Revista Brasileira de Geociências

16(1): 54-72, março de 1986

# GRANITE-TYPES IN NORTHEAST BRAZIL: CURRENT KNOWLEDGE

ALCIDES N. SIAL*

**ABSTRACT** Several granitoids in Northeast Brazil, including the main granite-tytes, mostly located within the Cachoeirinha-Salgueiro foldbelt (CSF), Pernambuco and Paraíba States, have been studied. Four groups of granitoids have been identified in this foldbelt with syn- to post-orogenic emplacement: *a)* calc-alkalic, *b)* potassic-calcalkalic, *c)* peralkalic, and *d)* of trondhjemitic affinities. Rock compositions vary from tonalites, granodiorites, quartz-syenites, syenites to minor granites. The calc-alkalic plutons (Conceição-type), ilmenite-bearing, are strictly found piercing the Cachoeirinha low-grade metamorphics; the potassic-calc-alkalic granitoids (Itaporanga-type) intruded the gneiss-migmatite basement, adjacent to the northern boundary of the CSF while the peralkalic rocks (Triunfo-type) form a magnetite-bearing syenitoid line, roughly following the southern boundary of the CSF, or found as small stocks and dike swarms (e.g. Catingueira-type) intruding Cachoeirinha metasediments. Rocks with trondhjemitic affinities (Serrita-type) form the core of the two ring-complexes, next to Serrita, Pernambuco, intruding Salgueiro metasediments. Whole-rock $\delta^{18}O$ values most clearly correlate with types of host rocks. Granitoids in high-grade terranes show normal $\delta^{18}O$ values ($<+10$ permil$_{SMOW}$), as in Itaporanga, Serra da Lagoinha, Monte das Gameleiras (Paraíba), and Bodocó (Pernambuco). Conceição-type granitoids dysplay high $\delta^{18}O$ (+10 to +13 permil$_{SMOW}$), while those which intruded the Salgueiro metasediments (Serrita-type) show $\delta^{18}O$ values between 8 and 10 permil$_{SMOW}$, same happening with most peralkalic bodies. REE patterns for the calc-alkalic plutons are very LREE-enriched relative to HREE, with discrete, but significative, negative Eu anomaly, compatible with combined fractionation of plagioclase and hornblend. The parental magma probably derived from an amphibiolitc source from depht not greather than 45 km.. The potassic-calc-alkalic bodies exhibit LREE-enriched signatures relative to HREE, lacking Eu anomaly. Slight differences between oxygen fugacity, crystallization order, type, and amount of each fractionated phase during magma ascent have been responsible for the differences among these patterns. The peralkalic bodies (silica over to satureted) exhibit very fractionated REE signatures, with Eu anomaly usually absent. Over satured bodies show discret, positive Eu anomaly sometimes, while the satureted ones behave the opposite way. The major geochemistry and REE are in agreement in the four groups and are consistent with the behaviour of the oxygen isotopes, which vary sympathetically with $\Sigma$REE and $SiO_2$. Magmatic epidote, a high-pressure phase, in three of the groups of granitoids, suggests that these rocks crystallized at relatively great depth what demands further structural and petrological support.

**RESUMO** Diversos granitóides no Nordeste do Brasil (incluindo os granitos tipos Itaporanga, Conceição, Catingueira, Itapetim, Serrita e Triunfo), localizados dentro da faixa de dobramentos Cachoeirinha-Salgueiro (FCS), Pernambuco e Paraíba, foram estudados. Quatro grupos de granitóides sin a pós-orogênicos foram identificados: *a)* cálcio-alcalinos, *b)* cálcio-alcalinos potássicos, *c)* peralcalinos e *d)* com afinidades trondhjemíticas. Os plutões cálcio-alcalinos (tipo Conceição), a ilmenita, são encontrados, estritamente, perfurando rochas de baixo grau do Grupo Cachoeirinha; os cálcio-alcalinos potássicos (tipo Itaporanga) intrudem o embasamento adjacente ao bordo norte da FCS e os peralcalinos formam um cordão de sienitóides a magnetita, grosseiramente acompanhando o limite sul desta faixa de dobramentos, ou como *stocks* e enxames de diques, intrudindo metassedimentos Cachoeirinha. Rochas com afinidades trondhjemíticas formam os núcleos de dois *stocks* (Serrita, Pernambuco), que intrudem metassedimentos Salgueiro. Valores de $\delta^{18}O$ (rocha total) correlacionam-se com o tipo de rocha hospedeira. Corpos cálcio-alcalinos potássicos em terrenos de alto grau mostram valores "normais" de $\delta^{18}O$ ($<+10$ permil$_{SMOW}$), como em Serra da Lagoinha, Itaporanga, Monte das Gameleiras (Paraíba) e Bodocó (Pernambuco). Plutões, que intrudiram metassedimentos Cachoeirinha (cálcio-alcalinos, tipo Conceição), exibem alto $\delta^{18}O$ (+10 a +13 permil$_{SMOW}$) e os que intrudiram metassedimentos Salgueiro (tipo Serrita), $\delta^{18}O$ entre 8 e 10 permil$_{SMOW}$. As rochas peralcalinas, com uma exceção, mostram igual variação. Os padrões de TR nos plutões cálcio-alcalinos são enriquecidos em TR leves relativamente aos pesados, com discreta anomalia do Eu, compatível com fracionamento de plagioclásio e hornblenda. O magma progenitor provavelmente tenha derivado de uma fonte anfibolítica em profundidade não superior a 45 km. Nos corpos cálcio-alcalinos potássicos, enriquecidos em TR leves em relação aos pesados, sem anomalia de Eu, as diferenças entre seus padrões se devem às variações na fugacidade de oxigênio, ordem de cristalização, tipo e quantidade de cada fase fracionada na ascensão do magma. Os corpos peralcalinos exibem padrões de TR muito fracionados, sem anomalia de Eu. Os supersaturados mostram, às vezes, discreta anomalia positiva de Eu e os saturados, discreta anomalia negativa. Estas rochas representam cumulatos de K-feldspato (sienitos e quartzo sienitos). A geoquímica de TR concorda com a química de elementos maiores nos quatro grupos e é consistente com o comportamento de isótopos de oxigênio, que variam paralelamente com $\Sigma$ TR e $SiO_2$. Epídoto magmático, uma fase de alta pressão (6 a 8 kbar), em três dos grupos de granitóides, sugere cristalização a profundidade relativamente alta, a ser confirmada pelo estudo petrológico e estrutural das encaixantes.

**INTRODUCTION** Almeida *et al.* (1967) reviewed the granitoids of Northeast South America, mostly based on the literature. To the west of the states of Pernambuco and Paraíba, Northeast Brazil, abundant granitoids and dike swarms intruded Precambrian metamorphic rocks of the Cachoeirinha-Salgueiro foldbelt (CFS, same as Piancó-Alto

* Departamento de Geologia, Centro de Tecnologia, Universidade Federal de Pernambuco. CEP 50000, Recife, PE, Brasil

Brígida folding system; Brito Neves 1975) between the coordinates 7° and 8°15'S lat., and 37° and 40° W long (Fig. 1). Within this space, they defined four granite-types: *a)* synorogenic granodiorites, tonalites, and calc-alkalic porphyritic granites which are regarded as the oldest ones among the four types, and are referred to as of the *Conceição-type; b)* synorogenic, extremely porphyritic granodiorites with microcline megacrysts up to 10 cm long, to which the name *Itaporanga-type* was given; *c)* late-orogenic biotite-granites, with mineralogy similar to the Itaporanga-type granitoids of the *Itapetim-type,* and *d)* late-orogenic, syenite to quartz-syenite of the *Catingueira-type.* These four granite-types have been used for reference in most field work on Precambrian granitoids in Northeast Brazil.

Over 30 bodies of granodiorite-tonalites of the Conceição-type pierced the Cachoeirinha metamorphic rocks, whereas gray to pink, coarsely porphyritic granitic bodies of the Itaporanga-type (Itaporanga, Serra da Lagoinha, and Bodocó) intruded intermediate to high-grade metamorphic rocks of the basement along the northern contact of the CSF. Peralkalic syenites to quartz-syenites to granites are found intruding Cachoeirinha metasediments or its basement as dikes, ring-dikes, stocks or batholiths (Catingueira, Campo Grande, Urtiga, Paraíba state, and Triunfo; Batinga, Campo Alegre, Bom Nome, and Casé; Livramento, Duas Irmãs, and Paulo ridges; Quandu and Cavalos hills; Cana Brava, besides ring-dikes and dike swarms, in Pernambuco). A number of aegirine-bearing syenite to quartz-syenite bodies in the basement are aligned, accompanying the souther boundary of the CSF (Casé, Livramento, Duas Irmãs, and Paulo ridges, Bom Nome, Triunfo, Solidão), forming a magnetite-bearing syenitoid line (Fig. 1). Apparently, there are two peralkalic groups of rocks: the Catingueira-type and the *Triunfo-type.* Besides, tonalites to granodiorites with continental-trondhjemitic affinities have been identified at Serrita, Pernambuco, in two small stocks which intruded Salgueiro schists *(Serrita-type).* These stocks are actually ring-complexes where these tonalites occupy the core (Sial 1984a, 1984b).

Crosscut relationships have shown that the Conceição-type granitoids are older than those of the Itaporanga-type which, by their turn, are older than the peralkalic Catingueira-type. The Serrita-type granitoid is probably the older one among these four types, since narrow, calcalkalic dikes cut it.

Many other granite-types have been proposed in North-

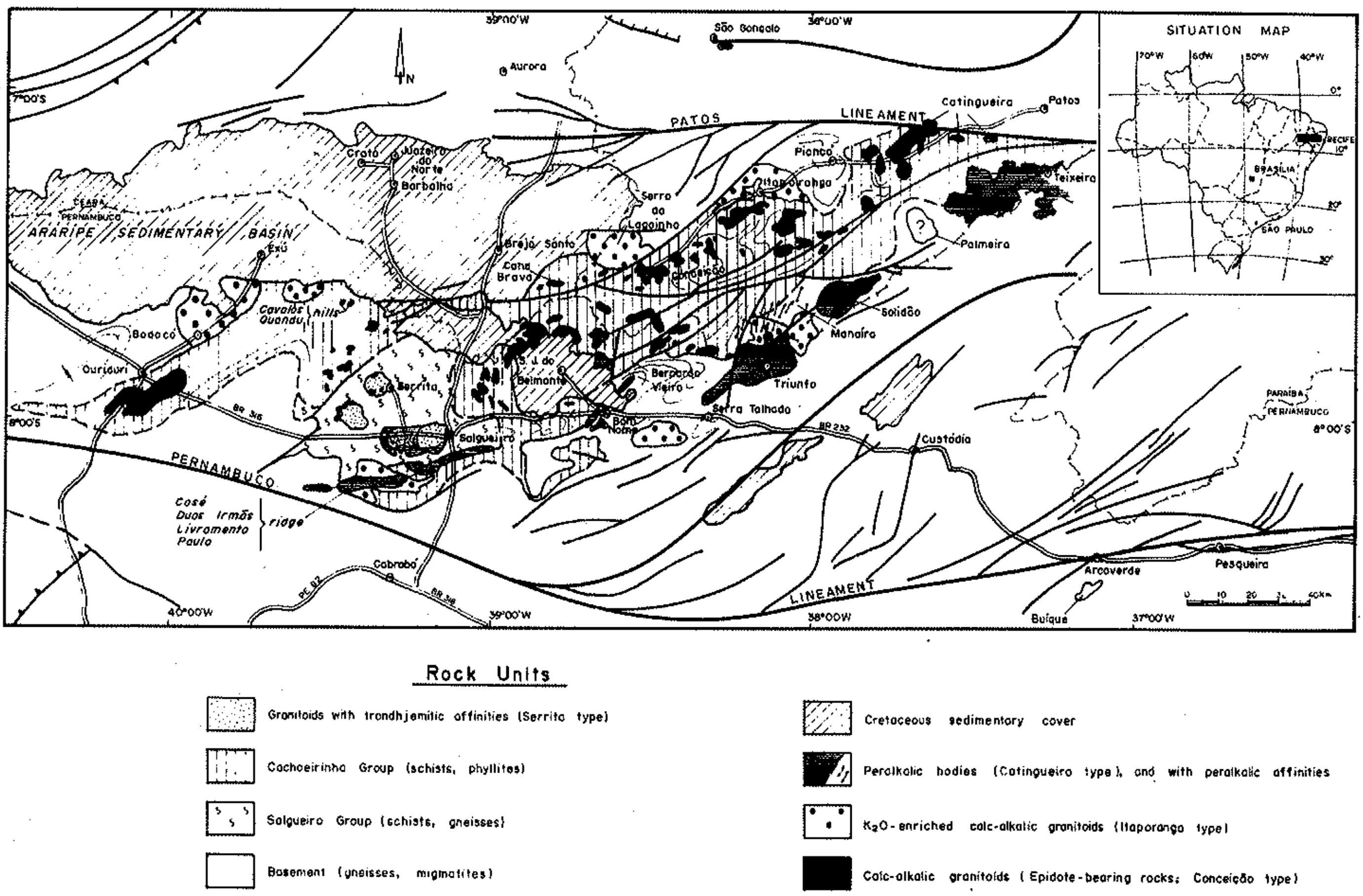



*Figure 1 – Geological sketch of the Cachoeirinha-Salgueiro foldbelt (Piancó-Alto Brígida), Northeast Brazil. Four different groups of granitoids are shown (modified from Brito Neves 1983, Assunção 1983, Sial 1984a,b); 1. Granitoids with trondhjemitic affinities (Serrita type); 2. Cachoeirinha Group (schists, phyllites); 3. Salgueiro Group (schists, gneisses); 4. Bocemont (gneisses, migmatites); 5. Cretaceous sedimentary cover; 6. Peralkalic bodies (Catingueira type), and with peralkalic affinities; 7. $K_2O$-enriched calc-alkalic granitoids (Itaporanga type); 8. Calc-alkalic granitoids (epidote-bearing rocks; Conceição type)*

