GEOLOGICAL AND GEOCHRONOLOGICAL FEATURES AND THE PALEOPROTEROZOIC COLLISION OF THE FOUR ARCHEAN CRUSTAL SEGMENTS OF THE SÃO FRANCISCO CRATON, BAHIA, BRAZIL.

BARBOSA J.S.F. [1] & SABATÉ, P. [2] [1]CPGG - Centro de Pesquisa em Geofisica e Geologia/UFBA, Bahia, Brazil; [2] IRD/ORSTOM, Montpellier, France.

SUMMARY

Recent geological, geochronological and isotopic research discriminated four important Archean crustal segments in the basement of the São Francisco Craton in the State of Bahia. The oldest **Gavião Block** occurs in the WSW part. In it a continental crust of an essentially granitic, granodioritic and migmatitic composition has been identified, which includes remnants of TTGs, considered to represent the oldest rocks in the South American continent (~3,4Ga) and associated with Archean greenstone belt sequences. Along the Atlantic Coast, from the SE part of Bahia up to Salvador and then along a NE trend, the youngest segment, termed the **Itabuna-Salvador-Curaçá Belt** is exposed. It is mainly composed by tonalite/trondhjemites and also includes stripes of intercalated metasediments and ocean-floor/back-arc gabbros and basalts. In the SSW area, the **Jequié Block** is exposed, being characterized by granulitic migmatites with supracrustal inclusions and multiples charnockitic intrusions. In the NE, occurs the **Serrinha Block**, composed of orthogneisses and migmatites, which represent the basement of Paleoproterozoic greenstone belts sequences. During the **Paleoproterozoic Transamazonian Cycle**, these four crustal segments collided, resulting in the formation of an important mountain belt. The regional metamorphism resulting from crustal thickening associated with the collision process is dated at around 2.0 Ga.

INTRODUCTION

Under the light of the present knowledge, a synthesis is presented here, aiming to explain the geological-geotectonic evolution of the basement rocks of the São Francisco Craton in Bahia. In this context, the most important geological studies of the last ten years about the Archean and Paleoproterozoic metamorphic rocks were analyzed. This resulted in a significative advance of the scientific knowledge of the Craton, not only from the point of view of the regional mapping but also from the point of view of the petrology, geochronology and also isotopic geology. These cratonic rocks are composed almost exclusively of high to medium grade metamorphic lithologies, occuping about 50% of the total area of the state of Bahia. They include the lithologies of the greenschist facies which compose the greenstone belts, though they represent very small areas when compared to those of high to medium grade. For a better understanding, the geochronological ages are listed in the text in decreasing order and in approximated values, both those related to the formation of the rocks and those related to the metamorphic processes.

THE ARCHEAN BLOCKS

Each aforementioned segment is well discriminated by Sm-Nd model ages (Fig.1), as well as the distribution in the εNd x εSr diagram (Fig.2), supporting their distinct origin, evolution and metallogenetic characteristics.

In the **Gavião Block** (Figs.1, 3, 4), dated by the U-Pb SHRIMP on zircon, two groups of TTG rocks constituted the early continental crust into the amphibolite facies. The first with age

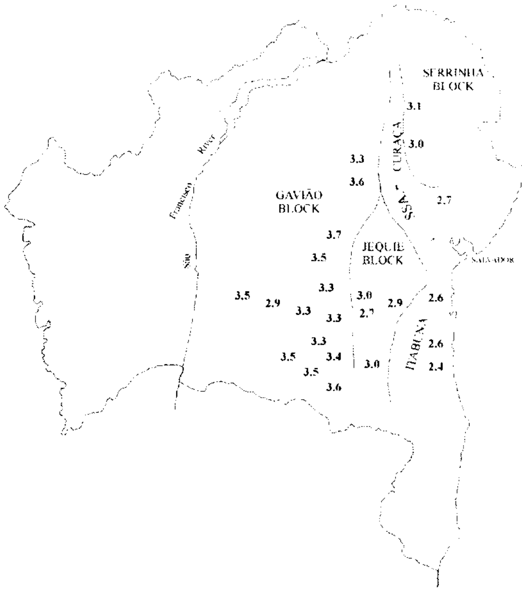

Fig. 1- Situation of Sm-Nd (TDM) archean and paleoproterozoic ages

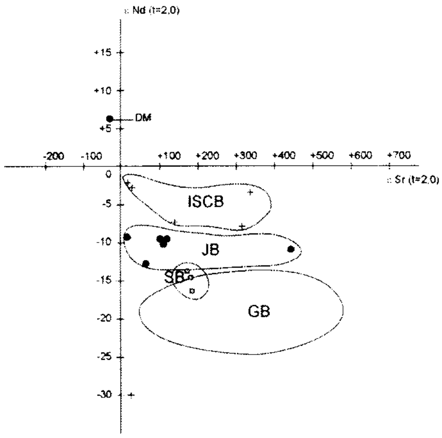

Fig 2- Isotopic diagram εNd x εSr (t=2.0 Ga)

