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The Jequié Complex Revisited: a U-Pb Geochronological Reappraisal of the Geology and Stratigraphy of the Jequié-Itagi Area (Bahia, Brazil)

Reavaliação do Complexo Jequié: Um Olhar Geocronológico Sobre a Geologia da Área Jequié-Itagi (Bahia, Brasil)

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Abstract

New geological and litogeochemical data plus La-ICP-MS U-Pb isotopic study on the Jequié Complex, or Jequié "Block", a granulite facies terrain of the Northeastern São Francisco Craton, allowed to propose that a new lithodemic unit, the Volta do Rio Plutonic Suite, should be created as a lower rank unit. The Jequié Complex is defined here as an intrusive complex metamorphosed in the granulite facies, containing an assemblage of plutonic calc-alkalic mafic to intermediate rocks, fractionated trondhjemites, tonalites and granodiorites, besides normal calc-alkaline tonalites/granodiorites and rare metasedimentary remnants plus two different sets of leucogranites. The Volta do Rio Plutonic Suite is proposed as a lower range lithodemic unit belonging to the Jequié Complex. It is composed of granodiorites and monzogranites with porphyroclastic texture, even--grained granitoids and fine-grained granitoids, besides an association of amphibole-bearing leucogranites and mafic to intermediate rocks. The metamorphosed mafic, intermediate and felsic rocks of the Jequié Complex compose a Cordilleran-type magnesian calc-alkalic association, which age is 2.7 Ga. In contrast, all the metagranitoids of the Volta do Rio Plutonic Suite show a distinctive ferroan ("A-type") geochemical signature and the mafic and intermediate rocks associated to metaleucogranites show alkaline characteristics and host locally high-grade REE mineralizations contained in chevkinite group minerals. In the Volta do Rio Plutonic Suite, the porphyroclastic granites were dated at 2.6 Ga.The provisional age of alkaline mafic rocks with magmatic-hydrothermal REE mineralizations and of possibly coeval leucogranites is 2.5 Ga. These mineralizations are inedit in the world and the obtained time frame indicates the need to re-evaluate the geology and metallogenic potential of the Jequié Complex by considering its primordial igneous nature and by screening out its "granulitic" or "charnockitic" nature.
Keywords: Neoarchean; granulite; charnockite; REE mineralization

Resumo

Novos dados geológicos e geoquímicos associados a dados geocronológicos (U-Pb, LA-ICP-MS) permitiram a criação de uma nova unidade litodêmica, a Suite Plutônica Volta do Rio, como parte do Complexo Jequié O Complexo Jequié é descrito aqui como uma associação de rochas plutônicas máficas a intermediárias, tonalitos-trondhjemitos-granodioritos com forte fracionamento de terras raras, tonalitos/granodioritos com padrões de terras raras não fracionados e raros enclaves de metassedimentos. Estas rochas são intrudidas por leucogranitos, a hiperstênio ou a granada, e o conjunto inteiro foi metamorfizado no facies granulito. A Suíte Plutônica Volta do Rio, também metamorfizada em facies granulito, é composta de granodioritos e monzogranitos porfiroclásticos, equigranulares e de granulação fina, bem como uma associação de hornblenda-leucogranitos com rochas máficas a intermediárias. A associação de rochas máficas, tonalitos, trondhjemitos e granodioritos tem idade de 2.7 Ga e tem características "Cordilleranas", i.e., magnesiana do tipo cálcico a calc-alcálico.Todas as rochas da Suíte Plutônica Volta do Rio, em contraste, mostram uma assinatura geoquímica de granitos alto K "ferroan" ("Tipo A"), isto é, com alto FeOt/(FeOt+MgO). Já as rochas máficas e intermediárias associadas a estes leucogranitos têm características alcalinas saturadas em sílica e são mineralizadas em terras raras, contendo minerais do grupo da chevkinita localmente em alto volume. Neste trabalho, obteve-se uma idade de 2.6 Ga em granodioritos e monzogranitos porfiroclásticos da Suíte Plutônica Volta do Rio, e em uma rocha máfica mineralizada em terras raras, possivelmente coetânea a leucogranitos, obteve-se uma idade provisória de 2.5 Ga. Os dados indicam a necessidade de refinar a estratigrafia do Complexo Jequié, dadas as implicações metalogenéticas: rochas máficas e leucogranitos da Suíte Volta do Rio têm mineralizações magmáticas-hidrotermais de terras raras inéditas no mundo, sendo urgente detalhar a sucessão de eventos ígneos e magmáticos-hidrotermais e tipificar suas encaixantes de forma a considerar sua natureza ígnea primordial e abstrair sua natureza "granulítica" ou "charnockítica".
Palavras-chave: Neoarqueano; granulito; charnockito; mineralizações de terras raras

1 Introduction

The Jequié – Itagi area is located in the Jequié Complex, which is part of the São Francisco Craton (Almeida, 1977; Figure 1), the most extensive Archean – Paleoproterozoic crustal segment in South America. The Jequié Complex was described by Cordani (1973) as *an association of granulite facies rocks*. It comprised an area of more than 100,000 km2 and was considered one of the largest areas of granulite facies rocks in the world (Barbosa, 1990). The complex has been later splitted by Barbosa & Sabaté (2002) in two different geotectonic entities: the so-called "Jequié Block" and the "Itabuna – Salvador – Curaçá Block" (Figure 1). The designation "Jequié Block" comes after the original proposal of Loureiro (1986) who studied part of the Jequié Complex and recognized a *Jequié Nucleus*, which was delimited based on gravimetric data and on the predominance of Archean ages as compared to mostly Paleoproterozoic adjoining areas eastwards.

The original designation of Cordani (1973) has been left out in papers from 1986 to the present (e.g. Barbosa, 1986; Barbosa *et al*., 2002), except for the Brazilian Geological Survey (CPRM) that still uses the "Complex" category to refer to the Jequié rocks (CPRM, 2009), following the Brazilian and international norms for the naming of lithodemic units (Petri *et al*., 1986; NACSN, 1983). Nowadays, the term "Jequié Complex" stands for the"Jequié Block" (Barbosa & Sabaté, 2002) which is the same as the former Archean Jequié Nucleus of Loureiro (1986). Thus, the Jequié Complex is bounded to the East by the "Itabuna-Salvador-Curaçá Block", which has been considered as a Paleoproterozoic continental margin represented by ~2.1 Ga calc-alkaline igneous rocks (Silva *et al*., 2002; Peucat *et al*., 2011).