*Table 1 – Some of the granite-types in Northeast Brazil*

| Locality | Granite-type | Type of intrusion, area of exposure in the type locality | Host-rock | Mineralogy | Petrographic type | Reference |
|---|---|---|---|---|---|---|
| Itaporanga, Conceição (Serra da Logoinha), Paraíba); Bodocó (Pernambuco), and (Monte das Gameleiras in the Rio Grande do Norte-Paraíba state boundary | Itaporanga | Batholiths; 300 km² | Migmatites of the Uauá Group | Biotite, hornblende plagioclase, quartz, zircon, allanite, sphene, magnetite | Porphyritic biotite granodiorite | Almeida *et al.* (1967); Sial (1984a); Sial (1984b); Barriga (written com.); This study. |
| Conceição, Itaporanga, Emas, Diamante (Paraíba); Ipueiras, Penaforte, Verdejante, Tamboril, Ori (Pernambuco) | Conceição | Stocks with variable size; 35 km² | Cachoeirinha Group metasediments (mainly phyllites) | Biotite, hornblende, plagioclase, quartz, epidote, sphene, allanite, ilmenite | Biotite, tonalite to granidiorite | Almeida *et al.* (1967); Sial (1984a); Sial (1984b); Barriga (written com.); This study. |
| Catingueira Urtiga, Campo Grande, São Gonçalo (Paraíba), Solidão (Pernambuco) | Catingueira | Dikes of variable widht and length (12 km² long); and batholith | Cachoeirinha metasediments (phyllites) and Pajéu-Paraíba metasediments | Microcline, aegirine, quartz ± biotite ± alkali-amphibole, magnetite | Peralkalic syenite to quartz-syenite | Almeida *et al.* (1967); Sial (1984a); Sial (1984b); Vandoros & Coutinho (1966); Ferreira & Sial (1985a); Ferreira & Sial (1985b); This study. |
| Itapetim (Pernambuco), Santa Luzia (Paraíba), and Cargalheiras (Rio Grande do Norte) | Itapetim | Batholiths with variable size; 200 km² | Migmatites of the Uauá | Microcline, plagioclase, biotite, quartz, epidote, sphene, and rare magnetite | Biotite granite to biotite granodiorite | Almeida *et al.* (1967); Brito Neves & Pessoa (1974); This study. |
| Triunfo, Casé Paulo, Livramento, and Duas Irmãs ridges, Bom Nome (Pernambuco) | Triunfo (also known as Baixa Verde) | Batholith with about 600 km², and dikes | Salgueiro and Cachoeirinha metasediments, and Uauá gneiss-megmatites | Microcline, aegirine, ± alkali, amphibole, magnetite | Peralkalic syenite to quartz syenite | Ferreira & Sial (1985b); Brito Neves & Pessoa (1974); Sadowski (1973); Sial *et al.* (1982); This study. |
| Serrita, Barra Verde, Granito, part of the Salgueiro batholith (Pernambuco) | Serrita | Stock with about 70 km², or dikes | Salgueiro and Cachoeirinha Groups metasediments | Microcline, ± amphibole, biotite, ± epidote, ± muscovite, magnetite, sphene, zircon | Biotite-tonalite to granidiorite with trondhjemitic affinities | Sial (1984a); Sial (1984b); Brito Neves & Pessoa (1974); Caldasso (1967); Sial *et al.* (1981); This study. |
| Buíque (Pernambuco) | Buíque | Batholith with about 200 km² | Migmatites of the Itaíba massif | Microcline, plagioclase, quartz, biotite, magnetite | Biotite granite to monzonite | Santos (1977) |
| Moderna (Pernambuco) | Moderna | Deformed stocks, with less than 30 km² | Cataclastic migmatites in the Itaíba | Microcline, plagioclase, quartz, massif | Ferrohasting site-hedenbergite granodiorite hedenbergite ferrohastin gsite, acessory phases* | Santos (1977); Santos (1971). |
| Caríba (Pernambuco) | Caríba | Batholith with about 200 km² | Migmatites, of Itaíba massif | Quartz, plagioclase, microcline, muscovite, acessory phases* | Biotite-muscovite granite | Santos (1977) |
| Águas Belas | Águas Belas | Batholith with about 200 km² | Migmatites of the Itaíba massif | Plagioclase, microcline quartz, hornblende, accessory phases* | Hornblende de monzonite | Santos (1977) |
| Arcoverde (Pernambuco) | Arcoverde | Batholith with about 400 km² | Migmatites of the Itaíba | Plagioclase, quartz, microcline, biotite, accessory phases* | Biotite-bearing-granodiorite | Santos (1977) |
| Sítio dos Nunes (Pernambuco) | Sítio dos Nunes | Large stock | Migmatites of the Itaíba massif | Quartz, biotite, plagioclase, microcline, accessory phases* | Biotite-granodiorite | Santos (1971) |
| Arcoverde (Pernambuco) | Pinheiro | Large stock | Migmatites of the Itaíba | Plagioclase quartz, garnet, accessory phases* | Garnet-bearing tonalite | Santos (1971) |
| Itabi and Gloria Sergipe state (from Macururé to Propriá) | Itabi Glória | Usually stocks, variable size | Low-grade schists of the Sergipean, system | Microcline, plagioclase, biotite, muscovite, quartz, accessory phases* | Biotite-granodiorite, quartz, monzonite, granite | Brito Neves & Pessoa (1974); Santos & Brito Neves (1984). |

* There is no accurate petrographic description.

east Brazil (Brito Neves & Pessoa 1974, Santos 1971, 1977; Santos & Brito Neves 1984). Among these types, nine became better known and frequently used for reference: Buíque, Moderna, Arcoverde, Águas Belas, Cariba, Sítio dos Nunes and Pinheiro, in Pernambuco, and Itabi and Gloria, in Sergipe state. Except for the Itabi and Gloria, all of them intruded migmatits of the Itaíba massif of Archean (? ) age. The Ibabi-type (Brito Neves *et al.* 1974), mostly composed of biotite-granodiorites and the Gloria-type, composed of quartz-monzonites, granodiorites, and granites intruded low-grade metamorphics of the Sergipean system.

The Buíque batholith shows two petrographic facies, a biotite-granite and a biotite-monzonite locally crosscut by narrow, muscovite-bearing-pegmatite dikes. Both facies are pink and locally porphyritic. The Moderna-type granitoid has been described by Santos (1971, 1977) as a body which intruded cataclastic migmatites of the Itaíba massif, composed of ferrohastingsite-hedenbergite granodiorite, and monzodiorite. The Arcoverde-type is mainly composed of biotite-bearing granodiorite, while the Águas Belas-type is chiefly composed of hornblende-monzonite. The Cariba-type is the only one which is a muscovite-bearing granitoid (two mica-granodiorite) found between Águas Belas and Itaíba, Pernambuco, with two textural patterns, a coarse and a fine-grained one. The Sítio dos Nunes-type is essentially a pink, biotite-granodiorite, medium-to-coarse-grained, with gneiss and limestome xenoliths. The Pinheiro-type, next to Arcoverde, is a locally garnet-bearing tonalite, cut by amazonite-bearing pegmatite dikes (Santos 1971). A summary of the characteristics of these granite-types is found in table 1.

In this study, the $^{18}O/^{16}O$ data from several bodies chosen among these granite-types (including the type localities) are combined with REE (rare earth elements), major and trace chemistry besides petrologic data to delineate sub-crustal elements placing constraints on the protoliths from which these granites were derived. Unfortunately, except for the Buíque and Itapetim batholiths, the data available concern only granite-types of the CSF and, therefore, the other types will be excluded in this study.

**REGIONAL SETTING** The regional geological features in this area include an elongate belt of predominantly low to medium-grade metamorphic supracrustal rocks of the Precambrian Cachoeirinha Group (part of the Piancó-Alto Brígida folding system of Brito Neves 1975), whose major foliation trends SW–NE, the biotite-schist to quartzites of the Salgueiro Group, and the older gneiss-migmatite terrane of the Uauá Group (Barbosa 1970).

Since Barbosa (*op. cit.*) proposed the stratigraphic division of this area into Uauá, Salgueiro, and Cachoeirinha Groups, this has been used by most geologists working in this portion of the states of Pernambuco and Paraíba. There was always a great difficult in distinguishing between the Cachoeirinha and Salgueiro metasediments, due to the lack of a visible unconformity between these two groups.

Recently, the Companhia de Pesquisas de Recursos Minerais (CPRM) finished a mapping program in this area (Silva Filho 1985) and proposed a detailed subdivision of the Cachoeirinha and Salgueiro Groups. The latter, regarded as Mid-Proterozoic, comprises five units of metavolcanic-metasedimentary character, bimodal volcanism divided in three units and dominant sedimentary content. Immature rocks of the molasse-type covering the Cachoeirinha Group were observed.

A tectonic model for the evolution of the CSF has never been proposed. A well orchestrated structural analysis and granite emplacement study, followed by accurate geochronological work, are indispensable before a tectonic model can be conceived.

**GEOCHRONOLOGY** Most of the studied bodies lacks dating and only few determinations have been done through K-Ar or Rb-Sr reference isochrons. Almeida *et al.* (1967) suggested that synorogenic granodiorites, tonalites, and calc-alkalic granites formed between 650 and 520 Ma, while peralkalic granites and syenites of the Catingueira type were of Cambrian age. Bon & Prien (1973) found through Rb-Sr reference isochron an age of 527±18 Ma (decay constant of $1.47 \times 10^{-11} y^{-1}$)for the Serrita, Jati, Bodocó, and Exu bodies. On the grounds of the present geochemical and petrographical data, this number is meaningless since samples used belong to different suites which surely differ in initial $^{87}Sr/^{86}Sr$. Hurley *et al.* (1966) determined a K-Ar age for the Serrita stock, in biotite, of 530±30 Ma which probably corresponds to the cooling age of that pluton. An attempt to date it through the Rb-Sr method was made by K. Kawashita (written com.) at the São Paulo University, Brazil. The major problem encountered was that the samples show very high Sr contents along very low Rb. Six samples yielded present day $^{87}Sr/^{86}Sr$ ratios between 0.7054 and 0.7065 against very low values of $^{87}Rb/^{86}Sr$. Since these values lie close to the *y*-axis, they do not allow to trace a reliable isochron, but assure that the initial $^{87}Sr/^{86}Sr$ ratio is around 0.705 or lower.

For the Salgueiro batholith, a preliminary Rb-Sr isochron with three points was obtained by K. Kawashita (*apud* Silva Filho 1982) yielding an age of 836 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7040±0.0001. As the points lie much close to each other (spreading is lower than 0.5) this isochron is of little value.

The body at Serra Talhada, next to the Triunfo syenitic batholith, has a K-Ar age of 527±8 Ma, while the Triunfo body itself (known also as Baixa Verde), showed K-Ar age of 570 Ma (Vandoros & Coutinho 1966). The Catingueira dike, dated through K-Ar on pyroxene, yielded an apparent age of 1220±220 Ma.

The Itaporanga batholith showed a Rb-Sr isochron age of 620±22 Ma with an initial $^{87}Sr/^{86}Sr$ of 0.7058±0.003 (Leon E. Long, written communication).

**PETROGRAPHY** **The $K_2O$-enriched group (Itaporanga-type).** This includes the Bodocó, Serra da Lagoinha (next to Conceição), and the Itaporanga batholiths, similar to each other in many respects.

In the Itaporanga body, microcline is the main feldspar, originally crystallized as orthoclase and inverted to microcline upon cooling. This body is very inhomogeneous with large, zoned, white feldspar cummulates irregularly distributed within a more mafic, more fine-grained matrix, quartz-diorite to tonalite in composition. K-feldspars may have floted in a more mafic magma prior to its final emplacement. Sometimes, this mineral is zoned (oscillatory zoning) and often includes poikilitically quartz, plagioclase, and biotite next to its margins, and seldomly forms flame, film, and patch perthites. Plagioclase, sometimes zoned, is often seen surrounding microcline and usually shows myrmekitic lobes which penetrate into microcline. Quartz usually looks built up of independent plates and often shows flame shadow patterns. Fe-enriched biotite, more abundant than amphibole, usually fills the interstices. Accessories are represented by apatite, zircon, allanite, primary epidote, sphene, and magnetite. Allanite is sometimes zoned, surrounded by epidote and found inside biotite.

Xenoliths of variable composition, but rather mafic, are abundant, preferentially oriented E–W. An incipient schistosity is observed and seems to go through the xenoliths.

Locally, this body shows pink, sometimes deformed, microcline, up to 10 cm long, often mantled by plagioclase, or with concentric rows of biotite. The Itaporanga body is chiefly composed of porphyritic granite to granodiorite (Fig. 2).

Next to Conceição town (Paraíba), a large body of porphyritic granitoid was emplaced in the migmatites of the basement adjacent to the northern boundary of the CSF, well represented at Serra da Lagoinha (Lagoinha ridge). This body is ovoid, 26 km long and 9 km wide, faulted at its southeastern portion and, within it, porphyritic K-diorite megafragments with pink K-feldspar megacrysts surrounded by white plagioclase in an amphibole-rich matrix full of fine-grained dark xenoliths are found. This rock is observed in the road Conceição–Mauriti and Barriga (written communication) mapped seven of these megafragments.

The Serra da Lagoinha body is essentially leucocratic, very porphyritic with pink and white microcline, up to 5 cm long. The groundmass is mainly composed of quartz, feldspar, biotite, amphibole, iron oxide minerals, and accessories, and this body resembles the Itaporanga, texturally and mineralogically. Xenoliths of the Conceição-type tonalite suggest that this body is younger.

In the K-diorites (locally quartz-diorites) large pink orthoclase megacrysts have been inverted to microcline on cooling, and are surrounded by oligoclase to andesine, sometimes altered to sericite. Myrmekites are rare and film perthites, common. Quartz is present in minor quantities. Fe-rich biotite and amphibole are found at about the same amount. Pyroxene and the accessories sphene, primary epidote, ilmenite, and magnetite are also observed. Microcline megacrysts surrounded by plagioclase suggest magma mixing (Hibbard 1979). The relationship between the K-diorite and the Serra da Lagoinha body is not clear.

The Bodocó batholith, next to Bodocó, Pernambuco, shows multiply zoned microcline megacrysts, up to 15 cm long, in a mafic groundmass composed of hornblende, biotite, sphene, and quartz. In some places, inclusions of metamorphic rocks (mainly schists) are seen as swarms, varying from a few centimeters to 1 m. Oval to elongate mafic autoliths show isolate, zoned microcline crystals. As the Itaporanga batholith, this exhibits microcline cummulates distributed in a less coarse matrix. Judging from the deformation in the feldspars, attained in a plastic state, this body was probably emplaced synorogenically.

Microscopically, zoned microcline is extremely perthitic (flame, film, and patch perthites) with sigmoidal shapes very often. Inside of then, anhedral plagioclase is found isolated or in mosaic, usually with calcic core which may represent restite of the source rock. Hornblende cummulates perhaps resulted from the early crystallization of this amphibole or represent xenoliths from the source rocks. Pyroxenes, partially transformed into amphibole, are maybe fragments of restites. Quartz with deformation lamellae and flame shadow patterns, allanite, zircon, primary epidote, primary and secondary muscovite, apatite, and magnetite are the other components. Mortar textures are locally seen and petrographically, the Bodocó batholith varies from a true granite to granodiorite (Fig. 2).

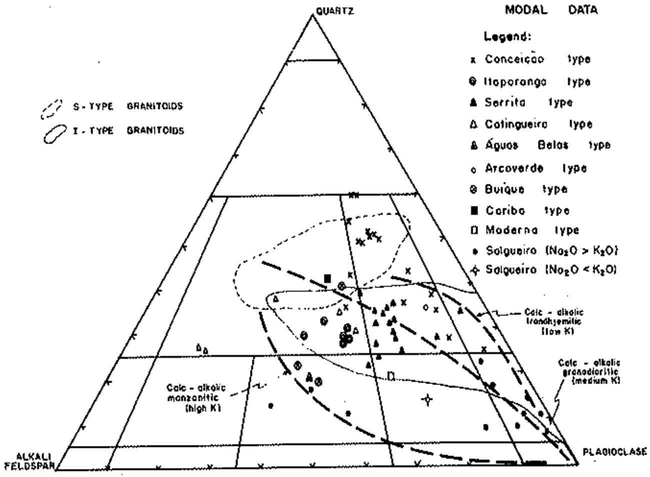



*Figure 2 – Streckeisen's (1973) QAP ternary plot. Typical areas for S and I-type granitoids of Loiselle & Wones (1979) are shown. The three major trends indicated are from Lameyre & Bowden (1982): a = calc-alkalic-trondhjemite (low K); b = calc-alkalic-granodiorite (medium K); and c = calc-alkalic-monzonite (high K)*

**The calc-alkalic group (Conceição type)** This includes bodies which pierced the Cachoeirinha metasediments, in Paraíba and Pernambuco, and form small, subcircular to elongate massifs, locally deformed by tectonic processes. Xenoliths or autoliths of amphibole-rich rock are common.

Petrographically, they are represented by granodiorites and tonalites (Fig. 2). These are gray rocks, fine to medium-grained, porphyritic with phenocrysts up to 0.5 cm long, often referred to as *couro-de-sapo* (toad's leather) granitoids. Locally, they are cut by pegmatite and aplite veins. The relationship between the Conceição stock (type locality) and the K-diorite mega-fragments within the Serra da Lagoinha body, is unclear.

The Conceição tonalite shows little textural and petrographic variation a characteristic shared by almost all Conceição-type granitoids within the CSF (Emas, Penaforte, Tamboril, Mata Boi, Ipueiras, Conceição, Boa Ventura, Carmo, and several others).

Microscopically, plagioclase phenocrysts show oscillatory or normal zoning and a great number of inclusions (epidote, sillimanite? ), in some cases with no preferential orientation, a feature common to almost every plagioclase phenocryst of Conceição-type plutons. The large intergrowths of skeletal zoisite in plagioclase are the product of solid-state alteration as the plagioclase-bearing magma ascended through the crust (Zen &Hammastrom 1983). Sometimes, smaller plagioclase grains are included in plagioclase phenocrysts and often show an overgrowth rim with compositional discontinuity. The outer rim is usually albite in composition.