varying between 3.4-3.2 Ga has been considered, through a geochemical modelling, as originated from the melting of tholeíitic basalts resting, as residues, garnets anphibolites or eclogites. The second with age of 3.2-3.1 Ga., had similar origin but with some crustal contamination (Martin *et al.* 1991, Santos Pinto 1996, Cunha *et al.* 1996, Bastos Leal 1998). The greenstone belts in the greenschist facies (Contendas Mirante, Umburanas, Mundo Novo) (Marinho 1991, Mascarenhas & Silva 1994, Cunha *et al.*1996), have been formed in intra-cratonic basins of the early TTG crust, initially with the formation of continental basalts (3.3Ga, Pb-Pb whole rock) which, after oceanization, have been superposed by basal komatiites, pyroclastic rocks, chemical exhalative sediments and tholeiitic basalts with pillow-lava (3.1Ga, dated by zircon Pb-Pb evaporation and U-Pb SHRIMP). The granitic / granodioritic / migmatitic crust, of the anphibolite facies and ages of 2.8-2.7Ga (Rb-Sr and Pb-Pb, whole rock) is interpreted as products of partial melting of the TTG (Santos Pinto 1996) during the closing of these basins. Calc-alkaline volcanics (2.6Ga), granite intrusions (Pé de Serra Granite, 2.5Ga) and mafic ultra-mafic intrusions (Rio Jacaré Sill, 2.4Ga), besides phyllites and grawackes occur associated to the Archean greenstone belts (Marinho 1991).

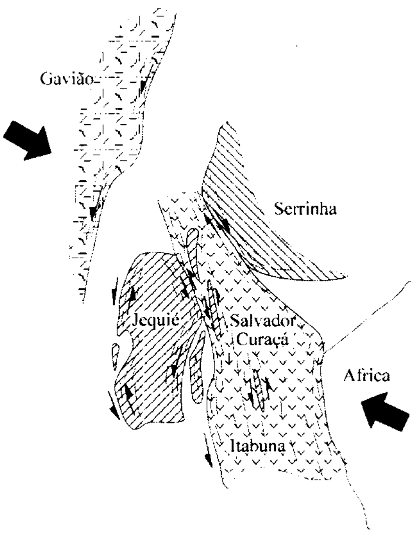

Fig 3 - Approximated position of the archean blocks prior to collision

The **Itabuna-Salvador-Curaçá Belt** (Figs. 1, 3, 4) is composed by at least three tonalite/trondhjemites groups with 2.7-2.6Ga, obtained in zircons, by the Pb-Pb evaporation and U-Pb SHRIMP methods (Silva *et al.* 1997). These tonalites/trondhjemites are interpreted, mainly by the Rare Earth Elements geochemistry, as resulting of the tholeiitic oceanic crust melting. These rocks, reequilibrated in the granulite facies, also include charnockite bodies and stripes of intercalated metasediments (quartzites with garnet, Al-Mg gneisses with sapphirine, graphitites and manganesiferous formations) and ocean-floor/back-arc gabbros and basalts, originated from mantle sources (Teixeira 1997). Monzonites with an essentially shoshonitic affinity and with age about 2.4Ga, according to Rb-Sr isochrons and Pb-Pb evaporation in zircons (Ledru et al 1993) occur in this Belt as important intrusive bodies. The island-arcs, back-arc basins and subduction zones were the predominant environments during the construction of this Belt (Barbosa 1990, 1997).

The **Jequié Block** (Figs. 1, 3, 4) is characterized by migmatites with supracrustal inclusions (the oldest component, with 3.0-2.8Ga, dated in zircons by Pb-Pb evaporation method) and granodiorític–granitic intrusions (the youngest component, with 2.8-2.7Ga, dated in zircons by U-Pb SHRIMP method). The oldest component is mainly constituted of tonalitic and granitic rocks that form the basement of the rift-type intracratonic basins, where basalts and andesitic basalts, cherts, banded iron formation, graphitites and kinzigites were accumulated. The youngest component is constituted of multiple intrusions of granodiorites and granites of high to low Ti that eventually contain mega-enclaves of the oldest component. The rocks of the Jequié Block have been intensely deformed and re-equilibrated into the granulite facies during the Paleoproterozoic Transamazonian Cycle, referred ahead.

