IGCP 509

Palaeoproterozoic Supercontinents & Global Evolution

A Complete Tectonic Cycle Representing the Evolving Core, Mantle, Lithosphere, Hydrosphere, Atmosphere, and Biosphere

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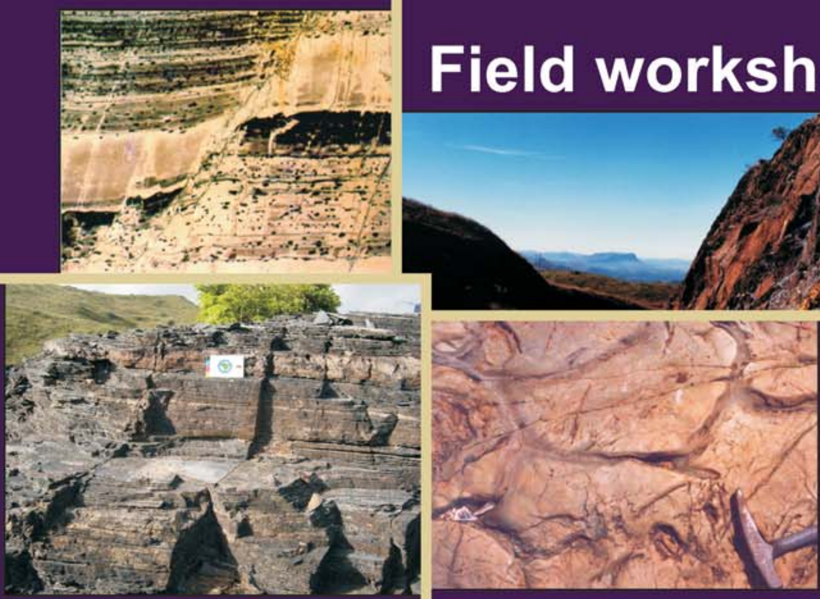
Field Guide & Abstracts

The Paleoproterozoic record of the São Francisco craton

Field workshop



Brazil, Sept. 9-21, 2006

Hosted by

Universidade Federal da Bahia

UFOP

F. F. Alkmim & C. M. Noce (eds.)

THE PALEOPROTEROZOIC RECORD OF THE SÃO FRANCISCO CRATON

Field workshop

9-21 September 2006

Bahia and Minas Gerais, Brazil

Hosted by the

Departamento de Geologia,

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and

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PREFACE

The field workshop on the Paleoproterozoic record of the São Francisco craton was designed to provide the participants with a general view of the Paleoproterozoic geology of this part of the South American continent, and thus afford the opportunity to discuss outcrop evidence for the following topics of the scope of the IGCP 509:

- Paleoclimatic and Paleoecological significance of Paleoproterozoic banded iron formation and carbonate sequences.
- Significance of the Paleoproterozoic orogenic domains of the São Francisco craton in terms of a supercontinent assembly between 2.1 and 1.9 Ga.
- The Paleoproterozoic orogenic architecture as a transition between Archean and Phanerozoic tectonic styles.
- The differential response of the Paleoproterozoic lithosphere to extensional tectonism.
- Paleoproterozoic mineralization processes.

During the first part of the workshop, the field trip traverses the Paleoproterozoic orogenic domain of northern São Francisco craton in Bahia State, emphasizing its most representative rock assemblages, tectonic features, and mineral deposits. The second field trip concentrates on the mining district of the Quadrilátero Ferrífero in Minas Gerais State, which corresponds to the foreland domain of the Paleoproterozoic Mineiro belt of the southern São Francisco craton. This trip focuses on the Paleoproterozoic rock record, tectonic processes and mineral deposits of the Quadrilátero Ferrífero.

After a brief note on the São Francisco craton, this field guide book provides introductory summaries on the geology of both the Paleoproterozoic orogenic domain of eastern Bahia and Quadrilátero Ferrífero, followed by the description of the outcrops examined during the field trips. The last section contains the abstracts presented during the meeting at the Escola de Minas in Ouro Preto.

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THE PALEOPROTEROZOIC RECORD OF THE SÃO FRANCISCO CRATON

F.F. Alkmim

C.M .Noce

The Brazilian territory comprises almost the whole Precambrian core of the South American continent known as the South American platform. The South American platform is made up of two distinct lithospheric components: cratons and Neoproterozoic orogenic belts (Almeida et al. 1981; Almeida et al. 2000) (Fig.1).The cratons, consisting of Archean nuclei bounded by Paleo- or Mesoproterozoic orogenic belts, correspond to lithospheric segments that remained relatively stable during the Neoproterozoic Brasiliano orogenies. They represent the internal portions of the plates that collided to form West Gondwana by the end of the Neoproterozoic (Brito Neves et al. 1999, Almeida et al. 2000, Campos Neto 2000, Alkmim et al. 2001).

The São Francisco craton in eastern Brazil contains an Archean core and two segments of a collisional orogen developed between 2.1 and 1.9 Ga, during the episode usually referred to as the Transmazonian event in the Brazilian geologic literature. The ca. 1200 km long and 500 km wide Archean core is almost entirely covered by Proterozoic and Phanerozoic sedimentary successions, which accumulated in two distinct basins: the São Francisco basin and the Paramirim aulacogen (Fig.1).

The northern portion of the craton in Bahia state hosts a 300 km wide and 600 km long Paleoproterozoic belt of amphibolite to granulite facies rocks that comprises three distinct Archean blocks and a Neoarchean/Paleoproterozoic magmatic arc (Barbosa and Sabaté 2004) (Fig.1). The Paleoproterozoic rock assemblage of this belt consists of acid, basic, and ultrabasic intrusions related to a ca. 2.5 Ga rifting event, a 2.2-2.1 Ga old greenstone belt sequence, alluvial to marine foreland basin strata, and a ca. 2.0 Ga old late to post-collisional granite suite.

The Mineiro belt (Teixeira and Figueiredo 1991, Teixeira et al. 2000), located in the southern end of the craton, in the highlands of Minas Gerais, involves an Archean basement, 2.5-2.0 Ga old passive margin to foreland basin strata, and a large volume of granitic rocks. The Paleoproterozoic section is best exposed in the mining district known as the Quadrilátero Ferrífero (Iron Quadrangle) (Fig. 1).

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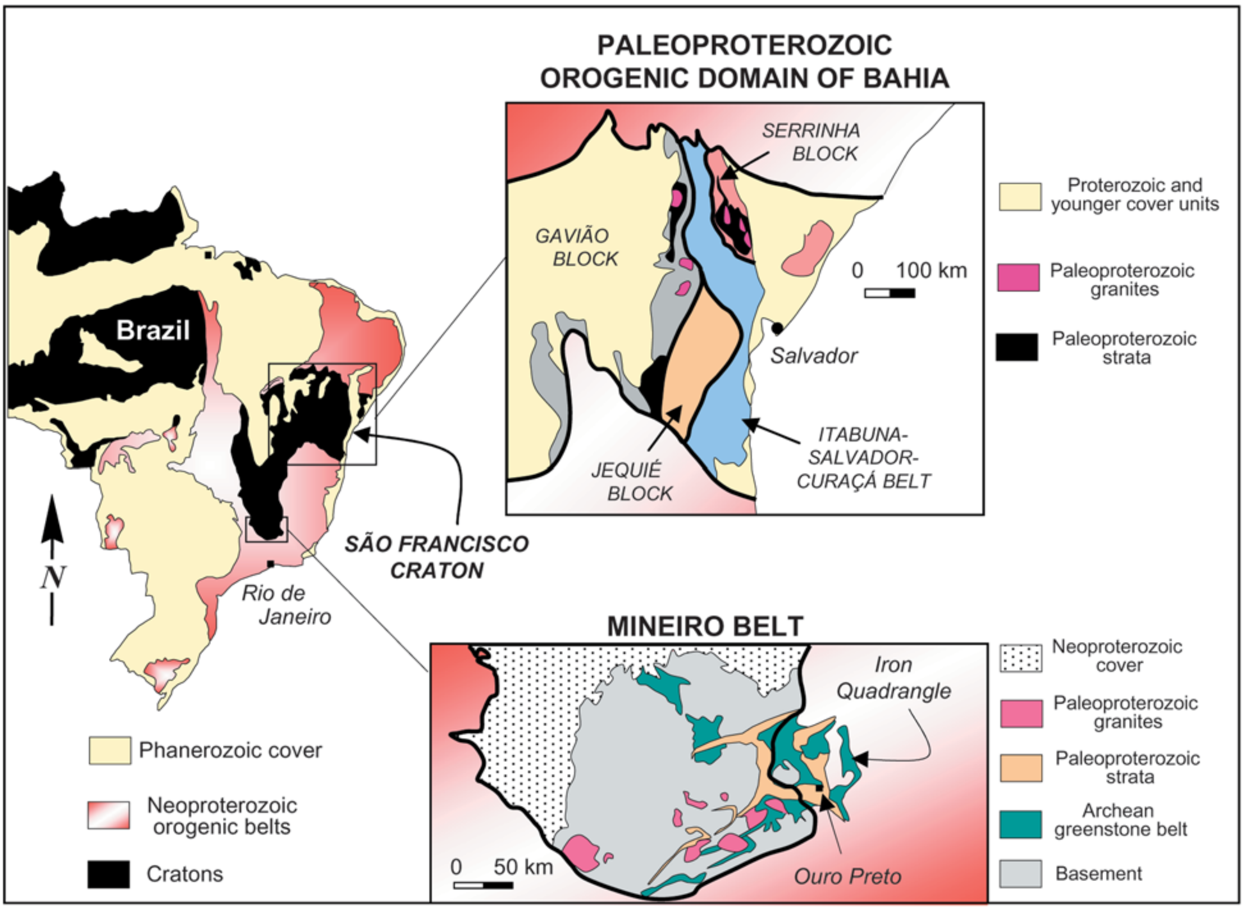

Fig.1 Simplified tectonic map of Brazil and the Paleoproterozoic orogenic belts of the São Francisco craton.

FIELD TRIP 1

THE PALEOPROTEROZOIC OROGENIC DOMAIN OF EASTERN BAHIA

ON THE GEOLOGY OF THE PALEOPROTEROZOIC OROGENIC DOMAIN OF EASTERN BAHIA

Johildo S. F. Barbosa[1]

INTRODUCTION

The northern portion of the São Francisco craton (Almeida 1977, Alkmim et al. 1993) encompasses a ca. 600 km long and 300km wide Paleoproterozoic orogenic domain, which forms a roughly NS-trending belt in the eastern Bahia state (Fig. 1.1). This belt can be viewed as the W-verging half of a 2,1-2,0 Ga old collisional orogen, whose E-verging counterpart is preserved in the Congo craton in Gabon (Ledru et al.1993, 1994, Barbosa and Sabaté 2002, 2004). The Brazilian portion of this orogen, differently from the African counterpart, experienced a long history of uplift and erosion, and is now exposed in the level of its roots. As a consequence of that, high grade Archean basement rocks predominate throughout the region, but Paleoproterozoic rock assemblages also occur in many sectors of the belt.