Subordinate microcline, slightly perthitized, includes biotite, sphene, plagioclase, and amphibole. The last one is found as euhedral crystals, sometimes twinned or forming clots, Biotite is Fe-enriched, inclusion-free, sometimes found inside the amphibole. Quartz forms mosaics with wavy extinction, sphene, zircon, zoned, twinned, euhedral allanite, euhedral to subhedral, sometimes zoned, and twinned primary epidote are the main accessory phases. Iron oxide minerals are mainly represented by ilmenite.

The oscillatory zoning of the plagioclase phenocrysts suggests that during crystallization the magma probably was submitted to a convection regime or that water content increased discontinuously in such way to lower the solidus within more or less regular time intervals. The relatively high water content of the magma at this stage allowed amphibole to crystallize along plagioclase which was probably the first phase to crystallize, followed by amphibole, epidote, quartz, microcline, and biotite. These rocks are quartz-enriched tonalites and granodiorites (Fig. 2).

**Granitoids with trondhjemitic affinities (Serrita-type)** This type studied by Sial *et al.* (1981) is represented by two stocks nearby Serrita, a portion of the Salgueiro batholith, a stock at Barra Verde, north of Serrita, and a dike at Granito, all of them in Pernambuco. They are usually eroded to the ground level.

The round-shaped stocks at Serrita are composed of a leucocratic rock (tonalite to albite-granodiorite) with albite, quartz, microcline, biotite, amphibole, muscovite, and sphene, zircon, and magnetite as acessories. At Barra Verde, a similar mineralogy is observed and fluorite is present. Albite usually predominates over microcline, includes poikilitically zircon, apatite and, less frequently, biotite. Plagioclase shows kinkbands and was invaded by late solutions and during crystallization reacted with the liquid to form microcline. The almost total lack of perthite and myrmekite suggests a crystallization in a pre-aqueous stage (Hibbard 1979).

Quartz forms large crystals, sometimes occupies interstices, and crystallized at least in part, simultaneously with microcline and plagioclase. Biotite is usually interstitial but small flakes were found inside the plagioclase indicating that this mineral had a long period of crystallization. Amphibole is also interstitial but there are early crystallized amphiboles which reacted with the liquid.

Zircons appear in contact with about every phase and include apatite. Epidote is seen very often inside or in the neighborhood of biotite, suggesting it resulted from the reaction between biotite and the liquid towards the end stages of crystallization, as suggested by Naney (1977).

The Salgueiro batholith nearby Salgueiro town probably represents a late emplaced batholith which intruded the Salgueiro schists of Barbosa (1970), and shows no indication of pervasive, post-intrusion metamorphism. Its petrography was summarized by Silva Filho *et al.* (1982) and the mineral chemistry by Sial *et al.* (1983). This batholith, with about 200 km$^2$, in its western portion was eroded down to the ground level. The schists in contact with it dip inwards suggesting the present level of exposure represent the lower section of the batholith. Granodiorite, which occupies the largest area of the batholith, resembles the innermost portion of the stocks at Serrita, and is composed of albite, microcline, amphibole, biotite, quartz, perthite, sphene, apatite, allanite, and zircon. Texturally, it is mostly fine-grained with granular texture.

**The peralkalic group (Catingueira and Triunfo-types)** It seems that the latest magmatic event in the CSF is represented by dikes, stocks, and batholiths of peralkalic character (for details see Ferreira & Sial 1985b), which includes oversaturated and saturated rocks. Among them the Catingueira dike, about 12 km long and 300 m wide, became known since Almeida *et al.* (1967). It intruded Cachoeirinha metamorphics, developed a contact aureole with staurolite phenoblasts, and has been partially sheared by movements along the Tigre fault, which trends parallelly to the Patos lineament. It is composed of a leucocratic syenite to quartz-syenite with albite, microcline, alkali-pyroxene, quartz, biotite, sphene, zircon, and magnetite. Albite, sometimes zoned, predominates over microcline which is slightly perthitized (patch perthites) and includes pyroxene a few times. Greenish biotite flakes, zircon, and euhedral magnetite are present at low quantities. Quartz often shows wavy extinction and deep green, pleochroic pyroxene phenocrystals sometimes include small biotite flakes. The dikes related to this event show composition varying from peralkalic granite to quartz-syenite (Urtiga, Campo Grande, and Catingueira), and two dikes parallel to the Catingueira one.

The peralkalic syenites in the syenitoid line (Triunfo-type; Fig. 1) differ slightly from the Catingueira-type granitoids and related rocks. The latter are biotite-bearing, show less amount of alkali-pyroxene and lack the pyroxene autoliths, widespread in the Triunfo batholith. To the moment, no detailed isotopic work has been done to allow any firm conclusion on this. The bodies in the syenitoid line (Casé, Duas Irmãs, Paulo, and Livramento dike, Bom Nome dike, Triunfo, and Solidão batholiths) are mainly composed of alkali-pyroxene (ferroaugite soda-augite to aegirine), microcline, and magnetite, with minor quartz. Locally, alkali amphibole is present, usually resulting from the reaction between the alkali-pyroxene and the liquid. The body at Teixeira, Paraíba, in the extension of this syenitoid line, is perhaps of peralkalic affinity, but this needs further confirmation. The Quandu and Riacho dos Cavalos hills, not far from Sítio dos Moreiras, Pernambuco, the Cana Brava ridge north of Carmo, Batinga, and Campo Alegre hills next to Bernardo Vieira, all in Pernambuco, are composed of aegirine-bearing rocks.

The two stocks at Serrita show at their outermost portion, aegirine-bearing ring-dikes (e.g. Macacos, Vassouras, Serrita hills, etc.) which are in topographic relief, as almost every peralkalic body in the CSF. The Salgueiro batholith has in its outermost portion in its eastern side rocks with ferroaugite which resembles peralkalic rocks at the Macacos ring-dike. Considering the distribution of acmite-normative rocks within this batholith (Silva Filho 1982), it is possible that it represents the emplacement of two adjacent ring-complexes similar to the ones found next to Serrita.

Peralkalic dike swarms are observed next to Princesa Isabel and Manaíra, Paraíba, within the Salgueiro batholith, next to Terra Nova, next to Santo Antônio Creek (30 km north of Serrita), and Barra de São Pedro, next to Ouricuri, all in Pernambuco. Several of these dikes show microcline phenocrysts, aegirine, and magnetite, in a fine-grained matrix mainly composed of quartz and long needles of alkali-amphibole. Judging from textural patterns, they must have been emplaced at shallow depth.

Dikes similar to the Catingueira one are found between Patos and São Gonçalo, Paraíba (Almeida *et al.* 1967), beyond the limits of the area under consideration here (Fig. 1). Undersaturated dikes are mentioned at Ipueiras, Pernambuco, by Silva Filho (1985), represented by olivine-malignite to olivine-shonkinite, with olivine, nepheline, aegirine-augite, and red biotite. More details about the peralkalic rocks referred to here can be found in Ferreira & Sial (1985b).

**Other granitoids** For other proposed granite-types (Itapetim, Buíque, Arcoverde, Moderna, Águas Belas, and Cariba), only limited data are available and these concern mainly mineralogy and modal composition (Fig. 2). For the Itapetim and Buíque batholiths some geochemical data are available (Sial 1984a,b). The Itapetim body resembles the Itaporanga-type granitoids and the Buique batholith is partially similar to Serrita rocks. As they are composite batholiths, petrographic facies mapping followed by geochemical study are necessary to a better comparison between these types. The use of these granite-types for reference has been limited by these reasons and perhaps some of them will not stand an accurate petrographic and geochemical study, as they can be equivalent to some of the better known types (Itaporanga, Conceição, Serrita, Triunfo, Catingueira, etc.).

**GEOCHEMISTRY** Most of the major element analyses in this study was accomplished at the Geosol Laboratory, Belo Horizonte, Brazil. Only some representative analyses of granitoids of the Itaporanga, Conceicão, Serrita, Catingueira, Itapetim, and Buíque types (Table 2) are incorporated here with respective CIPW norms. Trace elements, including REE, were analysed at the Department of Geology of the Memorial University of Newfoundland, Canada. Oxygen isotopes were analysed at the Department of Geology of the University of Georgia, Athens, USA.

**Major elements** Difficulties in point counting some of these rocks arise from their extremely porphyritic textures and for this reason analyses were plotted in the Streckeisen & Lemaitre (1979) diagram (Fig. 3). This also allowed a comparison between this chemical classification and Streckeisen's (1973) classification as shown in figure 3.

Analyses from the four groups of granitoids found in the CSF have been plotted in the $CaO$-$Al_2O_3$-$K_2O$+$Na_2O$ (molecular, Fig. 4a) diagram in which the areas where S and I-type granitoids should plot according to Loiselle & Wones (1979) are also shown. The $K_2O$-enriched plutons (Itaporanga-type) revealed to be partially metaluminous and partially peraluminous. The calc-alkalic plutons are all peraluminous, same happening to the granitoids with trondhjemitic affinities, except for two analyses. Analyses from the Salgueiro batholith plotted on an identical diagram (Fig. 4b) turned out to be partially peraluminous ($K_2O > Na_2O$), partially metaluminous ($K_2O > Na_2O$), and partially peralkalic ($Na_2O > K_2O$) which reflects the a possible composite character of this batholith. A better distinction between the $K_2O$- and $Na_2O$-enriched rocks at Salgueiro is found in figure 5, where the $Na_2O$-enriched

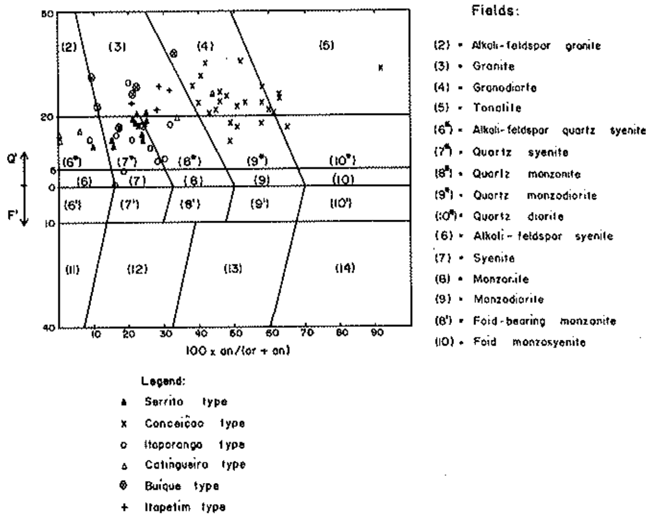



*Figure 3 – Streckeisen & Lemaitre (1979) plot, using the chemical data available*

rocks preferentially plot within the trondhjemite field, if O'Connor's (1965) field boundaries are taken into account, but they lie mostly in the granite field if Barker's (1979) field boundaries are considered. The analyses of the Serrita stocks, independently of which boundary lines are chosen, lie predominantly in the trondhjemite field.

In the AFM ternary plot (Fig. 6a), the $K_2O$-enriched plutons show two different trends. The Itaporanga and Serra da Lagoinha batholiths constitute more or less one single trend which seems to transect the boundaries between the calc-alkalic and the tholeitic fields and resemble the trends shown by augen-gneisses (e.g. Amitsoq augen-gneisses; Collerson & Bridgewater 1979). The Bodocó batholith, however, yielded a totally independent trend, which lies in the alkalic field and perhaps just reflects different oxygen fugacites prevailing during magma crystallization.

The calc-alkalic groups of granitoids exhibits a trend within the field of the calc-alkalic rocks, but surprisingly it seems to follow the trend proposed by Arth & Barker (1976) for the trondhjemites. These rocks probably crystallized under oxygen fugacity higher than the potassic group, except for the Bodocó batholith.

The two stocks near Serrita plot next to the A apex, suggesting that they represent a well-developed stage of magma differentiation and their analyses plot in the extension of the trend defined by the calc-alkalic plutons. In figure 6b, samples from the Salgueiro batholith have been plotted, defining a trend in the calc-alkalic field, without a clear distinction between the $Na_2O$- and $K_2O$-enriched rocks.

**Trace elements** Several trace elements have been analysed by X-ray fluorescente, at the Memorial University, Newfoundland, Canada. These elements, including Rb, Ba, Th, Nb, Ce, Zr, Sm, Y, and Yb have been analysed for the Itaporanga, Conceição, Catingueira, and Serrita-types of granitoids. These trace elements have been normalized to the Ocean ridge granite (ORG; according to Pearce *et al.* 1984) and averages are shown in Table 3. ORG-normalized representative samples show consistent patterns with negative slope, positive Ba and Sm anomalies, approaching ORG-values for Nb, Ce, Zr, and Sm. Averages for the four granite-types generated similar patterns which are shown in figure 7, and roughly approach the syn- to post-collision granites of Pearce *et al.* (1984).

**Oxygen isotopes** Granitic bodies of about the same compositon can have widely varying oxygen isotope composition, even when they escaped secondary hydrothermal or metamorphic processes (Taylor 1978). Recent studies have ascribed such differences in the isotope composition to the nature of the protolith. Very often, it has been assumed that $^{18}O$-enriched granitoids originated from metasedimentary-type protoliths, whereas the more $^{18}O$-depleted granitoids originated from igneous-type protoliths (O'Neil & Chappel 1977, O'Neil *et al.* 1977, Taylor & Silver 1978, Taylor & Turi 1976).

Systematic $^{18}O/^{16}O$ geographic patterns in suites of granitic plutons were observed in Australia (O'Neil & Chappel 1977, O'Neil *et al.* 1977), United States (Taylor & Silver 1978, Wenner 1981), and Italy (Taylor & Turi 1976). Apparently, $^{18}O$-enriched plutonic rocks outcrop away from continental margins, while $^{18}O$-depleted granitoids are located next to present-day ocean basins.

Taylor (1980) and Harmon & Halliday (1980) recognized a correlation between $^{18}O/^{16}O$ and initial $^{87}Sr/^{86}Sr$ ratios in granitic plutons. Oxygen isotope analyses is also one of the best parameters to distinguish S from I-type granitoids (O'Neil & Chappel 1977, O'Neil *et al.* 1977).

In this study, oxygen isotope compositions were determined for a series of syn- to post-orogenic granitoids in the CSF or at the adjacent migmatite-gneiss basement. Besides, this study was also extended to three other plutons out of this region (Monte das Gameleiras and Dona Inês at the Paraíba-Rio Grande do Norte state boundary, and Buíque, Pernambuco), which bear some resemblance to major bodies in the area under consideration.

*ISOTOPE TECHNIQUE AND STANDARDS* All oxygen extractions were performed by reaction with fluorine. Isotopic analyses were made using a VG Micromass 602 C double collecting mass spectrometer. Routine intercomparisons of samples with rose quartz standard were made, the standard being defined as +8.45 permil relative to SMOW.

*WHOLE-ROCK OXYGEN ISOTOPIC DATA* In this study, no attempt to interpret the isotopic variations within each pluton will be made but only the regional oxygen isotope patterns will be of primary interest. The interpretations of patterns on individual plutons along REE and phase chemistry will be object of another paper to be published elsewhere.

Samples from seventeen bodies have been analysed and the means are found in table 4 and ranges in figure 8. An overview of the oxygen isotope data allows the following statements:

**1.** Almost all plutons for which five or more samples were analysed exhibit a total range of $\delta^{18}O$ values less than 2 permil.

**2.** A broad range of mean oxygen isotopic compositons is observed, varying from 6.93 to 12.79 permil. This range corresponds almost to the full range of primary isotopic compositions in granitoids.