In the NE, occurs the **Serrinha Block** (Figs. 1, 3, 4) with c.a. 2.9 Ga. orthogneisses and migmatites, which represent the basement of Paleoproterozoic greenstone belts, described ahead. This orthogneisses and migmatites are of the amphibolite facies, granític-granodioritic and with gabbroic enclaves.

THE PALEOPROTEROZOIC COLLISION

During the **Paleoproterozoic Transamazonian Cycle** (c.a.2.3-2.0Ga) (Barbosa & Dominguez 1996), these four crustal segments collided (Fig.3), resulting in the formation of an important mountain belt. The evidences of this collision are found not only through the structural elements, but also studying the pre- and syntectonic Paleoproterozoic rocks that are present in the above mentioned crustal segments, mainly in the Gavião Block, Itabuna-Salvador-Curaçá Belt and Serrinha Block (Fig.4).

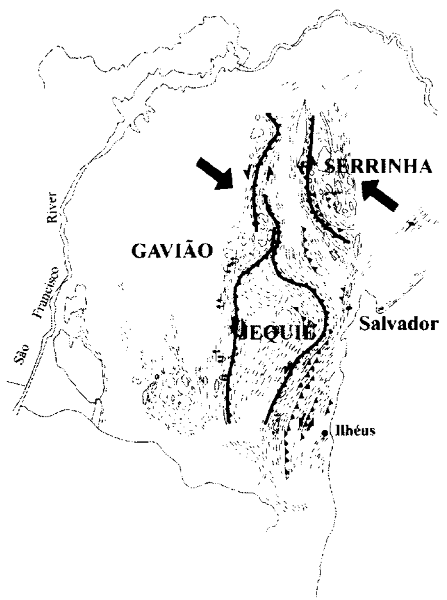

Fig 4- Display of the archean blocks after collision during the Paleoproterozoic Transamazonian Cycle

In the **Gavião Block** it was identified: (i) the Jacobina Group (foreland basin) formed by schists, banded iron formations, manganesiferous formations, quartzites and metaconglomerates with intrusions of mafic-ultramafic rocks (Mascarenhas *et al.* 1992), where the siliciclastic metassediments contain detrital zircons with ages 2.1Ga and (ii) the Areião Formation constituted of arkoses and sands, and the sands, also contain detrital zircons dated 2.1-2.2Ga by the U-Pb SHRIMP method (Figs. 5, 6).

In the **Itabuna-Salvador-Curaçá Belt**, the most important paleoproterozoic lithologies are: (i) tonalites and trondhjemites, with zircons dated approximately 2.1Ga, by Pb-Pb evaporation (Sabaté *et al.* 1994) and by U-Pb SHRIMP (Silva *et al.* 1997) (Fig.5); (ii) Caraiba norites and Medrado gabbros, both with ages slightly older than 2.0Ga (Oliveira & Lafon 1995) and containing important ore deposits, the first copper and the second chromium; (iii) and syntectonic granites dated about 2.1Ga (Sabaté *et al.* 1990) (Fig. 5).