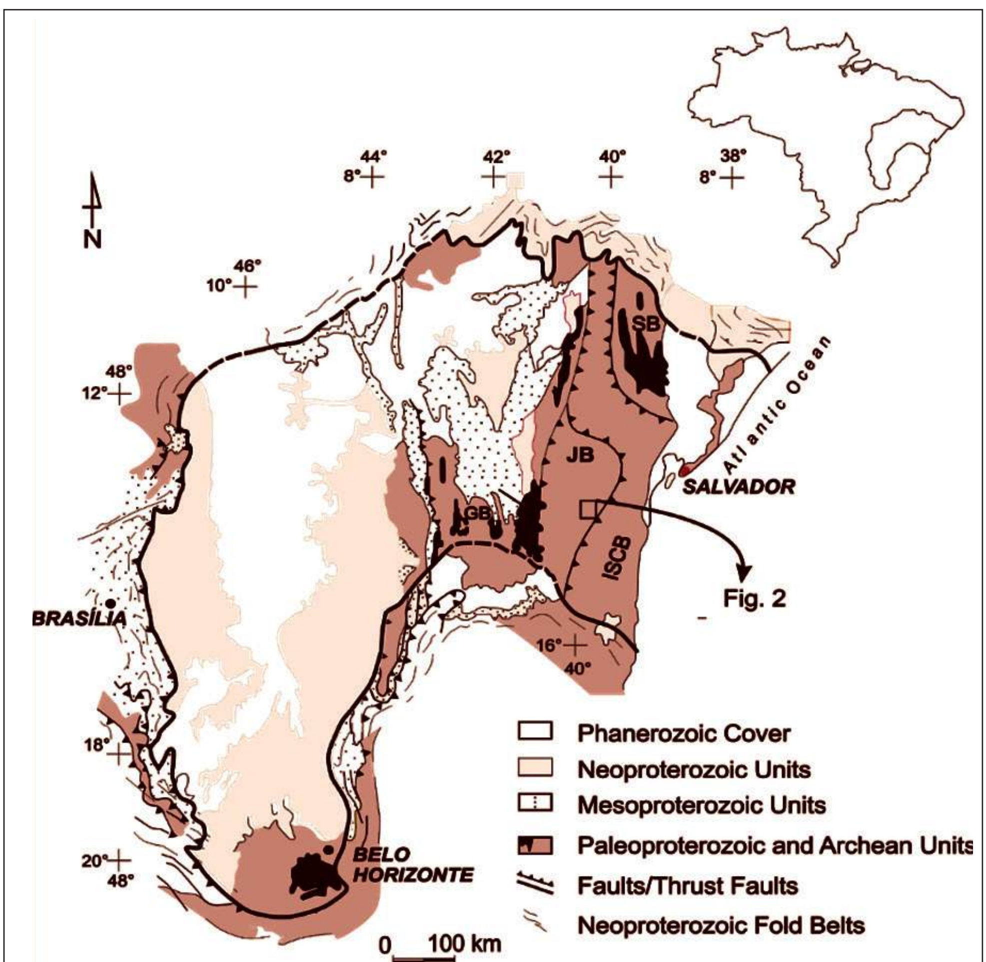

Figure 1 Schematic map of the São Francisco Craton and the Neoproterozoic (Brasiliano) Fold Belts. SB= Serrinha Block; JB= Jequié Block; GB= Gavião Block; ISCB= Itabuna-Salvador--Curaçá Block. (1) = Area of Figure 2. After Alkmin et al. (1993).

This paper presents data from recent geological mapping in the 1:100,000 scale besides new geochemical and geochronological (U-Pb, LA-ICP-MS) data. It is intended to review the geology of the Jequié Complex in the Jequié-Itagi region and to propose a new lower range stratigraphic unit, the Volta do Rio Plutonic Suite, which is composed of high-K ferroan ("A-type") granitoids and subordinate mafic to intermediate rocks. Although the Volta do Rio Suite was defined in the Jequié-Itagi region, there is evidence that it extends itself for more than 200 km northeastwards and to the South. It hosts high-grade REE mineralizations in mafic to intermediate rocks and magmatic-hydrothermal segregations and veins associated to leucogranites which are inedit in the world. The recognition of such a sequence of geological processes in the Jequié Complex and their dating may contribute to change the geological approaches to study the Jequié Complex and incentivate the exploration of its metallogenic potential for REE deposits.

2 Methodological Procedures

Geological mapping in an area of approximately 900 km2 (Figure 2) was performed in the 1:100,000 scale in parts of the SUDENE 1:100,000 quadrangles of Jequié (SD-24-V-D-IV), Jaguaquara (SD-24-V-D-V), Manoel Vitorino (SD-24-Y-B-I) and Ipiaú (SD-24-Y-B-II). Around 200 samples have been studied in thin section. Sixty-eight samples of granitoids, mafic rocks and a few enclaves of the undivided Jequié Complex and of the Volta do Rio Plutonic Suite were destined to chemical analysis. These were crushed into small fragments (2-3 cm) in the field and examined to avoid any contamination from veinlets of leucogranites.

After crushing to ~ 4 *mesh*, samples were reexamined to sort out possible granitic veinlets and then pulverized to –200 mesh in a tungsten carbide ring mill. Pulps have been sent to ACTLABS (Vancouver, Canada) where they were fused in a Lithium Tetraborate/ Metaborate flux and digested with nitric acid for major element and Sc, Be, V, Sr, Y, Zr analysis by ICP-OES. Detailed descriptions of analytical procedures for major and trace elements may be found at ACTLABS (2012).

Heavy minerals have been concentrated in a shaking table and thirty zircon grains were picked from each sample under a stereomicroscope after preconcentration with bromoform. Grains were examined by BSE imaging and cathodoluminescence. Isotopes were measured on individual zircon crystals by NewWave 213 nm laser workstations (New Wave UP213) inductively coupled to plasma mass spectrometry (LA-ICPMS). Geochronological analyses were performed at the Jack Satterly Geochronology Laboratory, University of Toronto, Canada (VG PQ Excell ICP-MS; samples 369B and 47C), and at LGI – Laboratório de Geologia Isotópica, Universidade Federal do Rio Grande do Sul, Brazil (MC-ICP-MS Neptune; samples 94 and 210-04).

Zircon crystals from porfiroclastic granitoids samples 94 and 210-04 have been analysed using static mode with spot sizes of 15 and 25 µm. Laser-induced elemental fractional and instrumental mass discrimination were corrected by the analyses of the reference zircon GJ-1 (Jackson *et al*., 2004) after every ten zircon spots. The external error was calculated after propagation error of the GJ-1 mean and the individual zircon (or spot).

At first, the more clear and transparent crystals found on samples 369B (leucodiorite) and 47C (gabbroic enclave) were mounted onto double sided tape and targeted on natural surfaces. In a second round of analyses pre-analyzed grains were picked and mounted in resin, have their surfaces polished, imaged by cathodoluminescence and then re-analysed. Selected sample spots were ablated at 5 Hz and about 5 J/cm2 with beam diameter of 40 microns. Mass spectrometry was carried out on a Plasmaquad quadrupole ICP-MS equipped an S-option 75 l/sec rotary pump to increase sensitivity. Data were collected on 88Sr (10 ms), 206Pb (30 ms), 207Pb (70 ms), 232Th (10 ms) and 238U (20 ms). Prior to analyses spots were pre-ablated using a raster pattern to clean the surface. Data were edited and reduced using custom VBA software written by the author (D.W. Davis). ^{88}Sr was monitored from zircon in order to detect intersection of the beam with zones of alteration or inclusions and data showing high Sr or irregular time resolved profiles were either averaged over restricted time windows or rejected. Laser-

-induced elemental fractional and instrumental mass discrimination were corrected by the analyses of the reference zircons DD-91-1, from Lac Fourniere Batholith (Jackson *et al*., 2004) and DD85-17, from the Marmion batholith (Tomlinson *et al*., 2003), both of Precambrian ages. Sets of 4 sample measurements are bracketed by measurements on standards. Differences between standards are time interpolated to correct sample measurements. A "standard-sample--standard" method was used to correct instrumental drift during a single laser-ablation session and common Pb correction was applied using an initial Pb composition taken from Stacey& Kramers (1975).

The Jequié Complex and nearby areas have been affected by Paleoproterozoic granulite facies metamorphism (Silva *et al*., 2002). However, in this text rock types have been also reffered to by their igneous classification, it being implicit that all of them have been metamorphosed in the granulite facies. The nomenclature of Streckeisen (1974) will be avoided since "charnockite" and related terms should be used for igneous rocks (Robertson, 1999) and im most of these rocks there is no indication that these rocks have igneous orthopyroxene.

In the following descriptions, grain-size will be defined according to Gillespie & Styles (1999): fine-grained (0,032- 0,25 mm); medium-grained (> 0,25-2,0 mm); coarse-grained (> 2,0- 16,0 mm

3 A New Proposal for the Geology and Stratigraphy of the Jequié Complex in the Jequié-Itagi Area

The Jequié Complex (Figure 2) is defined here as an assemblage of predominant metatonalites, metatrondhjemites and metagranodiorites (Figure 3A) closely associated with subordinate metabasic (mostly metagabbronorites) to intermediate rocks, metaultramafic rocks (Figures 3A, 3B; serpentinites and pyroxenites) and metasediments (Figure 4). The metasediments occur as small outcrops of quartzite, iron formation, graphite schist, marble, calc-silicate rock and biotite-garnet-cordierite-sillimanite-quartz fels (Robertson, 1999).