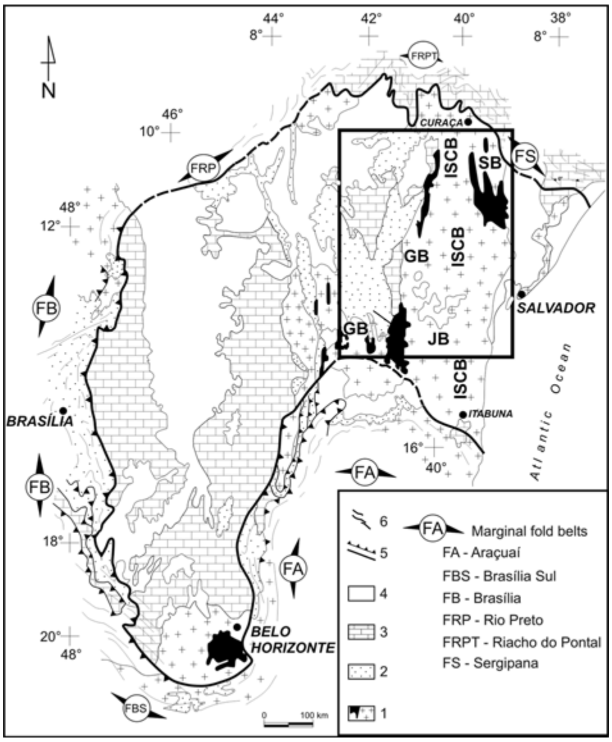

Figure 1.1 - Geologic map of the São Francisco craton with the distribution of the main lithostratigraphic units. The box shows the area of the Paleoproterozoic orogenic domain of eastern Bahia. 1. Archean/Paleoproterozoic basement with greenstone belt sequences (black); 2. Paleo/Mesoproterozoic units 3. Neoproterozoic units; 4. Phanerozoic cover; 5. Craton limits; 6. Brasiliano belts. GB. Gavião Block. JB. Jequié Block. SB. Serrinha Block; ISCB. Itabuna-Salvador-Curaçá Belt. Adapted from Alkmim et al. (1993).

LITHOTECTONIC ASSEMBLAGES

From a tectonic point of view, the eastern Bahia orogenic domain comprises three distinct Archean blocks, the Gavião, Jequié and Serrinha, as well as the Itabuna-Salvador-Curaçá belt, which represents a Neoarchean magmatic arc represented by the (Barbosa and Sabaté 2002, 2004) (Fig.1.2). Each one of these crustal segments can be viewed as an individual terrane, with distinct origin and tectonic history, as demonstrated by their Sm-Nd model ages (Fig.1.2) and $\varepsilon_{Nd} \times \varepsilon_{Sr}$ data (Fig.1.3). Furthermore, Sm-Nd T_{DM} data show a progressive decrease in ages towards east, i.e, from the Gavião Block, the oldest, to the Itabuna-Salvador-Curaçá belt, the youngest.

Gavião block

The basement of the Gavião Block consists of two TTG suites metamorphosed in the amphibolite facies. The ages of these suítes fall into the 3.4-3.2 Ga time range (Sete Voltas/Boa Vista Mata Verde TTGs and Bernarda Tonalite, Tab.I) and 3.2-3.1 Ga (Serra do Eixo/Mariana/Piripá Granitoids, Tab.I)

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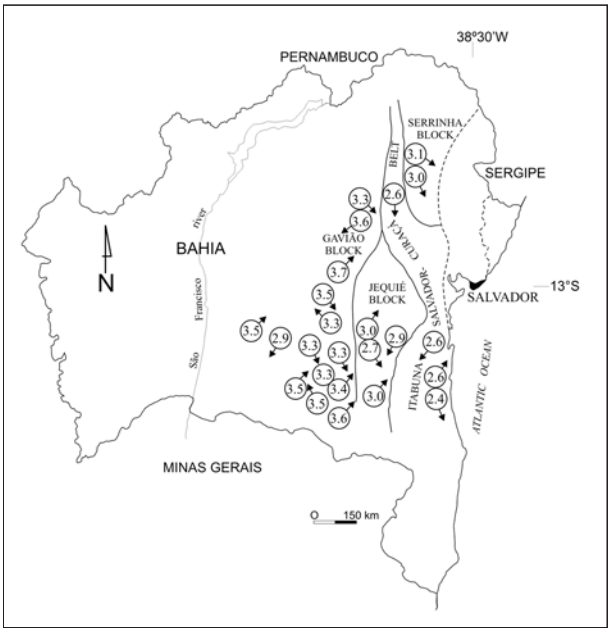

Figure 1.2 - Distribution of Sm-Nd (T_{DM}) ages in the Paleoproterozoic orogenic domain of eastern Bahia. (For data sources, see tables I-V).

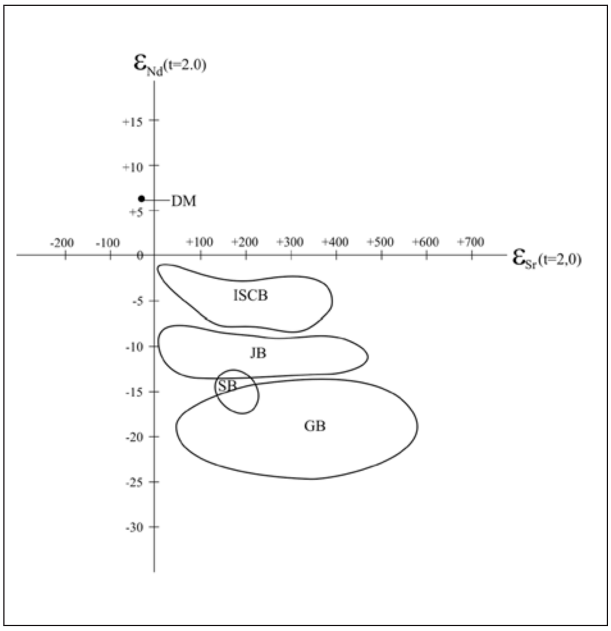

Figure 1.3 - ε_{Nd} x ε_{Sr} (t = 2.0 Ga) diagram showing distinct fields for the ISCB (Itabuna-Salvador-Curaçá Belt), JB (Jequié Block), SB (Serrinha Block), and GB (Gavião Block).

(Martin et al. 1991, Marinho 1991, Santos Pinto 1996, Cunha et al. 1996, Bastos Leal 1998). The Archean supracrustal assemblage comprises the volcano-sedimentary units of the Contendas Mirante, Umburanas, and Mundo Novo greenstone belts (Marinho 1991, Mascarenhas and Alves da Silva 1994, Cunha et al. 1996, Bastos Leal 1998). They represent the filling of intra-continental rift basins developed on TTG crust around 3.3*Ga* (Contendas acid volcanics and Jurema-Travessão Tholeiites, Tab.I). The basal section of these sequences contains komatiites, pyroclastic rocks, chemical exhalative sediments, and 3.2 Ga old pillowed-basalts. The upper section is made up of detrital sediments, whose minimum ages fall into the interval between 3.0 and 2.8 Ga (Umburanas and Guajerú sediments, Tab. I). Closure of these small rift basins at about 2.8-2.7Ga led to the formation of the mentioned greenstone belts and partial melting of TTG basement (Malhada de Pedra Granite, Tab.I) (Santos Pinto 1996).

The Paleoproterozoic rock assemblage of the Gavião block includes:

- A group of plutonic rocks, which records a rift-related magmatic event that took place between 2,5 and 2,4 Ga (2,5 Ga calc-alkaline volcanics, 2,5 Ga Pé de Serra Granite, and 2.4 Ga Jacaré ultramafic sill).
- Pelites and greywackes that occur as a platformal cover of the Archean greenstone belts (Marinho 1991).
- The ca. 5000m thick Jacobina Group is a quartz-sandstone dominated package that also contains pelites and conglomerates (Mascarenhas and Alves da Silva 1994, Ledru et al. 1997, Teixeira et al. 2000). Detrital zircons extracted from the basal conglomerates (gold bearing) yield a Pb-Pb evaporation age of 2.086$\pm$43Ma, interpreted as the maximum depositional age of the group (Mougeot 1996, Mougeot et al. 1996). The minimum age unit is given by the 1940 to 1910 Ma Ar-Ar ages obtained by Ledru et al. (1993) on muscovite and biotite extrated from shear zones affecting Jacobina metasedimentary rocks. According to Mascarenhas and Alves da Silva

Table I – Gavião Block. Ages of Archean plutonic and supracrustal rocks according to different radiometric methods. References: Martin et al. (1991) (1), Marinho (1991) (2) Nutman & Cordani (1994) (3), Santos Pinto (1996) (4), Bastos Leal (1998) (5). * = SHRIMP data.

Rock Unit		Rb-Sr (Ma)	Pb-Pb WR (Ma)	Pb-Pb Single zircon (Ma)	U-Pb Zircon (Ma)	T_{DM} (Ga)
Sete Voltas TTG (1, 2, 3)	CM	3420 ± 90		3394 ± 5	3378 ± 12 *	3.6
Boa Vista / Mata Verde TTG (1, 2, 3)	CM	3550 ± 67	3381 ± 83		3384 ± 5 *	3.5
Bernarda Tonalite (4)	BE			3332 ± 4		3.3
Serra do Eixo Granitoid (4)	SE			3158 ± 5		3.3
Mariana Granitoid (4)	MA			3259 ± 5		3.5
Piripá Gneisses (5)	PI				3200 ± 11 *	3.5
Malhada de Pedra Granite (4)	MP	2840 ± 34				3.3
Pé de Serra Granite (2)	PE	2560 ± 110				3.1
Contendas Acid Sub-Volcanic (2)	CM		3011 ± 159		3304 ± 31	3.3
Jurema-Travessão Tholeiites (2)	CM		3010 ± 160			3.3
BIF (2)	CM		3265 ± 21			3.3
Calc-Alkaline Volcanic (2)	CM		2519 ± 16			3.4
Jacaré Sill (2)	CM		2474 ± 72			3.3
Umburanas Detritic Sediments (5)	UM				3335 ± 24 * 3040 ± 24 *	
Guajeru Detritic Sediments (5)	GU			2861 ± 3 2664 ± 12		

(1994), the Jacobina sediments were deposited in a rift basin, whereas Ledru et al. (1997) portrayed the Jacobina Group as the filling of a downwarp basin, formed in response to thrust propagation toward the Gavião foreland at around 2.0 Ga.

- Peraluminous granite bodies, intruded at ca. 2.0 Ga, represent crustal melts generated in the late stages of the Transamazonian collision (Sabaté et al. 1990).

Jequié block

The oldest rocks of the Jequié block, dated at 3,0-2,9 Ga, comprise heterogeneous migmatites with mega-enclaves of supracrustal rocks (Ubaira and Jequié migmatites, basic enclaves, Tab.II), intruded by 2.8-2.6 Ga old granitoids (Maracás, Laje and Mutuipe Granites and Granodiorites Tab.II) (Wilson 1987, Marinho 1991, Alibert and Barbosa 1992, Marinho et al. 1994). These rocks form the basement of a series of rift basins, in which basalts, cherts, banded iron formations, C-rich sediments and pelites accumulated (Barbosa 1990). The Jequié block rocks have been intensely deformed and re-equilibrated in the granulite facies during the Paleoproterozoic collisional event.

Serrinha block

The Serrinha Block (Fig.1.2) in the NE portion of the domain consists of 3.0- 2.9 Ga old

Table II – Jequié Block. Ages of Archean plutonic rocks according to different radiometric methods. References: Marinho (1991) (2), Wilson (1987) (8), Marinho et al. (1994) (9), Alibert & Barbosa (1992) (10). * = SHRIMP data.

Rock Unit		Rb-Sr (Ma)	Pb-Pb WR (Ma)	U-Pb Zircon (Ma)	T_{DM} (Ga)
Ubaíra Basic Enclaves (8, 9)	UB				3.3
Ubaíra Migmatites (8, 9)	UB	2900 ± 24			3.2
Jequié Migmatite (8, 9)	JE				2.9
Maracás Granite (2)	MC	2800 ± 12	2660 ± 70		3.2
Laje Granodiorite (10)	LJ			2689 ± 1 *	3.0
Mutuípe Granodiorite (10)	MU			2810 *	3.0

orthogneisses, migmatites and tonalites with gabbroic enclaves (porphyritic orthogneiss and Rio Capim Tonalite, Tab. III). These rocks, which form the basement of the Paleoproterozoic Rio Itapicuru and Capim greenstone belts (Gaal et al. 1987, Oliveira et al. 1999, Mello et al. 2000), experienced deformation and metamorphism under amphibolite facies conditions during the 2.0 Ga collisional event.