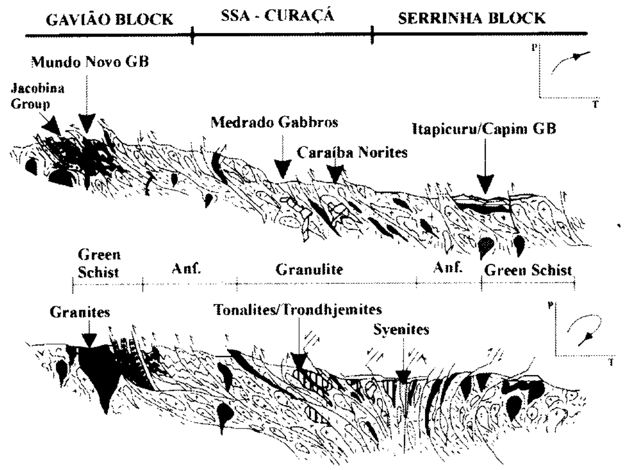

Fig. 5- Geotectonic W-E sections in NNE Bahia

In the **Serrinha Block**, occurs the Greenstone Belts Rio Itapicuru and Capim, formed from back-arc basins (Silva 1992, 1996; Winge 1984) where: (i) the lower unit of basaltic lava (2.2Ga) is constituted by tholeiitic basalts and maffic tuffs, associated with banded iron formation, cherts, and grafitic phyllites; (ii) the intermediate unit is formed mainly by felsic rocks (2.1Ga), with its composition varying from andesites to calcalkaline dacites; (iii) and the upper unit is composed by thick packages of psefites, psamites and pelites. These Paleoproterozoics greenstone belts are essentially different from the Archean greenstone belts of the Gavião Block mainly because they lack significant komatiitic volcanic rocks (Fig.5).

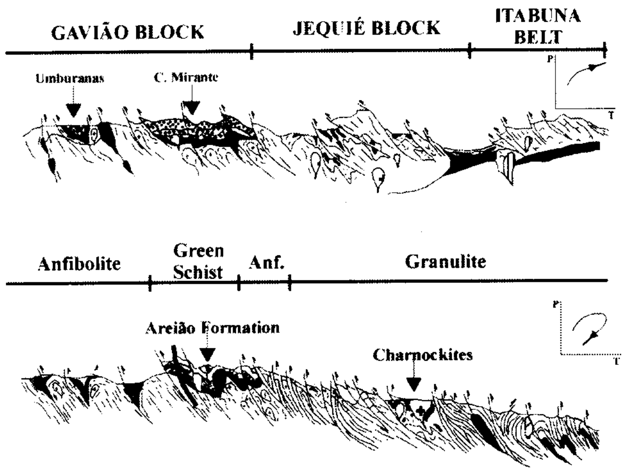

Fig. 6- Geotectonic W-E sections in SSE-SSW Bahia

The Paleoproterozoic collision occurred with the movement of the four blocks in the NW-SE sense, identified by the presence of large thrusts and transcurrence zones, in general sinistral, as the kinematics of the late ductile shear zones demonstrate (Fig. 4). The approximation of the Serrinha Block towards the Gavião Block promoted an important crustal shortening, along an axis identified by a centrifugal vergence of the granulites, in the north of the Itabuna-Salvador-Curaçá Belt (Fig.5), which continues towards the western part of Gabon, Africa. During the initial steps of this collision, at about 2.4Ga (Ledru *et al.* 1993), a frontal ramp tangential tectonic originated the obduction of the Itabuna-Salvador-Curaçá Belt upon the Jequié Block and, of this, upon the Gavião Block (Fig. 6). Recumbent folds with vergence to the west, coaxially refolded and exhibiting isoclinal shapes, are found sometimes in these high-grade metamorphic terrains, testifying the style of the ductile deformations.

The transamazonic hight grade metamorphism possesses average pressures of 7kbar and temperatures of about 850°C, with its peak occuring at about 2.0Ga (Barbosa 1990, 1997). It is considered as originating from the crust thickening related to the tectonic superposition of blocks during the collision (Figs. 5, 6). Along the Itabuna-Salvador-Curaçá Belt, this metamorphism reached the granulite grade. In the transition zones between this Belt and the Gavião and Serrinha Blocks, new crustal environments have been established in the granulite, anfibolite and green schist facies (Fig.5). In the raising phase, tectonic ramps with thrust sectioned the isogrades of the metamorphism, allowing the placement of the megablocks of granulitic rocks, over rocks of the anphibolite and green schist facies (Fig. 5) (Barbosa 1997). This structure where terrenes of higher degree are positioned over those of lower degree is also observed in the SSE and SSW. In these areas, the obduction of the Itabuna-Salvador-Curaçá Belt over the Jequié Block transformed the Jequié rocks, from the anphibolite to the granulite facies. Consecutively all this set of high grade lithologies has been placed above the Gavião Block and the Contendas-Mirante Greenstone Belt (Fig. 6). The presence of coronitic reactions of destruction of garnet-quartz or garnet-cordierite, producing simplectites of orthopyroxene-plagioclase, observed in the high degree gneisses, both in the SSE, SSW, and NE, has been interpreted as an indication of pressure release. This fact reinforces the presence of these collision processes and of great thrusts, that brought blocks of rocks from deep zones to the more surficial parts of the crust. PTt diagrams elaborated for these metamorphites show a trajectory of the metamorphism of the clock-wise type, confirming the collision context (Barbosa 1990, 1997) (Figs. 5, 6).