Besides these rocks, the Jequié Complex contains a great diversity of younger felsic metaplutonic rocks, which constitute the main aim of this paper: (i) the Volta do Rio Plutonic Suite, (ii) the Aiquara Massif, (iii) orthopyroxene-metaleucogranites and garnet-metaleucogranites (Figure 2; Figures 3C, 3D).

The Aiquara Massif (AM, Figure 2) has been recognized for the first time during the field work for the study presented here. There is still no geochronological data available for it, although we especulate that it may be paleoproterozoic.

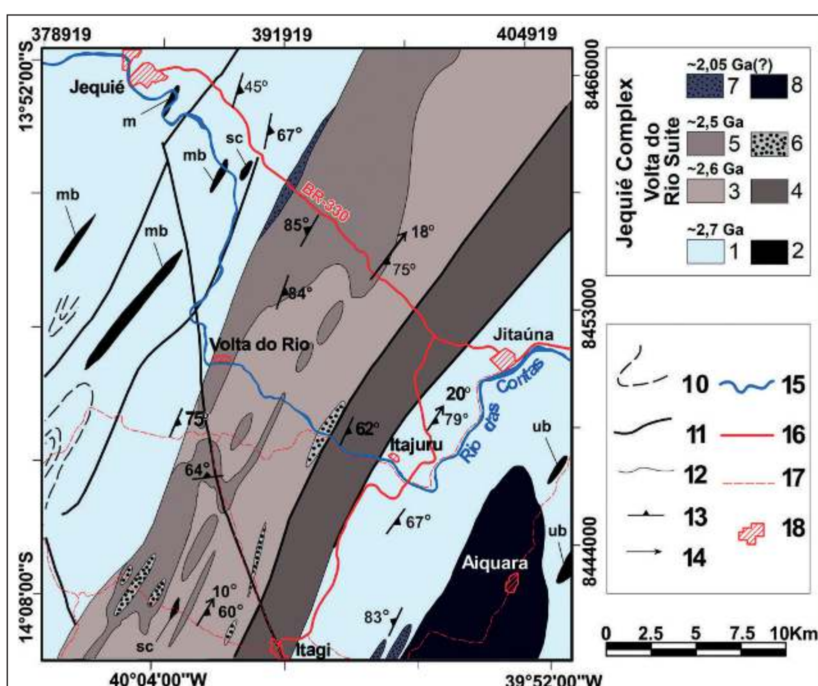

Figure 2 A new geological proposal for the Jequié-Itagi area (this paper). Jequié Complex: (1) Metatonalites, metatrondhjemites, and metagranodiorites, with subordinate metamafics, metaultramafics, metasupracrustal rocks, intrusive hypersthene- and garnet-bearing granites; (2) metabasites (mb), metaultrabasites (ub) and garnet-cordierite-sillimanite-quartz fels (Robertson, 1999) (sc) and marbles (m) (dimensions of metasediments have been exaggerated in the map). Volta do Rio Suite: (3) metagranodiorites and metamonzogranites with porphyroclastic texture, and subordinately equigranular even-grained and fine-grained metagranodiorites; (4) predominantly even-grained metagranites with subordinate fine-grained metagranodiorites; (5) Amphibole- and magnetite- bearing leucogranites and apparently coeval mafics and ultramafic rocks plus pegmatites and aplites; (6) pegmatites and aplites; (7) Garnet-leucogranites; (8) Aiquara Massif, unknown age; (9) foliation trends; (10) structural lineaments; (11) geological contacts; (12) foliation; (13) stretching lineation; (14) Rio das Contas river; (15) main road; (16) secondary road; (17) town / village.

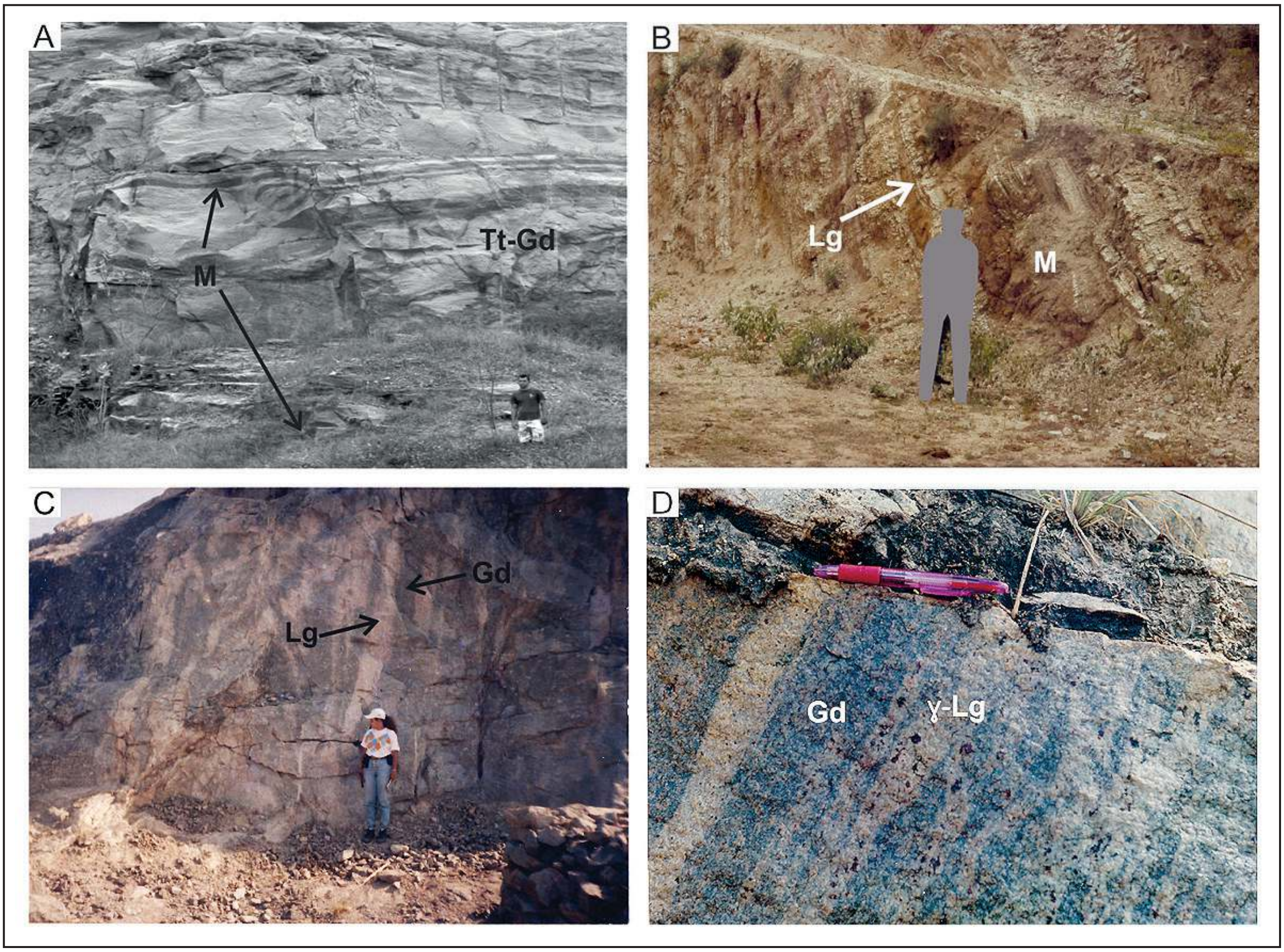

Figure 3 Field aspects of the undivided Jequié Complex rocks. (A) Granodiorite with mafic sheets and interleaved hypersthene leucogranites; (B) Weathered deformed mafic and tonalites rocks with sheets and veins of leucogranites (C) Deformed veins of leucogranite in granodiorites ("intrusive complex" in the sense of Sawyer, 2008). (D) Garnet-bearing leucogranite intruded in granodiorites (dark grey). M=mafic rock; Tt-Gd = Tonalites and Trondhjemites; Lg= leucogranite; Gd= Granodiorite; γ-Lg= garnet-leucogranite. Human scales are around 1.65m tall. Pen in (D) is 16 centimetres long.