The lithological assemblages of the Rio Itapicuru and Capim greenstone belts represent the fill of back-arc basins (Silva 1987, 1992, 1996, Winge 1984). They comprise a lower unit of basaltic lava (2.2 Ga old Itapicuru basic volcanics, Tab.IV) associated with banded iron formation, cherts, and graphitic phyllites; a middle unit made up mainly of felsic rocks (2.1Ga Itapicuru felsic volcanics, Tab.IV); and an upper unit composed of a thick package of detrital sediments. From a petrological and geochemical stand point, these Paleoproterozoic greenstone belts differ from their Archean equivalents in a very significant aspect: the lack of komatiitic rocks, a fact that might reflect a major change in the Earth system during Archean-Paleoproterozoic transition.

Itabuna-Salvador-Curacá belt

The Itabuna-Salvador-Curaçá belt (Fig. 1.2) is composed of three distinct Archean (ca. 2.6 Ga) and one Paleoproterozoic (2,1Ga) tonalite/trondhjemite suites (Tab.V) (Ledru et al. 1993, Silva et al. 1997), which have been interpreted as products of melting of a tholeiitic oceanic crust (Barbosa and Peucat, in preparation). The Itabuna-Salvador-Curaçá belt also includes ca. 2.6 Ga charnockite bodies (the Caraiba Charnockite, Tab.V), metasedimentary rocks such as garnet bearing quartzites, Al-Mg-rich gneisses with sapphirine, graphitites and manganese-rich schists, and ocean-floor/back-arc gabbros and basalts (Teixeira 1997). Monzonites of shoshonitic affinity (Barbosa 1990), dated at ca. 2.4 Ga by the zircon Pb-Pb evaporation method (Ledru et al. 1993), occur as large intrusive bodies in the southern portion of the belt. All these rocks have been deformed, metamorphosed in the granulite facies, and intruded by syn-kinematic granitoids during the Paleoproterozoic collisional event.

An island-arc, with preserved portions of the accretionary prism and back-arc basins, is the tectonic scenario postulated for the Itabuna-Salvador-Curaçá rock assemblage (Barbosa 1990, 1997, Figueiredo 1989, Teixeira and Figueiredo 1991).

Table III – Serrinha Block. Ages of Archean plutonic rocks according to different radiometric methods. References: Gaal et al. (1987) (11), Oliveira et al.(1999) (12).

Rock Unit		Rb-Sr (Ma)	Pb-Pb Single zircon (Ma)	U-Pb Zircon (Ma)	T_{DM} (Ga)
Serrinha Porphiritic Orthogneiss (11)	SR			2991 ± 22 3070 ± 3	3.0 3.2
Rio Capim Tonalite (12)	RC	3120	3000 2900 2650		

Table IV – Gavião, Jequié and Serrinha blocks, and Itabuna-Salvador-Curaçá Belt. Ages of Archean plutonic and supracrustal rocks according to different radiometric methods. References: Gaal et al. (1987) (11), Ledru et al. (1993) (6), Santos Pinto (1996) (4), Bastos Leal (1998) (5), Nutman et al. 1994 (13), Mougeot (1996) (14), Silva (1987) (15), Barbosa et al., in preparation (16), Oliveira & Lafon (1995) (17), Corrêa Gomes (2000) (18). * = SHRIMP data.

Rock Unit		Rb-Sr (Ma)	Pb-Pb WR (Ma)	Pb-Pb Single zircon (Ma)	U-Pb Zircon (Ma)	T_{DM} (Ga)
Caculé Granite (4)	CG			2015 ± 27		2.6
Serra da Franga Granite (4)	FG			2039 ± 11		
Campo Formoso Granite (14)	CF	1969 ± 29				2.6
Contendas Mirante Detritic Sediments (13)	CM				2168 ±18 *	
Jacobina Conglomerate (14)	JC			3353 ± 11 2086 ± 43		
Itapicuru Basic Volcanic (15)	IT		2209 ± 60			2.2
Itapicuru Felsic Volcanic (15)	IT	2080 ± 90	2109 ± 80			2.1
Poço Grande Granite (5)	IT				2070 ± 47	
Ambrósio Granite (11)	IT				2000	2.1
Barra do Rocha Tonalite (6)	BR			2092 ± 13		
Itabuna Tonalite (16)	UT		2130			2.6
Pau Brasil Tonalite (18)	PB			2089 ± 4		
Caraíba Norite (17)	CB				2051	2.8
Mairi Quartz-Monzonite (17)	MM				2126 ± 19	
Medrado Gabbro (17)	MG				2059	2.9
Brejões Charnockite (16)	BJ			2026 ± 4		

Table V – Itabuna-Salvador-Curaçá belt. Ages of Archean plutonic rocks according to different radiometric methods. References: Ledru et al. (1993) (6), Silva et al. (1997) (7). * = SHRIMP data.

Rock Unit		Pb-Pb Single zircon (Ma)	U-Pb Zircon (Ma)	T_{DM} (Ga)
Ipiaú Tonalite (6)	IP	2634 ± 7		
Caraíba TTG (7)	CB		2695 ± 12 *	3.4
Caraíba Chanockite (7)	CB		2634 ± 19 *	3.4
Ipiaú Monzonite (6)	IP	2450 ± 1		2.4

THE PALEOPROTEROZOIC COLLISION

Structural, petrological and geochronological data strongly suggest that the eastern Bahia orogenic domain represents a mountain belt formed in the course of a major collisional event that took place between 2,1 and 2,0 Ga and involved all previously described Archean blocks (Barbosa and Sabaté 2002, 2004). Figure 1.4 sketches the relative positions of the four Archean terranes and their relative motions during the Paleoproterozoic collision. The collision was probably oblique, resulting in an overall NW-directed tectonic transport, coupled with a left-lateral component of motion. During the collision, slices of the Jequié Block may have been incorporated in the Itabuna-Salvador Curaçá belt. Figure 1.5 illustrates the tectonic panorama of the orogen after the Paleoproterozoic collage.

The Paleoproterozoic metamorphism reached pressures of 7 kbar and temperatures of about 850°C, with peak conditions occurring at ca. 2.0 Ga (Barbosa 1990, 1997). During the main phase of shortening and uplift, thrust faults placed granulite-grade slices on top of amphibolite/greenschist facies rocks (Fig. 1.6). The presence of reaction coronas involving consumption of garnet-quartz or garnet-cordierite and production of simplectites of orthopyroxene-plagioclase in the high-grade gneisses are evidence for tectonic exhumation and decompression. PTt diagrams constructed for these rocks display a clockwise path, consistent with a collisional scenario (Barbosa 1990, 1997) (Figs. 1.6 and 1.7).

It is worthy noting that 2.0 Ga old charnockitic and granitic bodies (Brejões Charnockites, Tab.IV) cross-cut the tectonic grain of the northern portion of the Jequié block. In the other blocks, post-kinematic

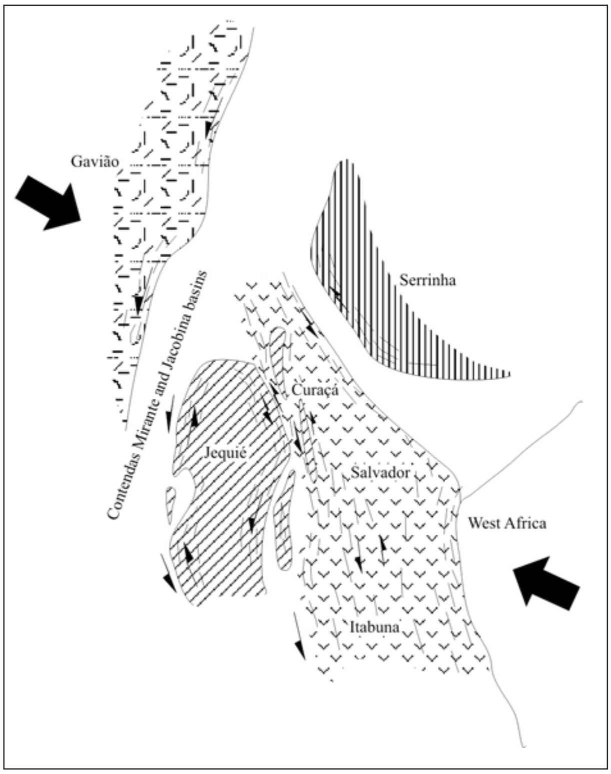

Figure 1.4 – Cartoon illustrating the relative position of the Archean blocks prior to Paleoproterozoic collision.

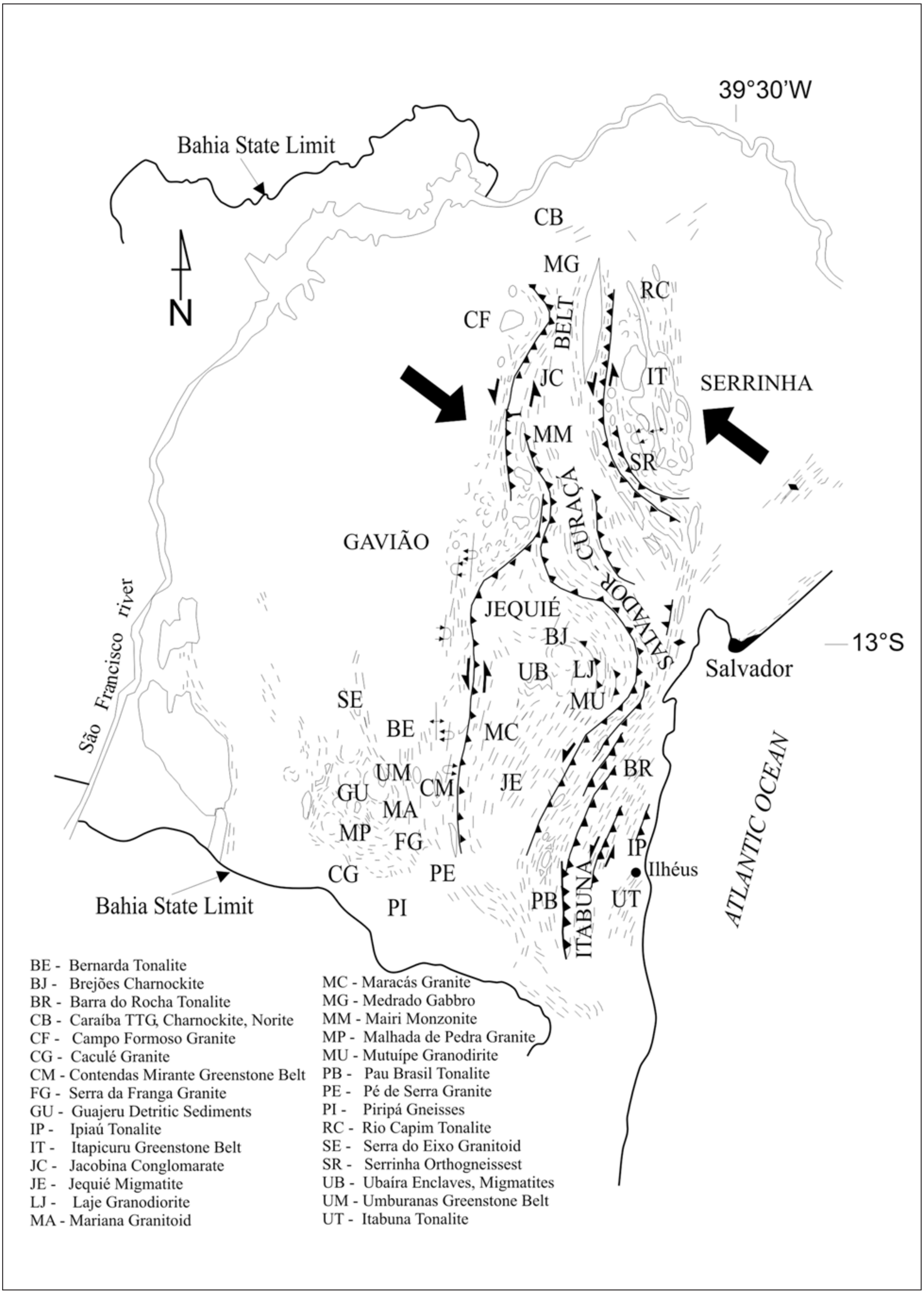

Figure 1.5 – Simplified structural-kinematic map of the Paleoproterozoic orogenic domain of eastern Bahia. Locations of age determinations listed in tables I-V are also shown in the map.