**3.** There is a systematic regional trend (Fig. 9) in which the most $^{18}O$-enriched rocks are represented by the calc-alkalic tonalites to granodiorites of the Conceição-type (Ipueiras, Penaforte, stock 30 km north of Serrita town, Carmo, and

*Table 2 – Whole-rock chemical analyses (major elements) for some granite types in Northeast Brazil*

| | Potassic – Calc-Alkalic Plutons | | | | | | | | Itaporanga Type | | | Calc-Alkalic-Plutons (Conceição Type) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Itaporanga Batholith | | | | | Serra da Lagoinha Batholith* | | | Bodocó Batholith | | | Stocks within the Cachoeirinha Salgueiro Foldbelt | | | |
| | I-10 | I-13 | I-23 | I-31 | I-43 | 205 | 208 | 193 | BOD-4 | BOD-5 | BOD-7 | SER-81 | SER-83 | SER-47 | SER-70 |
| **MAJOR ELEMENTS** | | | | | | | | | | | | | | | |
| $SiO_2$ | 63.90 | 63.80 | 67.90 | 59.00 | 70.20 | 61.61 | 66.53 | 66.53 | 60.95 | 58.97 | 59.72 | 70.50 | 66.03 | 63.99 | 58.33 |
| $TiO_2$ | 0.78 | 0.86 | 0.79 | 1.50 | 0.41 | 0.93 | 0.68 | 0.59 | 0.75 | 0.83 | 0.80 | 0.38 | 0.90 | 0.88 | 1.28 |
| $Al_2O_3$ | 16.60 | 15.70 | 16.80 | 16.70 | 15.60 | 16.46 | 15.10 | 15.75 | 15.69 | 15.12 | 15.12 | 14.29 | 14.04 | 15.43 | 15.47 |
| $Fe_2O_3$ | 1.60 | 1.30 | 1.60 | 2.50 | 1.30 | 0.80 | 0.89 | 0.36 | 1.83 | 1.95 | 1.69 | 0.57 | 1.07 | 1.26 | 2.29 |
| FeO | 3.35 | 4.28 | 2.86 | 3.64 | 1.21 | 4.14 | 2.85 | 3.05 | 2.31 | 3.07 | 2.38 | 1.22 | 2.52 | 2.28 | 3.38 |
| MnO | 0.07 | 0.08 | 0.04 | 0.08 | 0.03 | 0.10 | 0.06 | 0.06 | 0.05 | 0.06 | 0.06 | 0.02 | 0.04 | 0.05 | 0.08 |
| MgO | 1.10 | 1.10 | 1.00 | 1.80 | 0.60 | 1.67 | 1.08 | 0.73 | 2.50 | 3.40 | 3.27 | 0.47 | 1.31 | 1.57 | 3.02 |
| CaO | 2.80 | 2.60 | 2.40 | 4.40 | 1.60 | 3.09 | 2.16 | 2.02 | 4.34 | 4.90 | 4.78 | 2.69 | 3.92 | 3.98 | 5.88 |
| $Na_2O$ | 4.10 | 4.00 | 2.30 | 4.30 | 3.50 | 4.52 | 4.07 | 3.67 | 3.74 | 3.98 | 4.11 | 3.90 | 3.50 | 3.64 | 2.93 |
| $K_2O$ | 4.30 | 5.50 | 2.90 | 4.80 | 4.80 | 5.19 | 5.08 | 5.47 | 5,20 | 4.40 | 5.20 | 3.01 | 3.10 | 3.38 | 3.20 |
| $P_2O_5$ | 0.30 | 0.24 | 0.25 | 0.57 | 0.11 | 0.38 | 0.24 | 0.18 | 0.46 | 0.52 | 0.52 | 0.22 | 0.30 | 0.07 | 0.49 |
| $H_2O^+$ | 1.07 | 0.68 | 0.94 | 0.71 | 0.56 | 0.90 | 0.71 | 0.43 | 0.04 | 0.07 | 0.04 | 0.13 | 0.05 | 0.02 | 0.16 |
| $H_2O^-$ | 1.01 | 0.37 | 0.95 | 0.67 | 0.40 | – | – | – | 0.79 | 0.92 | 0.87 | 1.37 | 1.40 | 1.89 | 2.36 |
| **Total** | 100.98 | 100.51 | 100.73 | 100.67 | 100.32 | 99.79 | 99.45 | 98.84 | 98.60 | 98.19 | 98.56 | 98.77 | 98.18 | 98.34 | 09.87 |
| **CIPW NORMS** | | | | | | | | | | | | | | | |
| Q | 15.13 | 11.02 | 36.27 | 5.37 | 27.22 | 5.63 | 16.53 | 17.32 | 8.51 | 5.77 | 3.08 | 30.35 | 23.81 | 19.06 | 13.93 |
| C | 0.83 | 0.00 | 6.11 | 0.00 | 2.00 | 0.00 | 0.00 | 0.55 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| OR | 25.41 | 32.50 | 17.13 | 28.36 | 28.36 | 30.66 | 30.01 | 32.32 | 31.35 | 26.68 | 31.25 | 18.25 | 18.78 | 19.38 | 19.59 |
| AB | 34.69 | 33.85 | 19.46 | 36.39 | 29.62 | 38.25 | 34.44 | 31.06 | 32.29 | 34.56 | 35.37 | 33.87 | 30.37 | 30.80 | 25.69 |
| AN | 11.93 | 8.64 | 10.27 | 12.09 | 7.22 | 9.30 | 7.93 | 8.85 | 10.88 | 10.66 | 7.57 | ·12.92 | 13.78 | 16.08 | 20.31 |
| AC | 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 | 0.00 |
| NS | 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 | 0.00 |
| WO-DI | 0.00 | 1.12 | 0.00 | 2.51 | 0.00 | 1.48 | 0.51 | 0.00 | 3.75 | 5.05 | 10.00 | 0.09 | 3.48 | 0.63 | 3.12 |
| EN-DI | 0.00 | 0.38 | 0.00 | 1.56 | 0.00 | 0.63 | 0.22 | 0.00 | 2.72 | 3.49 | 4.19 | 0.05 | 1.95 | 2.14 | 2.18 |
| FS-DI | 0.00 | 0.77 | 0.00 | 0.80 | 0.00 | 0.85 | 0.29 | 0.00 | 0.69 | 1.15 | 1.31 | 0.05 | 1.40 | 1.37 | 0.68 |
| EN-HY | 2.74 | 2.36 | 2.49 | 2.92 | 1.49 | 3.53 | 2.47 | 1.82 | 3.65 | 5.20 | 4.10 | 1.16 | 1.40 | 2.54 | 5.62 |
| FS-HY | 3.67 | 4.74 | 2.70 | 1.49 | 0.53 | 4.74 | 3.20 | 4.44 | 0.93 | 1.70 | 1.28 | 1.17 | 1.00 | 1.16 | 1.76 |
| WO | 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 | 0.00 |
| MT | 2.32 | 1.88 | 2.32 | 3.62 | 1.88 | 1.16 | ·1.29 | 0.52 | 2.71 | 2.91 | 2.50 | 0.85 | 1.60 | 0.09 | 3.44 |
| HM | 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 | 0.00 |
| IL | 1.48 | 1.63 | 1.50 | 2.85 | 0.78 | 1.77 | 1.29 | 1.12 | 1.46 | 1.62 | 1.55 | 0.75 | 1.76 | 0.00 | 2.52 |
| AP | 0.71 | 0.57 | 0.59 | 1.35 | 0.26 | 0.90 | 0.57 | 0.43 | 1.12 | 1.27 | 1.26 | 0.54 | 0.79 | 0.71 | 1.21 |

| | Plutons with trondhjemitic affinities (Serrita type) | | | | Peralkalic plutons (Catingueira-type) | | | | Calc-alkalic pluton (Itapetim-type) | | | Calc-alkalic pluton (Buíque-type) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Serrita stock | | | | Catingueira dike | | | | Itapetim | | | Buíque Batholith | | |
| | SER-17 | SER-21 | SER-25 | SER-58 | CAT-1 | CAT-2 | CAT-5 | CAT-6 | ITIM-11 | ITIM-21 | ITIM-30 | B-8 | B-30 | B-50 |
| **MAJOR ELEMENTS** | | | | | | | | | | | | | | |
| $SiO_2$ | 69.50 | 67.31 | 68.01 | 67.60 | 68.60 | 68.60 | 68.40 | 68.80 | 69.50 | 68.00 | 67.50 | 71.90 | 68.70 | 75.60 |
| $TiO_2$ | 0.61 | 0.43 | 0.60 | 0.24 | 0.21 | 0.22 | 0.21 | 0.22 | 0,49 | 0.77 | 0.71 | 0.24 | 0.54 | 0.25 |
| $Al_2O_3$ | 17.00 | 18,27 | 18.23 | 18.90 | 14.90 | 14.80 | 14.80 | 14.70 | 14.30 | 14.50 | 15.20 | 14.40 | 14.40 | 12.50 |
| $Fe_2O_3$ | 0.10 | 0.26 | 0.33 | 0.08 | 1.10 | 2.10 | 1.20 | 0.75 | 1.50 | 1.60 | 1.70 | 0.81 | 1.80 | 0.06 |
| FeO | 0.90 | 0.50 | 0.36 | 0.50 | 1.28 | 0.29 | 1.00 | 1.00 | 2.57 | 2.28 | 1.71 | 1.43 | 1.50 | 1.57 |
| MnO | 0.03 | 0.02 | 0.01 | 0.01 | 0.05 | 0.06 | 0.05 | 0.04 | 0.07 | 0.03 | 0.05 | 0.04 | 0.03 | 0.03 |
| MgO | 0.17 | 0.21 | 0.10 | 0.11 | 0.43 | 0.41 | 0.43 | 0.47 | 0.70 | 0.70 | 1.00 | 0.38 | 0.60 | 0.53 |
| CaO | 1.82 | 1.33 | 1.19 | 1.29 | 1.40 | 1.50 | 1.40 | 1.40 | 2.40 | 2.90 | 3.30 | 1.70 | 1.50 | 1.60 |
| $Na_2O$ | 5.50 | 6.07 | 5.86 | 6.50 | 5.00 | 4.800 | 5.10 | 5.20 | 3.40 | 3.70 | 3.90 | 4.90 | 3.70 | 4.60 |
| $K_2O$ | 2.10 | 3.49 | 3.61 | 3.40 | 6.40 | 6.30 | 6.60 | 6.70 | 4.40 | 5.00 | 4.01 | 3.80 | 6.20 | 2.30 |
| $P_2O_5$ | 0.10 | 0.22 | 0.03 | 0.07 | 0.10 | 0.14 | 0.10 | 0.12 | 0.14 | 0.19 | 0.15 | 0.07 | 0.15 | 0.06 |
| $H_2O^+$ | 0.06 | 0.03 | 0.08 | 0.11 | 0.28 | 0.16 | 0.12 | 0.55 | 0.51 | 0.32 | 0.49 | 0.40 | 0.40 | 0.45 |
| $H_2O^-$ | 0.40 | 0.54 | 0.64 | 0.30 | 0.18 | 0.15 | 0.06 | 0.06 | 0.37 | 0.25 | 0.70 | 0.42 | 0.50 | 0.21 |
| **Total** | 98.20 | 98.88 | 99.11 | 99.10 | 99.33 | 100.31 | 99.47 | 100.02 | 100.35 | 100.24 | 100.42 | 100.49 | 100.02 | 100.76 |
| **CIPW NORMS** | | | | | | | | | | | | | | |
| Q | 25.24 | 16.09 | 17.49 | 13.83 | 12.63 | 13.86 | 11.64 | 13.32 | 25.87 | 20.94 | 21.74 | 24.51 | 20.02 | 35.05 |
| C | 2.61 | 2.62 | 2.59 | 2.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| OR | 12.41 | 20.62 | 21.33 | 20.09 | 37.81 | 37.22 | 39.00 | 39.59 | 26.00 | 29.54 | 36.63 | 22.45 | 36.63 | 13.59 |
| AB | 46.54 | 51.36 | 49.59 | 55.00 | 41.02 | 40.62 | 39.39 | 38.32 | 28.77 | 31.31 | 33.00 | 41.46 | 31.31 | 38.92 |
| AN | 9.38 | 5.16 | 5.17 | 5.94 | 0.00 | 0.24 | 0.00 | 0.00 | 10.77 | 8.19 | 12.31 | 6.03 | 4.38 | 6.67 |
| AC | 0.00 | 0.00 | 0.00 | 0.00 | 1.14 | 0.00 | 3.32 | 2.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NS | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WO-DI | 0.00 | 0.00 | 0.00 | 0.00 | 2.57 | 2.41 | 2.59 | 1.12 | 0.09 | 2.07 | 1.36 | 0.79 | 0.87 | 0.37 |
| EN-DI | 0.00 | 0.00 | 0.00 | 0.00 | 1.07 | 1.02 | 1.07 | 0.49 | 0.04 | 1.04 | 0.98 | 0.30 | 0.62 | 0.13 |
| FS-DI | 0.00 | 0.00 | 0.00 | 0.00 | 1.51 | 1.40 | 1.54 | 0.63 | 0.06 | 0.98 | 0.26 | 0.51 | 0.18 | 0.24 |
| EN-HY | 0.42 | 0.52 | 0.25 | 0.27 | 0.00 | 0.00 | 0.00 | 0.71 | 1.71 | 0.70 | 1.51 | 0.65 | 0.88 | 1.19 |
| FS-HY | 0.78 | 0.03 | 0.00 | 0.47 | 0.00 | 0.00 | 0.00 | 0.92 | 2.74 | 0.67 | 0.40 | 1.12 | 0.25 | 2.23 |
| WO | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.22 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| MT | 0.14 | 0.38 | 0.00 | 0.12 | 1.02 | 2.45 | 0.08 | 0.00 | 2.17 | 2.32 | 2.46 | 1.17 | 2.61 | 0.09 |
| HM | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| IL | 0.97 | 0.82 | 0.78 | 0.46 | 0.40 | 0.42 | 0.40 | 0.42 | 0.93 | 1.46 | 1.35 | 0.46 | 1.03 | 0.47 |
| AP | 0.24 | 0.52 | 0.07 | 0.17 | 0.24 | 0.33 | 0.24 | 1.25 | 0.33 | 0.45 | 0.36 | 0.17 | 0.36 | 0.14 |

* From V. Barriga (written communication)

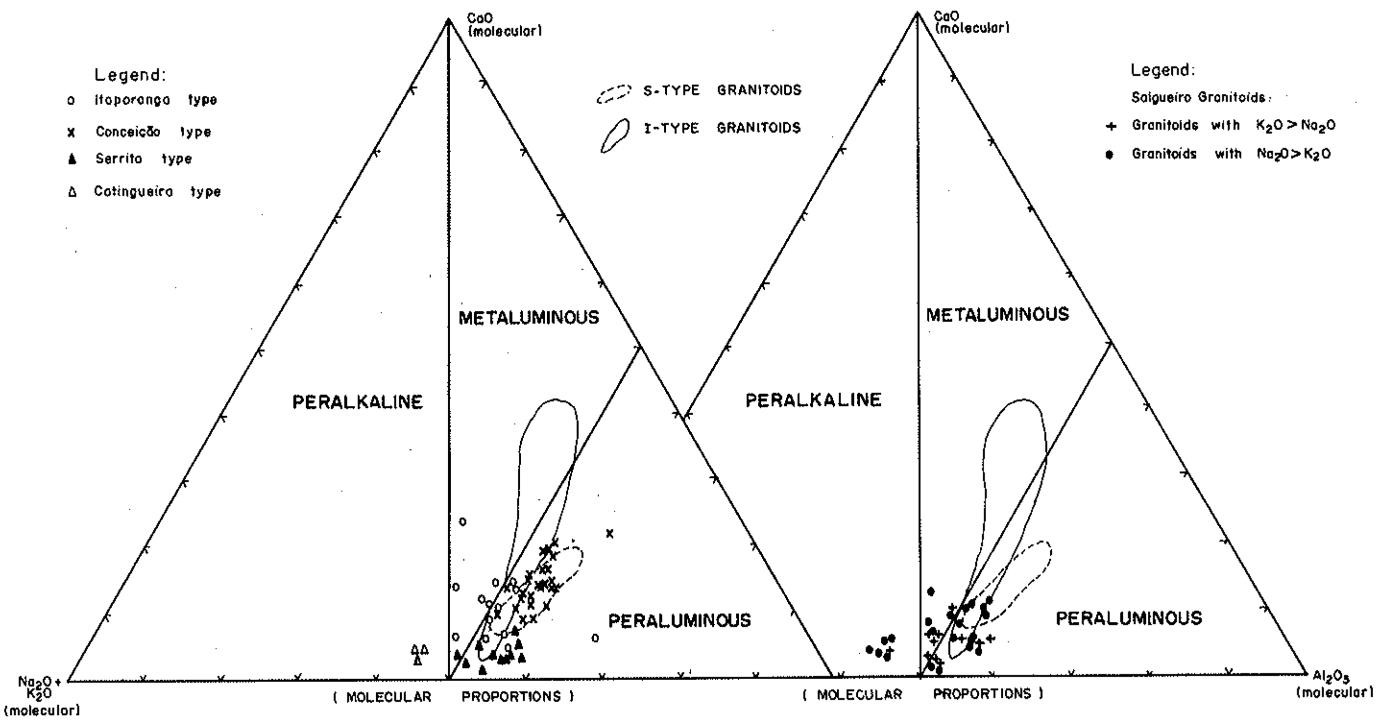



*Figure 4 – CaO-$Al_2O_3$-$K_2O$+$Na_2O$ Loiselle & Wones (1979) molecular plot, where areas for the S and I-type granitoids are also indicated: a) main groups of granitoids; and b) Salgueiro batholith*