The orthopyroxene-leucogranites and garnet leucogranites occur tipically as a pervasive assemblage of deformed centimetric to kilometric sheets, dykes and vein swarms cutting the tonalites - trondhjemites – granodiorites, amd associated mafics - intermediate rocks and the metasediments. The garnet leucogranites are peraluminous, with common xenoliths of biotite-garnet-cordierite-sillimanite-quartz fels (Robertson, 1999). They have been dated at ca. 2.05 Ga (Barbosa *et al.*, 2004) in the Brejões region, northwards (Figure 1). The orthopyroxene – bearing leucogranites are mostly metaluminous and their age is so far unknown.

The high density of veinlets, veins, sheets and dykes of these orthopyroxene- and garnet- leucogranites cutting the metaigneous rocks (tonalites- trondhjemites- granodiorites and mafic – intermediate rocks, Figure 3B, 3C) are probably the reason why part of the Jequié Complex was originally classified as "migmatites" (Barbosa, 1986). However, the clear intrusive character of the granitoids suggests that they correspond to a deformed and recrystallized intrusive complex (Sawyer, 2008), that we propose here.

3.1 Geology of the Volta do Rio Plutonic Suite

The Jequié Complex was intruded at 2.6 Ga by rocks that constitute the Volta do Rio Plutonic Suite (VRPS). The VRPS is here proposed as a

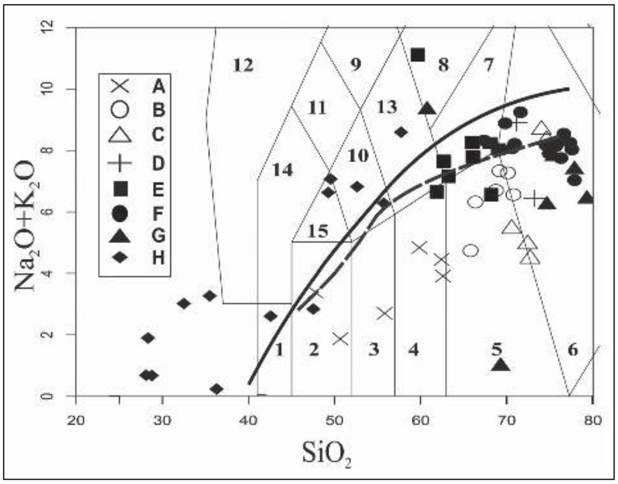

Figure 4 Chemical classification diagram (Middlemost, 1994) applied to the Jequié Complex and Volta do Rio Plutonic Suite. Symbols: Jequié Complex: (A) mafic to intermediate rocks; (B) tonalites, trondhjemites, granodiorites; (C) hypersthene-leucogranites; (D) garnet-leucogranites. Volta do Rio Plutonic Suite: (E) granodiorites/monzogranites; (F) leucogranites and leucosyenites; (G) aplites-pegmatites; (H) mafic to intermediate rocks and cumulates. Fields: 1 = Peridotite-gabbro; 2 = Gabbro; 3 = Gabbroic diorite; 4 = Diorite; 5 = Granodiorite; 6 = Granite; 7 = Quartz-monzonite; 8 = Syenite; 9 = Monzonite; 10 = Feldspathoid-syenite; 11 = Feldspathoid-monzogabbro; 12 = Foidolite; 13 = Monzodiorite; 14 = Feldspathoid-gabbro; 15 = Monzogabbro. The limits between subalkaline (bottom) and alkaline (top) associations is shown as a continuous line (Irvine & Baragar, 1971) and a dashed line (Kuno, 1966).

new lithodemic unit of the Jequié Complex, composed of three main petrographic rock types (Figure 4) deformed and metamorphosed:

(i) granodiorites and monzogranites with normal contents of mafic minerals (“high-M granitoids”), equigranular or porphyroclastic (Figure 5A) to medium- or fine-grained texture;

(ii) a bimodal association of amphibole-bearing-metaleucogranites (Figure 5B) and associated pegmatites–aplites (Figure 5D); and,

(iii) mafic-ultramafic to intermediate rocks and cumulates (Figure 5C).

These high K ferroan calk-alkalic to alkali-calcic felsics and subordinate mafic to intermediate rocks constitute a large NNE-SSW elongated batholith which outcrops East of Jequié City (Figure 2). Besides, there are a few small enclaves of paragranofels (Robertson, 1999). Most of the high-M granitoids of VRPS are even-grained, but a facies with mesoperthite porphyroclasts (Figure 5A) is present. This shows coarse-grained mesoperthite, ortho- and clinopyroxene and amphibole (± biotite) grains in a granoblastic-polygonal matrix composed of the same minerals. The fine-grained rocks with an orthopyroxene-bearing polygonal granoblastic texture seem to result from granulite facies comminution and recrystallization of the coarser-grained rocks.

Many rocks classified as granodiorites by petrography are quartz monzonites in chemical clas-

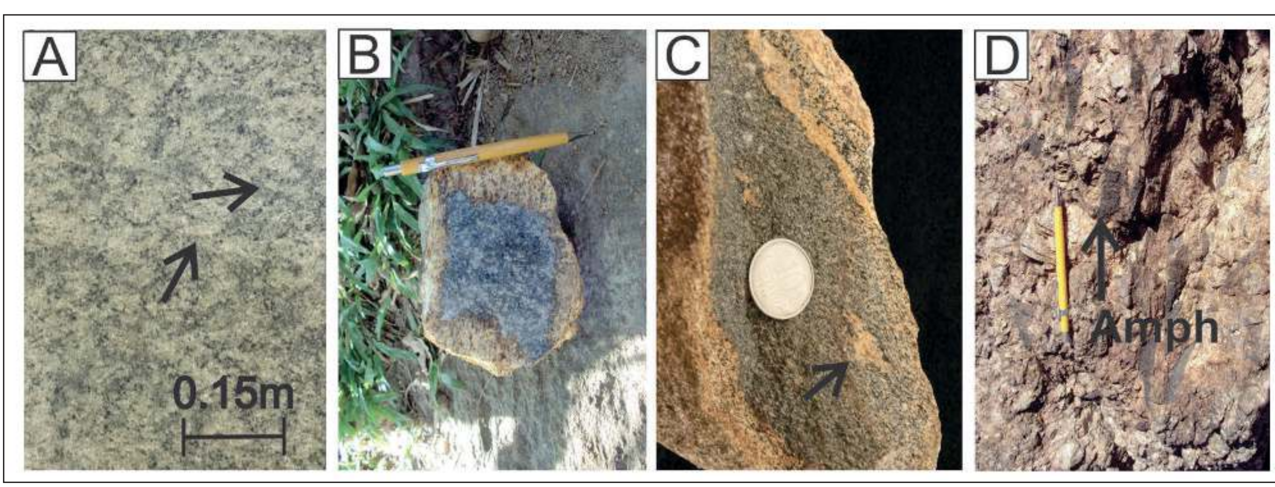

Figure 5 Volta do Rio Plutonic Suite. Field aspects: (A) Porphyroclastic monzogranite (sample 94, dated by U-Pb LA-ICP-MS); arrows show igneous subhedral mesoperthite grains; scale bar = 15 cm. (B) Amphibole-bearing leucogranite; (C) Gabbronorite (a monzodiorite in the TAS chemical classification, Figure 6) sheet in leucogranite; Arrow shows pockets of K-feldspar; on the top interaction between host leucogranite and mafic rock causes amphibole enrichment in the granite ; coin diameter = 2.1 cm (D) Pegmatitic hornblende syenite; arrow shows amphibole grains; pen = 15 cm long.

sifications (Figure 4) due to high alkali contents in mesoperthite and biotites. The granodiorites and monzogranites differ from the leucogranites in having high M and Q numbers numbers (Q ≈ 24 and M ≈ 12) (Streckeisen, 1976) and low silica contents (less than ~75% SiO_2, Figure 4). With no exception, all the granitoids of the VRPS differ from the other granitoid rocks of the Jequié Complex in being ferroan ("A-type") (Figure 6). Trace elements also confirm that all of the granitoid rocks of the VRPS are "A-type" (Fernandes *et al*., 2017).

