliminary $\delta^{18}O$ versus $^{87}Sr/^{86}Sr$ plot for the saturated peralkaline group and rocks with shoshonitic

affinities, Ferreira (1986) found the former to have undergone a source contamination while the latter suffered crustal contamination.

The regional geographic patterns displayed by the peralkaline plutons in the CSF, in which they seem to follow major sigmoidal fault zones (e.g. the syenitoid line and the horn-shaped Catingueira dike) are perhaps related to pull-apart processes along these zones, associated with the Patos-Aurora and Pernambuco transcurrent lineaments. The shoshonitic granitoids represent late tectonically emplaced plutons grading into post-tectonically emplaced, oversaturated peralkaline plutons. On the other hand, the emplacement of several dike swarms with peralkaline affinities probably followed the establishment of thermal anomalies responsible for doming and crustal fracturing during Late Brasiliano cycle in the CSF and elsewhere in Northeast Brazil.

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