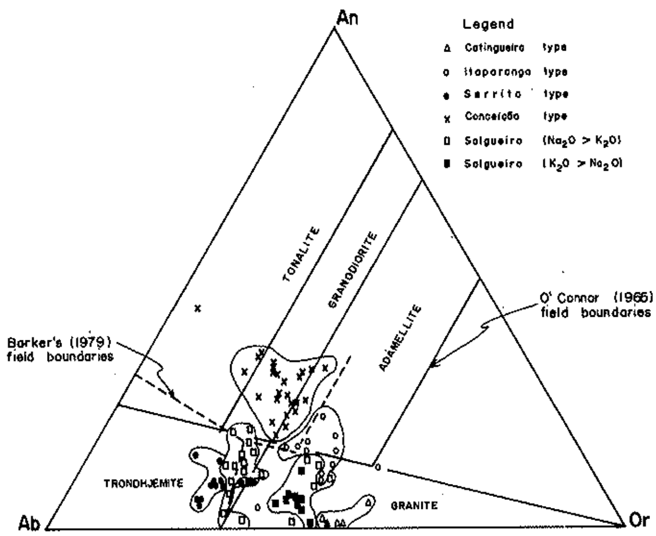



Fig. 5

*Figure 5 – O'Connor's (1965) An-Ab-Or ternary plot*

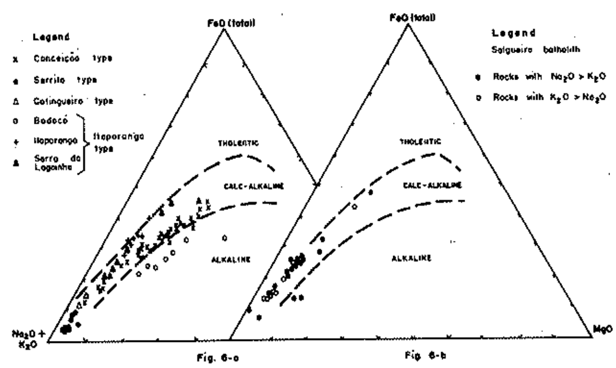



*Figure 6 – AFM ternary plot: a) main groups of granitoids within the Cachoeirinha-Salgueiro foldbelth; and b) Salgueiro batholith*

the body at Conceição), which intruded the Cachoeirinha supracrustal rocks (mean ranges from 11.57 to 12.79 permil), while the lowest mean $\delta^{18}O$ values (from 6.93 to 8,49 permil) are found in the $K_2O$-enriched, porphyritic bodies which pierced migmatites of the basement adjacent to the northern contact of the Cachoeirinha metasediments (e.g. Bodocó, Itaporanga, Serra da Lagoinha, next to Conceição). Intermediate mean $\delta^{18}O$ values (from 9.23 to 9.94 permil) are recorded in the bodies which intruded the Salgueiro metasediments of intermediate grade of metamorphism in the adjacent area south of the Cachoeirinha supracrustal rocks. Among these bodies, one finds the two stocks next to Serrita and the Salgueiro batholit. The peralkalic rocks at Catingueira show $\delta^{18}O$ values of 8.99 permil. However, peralkalic dikes which partially surround the stock 30 km north of Serrita show higher $\delta^{18}O$ (from 10.60 to 12.21 permil).

**4.** Among the potassic granitoids, mean $\delta^{18}O$ increases from Bodocó to Serra da Lagoinha to Itaporanga, that is, from west to east.

**5.** As a whole, the whole-rock $\delta^{18}O$ of these plutons correlate with the type and grade of metamorphism of the host

*Table 3 – Averages of ocean ridge granite (ORG)-normalized trace element for granite type, in the Cachoeirinha-Salgueiro foldbelt*

| Element | Itaporanga-type (avg. of 9 samples) | Conceição-type (avg. of 8 samples) | Serrita-type (avg. of 4 samples) | Catingueira (avg. of 4 samples) |
|---|---|---|---|---|
| $K_2O$ | 11.84(1.24)* | 7.62(1.22) | 8.2(2.09) | 16.27(0.45) |
| Rb | 30.48(5.2) | 24.6(4.40) | 12.87(1.79) | 30.77(4.2) |
| Ba | 42.48(16.7) | 19.42(4.94) | 106.35(48.63) | 94.07(4.5) |
| Th | 12.64(9.8) | 13.47(4.85) | 0.95 (1.9) | 6.59(3.99) |
| Ta | n.d. | n.d. | n.d. | n.d. |
| Nb | 2.71(1.4) | 1.3(0.23) | 1.25(0.43) | 1.47(0.17) |
| Ce | 1.94(0.56) | 1.3(0.29) | 1.0(0.24) | 0.92(0.18) |
| Hf | n.d. | n.d. | n.d. | n.d. |
| Zr | 0.87(0.40) | 0.55(0.05) | 0.35(0.05) | 0.42(0.05) |
| Sm | 1.15(0.35) | 0.76(0.26) | 0.32(0.09) | 0.53(0.16) |
| Y | 0.3(0.12) | 0.27(0.14) | 0.00 | 0.27(0.95) |
| Yb | 0.00 | 0.00 | 0.00 | 0.00 |

* Numbers in parentheses are the standards deviations. Normalizing values are those of Pearce *et al.* (1984, p. 964)
n.d. - Not determined

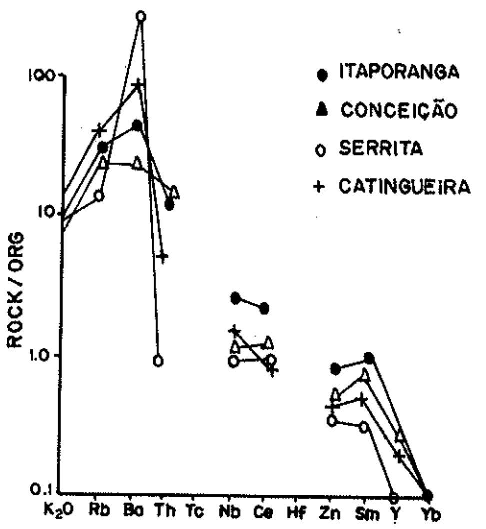



*Figure 7 – Ocean ridge granite (ORG) normalized patterns for averages of representatives samples from the main granite-types in the Cachoeirinha-Salgueiro foldbelt, Northeast Brazil*

rock, increasing from those which intruded gneiss-migmatite terranes of the Uauá Group to those which intruded phyllites of the Cachoeirinha group.

**6.** The potassic pluton of Monte das Gameleiras, much further east, out of the area under consideration, exhibits mean $\delta^{18}O$ of +8.24 permil and bears some resemblance to the Itaporanga body. The Dona Inês body, adjacent to it, to which a S-type protolith was anticipated from its mineralogy, Rb-Sr and major chemistry (McMurry 1982) shows, however, $\delta^{18}O$ of 7.30 permil, which can be explained if the protolith is a metasedimentary rock at the granulite facies.

**Oxygen isotopes on coexisting minerals** To decide if the whole-rock $^{18}O/^{16}O$ data represent the original magmatic isotopic composition or if they resulted from the overprinting of a secondary process, one has to know the $^{18}O/^{16}O$ fractionation among coexisting phases. In many cases, late stage events have changed completely the original oxigen isotope patterns of a particular pluton (Taylor 1977, Wenner & Taylor 1976).

Oxygen isotope analyses for coexisting quartz, feldspar, and biotite from representative samples are found in table 5

*Table 4 – Mean oxygen isotope data for 17 granitic plutons and host rocks. states of Paraíba and Pernambuco, Northeast Brazil*

| Plutons | Host rock | Mean $\delta^{18}O$ (SMOW) | N.º of samples |
|---|---|---|---|
| *a) $K_2O$-enriched plutons:* | | | |
| Bodocó, Pernambuco | Gneiss-migmatites of the Uauá Group | + 6.93 | 10 |
| Serra da Lagoinha (next to Conceição), Paraíba | | + 7.51 Normal | 4 |
| Itaporanga, Paraíba | | + 8.49 | 5 |
| *b) The calc-alkalic plutons:* | | | |
| Conceição, Paraíba | | + 11.57 | 2 |
| Serrote Cachoeirinha next to Itaporanga | | + 12.81 | 1 |
| Stock 30 km north fo Serrita, Pernambuco | Low-grade metamorphics of the Cachoeirinha supracrustal rocks | + 12.20 | 5 |
| Ipueiras, Pernambuco | | + 12.60 High | 3 |
| Penaforte, Pernambuco | | + 12.12 | 4 |
| Small stock, north of Serrita, Pernambuco | | + 11.87 | 4 |
| Carmo, Pernambuco | | + 12.79 | 2 |
| Itapetim, Pernambuco | Gneiss-migmatite (Uauá Group) | + 11.22 | 7 |
| *c) Bodies with or partially with trondhjemitic affinities* | | | |
| Serrita | | + 9.23 | 15 |
| Stock SW of Serrita | | + 9.42 | 8 |
| Salgueiro batholith ($Na_2O$< $K_2O$) | Salgueiro schists Schists | + 9.94 Normal | 17 |
| Salgueiro batholith ($Na_2O$<$K_2O$) | | + 9.93 | 11 |
| *d) Peralkalic bodies* | | | |
| Catingueira dike | | + 8.99 | 4 |
| Dike 30 km north of Serrita | | + 11.55 | 2 |
| SW of Serrita (Macacos Hill) | | + 9.66 | 1 |
| *e) Others* | | | |
| Monte das Gameleiras | Migmatites | + 8.24 | 10 |
| Dona Inês | Migmatites | + 7.30 Normal | 5 |
| Buíque | Migmatites | + 9.83 | 7 |
| *f) Host rocks:* | | | |
| Cachoeirinha supracrustal rocks (phyllites) | | + 15.65 | 1 |
| Salgueiro Group (micaschists) | | + 13.72 | 1 |
| Uauá Group (gneiss-migmatites) | | + 12.63 | 1 |

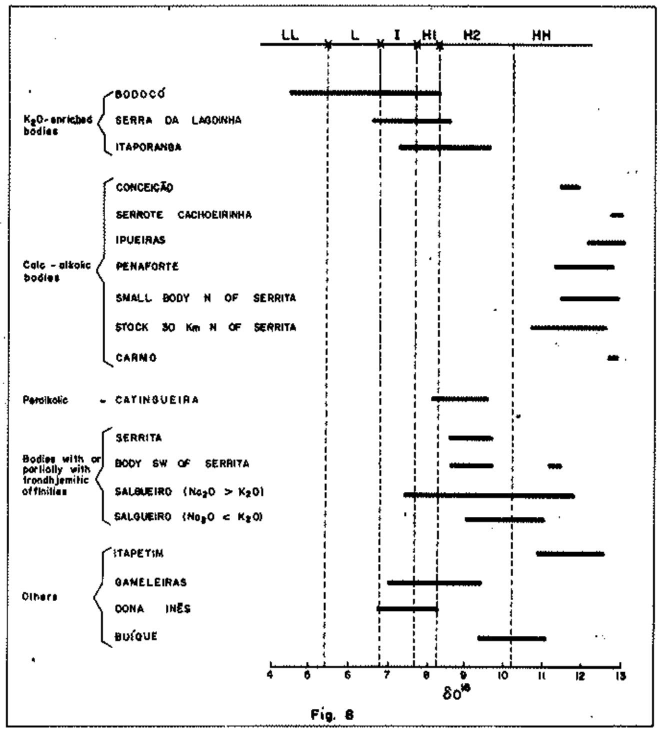



*Figure 8 – Oxygen isotope whole-rock values for granitic rocks from Northeast Brazil. The oxigen isotope classification scheme (LL, L, I, $H_1$, $H_2$, HH) is from Taylor (1968)*

and shown in figure 8. This diagram is useful to illustrate the degree of isotopic equilibrium attained between coexisting phases. In this attempt, it was chosen, in each body, the two samples with the highest and lowest whole-rocks $\delta^{18}O$, to testing how much they departed from internal isotopic

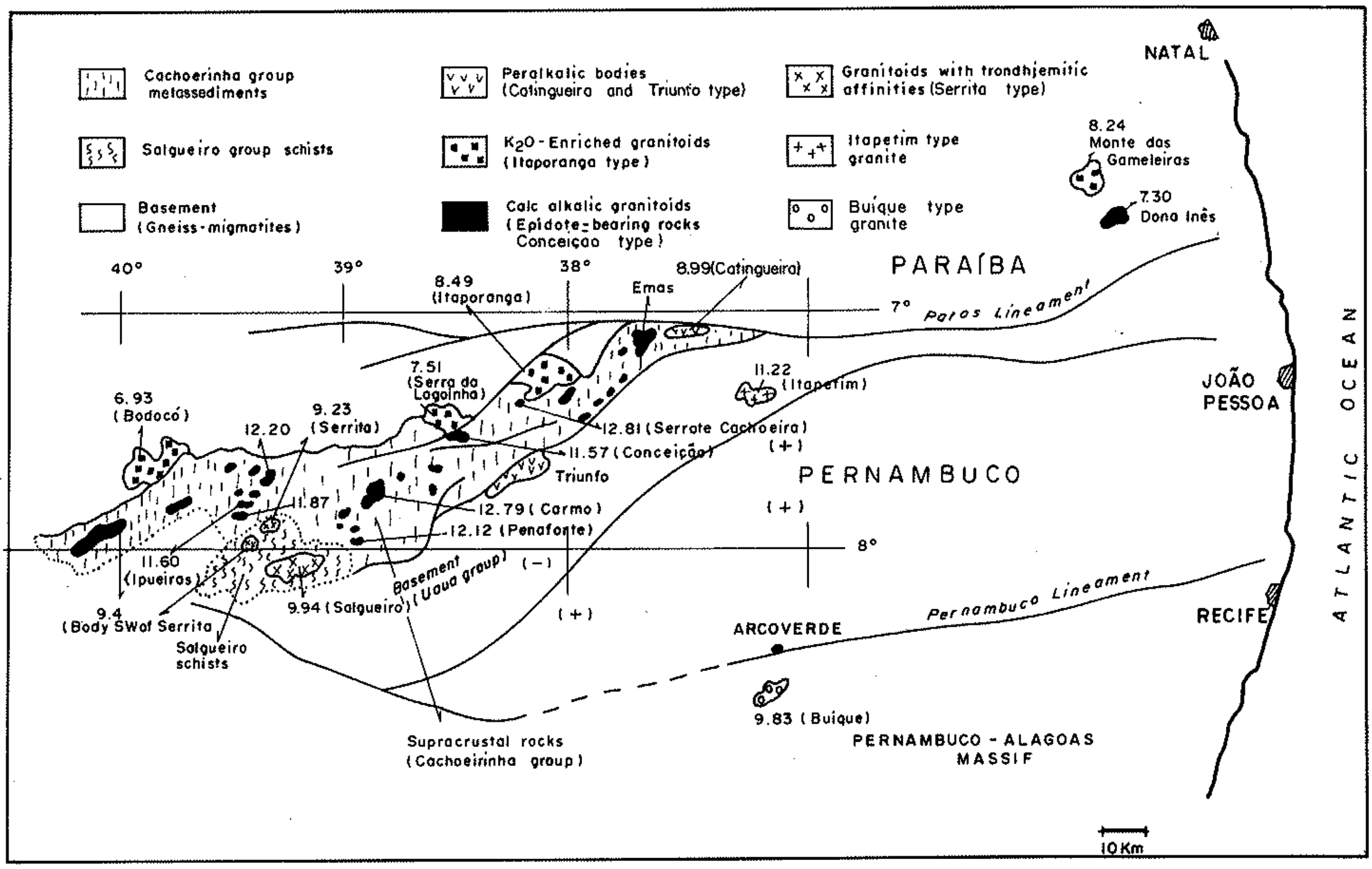



*Figure 9 – $\delta^{18}O$ systematic regional trend shown by granitoids within the Cachoeirinha-Salgueiro foldbelt. Buíque, Dona Inês, Monte das Gameleiras, and Itapetim plutons are also shown. Numbers next to the granitoids represent mean $\delta^{18}O$. (+) and (–) represent areas of positive and negative gravity anomalies, respectively*

equilibrium, assuming the rest of the samples approached equilibrium.