Some mafic to intermediate rocks and cumulates of the VRPS contain Chevkinite Group Minerals (CGM) and some individual samples with high contents of REE reach ore grade. Moreover, some quartz segregations linked to pegmatites and with CGM also reach ore grade in individual samples (Fernandes *et al*., 2018).

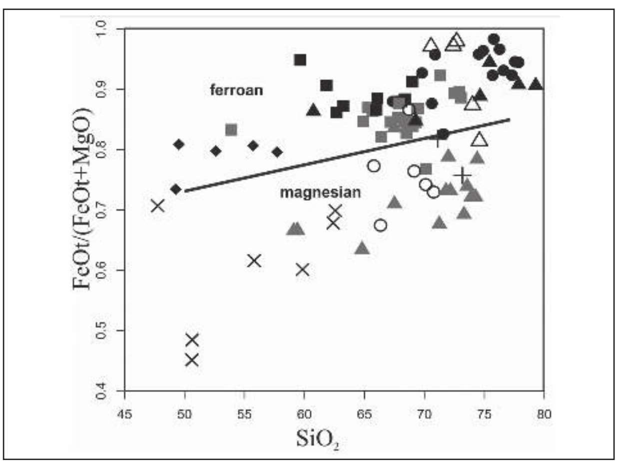

Figure 6 The Jequié Complex and the Volta do Rio Plutonic Suite in the chemical diagram proposed by Frost *et al*. (2001) (here modified to include low-silica samples). Symbols as in Figure 4. Samples from Barbosa et al. (2002) were added for comparison: grey squares = "CH2 High-Ti charnockites"; grey triangles= "CH1 Low-Ti Charnockites"

4 U-Pb LA-ICP-MS Geochronology

4.1 Ages of the Mafic to Intermediate Rocks of the Jequié Complex

Zircon grains from a calc-alkaline gabbronorite (a hypersthene diorite), sample 369B, located at the Cidade Nova Quarry, outskirts of Jequié (Figure 2), were dated by U-Pb-Th geochronology. These rocks are the basement for the VRPS. Sample 369B is associated to Mg-rich mafic rocks and to tonalites/trondhjemites and was intruded by hypersthene-bearing leucogranitoid veins and sheets. At 369B most zircon crystals are white to brown coloured, subhedral, prismatic and few of them display overgrowths. Some grains had fractures and/or are twinned.

Only three out of twelve grains directly mounted onto double-sided tape were targeted on natural surfaces. The results range from 2721±6 Ma (Zr1 core) to 2718±7Ma (Zr2 core). The most concordant result was yielded by Zr1 border, resulting in 2493±16Ma. Zr3 presented a low Th/U ratio (0.042) associated to a Neoproterozoic age (951±14Ma) and was interpreted as a metamorphic grain. As all of them presented a high level of discordance (Table 1) it was decided not to continue analyses on natural surfaces, transfering all grains to a resin polished mount in order to expose their interior

The less damaged grains provide a provisional four-point Pb-loss line with an age of 2681±48 Ma (MSWD = 6.3) (Figure 7, Table 1), been interpreted as the minimum crystallization age for the mafic to intermediate rocks of Jequié Complex.

4.2 The Ages of the Volta do Rio Plutonic Suite

U-Pb dating has been performed in zircon grains from two samples of porphyroclastic grani-

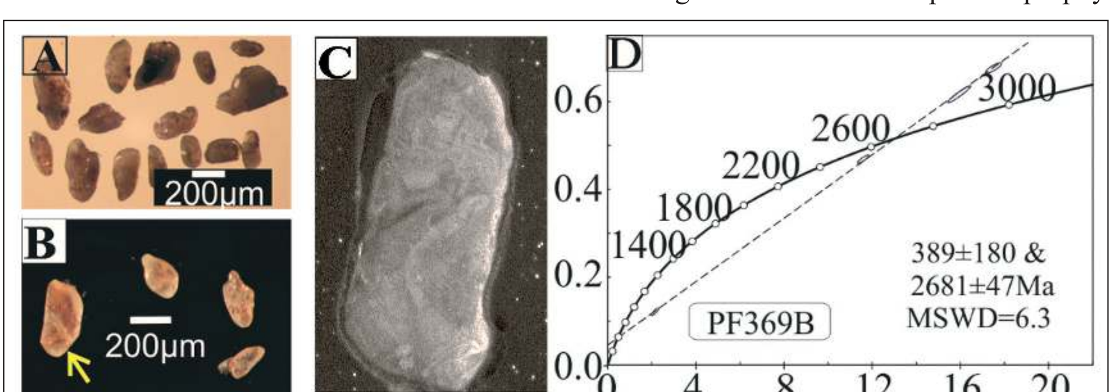

Figure 7 Sample 369B (A) the initial population of zircon concentrate. (B) Dated zircon grains. (C) Image of a grain (cathodoluminescence) shown with an arrow in (B). (D) Pb-loss curve for sample 369B.

toids belonging to the population of "granodiorites and monzogranites" of the VRPS. In addition to these U-Pb ages in granitoids a sample (47C) of a hypersthene monzodiorite, which shows evidence of being coeval with the leucogranites, has been dated.

4.2.1 The Granodiorites and Monzogranites

Samples 210-04 (a granodiorite) and 94 (a monzogranite) are porphyroclastic granitoids with amphibole and orthopyroxene and common accessory minerals as zircon, apatite and opaque minerals. Most of the coarser assemblage, including hypersthene, has been recrystallized in the granulite facies as a polygonal fine-grained matrix, which has a granulite facies paragenesis containing hypersthene+-clinopyroxene + amphibole. They show a ferroan ("A-type") high-K chemical signature (Figure 6).

In sample 94, collected in a dimension stone quarry, North from the road Jequié – Jitaúna, a crystallization age of 2.6 Ga can be constrained by analytical spots in zircon cores, which have been grouped in a 12-point Concordia of 2621±16 Ma, with MSWD of concordance of 0%, and probability of concordance = 0.995 (Table 1, Figures 8A to 8C).

Sample 210-04 was collected on a unpaved road, which links the town of Itagi to the village of Oriente Novo, in a small quarry where boulders with diameter up to 3 metres had been exploited for street paving. The analysis of the cores of igneous zircon grains (Table 1, Figures 8D, 8E) have defined a concordia with eleven points at 2576±30 Ma and MSWD = 3.1.

4.2.2 Mafic–Intermediate Alkaline Magmatism and REE Mineralization

Sample 47C is a coarse-grained gabbronorite (which is a monzodiorite in the TAS chemical classification, Figure 5) of the mafic-ultramafic intermediate group of rocks of VRPS. It is composed of biotite, amphibole, chevkinite group minerals, orthoclase mesoperthite plagioclase, zircon and opaque minerals. It was collected on a depression in a hilly area from metre-sized boulders.