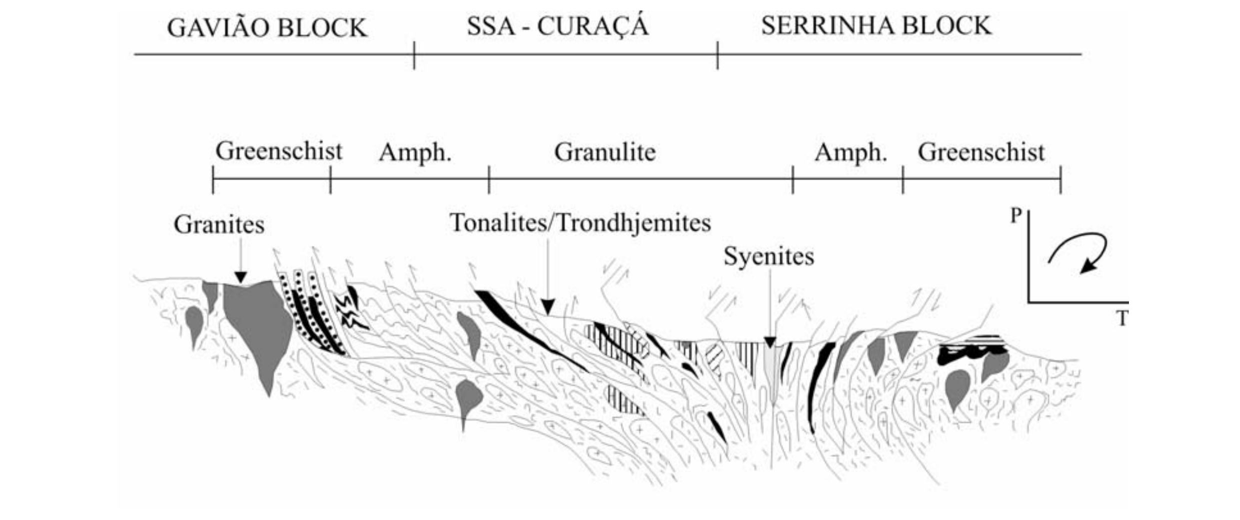

Figure 1.6 - Schematic cross-section of the northwestern portion of Paleoproterozoic orogenic domain of eastern Bahia The clockwise metamorphic path shown on the PTt diagram is consistent with the collisional context.

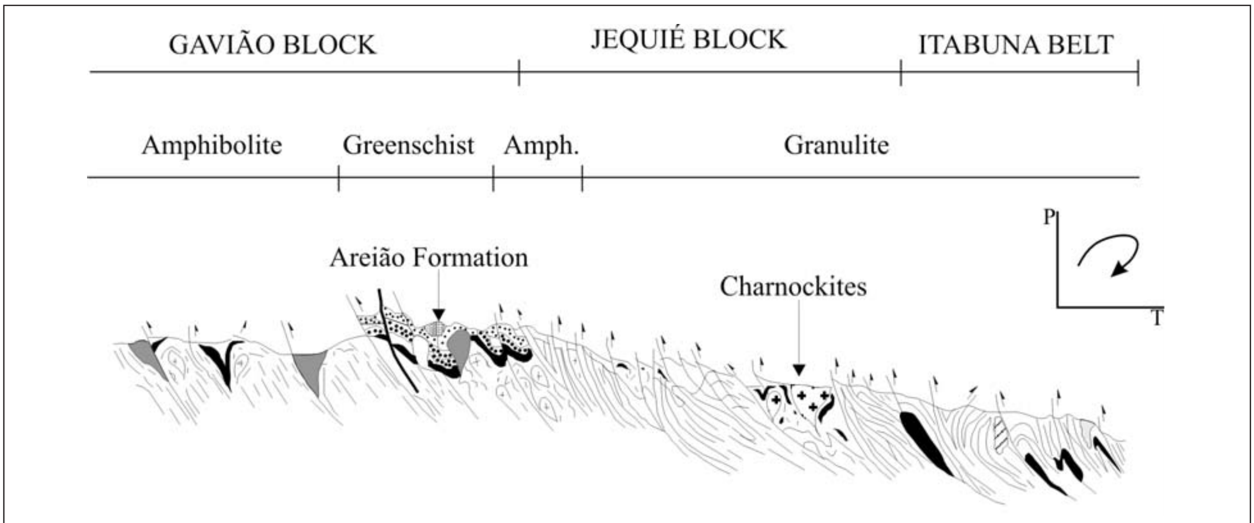

Figure 1.7 - Schematic cross-section of thesouthern portion of the Paleoproterozoic orogenic domain of eastern Bahia A PTt diagram is shown on the right-hand side of section.

intrusions show a peraluminous character and negative (–13 to –5) $\varepsilon_{Nd(t)}$ values. The geochemical and isotopic signatures of these late intrusions indicate that they have been produced predominantly by crustal melting (Sabaté et al. 1990). With a major concentration in the northwestern sector of the orogenic domain, these granites exhibit, in general, Pb/Pb ages around 2.0 Ga (Caculé, Serra da Franga, Poço Grande, Ambrósio and Campo Formoso Granites, Tab.IV) (Santos Pinto 1996, Bastos Leal 1998, Gaal et al. 1987, Mougeot et al. 1996).

Late stage deformation nucleated retrograde shear zones in the Archean blocks. It is assumed that alkaline syenitic bodies (Itiuba, São Felix) (Fig.1.6), with minimum ages of 1.9 Ga have been emplaced along these shear zones (Conceição 1993). The syenites intruded the granulites after these rocks had reached the amphibolite facies in the retrograde path. Figure 1.8 summarizes the evolution of the eastern Bahia orogenic domain.

Besides the Paleoproterozoic rock record, the Bahia field trips will also focus on the products of deformation and metamorphic processes acting on Archean terranes involved in the Paleoproterozoic collage, and the associated mineralization processes.

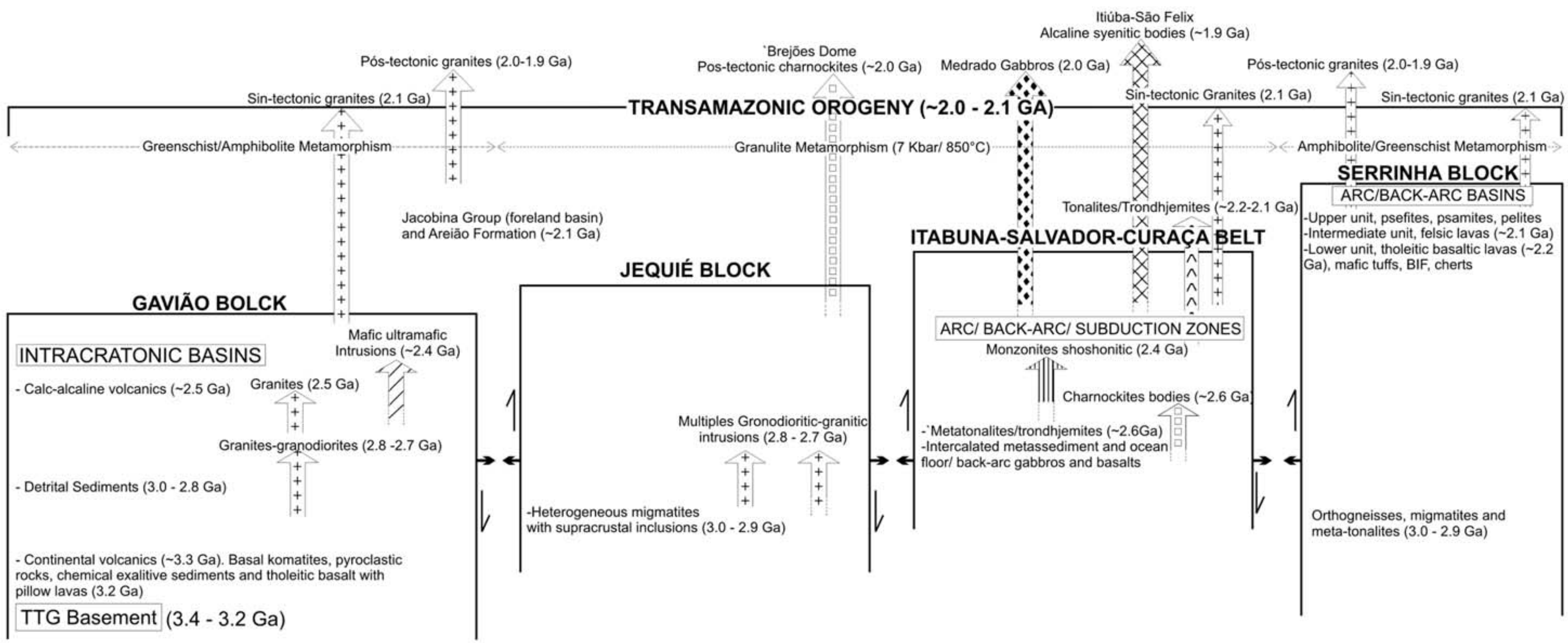

Figure 1.8 - Summary of the evolutionary stages of the Paleoproterozoic orogenic domain of eastern Bahia. Thick arrows represent the intrusion of the plutonic bodies; thin arrows represent the interaction among the various blocks.

DAYS 1 AND 2

SATURDAY AND SUNDAY, SEPTEMBER 9th AND 10th
FROM SALVADOR TO SANTA LUZ AND ITAPICURU RIVER VALLEY

Leader: *Maria da Glória da Silva*[1]
João Dalton de Souza[2]
João Batista Teixeira[1]

The first two days of the workshop will be spent in the region of the Paleoproterozoic Rio Itapicuru greenstone belt, the best exposed, and regarding Paleoproterozoic evolution, one of the most representative components of eastern Bahia orogenic domain.

The Rio Itapicuru greenstone belt extends over an area of approximately 8400 km^2 in the interior of the Serrinha Block (Fig.1.9). The Itapicuru river, flowing to the east, crosses the entire area occupied by the greenstone belt. Exhibiting a general N-S trend, the greenstone belt is surrounded by the Archean basement gneisses and migmatites (Fig.1.10). Its volcano-sedimentary section comprises, from the base to the top, three major lithostratigraphic units (Kishida 1979; Silva 1983, 1987):

1) A Mafic Volcanic Unit of toleiitic affinity and E-MORB type, consisting of massive, porphyritic, variolitic, or amygdaloidal basaltic flows, with pillowed intervals, flow-breccias, and intercalations of banded iron formation, chert and grafite-phyllites.

2) An Intermediate to Felsic Volcanic Unit of calc-alkaline affinity, composed of massive, porphyritic or variolitic lavas, as well as andesitic to dacitic pyroclastic rocks (tuffs, lapilli tuffs, crystal tuffs, welded tuffs and agglomerates).

3) A Sedimentary Unit, made up of conglomerates, sandstones, siltites and shales, derived from the previously mentioned volcanic units, and subordinated volcano-chemical rocks represented by laminated cherts, banded iron formations and manganese-rich rocks.

Gabroic sills and granite bodies of distinct generations intrude the suprarustal rock sequence. The largest bodies correspond to syn-tectonic granites that form the cores of a series of N-S trending domes (e.g., Ambrósio and Nordestina domes) (Fig.1.10), the most expressive structures of the greenstone belt. Like many other greenstone belts, the Rio Itapecuru exhibits a dome-and-keel architecture, in which elongated domes made up essentially of intrusive granites are surrounded by N-S trending synformal depressions that contain the volcano-sedimentary units.