An overview of the isotopic behavior of the minerals versus whole-rock can be found in figure 10. In almost all samples, quartz showed higher $\delta^{18}O$ values than feldspar and whole-rock, except in two samples. This supports the assumption that the whole-rock $\delta^{18}O$ values are rather primary and any modification that took place was negligible.

*Table 5 – Oxygen isotope compositions for mineral separates from granitoids in the Cachoeirinha-Salguyeiro foldbelt*

| Sample | | Quartz $\delta^{18}O$(SMOW) | Feldspar $\delta^{18}O$(SMOW) | Biotite $\delta^{18}O$(SMOW) |
|---|---|---|---|---|
| BOD-5 | Bodocó | + 9.55 | + 8.60 | – |
| BOD-7 | | +11.49 | + 9.15 | + 5.02 |
| I-10 | Itaporanga | +10.45 | + 9.75 | + 5.25 |
| I-42 | | + 9.65 | + 9.06 | + 6.38 |
| C-24 | Serra da Lagoinha | + 9.42 | + 8.84 | + 5.79 |
| C-4 | Conceição | +13.58 | +12.26 | + 9.07 |
| SER-49 | Stock 30 km north of Serrita | +13.07 | +11.53 | + 8.93 |
| SER-58 | Serrita | +10.28 | +10.95 | + 7.53 |
| SER-60 | | +10.56 | + 7.58 | – |
| S-7 | Salgueiro | +11.75 | + 8.92 | – |
| S-20 | | +12.22 | + 9.22 | – |
| CAT-1 | Catingueira | + 8.80 | + 8.45 | – |
| CAT-5 | | + 8.67 | +10.37 | – |
| ITIM-03 | Itapetim | +12.64 | +10.95 | + 7.86 |
| ITIM-11 | | +11:95 | +10.68 | + 7.35 |
| B-7 | Buíque | +11.49 | + 9.15 | + 5.02 |
| B-20 | | +11.63 | +10.36 | + 6.74 |
| GA-1 | Monte das Gameleiras | + 9.61 | + 8.79 | + 4.80 |
| CG-38 | | + 9.71 | + 8.33 | + 4.61 |
| DI-3C | Dona Inês | + 8.22 | + 6.75 | – |
| DI-5B | | + 8.93 | + 7.04 | – |

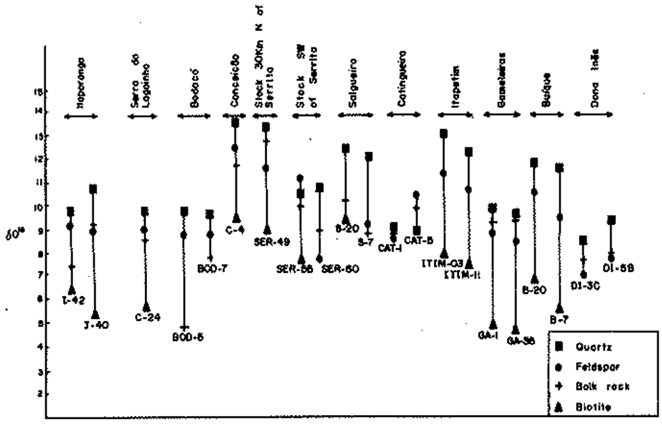



*Figure 10 – $\delta^{18}O$ mineral results for the granitoid rocks in this study*

Biotite, plagioclase, and K-feldspar are more susceptible to isotopic alteration and reequilibration than quartz and magnetite (Longstafffe & Gower 1983). Very often oxygen isotopes continue to reequilibrate between quartz and biotite at temperature below the solidus during prolonged cooling (O'Neil *et al. op. cit.*). Cole & Ohmoto (1976) found through experimental work that biotite exchanges faster with a fluid than feldspar depending upon the composition of the fluid. So, it is likely that feldspar and biotite have undergone minor modification on their primary $\delta^{18}O$ rather than quartz, being biotite probably more affected. As usually the amount of biotite is substantially lower than feldspar plus quartz, the effect of such a modification on the bulk $\delta^{18}O$ might have been minimum.

Oxygen-isotope data for minerals from these granitoid rocks indicate minor isotopic disequilibrium but no evidence exists for large-scalle depletion in $\delta^{18}O$ subsequent to granitoid formations. This conclusion supports the use of the bulk oxygen isotope data for petrogenetic interpretations.

*THE $K_2O$-ENRICHED PLUTONS* $\delta^{18}O$ in the range of the *I*-type granitoids (O'Neil *et al.* 1977) in consonance with the low initial $^{87}Sr/^{86}Sr$ (0.7058) found for the Itaporanga batholith which suggests a source in the mantle or in the lower crust. Most of the samples analysed indicate a metaluminous character, which essentially agrees with an igneous source. As noticed before, the mean $\delta^{18}O$ among these $K_2O$-enriched bodies increases from Bodocó to Itaporanga batholith (from west to east) and this either resulted from a more pronunced assimilation of metasedimentary material during magma ascent or from a gradual increase from west to east, in the amount of metasedimentary component in the source rocks. An alternative hypothesis is that amphibole fractionated out during magma ascent causing a partial peraluminous character (Cawthorn & O'Hara 1976) but in a different degree from west to east. Amphibole aggregates confirms the fractionation of this phase during a certain stage of the magma ascent. However, in a few cases, it was observed the presence of equilibrium texture (amphibole grains meeting at 120°) in these aggregates which suggests that they are xenoliths from the source rocks. As observed in figure 2, all $K_2O$-enriched granitoids (Itaporanga-type) lie in the area reserved for I-type granitoids, according to Loiselle & Wones (1979).

*THE CALC-ALKALIC PLUTONS* have $\delta^{18}O$ in the range of the *S*-type granitoids (O'Neil *et al.* 1977) as one can see in figure 8. All these rocks are peraluminous (Fig. 4) and much likely the magma had a metasedimentary source. Their mineralogy includes, in most cases, epidote which according to Speer *et al.* (1980) are indicative of *S*-type granitoids. Lee & Christiansen (1983), however, believe that epidote, sphene, magnetite, well-developed allanite, apatite, and zircon are an *I*-type assemblage. Besides, amphibole seems to have been largely fractionated during magma ascent as attested by the amphibole clots, and this probably contributed for the peraluminous character of these rocks.

At least, part of these plutons in synorogenic and they are hosted by high $\delta^{18}O$ low-grade metamorphics. The possibility that the parental magma originated in the lower crust or upper mantle and interacted with high $\delta^{18}O$ metamorphic fluids, active during the emplacement, cannot be discarded. On the other hand, as some of these bodies are tonalites, the likelihood of an origin by crustal anatexis during normal regional metamorphism is greatly diminished, according to Wyllie's (1977) concepts of magma generation in the crust. At present, as the initial $^{87}Sr/^{86}Sr$ are unknown, it is not possible to conclude about it.

*THE BODIES WITH TRONDHJEMITIC AFFINITIES* (the two stocks next to Serrita) show $\delta^{18}O$ values close to the upper limit of the *I*-type granitoids ($\cong$ 10 permil) as one can see in figure 8 and are very homogeneous. These rocks are peraluminous and their trondhjemitic affinities suggest that they probably originated by the partial fusion of an amphibolite or any meta-igneous source where amphibole was an important phase in the residue of the partial melting, according to Arth & Barker (1976) model. Either this mechanism or fractionation of amphibole during magma ascent (Cawthorn & O'Hara 1976) generated a peraluminous liquid.

The Salgueiro batholith is less homonegenous than the two stocks next to Serrita, in terms of $\delta^{18}O$ (Fig. 8). The oxygen isotopes reflect the peraluminous, metaluminous, and peralkalic facies of the batholith. The portion of the batholith with some trondhjemitc affinites (peraluminous) shows wider variation of $\delta^{18}O$ than the Serrita stocks.

*THE PERALKALIC BODIES* show $\delta^{18}O$ usually below 10 permil (Catingueira dike, Macacos ring-dike, and eastern border of the Salgueiro batholith). The dike at Santo Antônio Creek, 30 km north of Serrita (Pernambuco), however, shows values above 10 permil. Differences in the oxygen isotope composition of the source and different degree of differentiation or late alteration by interaction with meteoric water are possible explanations for such a divergence. As only limited number of analyses is available, it is not possible to elect one of these hypotheses as the more likely one. Just one sample (CAT-5) from the Catingueira dike has feldspar heavier than quartz, in terms of $\delta^{18}O$, which makes this sample useless for petrogenetic purposes.

Apparently, there are two populations of peralkalic rocks, one whose oxygen isotope ratios are below 10 permil and other above that, a critical number for distinguishing between *S* and *I*-type granitoids (O'Neil *et al.* 1977). As Catingueira and Santo Antônio Creek dikes intruded Cachoeirinha metasediments, the difference in oxygen isotopes is not related to host rocks.

Based solely on oxygen isotopes, most of the peralkalic rocks in the CSF seems to be mantle-derived or formed from igneous source with minor, if any, metasedimentary component. The Santo Antônio Creek dikes, however, may have derived from a metasedimentary source or undergone a significative crustal assimilation.

The eastern portion of the Salgueiro batholith (ferroaugite-quartz syenite) shows $\delta^{18}O$ values in the same range as the Catingueira dike and probably had a similar derivation.

*OTHER GRANITOIDS* The Itapetim body, Pernambuco, is mineralogically similar to the Itaporanga batholith, but without the large K-feldspar megacrystals. Also epidote-bearing, pierced migmatites of the Uauá Group and shows very high $\delta^{18}O$ ($>$10 permil, Fig. 8) and is essentialy peraluminous, bearing some S-type characteristics.

The Buíque batholith which crops out away from the area of the CSF (Fig. 9), but bears some similarity to the Serrita stock, show $\delta^{18}O$ values higher than those observed in that stock, with values below and above 10 permil. Magma generation and evolution seem to have been more dependent upon peraluminous metasediments than in the two stocks at Serrita, where trondhjemitic affinities are more pronounced.

The Monte das Gameleiras and Dona Inês bodies have been considered, respectively, as of the *I* and *S-type* (McMurry 1982). The first one keeps with the Itaporanga batholith a remarkable similarity, from the mineralogical and chemical viewpoints. Its $\delta^{18}O$ range is almost the same as in Itaporanga but its initial $^{87}Sr/^{86}Sr$ is of 0.7094±0.0002 according to McMurry and has been considered as derived from metasedimentary-metaigneous source. The Dona Inês body, however, although regarded from mineralogical and chemical viewpoints (reinforced by high initial $^{87}Sr/^{86}Sr$, McMurry 1982) as of the S-type, displays low w $\delta^{18}O$ (Fig. 8).

Longstaffe & Schwarcz (1977) recorded $\delta^{18}O$ in metasedimentary Archean gneisses in the high amphibolite to granulite facies, in Canada, equivalent to orthogneisses. Shieh & Schwarcz (1974) and Longstaffe (1979) showed that some Precambrian metasedimentary rocks, mesozonal to catazonal, exhibit low $\delta^{18}O$, probably due to an exchange with a mafic reservoir during high grade metamorphism. Halliday *et al.* (1981) admit that clastic sedimentary rocks are usually impoverished in $\delta^{18}O$ during high grade metamorphism, particularly in the granulite facies. Metasedimentary rocks could be impoverished in $\delta^{18}O$ before or during anatexis (Longstaffe *et al.* 1981).

Metasedimentary rocks, in the high amphibolite to granulite facies, alike to the observed low $\delta^{18}O$ and high $^{87}Sr/^{86}Sr$ initial ratio, served as source rocks for the magmas at Dona Inês.

**Rare-earth element geochemistry** The analytical method for the REE in this study was a modified version (Fryer 1977) of the thin film X-ray fluorescence procedure of Eby (1972). The rare-earths have been separated as a group by ion-exchange chromatography and transferred onto the SA-2 ion exchange paper, previously cut to fit the sample holders. Prior to separation, 50 Mg of Tm was added as an internal yield standard. All samples were analysed on a Phillips PW 1450 X-ray fluorescence spectrometer with a tungsten tube. The analytical error is estimated to be less than 10% for all the elements tabulated. Results for Pr, Tb, Ho, and Lu are not reported because of large analytical errors, and Tm is not reported because its use in correcting for chemical yield.

The chondritic values used for normalization are Leedey chondrite data (Masuda *et al.* 1973) divided by 1.20 (Sun & Hanson 1976, Taylor & Gorton 1977) to make these data comparable to average chondrite data. Samples analysed for REE were also analysed for $^{18}O/^{16}O$.

*THE ITAPORANGA-TYPE GRANITOIDS* Eleven whole-rock samples from these granitoids (Bodocó, Serra da Lagoinha, and Itaporanga) were analysed for REE (Table *6*) and patterns are shown in figures 11a, 11b and 11c where $SiO_2$, when available, and $\delta^{18}O$ are also indicated. Rocks from these three plutons are characterized by a strong relative LREE-enrichment compared to a chondritic average ($Ce_N/Yb_N$ ranges from 30 to 49 for the Bodocó rocks; 28 to 72 for the Serra da Lagoinha body; and from 42 to 217 for the Itaporanga body) and depleted in HREE (Gd-Yb) relative to LREE (La-Sm).

The REE patterns for the Bodocó batholith (Fig. 11a) show steep slope and lack Eu anomaly (Eu/Eu* varies from 0.89 to 1.00, where Eu* refers to the normalized Eu abundance anticipated by smooth interpolation between the adjacent elements Sm and Gd). In the samples analysed, Yb is found in concentrations below 1 ppm. The patterns are very similar to each other from Ce to Dy and differ slightly with respect to Er and Yb contents. There seems to be a certain positive correlation between $SiO_2$ and $\Sigma$REE in these samples. In this respect, it differs from the Serra da Lagoinha and Itaporanga batholiths. The Serra da Lagoinha REE signatures (Fig. 11b) are enriched relative to chondrite abundances, depleted in HREE relative to LREE, and Eu anomaly is absent except for two samples (Eu/Eu* varies from 0.90 to 1.19) These samples show LREE remarkably parallel ($La_N/Sm_N$) are very depleted in Yb, always lower than 1 ppm, except for one sample. It seems to exist a certain negative correlation between $SiO_2$ and $\Sigma$REE.