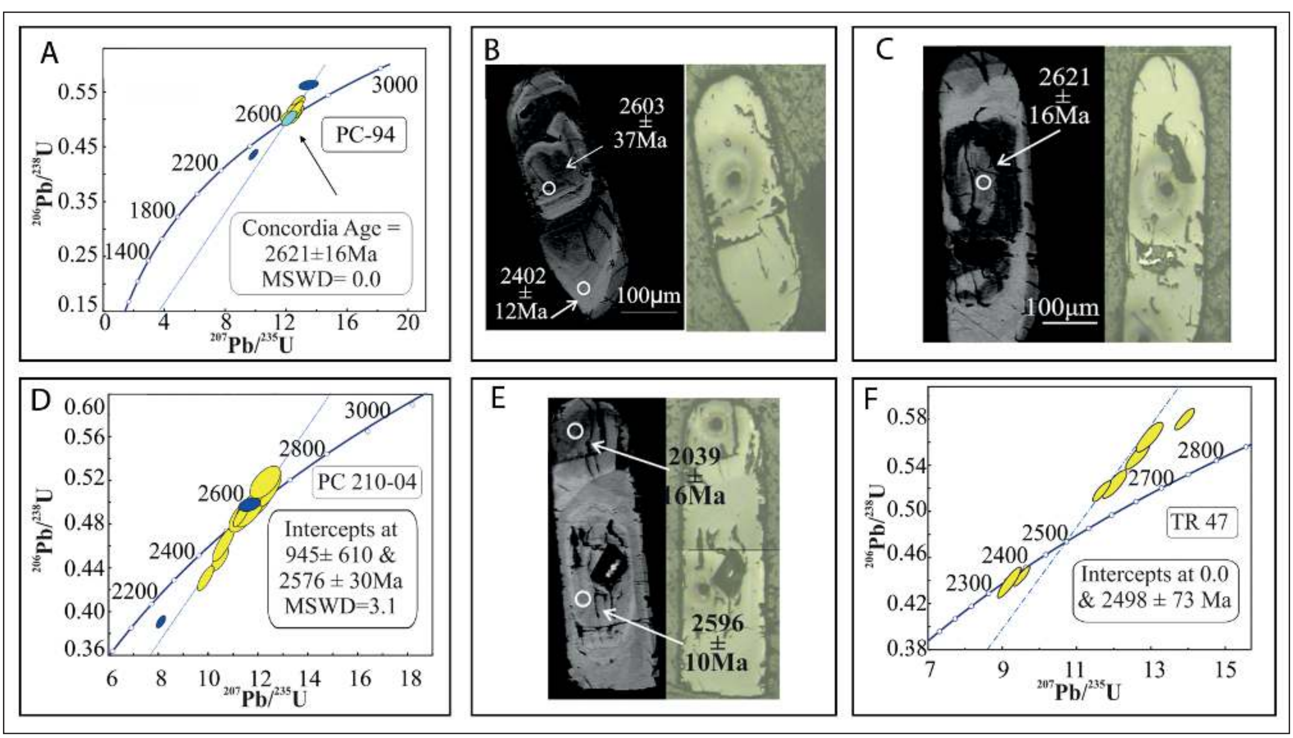

Figure 8 Volta do Rio Plutonic Suite. Archean U-Pb ages. U-Pb age and images of selected zircon grains from monzonites and monzogranites (A to C, sample PC- 94). From D to E, data for sample 210-04, a metamorphosed granodiorite. In (F), sample 47B, a gabbronorite.