A structural and geochronological study performed by Alves da Silva (1994) in this region indicates that the precursor basin of the greenstone belt closed in two main phases of deformation induced by an overall SE-NW oriented contractional field. NW-directed thrust faults and associated folds nucleated during the first deformation phase, which was followed by the emplacement of granites and consequent development of syn-kinematic domes. Since formed, the domes introduced a new rheological component in the system, thereby triggering strike-

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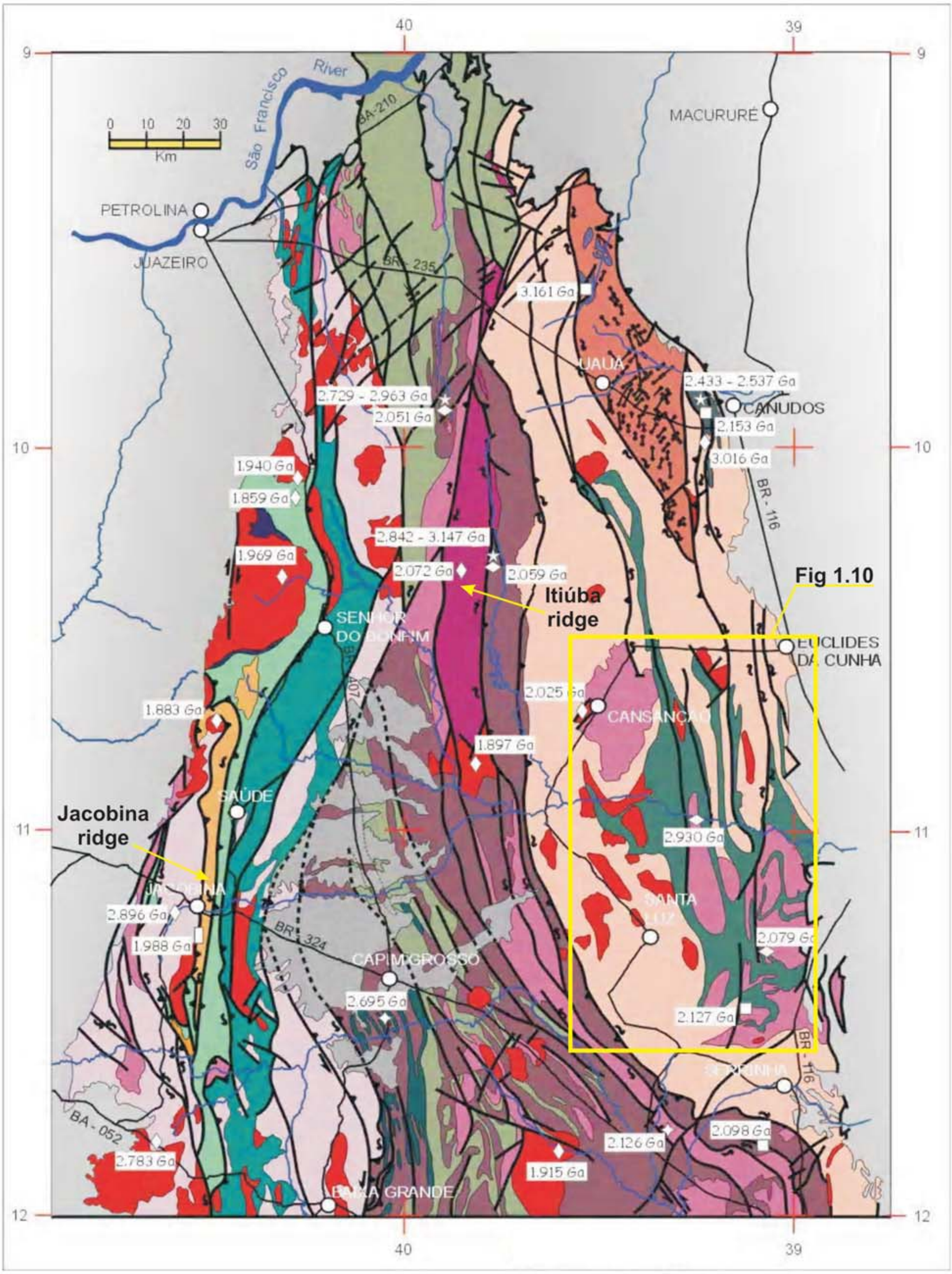
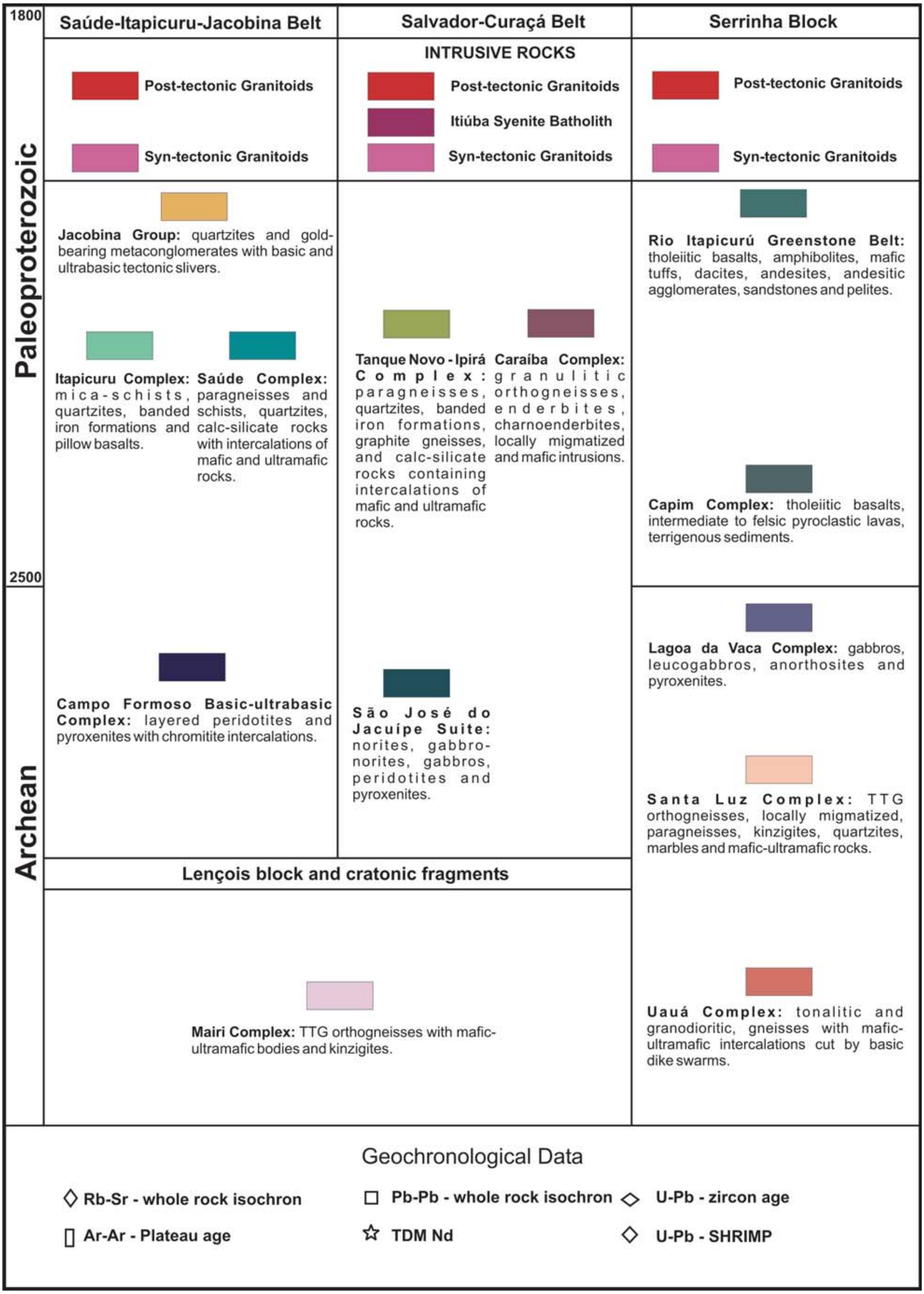


Fig. 1.9 - Geologic map of the northwestern portion of the Paleoproterozoic orogenic domain of eastern Bahia. Modified from Dalton de Souza et al. (2003).The box shows the area of the Rio Itapecuru Greenstone belt reproduced on Fig. 1.10. The white labels represent age determinations.


1800
2500
Paleoproterozoic
Archean
Saúde-Itapicuru-Jacobina Belt
Salvador-Curaçá Belt
Serrinha Block
INTRUSIVE ROCKS
Post-tectonic Granitoids
Itiúba Syenite Batholith
Syn-tectonic Granitoids
Jacobina Group: quartzites and gold-bearing metaconglomerates with basic and ultrabasic tectonic slivers.
Itapicuru Complex: mica-schists, quartzites, banded iron formations and pillow basalts.
Saúde Complex: paragneisses and schists, quartzites, calc-silicate rocks with intercalations of mafic and ultramafic rocks.
Tanque Novo - Ipirá Complex: paragneisses, quartzites, banded iron formations, graphite gneisses, and calc-silicate rocks containing intercalations of mafic and ultramafic rocks.
Caraíba Complex: granulitic orthogneisses, enderbites, charnoenderbites, locally migmatized and mafic intrusions.
Rio Itapicurú Greenstone Belt: tholeiitic basalts, amphibolites, mafic tuffs, dacites, andesites, andesitic agglomerates, sandstones and pelites.
Capim Complex: tholeiitic basalts, intermediate to felsic pyroclastic lavas, terrigenous sediments.
Campo Formoso Basic-ultrabasic Complex: layered peridotites and pyroxenites with chromitite intercalations.
São José do Jacuípe Suite: norites, gabbro-norites, gabbros, peridotites and pyroxenites.
Lagoa da Vaca Complex: gabbros, leucogabbros, anorthosites and pyroxenites.
Santa Luz Complex: TTG orthogneisses, locally migmatized, paragneisses, kinzigites, quartzites, marbles and mafic-ultramafic rocks.
Lençois block and cratonic fragments
Mairi Complex: TTG orthogneisses with mafic-ultramafic bodies and kinzigites.
Uauá Complex: tonalitic and granodioritic, gneisses with mafic-ultramafic intercalations cut by basic dike swarms.
Geochronological Data
Rb-Sr - whole rock isochron
Pb-Pb - whole rock isochron
U-Pb - zircon age
Ar-Ar - Plateau age
TDM Nd
U-Pb - SHRIMP