The Itaporanga batholith displays enriched REE signatures relative to chondrite, depleted in HREE relative to LREE (Fig. 11c). They are characterized by a relative steep slope ($Ce_N/Yb_N$ from 42 to 217), Yb depletion, and absence of Eu anomaly (Eu/Eu* ranges from 0.87 to 1.01). It seems to exist a certain negative correlation between $SiO_2$ and $\Sigma$REE.

Apparently, these three plutons are quite similar in terms of REE behavior, and this suggests that the major processes leading to their formation were about the same, and that the source rocks do not differ drastically. Minor differences resulted from oxygen fugacity differences, order and amount of phases fractionated or during magma ascent, and, at a less extent, to the source rocks. Amphibole cummulates attest to an early fractionation of this phase which contributed to deplete the magma in HREE and to enhance the LREE. A high oxygen fugacity avoided building a negative Eu anomaly.

*THE CONCEIÇÃO-TYPE GRANITOIDS* They are enriched in REE relative to chondrite abundances, depleted in HREE in relation to LREE (Fig. 12), with very low Yb contents (lower than 1.45 ppm). They show a variable negative Eu anomaly (Eu/Eu* varies from 0.75 to 0.91), and $\Sigma$REE varies from 116 to 166 ppm. There is no correlation between $SiO_2$ and $\Sigma$REE. Rare-earths are less abundant in these rocks than in the Itaporanga-type granitoids, and LREE show a less pronounced slope. LREE patterns are approximately parallel ($La_N/Sm_N$ varies from 1.90 to 2.67) while the HREE patterns are so uniform. There is also less variation in $\Sigma$LREE than in $\Sigma$HREE.

These patterns are compatible with combined fractionation of amphibole and plagioclase. Amphibole clots seem to demonstrate that fractionation of this phase played an important role in the evolution of the magma. This probably contributed to enhance the LREE and deplete the REE, counteracting with the plagioclase fractionation, the resulting REE patterns being mainly a function of the relative proportion of fractionation of these phases and of the REE composition of the initial liquid formed. The discrete, but significative Eu anomaly, is also a consequence of such a fractionation scheme. Early crystallized epidote which appears included in plagioclase probably contributed to the observed patterns (late crystallized epidote has a REE pattern strongly dependent upon the REE composition of the residual liquid, with which it is in equilibrium, according to Stuckless & Miesch 1981).

*Table 6 – Whole-rock rare earth data (ppm)*

| | Bodocó Batholith | | | Serra da Lagoinha Batholith | | | | Itaporanga Batholith | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BOD-4 | BOD-5 | BOD-7 | C013 | C-24 | C-26 | C-29 | I-13 | I-23 | I-31 | I-43 |
| La (ppm) | 73.74 | 54.68 | 67.22 | 53.36 | 72.56 | 52.28 | 93.73 | 80.71 | 70.80 | 77.87 | 40.71 |
| Ce | 151.94 | 125.20 | 139.73 | 111.72 | 153.67 | 112.49 | 219.60 | 162.54 | 139.71 | 162.06 | 84.45 |
| Pr | 15.42 | 14.05 | 15.07 | 12.21 | 16.64 | 12.87 | 25.06 | 15.08 | 13.09 | 17.51 | 8.36 |
| Nd | 60.57 | 54.75 | 54.87 | 49.04 | 63.06 | 46.17 | 100.27 | 59.54 | 49.43 | 66.93 | 30.75 |
| Sm | 10.73 | 10.14 | 9.24 | 9.59 | 12.49 | 8.91 | 17.70 | 10.75 | 8.27 | 12.08 | 5.96 |
| Eu | 2.90 | 2.42 | 2.29 | 3.15 | 3.32 | 3.02 | 4.36 | 2.60 | 2.39 | 2.97 | 1.59 |
| Gd | 6.57 | 6.09 | 5.63 | 6.77 | 8.11 | 6.45 | 11.28 | 7.23 | 6.11 | 7.78 | 3.69 |
| Tb | 1.28 | 1.03 | 0.91 | 1.16 | 1.44 | 1.41 | 1.84 | 1.72 | 1.10 | 1.44 | 0.74 |
| Dy | 3.37 | 3.37 | 3.07 | 4.63 | 4.59 | 4.06 | 5.83 | 4.95 | 3.71 | 3.72 | 1.91 |
| Ho | 0.29 | 0.00 | 0.15 | 0.68 | 0.60 | 0.65 | 0.45 | 0.34 | 0.00 | 0.00 | 0.09 |
| Er | 1.57 | 1.12 | 1.22 | 1.46 | 1.72 | 1.99 | 2.05 | 1.56 | 1.12 | 1.04 | 0.79 |
| Yb | 0.79 | 0.66 | 0.05 | 0.40 | 1.06 | 0.53 | 0.16 | 0.88 | 0.16 | 0.22 | 0.51 |
| $\Sigma$ REE | 329.17 | 273.51 | 299.44 | 254.17 | 339.26 | 250.83 | 482.33 | 347.90 | 285.89 | 353.62 | 179.55 |
| $La_N/Sm_N$ | 4.29 | 3.37 | 4.45 | 3.47 | 3.63 | 3.67 | 3.31 | 4.69 | 5.35 | 4.03 | 4.26 |
| $Ce_N/Yb_N$ | 49.05 | 48.88 | 29.89** | 71.94 | 36.99 | 54.05 | 28.07** | 47.26 | 217.5 | 189.83 | 42.22 |
| Eu/Eu* | 1.00 | 0.89 | 0.92 | 1.16 | 0.97 | 1.19 | 0.90 | 0.87 | 1.01 | 0.90 | 0.98 |

| | Stocks of the Conceição type | | | | | | Serrita Stock | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SER-39 | SER-43 | SER-47 | SER-71 | SER-77 | SER-83 | SER-17 | SER-21 | SER-58 | SER-60 |
| La (ppm) | 31.72 | 18.82 | 21.34 | 30.28 | 29.05 | 25.85 | 31.05 | 16.88 | 5.00 | 27.30 |
| Ce | 70.23 | 36.32 | 50.91 | 66.44 | 69.61 | 61.98 | 61.28 | 35.70 | 16.91 | 52.00 |
| Pr | 8.54 | 3.86 | 6.96 | 8.78 | 8.75 | 8.11 | 5.62 | 3.66 | 1.21 | 4.94 |
| Nd | 32.67 | 14.38 | 27.30 | 32.84 | 37.41 | 31.88 | 22.82 | 13.93 | 5.59 | 19.29 |
| Sm | 7.42 | 3.36 | 6.69 | 8.11 | 9.53 | 7.46 | 3.95 | 3.03 | 1.59 | 3.68 |
| Eu | 1.94 | 1.16 | 1.67 | 1.87 | 2.35 | 1.99 | 1.30 | 1.17 | 0.74 | 1.32 |
| Gd | 2.52 | 3.12 | 5.63 | 7.04 | 8.78 | 5.70 | 2.26 | 1.75 | 1.40 | 2.35 |
| Tb | 0.93 | 0.83 | 0.98 | 1.10 | 1.31 | 0.73 | 0.35 | 0.64 | 0.38 | 0.55 |
| Dy | 3.13 | 2.26 | 2.46 | 3.81 | 5.74 | 2.51 | 0.91 | 1.00 | 0.68 | 1.11 |
| Ho | 0.34 | 0.00 | 0.00 | 0.00 | 0.74 | 0.08 | 0.00 | 0.04 | 0.00 | 0.01 |
| Er | 1.27 | 1.29 | 0.78 | 1.25 | 2.52 | 0.79 | 0.12 | 0.30 | 0.00 | 0.08 |
| Yb | 0.71 | 0.44 | 0.14 | 0.10 | 1.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $\Sigma$ REE | 165.42 | 85.84 | 124.85 | 161.62 | 177.24 | 147.08 | 129.60 | 78.10 | 33.50 | 112.63 |
| $La_N/Sm_N$ | 2.67 | 3.49 | 1.99 | 2.33 | 1.90 | 2.16 | 4.91 | 3.48 | 1.96 | 4.64 |
| $Ce_N/Yb_N$ | 25.40 | 21.07 | 89.45 | 13.96** | 12.31 | 20.6** | 132.23** | 31.58** | 9.85*** | 159.9** |
| Eu/Eu* | 0.91 | 1.10 | 0.82 | 0.75 | 0.79 | 0.91 | 1.25 | 1.46 | 1.51 | 1.32 |

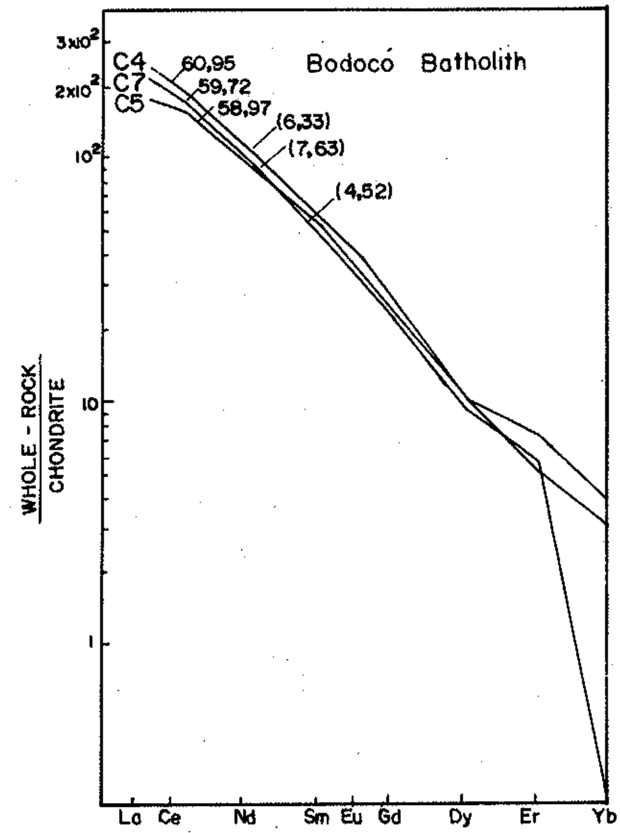
| | Catingueira Dike | | | | Itapetim Batholith | | | | Buíque Batholith | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | CAT-1 | CAT-2 | CAT-5 | CAT-6 | ITIM-11 | ITIM-14 | ITIM-30 | ITIM-50 | B-7 | B-30 | B-60 |
| La (ppm) | 28.72 | 24.40 | 27.35 | 25.54 | 72.22 | 15.23 | 37.35 | 30.60 | 8.64 | 101.42 | 66.02 |
| Ce | 74.68 | 51.81 | 62.77 | 54.00 | 163.86 | 37.09 | 79.78 | 67.12 | 17.41 | 203.03 | 131.77 |
| Pr | 9.18 | 5.81 | 7.02 | 6.46 | 17.18 | 4.49 | 8.44 | 7.18 | 1.68 | 21.11 | 14.47 |
| Nd | 36.83 | 23.18 | 28.09 | 26.89 | 66.67 | 16.64 | 34.46 | 28.36 | 7.05 | 78.61 | 54.44 |
| Sm | 8.53 | 4.86 | 5.77 | 5.81 | 14.99 | 4.48 | 7.09 | 6.23 | 1.77 | 13.77 | 9.30 |
| Eu | 2.57 | 1.69 | 1.88 | 2.06 | 3.56 | 0.62 | 1.93 | 1.66 | 0.66 | 3.30 | 2.34 |
| Gd | 6.69 | 3.50 | 4.11 | 4.39 | 10.60 | 4.05 | 5.64 | 4.84 | 1.56 | 7.36 | 6.67 |
| Tb | 0.86 | 0.57 | 0.72 | 0.47 | 2.35 | 0.42 | 0.96 | 0.97 | 0.24 | 1.15 | 1.20 |
| Dy | 4.41 | 2.19 | 2.62 | 2.77 | 8.35 | 3.14 | 3.70 | 3.25 | 0.88 | 3.26 | 3.78 |
| Ho | 0.74 | 0.26 | 0.36 | 0.17 | 1.41 | 0.52 | 0.41 | 0.35 | 0.09 | 0.00 | 0.40 |
| Er | 1.88 | 0.78 | 0.99 | 1.10 | 3.58 | 1.11 | 1.32 | 1.25 | 0.43 | 0.88 | 1.33 |
| Yb | 1.33 | 0.40 | 0.26 | 0.55 | 1.26 | 0.64 | 0.70 | 0.51 | 0.35 | 0.54 | 0.87 |
| $\Sigma$ REE | 176.42 | 113.64 | 141.94 | 130.21 | 366.03 | 88.43 | 181.78 | 152.32 | 40.76 | 433.98 | 292.59 |
| $La_N/Sm_N$ | 2.10 | 3.13 | 2.96 | 2.74 | 3.01 | 2.12 | 3.29 | 3.07 | 3.04 | 4.59 | 4.42 |
| $Ce_N/Yb_N$ | 14.35 | 33.18 | 62.26 | 24.97 | 33.20 | 14.90 | 29.03 | 33.83 | 12.82 | 96.05 | 38.68 |
| Eu/Eu* | 1.02 | 1.22 | 1.15 | 1.22 | 0.84 | 0.44 | 0.92 | 0.91 | 1.22 | 0.92 | 0.88 |

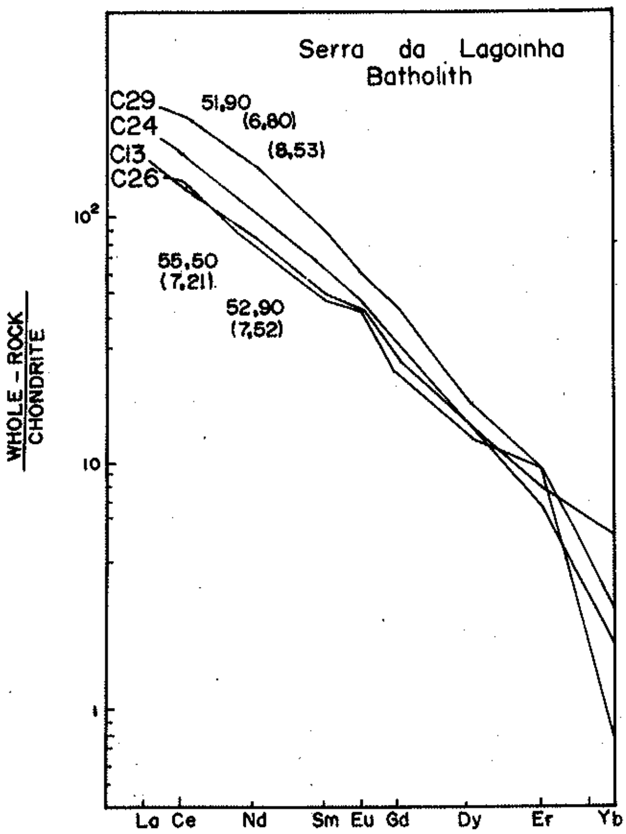
$\Sigma$ REE: sum of the REE

Eu/Eu* = $Eu_N$: Eu (interpolation between $Sm_N$ and $Gd_N$)

**means $Ce_N/Er_N$

***= $Ce_N/Dy_N$



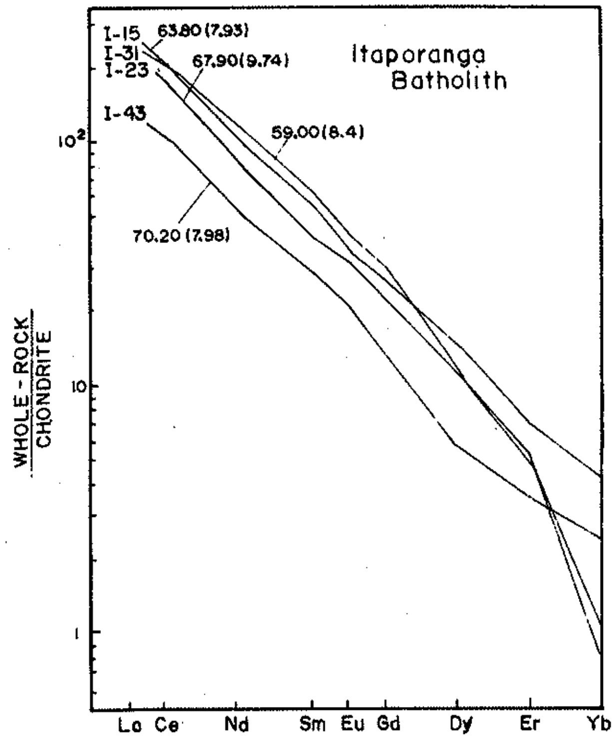




*Figure 11 – REE signatures for the potassic-calc-alkalic granitoids: a) Bodocó; b) Serra da Lagoinha; and c) Itaporanga batholiths*

Experimental studies suggest that hornblende is unstable in liquids of tonalitic composition at pressures greater than 20 kbar (Lambert & Wyllie 1974). Thus, if hornblende played an important role in the formation or evolution of the magma, which in several cases is tonalitic, the process must have occurred at depths of less than 60 km. However, as plagioclase is not stable in a tonalitic liquid at pressures greater than 15 kbar, one assumes that the magma was not formed at a depth greater than 45 km.