Spot number		$^{207}Pb/^{235}U$	±	$^{206}Pb/^{238}U$	±	Rho XY	$^{207}Pb/^{206}Pb$	±	$^{206}Pb/^{238}U$	±	$^{207}Pb/^{235}U$	±	$^{207}Pb/^{206}Pb$	±	$^{232}Th/^{238}U$	Disc
		(%)		(%)			(%)				Age (Ma)					(%)
Sample PF-369		**Location: 13º52' 57.1" S; 40º 05' 19.8" W**							**Error in 2 sigma**				**DD91-1 Standard**			
				Analyzed at JSGL, University of Toronto												
PF369B-1.1		15.943433	0.211	0.6167443	0.008	0.9554	0.1877081	0.001	3097	31.04	2873.4	12.60	2720.3	6.44	1.2045	-17.5
PF369B-1.2		11.593248	0.107	0.4690899	0.004	0.89442	0.1799455	0.001	2479.6	16.93	2572.1	8.59	2645.9	6.82	0.8562	7.6
PF369B-2.1		17.506601	0.148	0.6766946	0.005	0.83136	0.1888789	0.001	3331.7	18.32	2963	8.13	2721.5	7.75	0.546	-28.8
PF369B-3.1		2.1507046	0.069	0.1215637	0.003	0.87443	0.1301833	0.002	739.56	19.52	1165.3	22.00	2075	27.11	0.0554	68.0
Sample PC-94		**Location: 13°08'00" S; 39°57'22" W**							**Error in 1 sigma**				**GJ-1 Standard**			
				Analyzed at Federal University of Rio Grande do Sul												
Zr-090-B-II-03		12.27998	1.560	0.50772	1.133	0.73	0.17542	1.072	2647	30	2626	40.96	2610	27.97	0.40	-1.4
Zr-090-B-II-05-1		12.62306	1.462	0.51490	0.857	0.59	0.17781	1.185	2677	23	2652	38.77	2633	31.19	0.63	-1.7
Zr-090-B-II-05 -2		12.69643	1.706	0.52708	1.219	0.71	0.17470	1.193	2729	33	2657	45.32	2603	31.05	0.24	-4.8
Zr-090-B-II-06 -2		12.53419	1.074	0.51939	0.857	0.80	0.17502	0.648	2697	23	2645	28.41	2606	16.88	0.12	-3.5
Zr-090-C-IV-03 -2		9.84176	1.245	0.43540	0.897	0.72	0.16394	0.863	2330	21	2420	30.12	2497	21.55	0.34	6.7
Zr-090-C-IV-03 -1		12.21371	1.677	0.50164	1.137	0.68	0.17658	1.233	2621	30	2621	43.96	2621	32.31	0.72	0.0
Zr-090-D-VI-04		12.60462	1.072	0.51564	0.853	0.80	0.17729	0.649	2681	23	2651	28.42	2628	17.06	0.18	-2.0
Zr-090-D-VI-05		12.31720	0.952	0.51927	0.628	0.66	0.17204	0.715	2696	17	2629	25.02	2578	18.44	0.23	-4.6
Zr-090-E-VIII-01		13.45417	1.924	0.56247	0.633	0.33	0.17348	1.817	2877	18	2712	52.19	2592	47.09	0.24	-11.0
Zr-090-F-X-03 -2		12.68425	1.497	0.50788	1.271	0.85	0.18114	0.791	2648	34	2656	39.78	2663	21.08	0.29	0.6
Zr-090-G-XII-05		12.85382	1.143	0.52708	0.978	0.86	0.17687	0.592	2729	27	2669	30.50	2624	15.53	0.16	-4.0
Zr-090-H-XIV-02 1		12.61184	1.251	0.50935	0.817	0.65	0.17958	0.947	2654	22	2651	33.17	2649	25.09	0.33	-0.2
Zr-090-I-XVI-03		12.55010	1.800	0.51348	1.528	0.85	0.17727	0.952	2671	41	2646	47.64	2627	25.02	0.30	-1.7
Zr-090-J-XVIII-02a		11.94502	1.132	0.50468	0.704	0.62	0.17166	0.887	2634	19	2600	29.43	2574	22.83	0.58	-2.3
Zr-090-J-XVIII-02 b		9.70562	1.069	0.45762	0.827	0.77	0.15382	0.678	2429	20	2407	25.73	2389	16.19	0.37	-1.7
Zr-090-E-VIII-05		6.57613	1.356	0.37781	1.085	0.80	0.12624	0.813	2066	22	2056	27.87	2046	16.63	0.98	-1.0
Zr-090-I-XVI-05 a		6.48983	1.706	0.37427	1.133	0.66	0.12576	1.275	2049	23	2045	34.87	2040	26.00	0.88	-0.5
Zr-090-G-XII-03		5.64105	8.035	0.26258	4.781	0.60	0.15581	6.458	1503	72	1922	154.46	2411	155.68	0.17	37.7
Zr-090-H-XIV-02		4.47491	1.706	0.26753	0.789	0.46	0.12131	1.513	1528	12	1726	29.45	1976	29.89	0.12	22.6
Zr-090-I-XVI-05		4.05726	1.357	0.24861	1.030	0.76	0.11836	0.884	1431	15	1646	22.34	1932	17.08	0.14	25.9
Sample PC-210-04 - Archean				**Location: 14°09'05.1"S; 40°02'27"W**						**Error in 1 sigma**				**GJ-1 Standard**		
				Analyzed at Federal University of Rio Grande do Sul												
Zr-090-A-I-01		10.46070	1.327	0.44753	0.980	0.74	0.16953	0.894	2384	23	2476	32.85	2553	22.82	0.26	6.6
Zr-090-A-I-03 a		9.88711	1.375	0.43028	1.080	0.79	0.16665	0.851	2307	25	2424	33.34	2524	21.48	0.49	8.6
Zr-090-B-III-02 a		11.66840	1.514	0.49774	0.500	0.33	0.17002	1.429	2604	13	2578	39.04	2558	36.56	0.22	-1.8
Zr-090-B-III-06 a		10.60300	1.706	0.46144	1.411	0.83	0.16665	0.959	2446	35	2489	42.47	2524	24.22	0.68	3.1
Zr-090-B-III-06 a2		12.14250	1.580	0.50133	1.146	0.73	0.17566	1.088	2620	30	2615	41.32	2612	28.42	0.40	-0.3
Zr-090-B-III-06 a3		11.37982	1.983	0.48736	1.269	0.64	0.16935	1.524	2559	32	2555	50.67	2551	38.88	0.31	-0.3
Zr-090-D-VII-03 a		11.66045	2.063	0.49302	1.332	0.65	0.17153	1.576	2584	34	2578	53.19	2573	40.55	0.49	-0.4
Zr-090-H-XV-01 a		11.31305	1.127	0.48779	0.884	0.78	0.16821	0.699	2561	23	2549	28.72	2540	17.74	0.02	-0.8
Zr-090-H-XV-01 a2		12.49614	1.387	0.51050	1.155	0.83	0.17753	0.769	2659	31	2642	36.66	2630	20.22	0.23	-1.1
Zr-090-I-XVII-05		12.28131	2.032	0.51811	1.172	0.58	0.17192	1.660	2691	32	2626	53.37	2576	42.78	0.41	-4.5
Zr-090-D-VII-01a		8.11668	0.964	0.39085	0.595	0.62	0.15061	0.759	2127	13	2244	21.64	2353	17.86	0.28	9.6
Zr-090-C-V-05		10.91067	3.687	0.45833	1.138	0.31	0.17265	3.507	2432	28	2516	92.75	2584	90.60	0.53	5.9
Sample PC-210-04		**Palaeoproterozoic**				**Location: 14°09'05.1"S; 40°02'27"W**					**Error in 1 sigma**				**GJ-1 Standard**	
				Analyzed at Federal University of Rio Grande do Sul												
Zr-090-B-III-02 b	M	6.42143	1.871	0.36894	1.554	0.83	0.12623	1.043	2024	31	2035	38.09	2046	21.34	0.17	1.1
Zr-090-A-I-03 b	M	3.91391	1.214	0.23085	0.848	0.70	0.12297	0.869	1339	11	1617	19.63	2000	17.37	0.14	33.0
Zr-090-C-V-02	M	4.72486	1.272	0.27146	0.907	0.71	0.12623	0.892	1548	14	1772	22.54	2046	18.25	0.14	24.3
Zr-090-D-VII-01b	M	3.35499	1.343	0.19880	0.928	0.69	0.12240	0.971	1169	11	1494	20.06	1991	19.33	0.13	41.3
Zr-090-D-VII-03 b	M	3.31357	2.654	0.20218	2.320	0.87	0.11887	1.290	1187	28	1484	39.40	1939	25.02	0.11	38.8
Zr-090-K-XXI-04 b	M	6.60940	1.754	0.37780	0.884	0.50	0.12688	1.514	2066	18	2061	36.13	2055	31.12	0.16	-0.5
Zr-090-K-XXI-04a	I	6.91368	1.413	0.38549	1.076	0.76	0.13008	0.916	2102	23	2100	29.67	2099	19.22	0.44	-0.1
Zr-090-C-V-01	M	5.45840	1.385	0.33007	0.848	0.61	0.11994	1.095	1839	16	1894	26.23	1955	21.41	0.20	6.0
Sample PF-47		**Location: 14°00'52.5"S; 40°03'42.2"W**							**Error in 2 sigma**				**DD91-1 Standard**			
				Analyzed at JSGL, University of Toronto												
PF47-2.1		11.674422	0.098	0.5174754	0.004	0.84834	0.1634209	0.000	2688.5	15.71	2578.7	7.88	2493.4	7.51	0.1445	-9.6
PF47-3.1		12.973789	0.149	0.5644605	0.005	0.81363	0.1664786	0.001	2885	21.66	2677.8	10.78	2524.8	11.15	0.6093	-17.7
PF47-4.1		13.923443	0.110	0.5799387	0.004	0.83976	0.1737941	0.001	2948.5	15.66	2744.5	7.47	2597.7	7.13	0.4769	-16.9
PF47-5.1		12.658923	0.135	0.5484932	0.005	0.86094	0.1670647	0.001	2818.9	20.95	2654.6	10.02	2531.7	9.09	0.3753	-14.0
PF47-6.1		9.1873446	0.129	0.4382558	0.005	0.88891	0.1520956	0.001	2342.8	24.47	2356.9	12.81	2369	10.94	0.3786	1.3
PF47-7.1		12.028647	0.134	0.523645	0.005	0.84814	0.1668331	0.001	2714.6	20.85	2606.6	10.39	2523.8	9.86	0.4927	-9.3
PF47-9.1		9.5346012	0.091	0.4439789	0.004	0.85164	0.1568512	0.000	2368.4	16.09	2390.9	8.77	2410.1	8.49	0.0635	2.1
PF47-12.1		4.961802	0.055	0.2905923	0.003	0.87129	0.1261101	0.000	1644.5	14.09	1812.8	9.41	2012.2	9.70	0.1496	20.7
PF47-12.2		1.8560718	0.025	0.138311	0.001	0.73559	0.0984635	0.001	835.1	7.881	1065.6	9.01	1573.5	17.28	0.1089	50.0
PF47-1.2		5.6936183	0.050	0.3362744	0.002	0.84564	0.1225853	0.000	1868.7	12.04	1930.4	7.58	1997.3	8.32	0.2191	7.4
PF47-4.2		3.8448219	0.029	0.2355844	0.002	0.86008	0.1180716	0.000	1363.7	7.964	1602.2	6.07	1931.7	6.88	0.1479	32.6
PF47-5.2		5.3426514	0.043	0.328968	0.002	0.82164	0.1176956	0.000	1833.4	10.49	1875.7	6.84	1922.9	8.17	0.2089	5.3
PF47-7.2		5.473433	0.060	0.3304552	0.003	0.83662	0.120282	0.001	1840.6	14.58	1896.4	9.33	1958.1	10.63	0.1804	6.9

*Sample and standard corrected after Pb and Hg blanks; 207Pb/206Pb and 206Pb/238U corrected after common Pb. Common Pb is calculated after 206Pb/238U-207Pb/235U concordant age; 235U = 1/137.88*total U; Bold = error too large (not used for concordia age); M = Metamorphic; I = Igneous.*

Table 1 U-Pb LA-ICP-MS Geochronological Data.

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Zircon crystals from sample 47C are euhedral, prismatic, dark brown in color, many with a transparent preserved core and a white cloudy border, also showing metamict, translucid and cloudy areas, and some with overgrowths, inclusions and zonation. Sample 47C seems to have a second population of colorless to pale brown, long prisms zircon crystals.

Eight zircon grains were dated by LA-ICP-MS. Selected crystals are euhedral, with a brown dusty core indicating severe radioactive damage and colourless transparent overgrowth rims. The results are not quite satisfactory in view of severe radioactive damage but yielded a provisional age of 2498 ± 78 Ma (Table 1, Figure 8E).

There is field evidence suggesting coeval emplacement of both mafic and intermediate rocks and their cumulates and the amphibole-bearing leucogranites (Fernandes *et al*., 2017) and therefore the 2.5 Ga age may be considered as an approximation to the age of leucogranitic magmatism of the Volta do Rio Suite. Besides radiation damage, the high MSWD may be a consequence of granulite facies metamorphism and Pb loss in the Paleoproterozoic, around 2.05 Ga (Silva *et al*., 2002). The dated sample is REE-rich, so 2.5 Ga is also a provisional minnimum age also for REE mineralization in mafic magmas and cumulates (Fernandes *et al*., 2018).