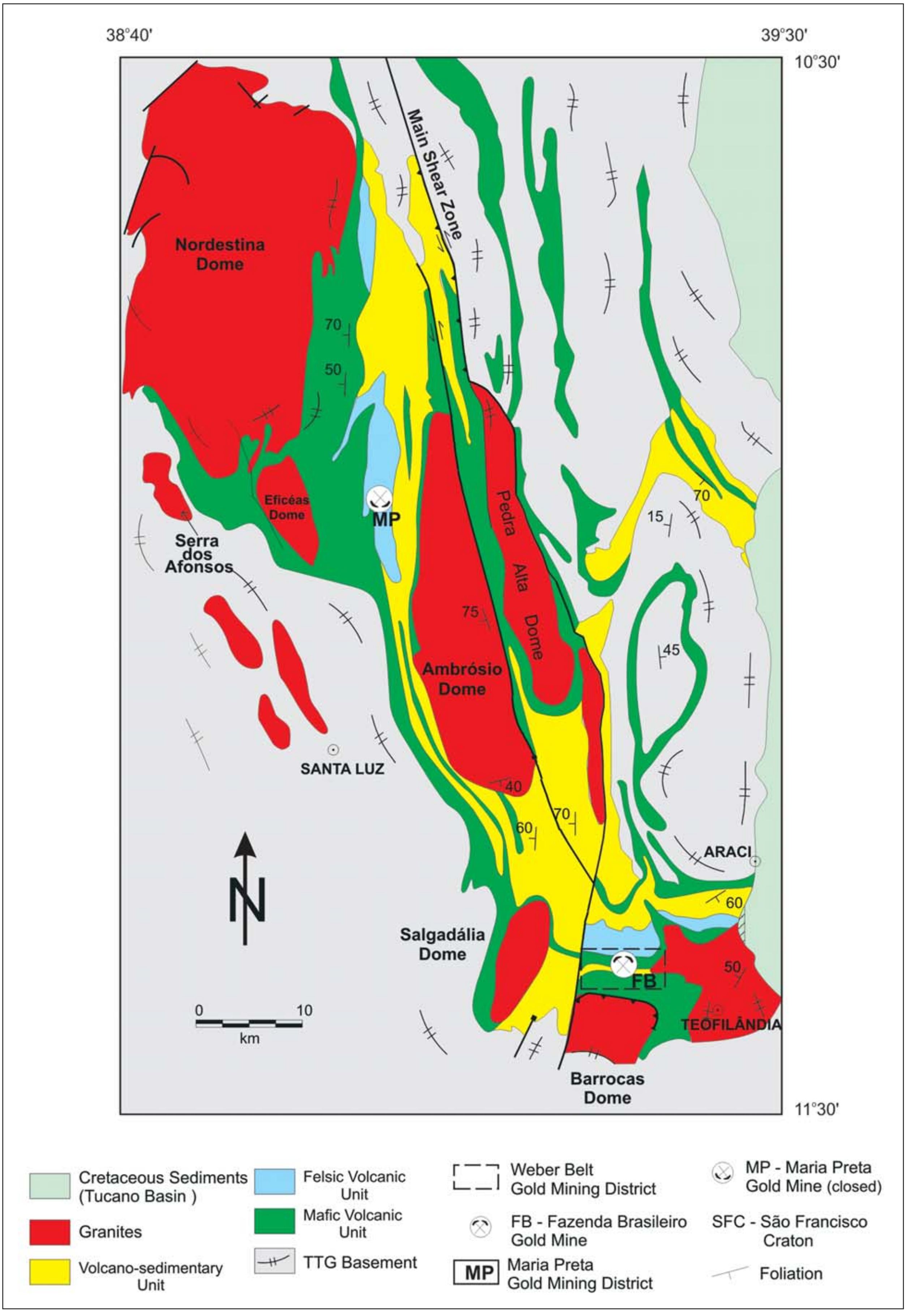


Fig. 1.10 – Simplified geologic map of the Itapicuru greenstone belt. Modified from Teixeira et al. (1982).

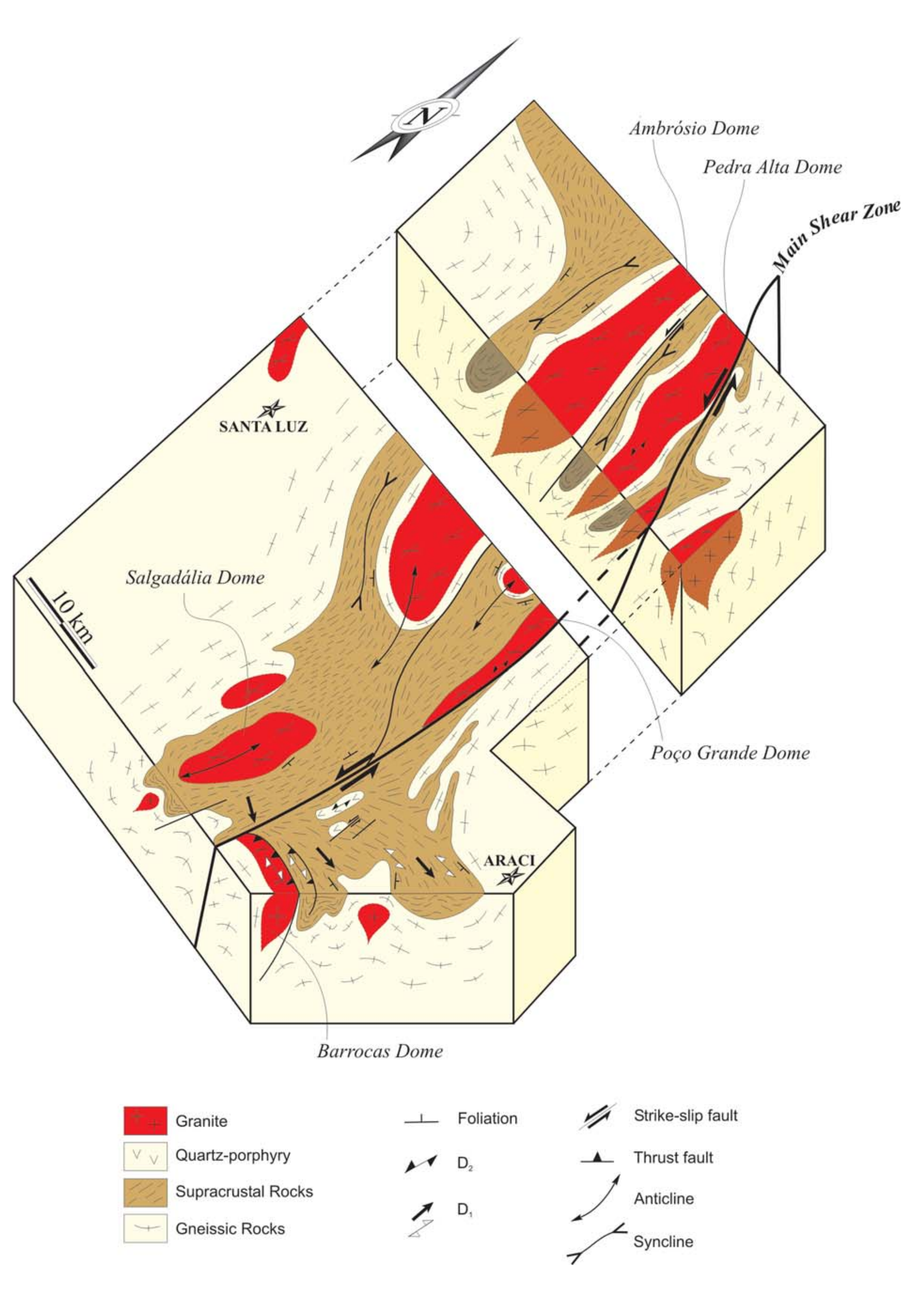


Fig. 1.11 - Block- diagram illustrating the geologic architecture of the Rio Itapicuru greenstone belt (From Alves da Silva 1994).

slip motions that were accommodated along pre-existent thrust planes and a new generation of left-lateral shear zones. The syn-kinematic mineral parageneses reflect a regional metamorphism in the conditions of greenschist to amphibolite facies (Silva 1983, 1987) (Fig. 1.11).

An intensive hydrothermal alteration affect the main shear zones, generating numerous gold deposits, especially in the southern portion of the belt. These alteration zones are marked by the occurrence of quartz, carbonates, albite, sericite, chlorite, sulfides (pyrite, arsenopyrite and subordinate pyrrotite), and tourmaline. Gold grades are higher in the areas where the host rocks contain iron oxides, iron silicates or black shales.

The geochrological data available for the Rio Itapicuru greenstone belt are shown on Tab. VI.

At the end of the fist day we will visit a chromite deposit near the town of Santa Luz, where we will stay for two nights. The stops of the second day follow a W-E transect along the Itapicuru River (Fig.1.12) and provide an overview of the stratigraphy and tectonics of the greenstone belt.

STOP 1.1 Pedras Pretas mine, 5 km to east of Santa Luz

The purpose of this stop is to examine the chromite deposit associated with the Paleoproterozoic Pedras Pretas ultramafic suite, which intrudes metasedimentary and metavolcanic rocks of the Itapecuru greenstone belt sequence.

According to Araújo (1998), two types of chromite bodies occur in the Pedras Pretas deposit: disseminated and massive chromites. The first category experienced major changes after the magmatic crystallization due to the action of sub-solidus metamorphic and/or hydrothermal processes. The massive bodies, in contrary, preserve their original signature, characterized by low Ti, high Cr, and Cr/(Cr+Al) values higher than 0,6, which are indicative of ophiolithic affinity.

STOP 2.1 Trilhado Farm

Small body of post-kinematic granodiorite intruding mafic volcanics of the Lower Unit. A hornfels texture can be observed along the contact zone between the two rock types.

STOP 2.2 Peixe creek at the confluence with the Itapicuru river

Flow breccias of the Lower Volcanic Unit containing basalt fragments in a basaltic matrix. Deformed pillows can also be observed in the same outcrop.

STOP 2.3 Maria Preta farm, Itapicuru right bank

Andesitic lavas of the Felsic Volcanic Unit showing a variety of textures, including massive, afanitic, porphyritic and spherulitic types.

STOP 2.4 Maria Preta farm, access road to the C1 gold deposit

Subvolcanic body of quartz-dioritic to gabroic composition that represents an intrusive equivalent of the Felsic Volcanic Unit.

STOP 2.5 Maria Preta farm, C1 gold deposit

A NE-SW-trending shear zone developed along the contact between dioritic/andesitic and dacitic lavas hosts a gold mineralization characterized by two distinct ore types:

TABELA VI - Geochronological data for the Rio Itapicuru greenstone belt. Authors: (1) Silva (1992); (2) Mascarenhas e Garcia (1989); (3) Alves da Silva 1994; (4) Mello (2000); (5) Teixeira (oral com.); (6) Gaal *et al.* (1986); (7) Sabaté *et al.* (1990); (8) Rios *et al.* (1999); (9) Silva *et al.* (2005).

ROCK UNIT		METHOD	AGE	Obs.	AUTHOR
Supracrustal	**Basalts**	Sm-Nd RT	T_{DM} 2200	ε +4	1
		Pb-Pb RT	2209 $\pm$ 60	μ 8,14	1
	Andesites	Rb-Sr RT	2089 $\pm$ 85	0,7016	2
		Sm-Nd RT	T_{DM} 2120	ε +2	1
		Pb-Pb RT	2170 $\pm$ 80	μ 8,0	1
Granitoids	**Araci**	Rb-Sr RT	2002 $\pm$ 55	Ri = 0,7049	2
	Barrocas	Pb-Pb zircon	2127 $\pm$ 5		3
		K-Ar biot	2029 $\pm$ 13		3
	Teofilândia	U-Pb SHRIMP	2130 $\pm$ 7	Tonalite	4
		U-Pb SHRIMP	2128 $\pm$ 8	QFP	4
	Ambrósio	Rb-Sr RT	2015 $\pm$ 59	Ri = 0,7099	5
		U-Pb zircon	2079 $\pm$ 47		6
		U-Pb SHRIMP	2080 $\pm$ 5	Xenotime in dike	4
		U-Pb SHRIMP	2077 $\pm$ 22 e 2063 $\pm$ 55	Zircon in granodiorite	4
	Poço Grande	U-Pb monazite	2079 $\pm$ 47		6
		Ar-Ar	2023 $\pm$ 13		3
	Nordestina	U-Pb monozircon	2100 $\pm$ 10		3
	Cansanção	Rb-Sr RT	2025 $\pm$ 47	0,7033	7
	Morro do Afonso	U-Pb zircão	2081 $\pm$ 27 e 2098 $\pm$ 9		8
	Morro do Lopes	U-Pb zircão	2003 $\pm$ 2		8
Mafic Intrusives	Sill Gabróico - Brasileiro Farm	Sm-Nd RT	2075 $\pm$ 50	ε +1,1	9
Metamorphism	Anfibolite	Ar-Ar	2085 $\pm$ 5	Hornblende	4
	Quartzie	U-Pb SHRIMP	2076 $\pm$ 10	Zircon	4
Hydrotermal Alteration / Mineralization	**Muscovite**	Ar-Ar	2050 $\pm$ 4 2054 $\pm$ 2		4

- Breccias and gashes veins that form a W-dipping and 10 to 40 m wide sigmoidal body of higher grade.
- Stockwork ore of lower grade hosted by a layer of felsic lava.

The grades vary around 2 g/ton and the metal occurs as inclusions in quartz veins, sulfide crystals and filling fractures in the host rock.

STOP 2.6 Itapicuru river right bank

Pyroclastic lavas of the Felsic Volcanic unit, including lappilli tuffs, crystal tuffs, and agglomerates of andesitic composition. The agglomerates contain fragments of andesitic lavas showing cooling features.