*THE SERRITA-TYPE GRANITOIDS* They display a strong relative enrichment in LREE compared to chondritic average, a extremely depletion in HREE and patterns are shown in figure 13 with respective $SiO_2$ and $\delta^{18}O$. They show a small, but significative, Eu anomaly (Eu/Eu* varies from 1.25 to 1.51), which suggests high oxygen fugacity, preventing Eu to enter the feldspar structure. One sample (SER-58) shows a slight concave upward LREE, pattern that resulted from a late hydrothermal alteration which removed some of these elements. The ΣREE are much lower than in the Itaporanga-type granitoids and slightly lower than in the Conceição-type bodies.

The whole-rock REE signatures of these rocks are much like the patterns for high-alumina trondhjemites and tonalities (Arth & Barker 1976), that is, strongly fractionated in HREE, close to those of chondrites, and small positive Eu anomalies. Such patterns are the result of amphibole fractionation which depleted the magma in all rare-earths, except Ce, but Eu was depleted less than Sm or Gd, and a positive Eu anomaly was generated. So, amphibole fractionation or its presence in the residue of the melting was responsible for the $Na_2O$-enriched liquid which gave rise to the Serrita stocks.

*THE CATINGUEIRA-TYPE GRANITOIDS* The Catingueira body shows REE patterns similar to each other (Fig. 14), enriched in LREE relative to chondritic abundances and enriched in LREE relative to chondritic abundances and depleted in HREE relative to LREE. They are characterized by a discrete, but significative, Eu anomaly (Eu/Eu* ranges from 1.02 to 1.22), and ΣREE varies from 113.64 to 174.42 ppm. These patterns resemble those of Serrita (also $\delta^{18}O$ are similar), which is something unexpected, once Serrita rocks are rather peraluminous. If the "orthoclase effect" (Bailey & Schairer 1964) drove the magma towards a peralkalic composition at Catingueira, generating syenites to quartz-syenites, did not leave the expected negative Eu anomaly. High oxygen fugacity predominating during crystallization may have precluded such an anomaly to develop or orthoclase fractionated was not removed.

*TRIUNFO-TYPE GRANITOIDS* The REE analyses are also available for the Triunfo batholith, ring-dikes at Serrita, Santo Antônio Creek (north of Serrita), and for other dikes next to Catingueira and Princesa Isabel-Manaíra. A detailed discussion is found is Ferreira & Sial (1985b).

*THE ITAPETIM AND BUÍQUE-TYPES* The REE analyses are also available for the Itapetim and Buíque batholiths (Figs. 15 and 16). In the Itapetim, all samples are REE--enriched relative to chondritic abundances and HREE--depleted relative to LREE (ITIM-14 represents a sheared megaxenolith). ΣREE varies from 82.87 to 345.09 ppm and only a very discrete negative Eu anormaly is present (Eu/Eu*, from 0.84 to 0.92), except for ITIM-14 where Eu/Eu* is 0.44. The REE patterns associated to $\delta^{18}O$ values support a crustal derivation for these rocks.

The Buíque batholith displays enriched-REE relative to chondritic abundances, HREE-depleted relative to LREE (Fig. 16). Two samples show a discrete Eu anomaly

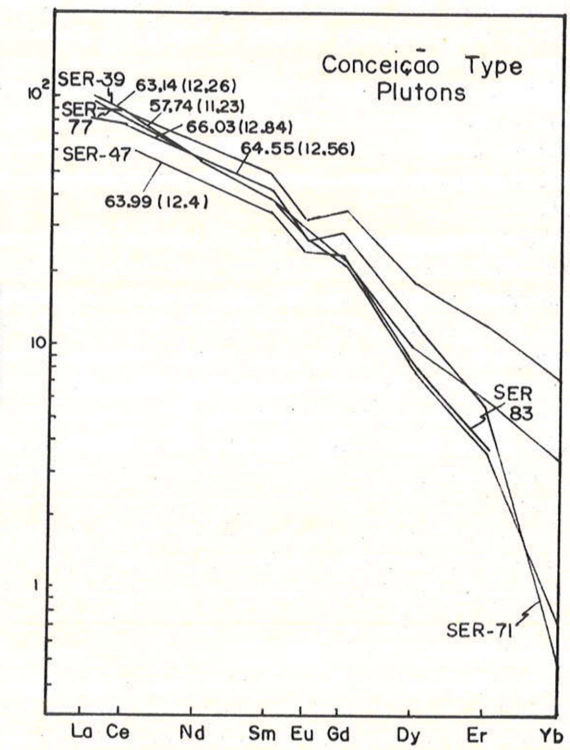



*Figure 12 – REE patterns for granitoids of the Conceição-type*

Eu/Eu* equals to 0.88 and 0.92) and one sample (B-7), with much lower ΣREE, displays a slightly positive Eu anomaly, with REE signature much like the trondhjemites, somehow similar to the Serrita stocks patterns.

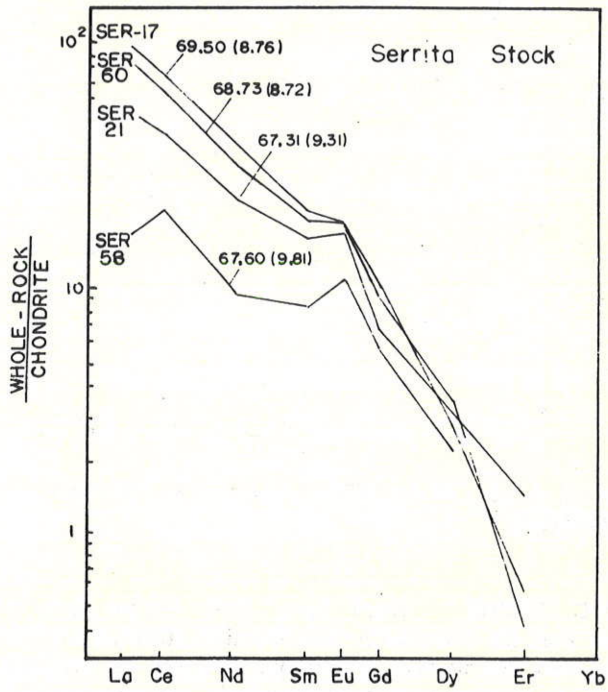



*Figure 13 – REE signatures for rocks with trondhjemitic affinities (Serrita-type)*

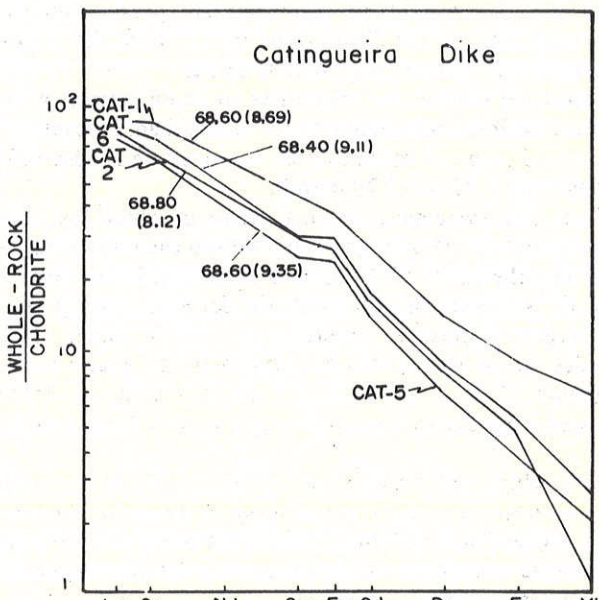



*Figure 14 – REE patterns for the Catingueira-type granitoids*

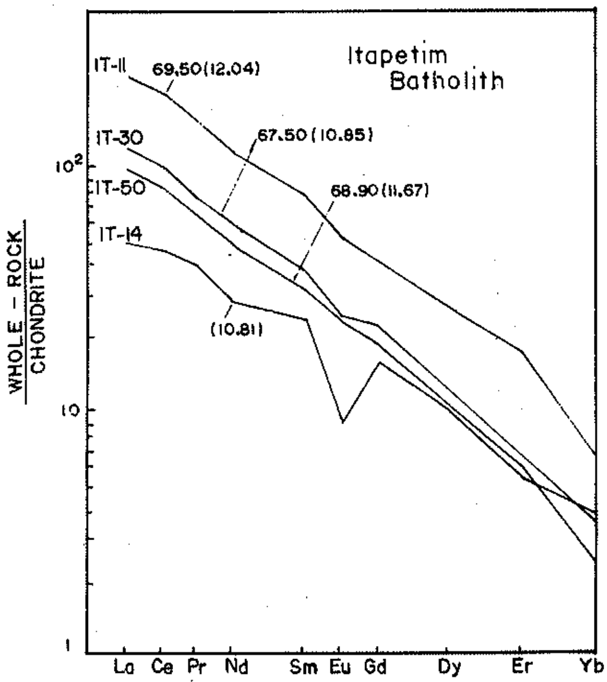



*Figure 15 – REE signatures for the Itapetim-type granitoids*

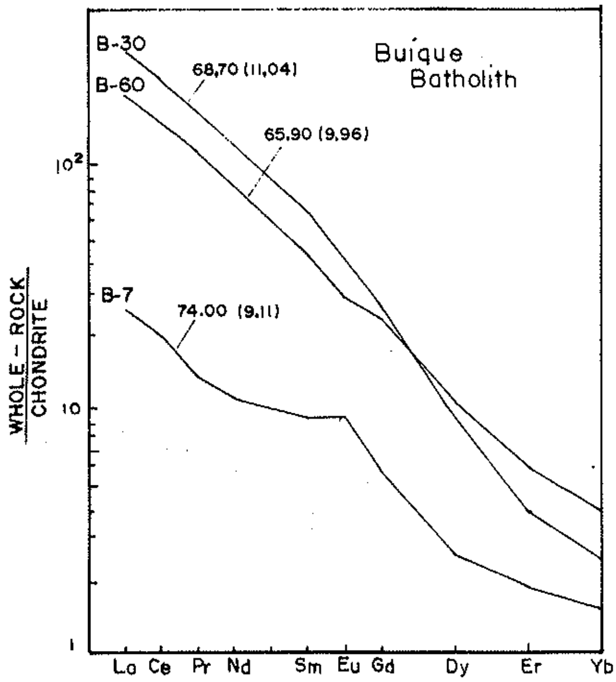



*Figure 16 – REE patterns for the Buíque-type granitoids*

**CONCLUSIONS** Based upon field relationships, it seems that the rocks with trondhjemitic affinities are the older ones (Serrita-type granitoids), followed by the calc-alkalic group (Conceição-type granitoids), the potassic-calc-alkalic group (Itaporanga-type granitoids) and finally by the peralkalic rocks (Catingueira-type). On the geochemical and petrographical grounds, the following conclusions can be drawn:

*a)* The Itaporanga-type granitoids crystallized under lower oxygen fugacity than the Conceição-type rocks, except for the Bodocó batholith.

*b)* All the Conceição-type granitoids are peraluminouns, same happening to the Serrita-type rocks, while the Itaporanga-type ones are partially metaluminous.

*c)* Almost all plutons for which five or more samples were analysed exhibit a total range of $\delta^{18}O$ less than 2 permil.

*d)* A broad range of mean oxygen composition is observed, varying from 6.93 to 12.79 permil.

*e)* There is a systematic regional trend in which the calc-alkalic granitoids (Conceição-type) within the Cachoeirinha space are the most $^{18}O$-enriched rocks, while the lowest mean $\delta^{18}O$ values are found in the $K_2O$-enriched (Itaporanga-type) granitoids. Intermediate $\delta^{18}O$ values were recorded in the bodies which intruded the Salgueiro metasediments. Among the potassic granitoids, mean $\delta^{18}O$ increases from Bodocó to Itaporanga, that is, from west to east.

*f)* As a whole, the whole-rock $\delta^{18}O$ of these plutons correlate with the type and grade of metamorphism of the host rocks, increasing from those which intruded the gneissic-migmatitic terranes to those which intruded the Cachoeirinha low-grade metamorphics.

*g)*aThe Itaporanga-type granitoids yielded very similar REE signatures, with negative slope and missing the Eu anomaly, and therefore the major processes leading to their formation might have been the same. Minor diferences are due to oxygen fugacity prevailing during crystallization, order and amount of fractionated phases and in the source rocks.

*h)* The Conceição-type granitoids display REE patterns with negative slope, variable negative Eu anomaly and ΣREE patterns lower than in Itaporanga-type granitoids. These patterns are compatible with combined fractionation of amphibole and plagioclase (from a basaltic hydrated liquid?). These magmas formed at depth nor greater than 45 km.

*i)* The Serrita-type granitoids (with trondhjemitic affinities) are characterized by a strong enrichment in LREE and depletion in HREE with a small positive Eu anomaly. ΣREE are much lower than in the Conceição-type granitoids.

*j)* The Catingueira-type granitoids yielded REE patterns much like those of the Serrita-type granitoids. The lack of a pronounced negative Eu anomaly, peculiar to peralkalic rocks, is a characteristic shared by all plutons of this kind, within the CSF (Triunfo-type rocks, Macacos ring-dike, dike swarm at Princesa Isabel-Manaíra, Santo Antônio Creek dike; Ferreira & Sial 1985b). The oversaturated peralkalic bodies show a slight positive Eu anomaly, while the saturated ones (e.g. Triunfo), a discrete negative Eu anomaly.

*k)* The calc-alkalic (Conceição-type) granitoids are essentially ilmenite-bearing rocks, while the peralkalic bodies of the Triunfo-type constitute a magnetite-bearing syenitoid line which roughly accompanies the southern boundary of the CSF, having intruded the basement.

*l)* The presence of magmatic epidote in the Itaporanga, Conceição, and Serrita-type granitoids suggest crystallization at relatively high pressure, according to Naney's experiments (1977), which shows this phase stable at 8 kbar ($P_t = P_W$) as a reaction product with hbl+melt under buffer conditions between NNO and HM. Epidote crystallizes between 6 and 10 kbar (20 to 30 km) and about 800°C. Zen (1985) and Zen & Hammarstrom (1982, 1983, 1984a, 1984b) also support the idea of being magmatic epidote a high pressure phase.

*m)* The other granite-types (Águas Belas, Arcoverde, Cariba, Moderna, Pinheiro, Sítio dos Nunes, Itabi and Glória) lack detailed geochemical and petrographical work. Perhaps after careful study, some of them will not stand as granite-types being analogous to one of the other types referred to in this study.

**Acknowledgements** The Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), which partially supported this project, is deeply acknowledged. I am also thankful to Brian J. Fryer at Memorial University of Newfoundland (MUM), St. John's, Canada, who allowed me to use his laboratory facilities for REE analyses; and Cleve Solomon and John Donahue, from the University of Georgia at Athens, USA, for helping with the oxygen isotope analyses. Finally, a last word of thanks goes to V.P. Ferreira who helped me with the preparation of the diagrams.

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**MANUSCRITO**
**Recebido em 17 de fevereiro de 1986**
**Revisão aceita em 5 de maio de 1986**