U-Pb dating performed in zircon grains from the porphyroclastic granitoids belonging to the population of "granodiorites and monzogranites" of the VRPS allowed the identification of a Neoarchean granitogenesis. Besides, it was possible to confim previous data on the age of Paleoproterozoic granulite facies metamorphism. In addition to these ages in granitoids, the hypersthene monzodiorite shows evidence of being coeval with the leucogranites and resulted in a younger crystallization age of ~2.5 Ga.

4.2.3 The age of the Paleoproterozoic Granulite Facies Metamorphism

At the granodiorites and monzogranites of the VRPS all the selected zircon grains show clear colourless rims (Figure 8). These areas have been dated in sample 94 where an age of 2050 ± 9.2 Ma (MSWD of concordance = 0.57; probability of concordance = 0.46) was obtained. In sample 210-04 the zircon grain rims defined an age of 2013 ± 47 Ma (MSWD = 4.6; n= 6, Table 1). Zircon grains of sample TR47B also record this Paleoproterozoic metamorphism on their borders as an ill-defined Pb-loss curve at 1915 ± 93 Ga. Silva *et al*. (2002) dated granulite facies metamorphism in the Jequié Block at 2.05 Ga in a nearby region, and as such we consider that the most acceptable age for granulite facies metamorphism is the age obtained in sample 210-04 (Figure 8E).

A 2.4 Ga age in a zircon grain from sample 94 seems to be an artefact, resulting from dating a spot that represents the edge between an Archean core and a Paleoproterozoic rim (Figure 8B).

5 Discussion

In the following paragraphs, we will discuss separately genetic aspects of the Jequié Complex and the Volta do Rio Plutonic Suite.

The mafic rocks of the Jequié Complex may be described as three different groups: (i) "normal" calc-alkaline mafic rocks; (ii) high-Mg cumulates and (iii) Fe-rich mafic rocks. The mafic to intermediate rocks plus tonalites, trondhjemites and granodiorites compose a calcic to calc-alkalic magnesian association in the sense of Frost *et al*. (2001, Figure 6). Major element data and trace element signatures of the calc-alkaline rocks are similar to those of contaminated continental arc calc-alkali plutonic and volcanic rocks with equivalent silica contents as the ones studied by Franchini *et al*. (2003); Hervé *et al*. (2007) in Andean batholiths.

Moreover, an association of "low-Ti" magnesian (Frost *et al*., 2001) tonalites, granodiorites and granites metamorphosed in the granulite facies (the so-called "CH1" "charnockites", "charnoenderbites" and "enderbites") was described by Barbosa *et al*. (2002) (Figure 6). These "CH1" charnockites and some granodioritic rocks metamorphosed in the granulite facies described nearby in Jaguaquara (Santos, 2014) share the same magnesian calc-alkalic metaluminous characteristics (Frost *et al*., 2001) as the 2.7 Ga "Cordilleran-type" association of mafic to intermediate plus tonalites-trondhjemites-granodiorites of the Jequié Complex (Figure 6). Among all the available geochemical data for the Jequié Complex (Barbosa *et al*, 2002; Macedo, 2006, this paper), the "CH1" "charnockites" and the rocks studied by Santos (2014), plus the tonalite-trondhjemite-granodiorite association of Jequié Complex rocks presented in this paper (Figures 4, 6) are the only ones to show this magnesian calcic to calc-alkalic (Frost *et al*., 2001) signature. The remaining felsic rocks of the Jequié "Block" being all ferroan ("A-type") (Fernandes *et al*, 2017).

Magnesian calcic to calc-alkalic associations with compositional ranges equivalent to the mafic rocks plus tonalites, trondhjemites and granodiorites as those of the Jequié Complex (Figures 4, 6) are found in the Cordilleran batholiths of North America and in the Andes, (Frost *et al*., 2001). Most rocks of these associations are melts of orthometamorphic rocks and they hold a position immediately next to the oceanwards portion of the continental batholiths (Frost *et al*., 2001). However, this resemblance to Cordilleran magmatic rocks does not necessarily imply that subducction processes generated the Jequié Cordilleran assemblage in the Archean, since according to Bedard (2018) and Van Kranendonk (2011), subduction processes would not have been operative before 2.5 Ga.

Although most of the Jequié Complex mafic to intermediate rocks show geochemical signatures traditionally attributed to arc processes (e.g. Ta-Nb-Ti negative anomalies) in Archean rocks, these features that can be mimicked by crustal contamination (Pearce, 2008; Condie, 2015). Bedard (2018) advocates that Archean calc-alkaline analogues of Cordilleran-type magmatism do not necessarily imply subduction processes and that Archaean basalts were derived from melting in overturn upwelling zones of fertile mantle. He also defends the notion that modern-style subduction only started operating at 2.5 Ga.

The hypersthene-bearing leucogranites, which intrude the Cordilleran assemblage of mafic to intermediate rocks and tonalites, trondhjemites and granodiorites of the Jequié Complex are ferroan and potassic, whilst the garnet-bearing leucogranites are magnesian (Figure 4). Similar garnet-bearing leucogranites were dated at 2.05 Ga in the Jequié Complex (Barbosa *et al*., 2004). They are certainly partial melts from Al-rich metasediments, as demonstrated by their metric enclaves of peraluminous gneisses with biotite + garnet + cordierite + sillimanite. The 2.05 Ga age links them to a continental collision between the Jequié "Block" and the Itabuna- Salvador--Curaçá "blocks" (Figure 1) which was proposed by Silva *et al*. (2002) and Peucat *et al*. (2011). On the other hand, the hypersthene-bearing ferroan leucogranites intruding the Jequié Complex are metaluminous to slightly peraluminous and their age and sources are unknown.

In contrast to the magnesian Cordilleran rocks of the Jequié Complex, all the Volta do Rio granitoids are high-K calc-alkaline and show ferroan (A-type) characteristics (Figure 6). This type of magmatism is considered to result from melting in an oxygen-poor environment, that is, in a source region with low fO_2, in a number of specific geotectonic settings and timings in the the Wilson Cycle (Frost *et al*., 2001).

6 Final Remarks

In summary, geochronological and geological data presented in this paper allowed recognizing:

(i) A 2.7 Ga association of Cordilleran-type igneous rocks which is similar to all "low--Ti charnockites" (Barbosa *et al*., 2002; Macedo, 2004) described elsewhere in the Jequié Complex.

(ii) An association of 2.6 Ga high-K " ferroan "A-type", the Volta do Rio granitoids, which has many representatives in rocks described elsewhere in the Jequié Complex, e.g., the "CH2" ("high-Ti charnockites"); "CHO" ("heterogeneous charnockites") and so on (e.g. Barbosa *et al*., 2002; Macedo, 2004; Santos, 2014). In fact, the "high-Ti" "CH2 charnockites" (Barbosa *et al*., 2002) are high-Fe rocks.

(iii) A 2.5 Ga association of mafic and intermediate rocks with alkaline characteristics, which contain REE and Th mineralizations;

(iv) The fact that both the 2.6 Ga Volta do Rio granites and the metaluminous leucogranites associated to the 2.5 Ga alkaline mafic rocks show post-orogenic characteristics (Fernandes *et al*., 2017).

The use of terms like "Cordilleran" or "post--orogenic" however does not imply that these rocks have been generated in a continental margin, since the idea of Archean plate ubduction is controversial (Bedard, 2018; Hahn *et al*., 2017; Barros *et al*., 2009) and more evidence to advocate a Neoarchean Jequié continental margin, such as eclogites, blueschists and ophiolites would be necessary. However, even if this evidence were present in Archean rocks, probably the pervasive high-strain and high-T granulite facies recrystallization at 2.05 Ga would have erased it.

Whatever the tectonic setting of the Jequié Complex was in the Neoarchean, these new geological and geochronological data show a sucession of geological events and constrain the REE mineralization to a specific geological association – that is, the mafic to intermediate rocks and ferroan ("A-type") amphibole-bearing leucogranites of the Volta do Rio Plutonic Suite – and propose a time reference (~2.5 Ga) for REE mineralization which however must be more precisely defined. The recognition of this sequence of geological events indicates an urge to investigate the Jequié rocks considering their primordial igneous pre-granulite facies metamorphism.

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