STOP 2.7 Saco creek, on the right bank of the Itapicuru river

Large exposure of turbiditic sands and pelites

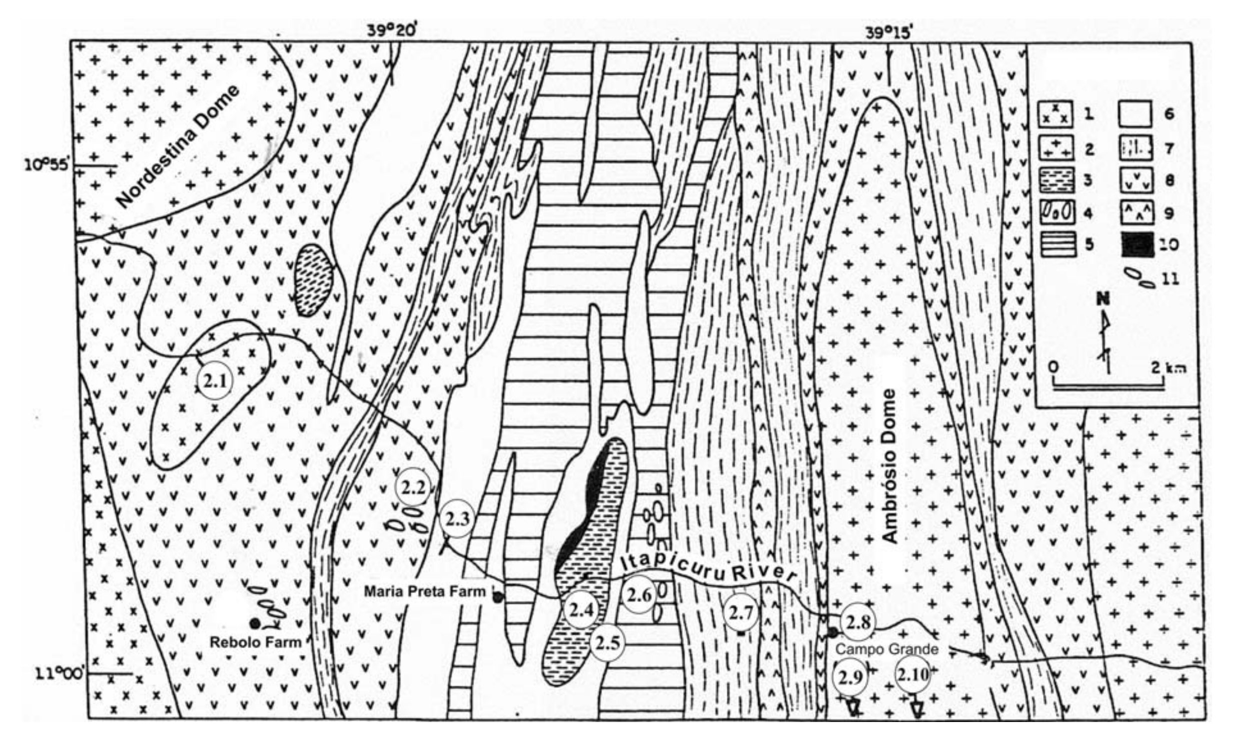


Figura 1.12 - Geologic map of the central sector of the Itapicuru greenstone belt, showing the field trip stops. Modified from Teixeira et al (1982). (1) Post tectonic granitoids; (2) Syntectonic granitoids; (3) Dioritic bodies; (4) Felsic volcanic agglomerates (UVF); (5) Andesitic and dacitic tuffs; (6) Andesitic and dacitic lavas with intercalated tuffs (UVF); (7) Detrital sediments of volcanic origin; (8) Basalts with intercalations of chemical and pelitic sediments (UVM); (9) Gabbroic sills; (10) Ultramafic bodies; (11) Pillow lavas in the UVM basalts.

of the Upper Sedimentary Unit showing Bouma sequences.

STOP 2.8 Campo Grande village

Shear zone that marks the western border of the Ambrósio dome, the most prominent dome structure of the Itapicuru dome-and-keel architecture. The shear zone affects a ganitoid (tonalitic/ granodioritic composition) cut by various generations of pegmatites.

STOP 2.9 Campo Grande - Ambrósio road

Slightly deformed granodiorite of the central portion of the Ambrósio dome.

STOP 2.10 Ambrósio village

Shear zone along the eastern border of the Ambrósio dome, characterized by mylonitic gneisses in which biotite/hornblend-rich bands alternate with quartz/feldspar-rich layers. Kinematic indicators attest a dominant left-lateral sense of shear.

DAY 3

MONDAY, SEPTEMBER 11th
FROM SANTA LUZ TO SENHOR DO BONFIM

Leader: *João Dalton de Souza*[2]

Maria da Glória da Silva[1]

After taking a look at the Itareru Tonalite, we will leave the Serrinha block and enter the northern portion of the Itabuna-Salvador-Curaçá belt (Fig.1.9). There, we will examine exposures of Paleoproterozoic mafic-ultramafic and alkaline intrusions, as well as lithological units of the Neoarchean basement.

Leaving Santa Luz (Fig. 1.9), we drive northwest on the route BA 120 for ca. 20 km up to the access road to the Gameleira farm. After this first stop at the farm, we return to route BA 120 and drive northwestwards up to the Jacuri dam. At this place, we turn north on an unpaved road that follows the escarpment of the Itiuba ridge drive to the town of Andorinha. In Andorinha we will visit the Ipuera-Medrado chromite mine. Leaving the mine, we will drive west and after crossing the Itiuba ridge, we arrive in Senhor do Bonfim, where we will stay for the night.

STOP 3.1 Gamelaira Farm, ca. 25km northwest of Santa Luz

The calc-alkaline, high-K and meta-aluminous Itareru Tonalite is composed of quartz, plagioclase, hornblende, biotite and K-feldspar. It contains dioritic and anfibolitic enclaves and is cut by numerous veins of aplite and pegmatite. Remarkable in this outcrop is the strong preferred orientation of phenocrystals and mafic enclaves, which define a near vertical magmatic lineation. In areas to the north and to the south of this outcrop, this lineation rotates progressively to the horizontal position. This fact seems to indicate that this outcrop, located in the central portion of the intrusion, exposes a near vertical magma feeding conduit.

The Itareru Tonalite, interpreted as a syn-tectonic intrusion, was dated at 2109 Ma by the U-Pb SHRIMP method. Sm-Nd model ages fall in interval between 2329 and 2401Ma, whereas $\varepsilon Nd(t)$ values range from 0 to -1.

STOP 3.2 Andorinha town, Ipueira-Medrado mine (FERBASA)

The Ipueira-Medrado mafic-ultramafic sill is one among 15 chromite-rich mafic-ultramafic bodies that intrude granulites and migmatites of the Itabuna-Salvador-Curaçá belt along the Jacurici river valley in northeastern Bahia, as shown on Fig.1.13. It corresponds to a folded sill (Figs.1.14 and 1.15) that

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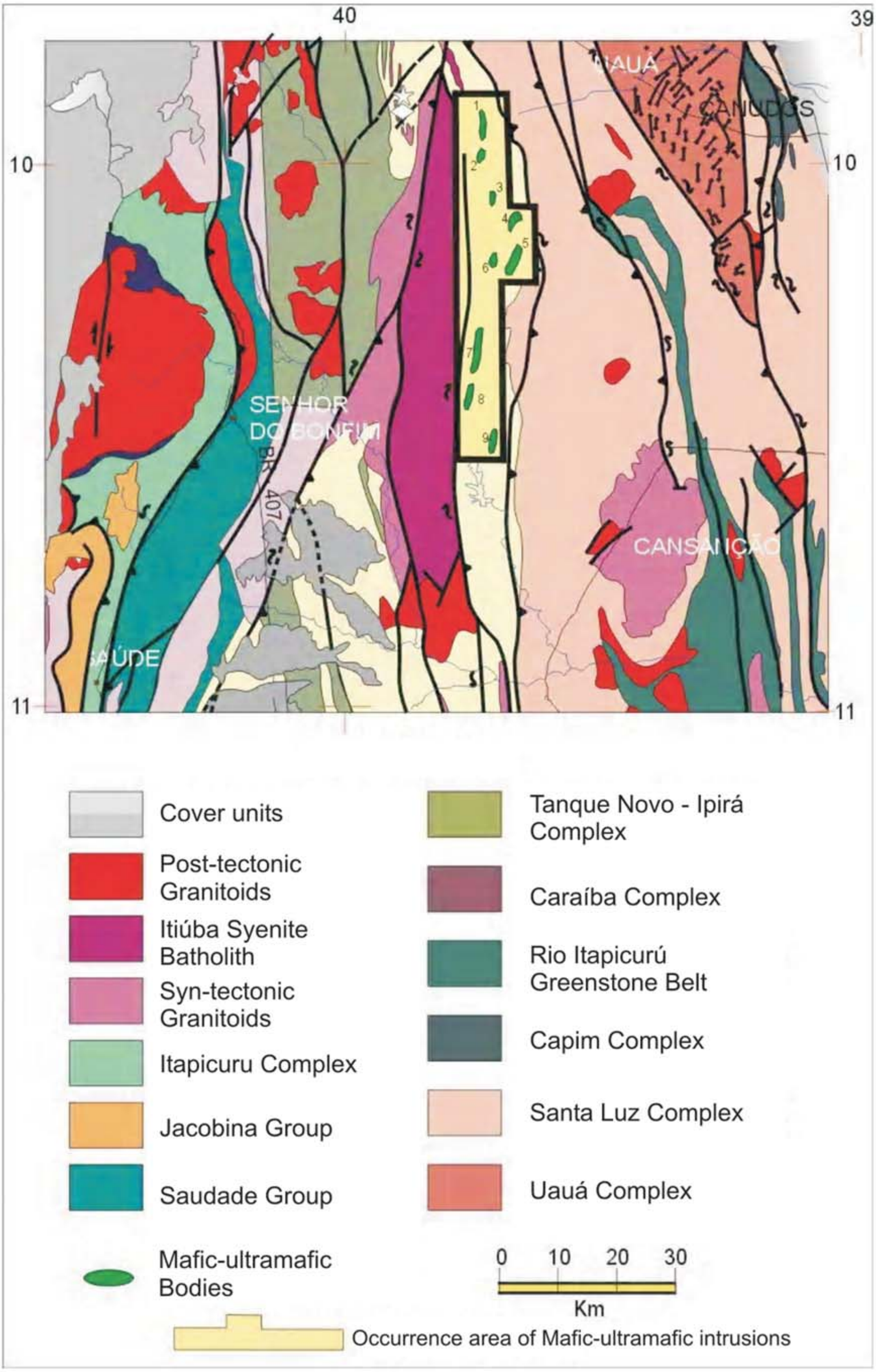

Fig. 1.13. Detail of the geologic map of Fig. 1.9, showing the location of the mafic-ultamafic bodies of the northwestern sector of the eastern Bahia orogenic domain.

defines a west-verging and south plunging synform. From the base to the top, the following succession can be observed in the intrusion:

1) plagioclase-orthopyroxene cumulate, ca. 29m
2) orthopyroxene cumulate, ca. 2m
3) orthopyroxene-olivine-spinel cumulate, ca. 33m
4) chromite cumulate, ca. 6m
5) olivine-orthopyroxene-spinel cumulate, ca. 60m

A petrological investigation carried out by Oliveira Jr (2002) on the Ipueira-Medrado body indicated a boninitic magma as source for this intrusion. Oliveira (2000) obtained an U-Pb zircon age of 2066 Ma for the sill.

STOP 3.3 Itiuba ridge, 4 km to the west of Andorinha

The Itiuba syenite (Fig.1.9) exposed in this outcrop occur in form of an elongated pluton that extends over 150km in the NS direction. With an average width of 50km, this late tectonic intrusion is bounded on both sides by shear zones, and represents a high- K, meta-aluminous syenite enriched in Ba, Sr and ETR (Conceição 1990). Oliveira et al. (2002) obtained an U-Pb SHRIMP zircon age of 2084 Ma for this syenite.