It is also worth while to observe the late charnockitic and granitic intrusions that crossed the segment of rocks stacked by the tectonic (Figs. 5, 6). Charnockitic bodies with ages of about 2.1Ga intruded the northern part of the Jequié Block, in all the other blocks, granitic bodies, in general with peraluminose characteristics, sometimes enriched in biotite and sometimes in muscovite, with a composition close to the minimum ternary and with negative values of $\varepsilon Nd(t)$, (-13 a -5) supports the hypothesis that they have been produced exclusively by crustal melting (Sabaté *et al.* 1990). With a major concentration in the NE of Bahia, these granites exhibit, in general, ages of about 2.0 Ga and can be assumed to have origin from the melt of hydrated rocks of the anphibolite facies, tectonically placed under rocks of the granulite facies as aforementioned.

Late deformations have formed retrograde shear zones in the Archean blocks under consideration. It is assumed that alkaline syenitic bodies, with minimum ages of 1.9 Ga in general, have been emplaced in them (Conceição 1993). The syenites intruded the granulites after these rocks reached the anphibolite facies crustal environment (Fig. 5).

CONCLUSIONS

In spite of achieving a reasonable explanation about the general evolution of the metamorphic terrains under consideration, great difficulties are still met when one tries to determine with a greater precision the physical and temporal limits between the geotectonic cycles. Therefore, under the present knowledge it can be concluded that in the archean and paleoproterozoic metamorphic rocks of the Bahia State, lithologies are found whose ages vary from 3.4Ga to about 1.9Ga. However, only between the ages of 2.4/2.3 and 1.9 Ga. one can identify with a better certainty the joint phenomena of rock formation, tectonic, metamorphism, intrusion, and erosion/exhumation that can lead to the characterization of a geotectonic cycle. This denominated Transamazonic Geotectonic had its apex about 2.1/2.0 Ga., and it was of such a strong intensity, that practically overprinted the evidences of the previous deformation and metamorphism, making it difficult to identify the older geotectonic cycles. Finally, it is possible to state that, in spite of the great effort done, the events denominated Jequié and Pre-Jequié in the São Francisco Craton basement can not yet be considered as geotectonic cycles well defined.

ACKNOWLEDGMENTS

We acknowledge the fellowship from CNPq, the support from CBPM, and the revision of the manuscript by Profs. E. Sampaio and R. Caby, and Mr. Jorge Andre Souza.

REFERENCES

Barbosa, J.S.F. 1990. The granulites of the Jequié Complex and Atlantic Mobile Belt, Southern Bahia, Brazil - An expression of Archean Proterozoic Plate Convergence. Granulites and Crustal Evolution. In:D. Vielzeuf and PH. VidaL.(Ed.) Springer-Verlag: 195-221, Clermont Ferrand, France.

Barbosa, J.S.F. 1997. Sintese do Conhecimento sobre a Evolução Geotectônica das Rochas Metamórficas Arqueanas e Paleoproterozoicas do Embasamento do Craton do S. Francisco na Bahia. Rev. Bras. Geoc. 27(3):241-256.

Barbosa, J.S.F. & Dominguez, J.M.L. 1996. Texto Explicativo para o Mapa Geológico da Bahia ao Milionésimo. SICM/SGM: 400, Salvador.

Bastos Leal, L.R. 1998. Geocronologia U/Pb (SHRIMP), $^{207}Pb/^{206}Pb$, Rb/Sr, Sm/Nd e K/Ar dos Terrenos Granito-Greenstone do Bloco do Gavião: Implicações para a Evolução Arqueana e Paleoproterozoica do Craton do São Francisco, Brasil. Tese de Doutoramento. Universidade de São Paulo: 178p.

Conceição, H. 1993. Sienitos do Estado da Bahia: Um Epítome do Tema e Interpretação à Luz do Conhecimento Atual. In: Dominguez, J.M.L. & Misi, A. (Ed.), O Craton do São Francisco, SBG/SGM/CNPq: 52-55, Salvador.

Cunha, J.C.; Bastos Leal, L.R.; Fróes, R.J.B.; Teixeira, W.; Macambira, M.J.B. 1996. Idade dos Greenstone Belts e dos Terrenos TTGs Associados da Região do Cráton do São Francisco (Bahia, Brasil). In: Congr. Bras. Geol., 29 Anais, SGB. v. 1: 62-65, Salvador.

Ledru, P.; Cocherie, A.; Barbosa, J.S.F.; Johan, V.; Onstott, T. 1993. Âge du Métamorphisme Granulitique dans le Craton du São Francisco (Brésil). Implications sur la Nature de l'Orogène Transmazonien. C.R. Acad. Sci. Paris, 211: 120-125.

Marinho, M.M. 1991. La Séquence Volcano-Sedimentaire de Contendas-Mirante et la Bordure Occidentale du Bloc Jequié (Cráton du São Francisco-Brésil): Un exemple de Transition Archéean-Protérozoique. Tese de Doutoramento. Université. Blaise Pascal, Clermont Ferrand, França. 388p.

Martin, H.;Sabaté, P.; Peucat, J.J.; Cunha,J.C. 1991. Un Segment de Croute Continentale d'Áge Archéean Ancien (3.4 milliards d'années): le Massif de Sete Voltas (Bahia-Brésil). C.R.Acad. Sci. Paris. 313 (Serie II): 531-538.

Mascarenhas, J. de F.; Conceição Filho, V.M.; Griffon, J.C. 1992. Contribuição à Geologia do Grupo Jacobina na Região Jacobina/ Pindobaçu. In: Congr. Bras. Geol., 37. Boletim de Resumos Expandidos. SBG, v. 2: 141-142.

Mascarenhas, J de F. & Silva, E.F.A. 1994. Greenstone Belt de Mundo Novo (Bahia): Caracterização e Implicações Metalogenéticas no Cráton do São Francisco. CBPM: 32 p, Salvador.

Oliveira, E.P. & Lafon, J.M. 1995. Age of ore-rich Caraiba and Medrado. Bahia, Brazil. In: Congr. Bras. Geoq. CD-ROM.

Sabaté, P.; Marinho, M. M.; Vidal, P.;Vachette, M. C. 1990. The 2-Ga Peraluminous Magmatism of the Jacobina-Contendas Mirante Belts (Bahia-Brazil):Geologic and Isotopic Constraints on the Sources. Chemical Geology, 83: 325-338.

Sabaté, P.; Peucat, J.J.; Melo, R.C.; Pereira, L.H.M. 1994. Datação por Pb evaporação de monozircão em ortognaisse do Complexo Caraiba. Expressão do Acrescimento Crustal Transamazônico do Cinturão Salvador-Curaçá (Craton do São Francisco-Bahia, Brasil). In: Congr. Bras. Geol., 38. Resumos Expandidos. SBG. v. 1: 219-220.

Santos Pinto, M.A. 1996. Le Recyclage de la Croûte Continentale Archéene: Exemple du Bloc du Gavião - Bahia, Brésil. Tese de Doutoramento. Universidade de Rennes I, 193p.

Silva, M. da G. da. 1992. Evidências Isotópicas e Geocronológicas de um Fenômeno de Acrescimento Crustal Transamazônico no Cráton do São Francisco, Estado da Bahia. In: Congr. Bras. Geol., 37, Anais, SBG. v. 2:181-182, São Paulo.

Silva, M. da G. da. 1996. Sequências Metassedimentares, Vulcanossedimentares e Greenstone Belts do Arqueano e Proterozoico Inferior. In: Barbosa, J.S.F. & Dominguez, J.M.L. (Ed.) Geologia da Bahia: Texto Explicativo para o Mapa Geológico ao Milionésimo, SICM/SGM: 85-102, Salvador.

Silva,L.C.da; McNaughton; R.C.deMelo;Fletcher, I.R. 1997.U-Pb SHRIMP ages in the Itabuna-Caraiba TTG hight-grade Complex: the first window beyond the Paleoproterozoic overprint of the eastern Jequié Craton, NE Brazil. In: ISGAM-Intern. Symp. On Granites and Assoc. Mineral. Salvador, Abstracts. 282-283.

Teixeira, L.R. 1997. O Complexo Caraíba e a Suite São José do Jacuipe no Cinturão Salvador-Curaçá (Bahia-Brasil): Petrologia, Geoquímica e Potencial Metalogenético. Tese de Doutoramento. Universidade Federal da Bahia, 201p.

Winge, M. 1984. A Sequencia Vulcanossedimentar do Grupo Rio Capim, Bahia. In: P.V. DA S. Viveiros & F.B. Duarte (Ed.) Geologia e Recursos Minerais do Estado da Bahia, Textos Básicos, SME/CPM., v. 5, 43-103, Salvador.