STOP 3.4 Road cut, route BA 120, 15 km to the west of Andorinha

The purpose of this stop is to take a look at the dominant rock unit of the northern Itabuna-Salvador-Curaça belt (Fig. 1.9), the Caraíba complex (Kosin et al. 2003). The Caraíba gneisses, together with the São José do Jacuípe Suite, the Tanque-Novo-Ipirá complex, Paleoproterozoic granites, and mafic-ultramic intrusions are involved in a NS-striking, left-lateral system of tranpressional shear zones, thus defing the northern Itabuna-Salvador-Curaça belt. The overall architecture of the northern Itabuna-Salvador-Curaçá characterizes a positive flower structure (Melo et al. 1995), in which the units involved - all bounded by shear zones -, display an anastomosed pattern in map view.

The Caraíba complex comprises a bimodal suite made up of enderbitic orthogneisses and gabro-dioritic rocks. According to Teixeira (1997), the protoliths of the enderbitic gneisses are low and high-k calc-alkaline rocks. The reactions involved in the metamorphism of this rocks during the Paleoproterozoic resulted in the paragenesis hyperstene+hornblende+ biotite, which marks the granulite-amphibolite facies transition (hydrogranulites). Under these conditions, partial melting is very common. In fact, migmatic features, such as schlieren, schöllen and nebulitic, are widespread in the complex.

Zircons extracted by Silva et al (1997) from enderbitic and charnockitic orthogneisses of the Caraíba complex yield U-Pb SHRIMP ages of 2695 and 2634 Ma for the crystallization of these rocks. The granulite facies metamorphism was dated at 2072Ma by the same authors.

a

b

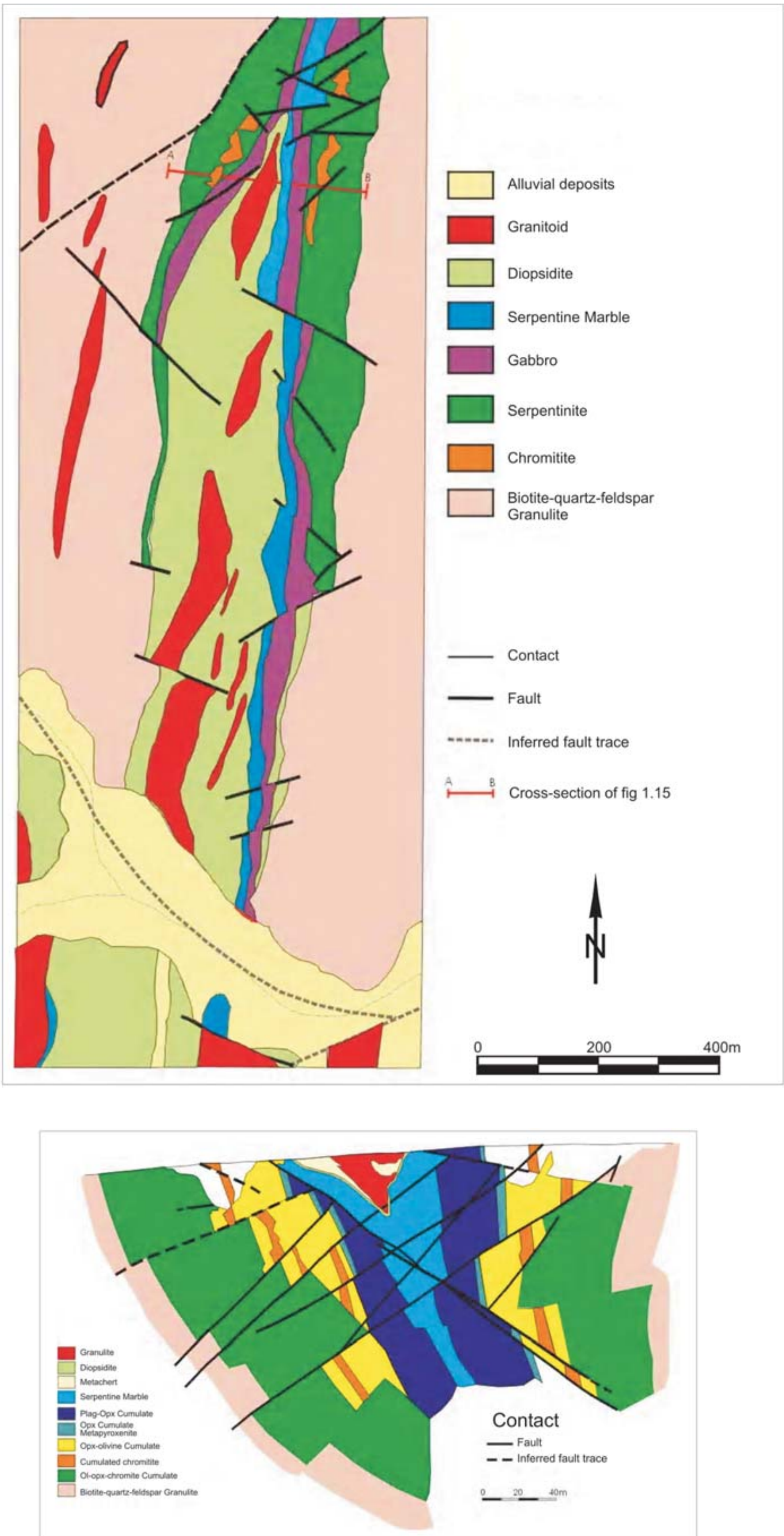

Fig. 1.14. (**a**) Geologic map of the Medrado sill (from Barbosa de Deus et al. 1982); (**b**) Cross-section of the Medrado sill, showing its the sinformal structure. (From Barbosa de Deus et al. 1982)

DAY 4

TUESDAY, SEPTEMBER 12th
FROM JACOBINA TO FEIRA DE SANTANA

Leader: *João Batista Teixeira*[1]

The 4th day field trip will be spent in the Jacobina Gold mine (Fig. 1.9), where, besides the stratigraphy of the Jacobina Group, we will be discussing tectonic and mineralization processes.

Gold deposits in the Serra de Jacobina occur in a belt of siliciclastic rocks intercalated with mafic and ultramafic bodies (Bahia Gold Belt). This succession rests unconformably on a tonalitic-trondhjemitic-granodioritic basement.

The siliciclastic sequence represents the remnants of a sedimentary basin, which formed in a passive margin-type setting. The basin was later subjected to a complex history of deformation, metamorphism, and hydrothermal activity, as a result of oblique collisional events in Neoarchean and Paleoproterozoic.

The most important auriferous occurrences in the area are hosted by quartz-pebble conglomerates, and resemble placer-type deposits. However, structurally-controlled hydrothermal orebodies, and the formation of gold occurrences also in quartzite and mafic-ultramafic intrusions, support an epigenetic model for the mineralizing event.

Gold mineralization is interpreted to be an integral part of the late (~1.9Ga) tectonothermal evolution of the Serra de Jacobina region. It is roughly coeval with the emplacement of large volume of post-collisional type, peraluminous granitic magmas, generated during a regional strike-slip regime.

Starting early in the morning from our hotel in Senhor do Bonfim we drive southwards to Jacobina via Pindobaçu. After visiting the mine and outcrops in the nearby Jacobina ridge, we depart to Feira de Santana.

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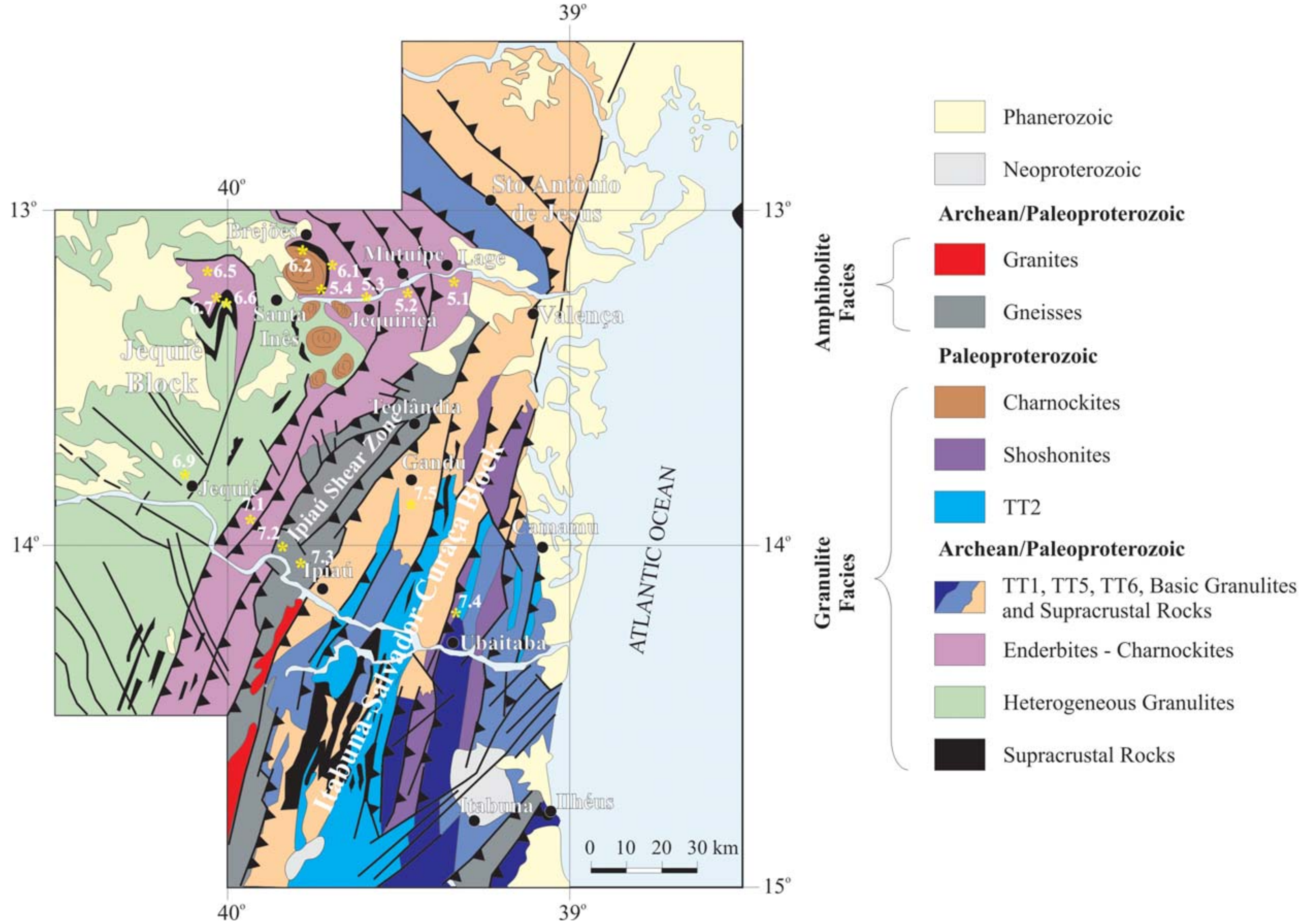

Fig. 1.15. Simplified geologic map of the northeastern portion of the Jequié block and southern Itabuna-Salvador-Curaçá belt. The numbers indicate the location of the field trip stops.

DAY 5

WEDNESDAY, SEPTEMBER 13th
FROM FEIRA DE SANTANA TO JIQUIRIÇÁ

Leader: *Johildo Barbosa*[1]

During the 5th day field trip we will be examining the high grade rocks of the Jequié block (Fig. 1.15) with especial emphasis on the metamorphic and deformational features related to the Paleoproterozoic collisional event.

We will start the day by driving southwestward on route BR 101 for ca. 150km. At the intersection with the access to Jequiriçá, we turn west and drive for more 15 km, up to the town of Lage, to our first stop. The next stops will be made along the Jiquiriçá river valley, following an E-W transect that ends near the town of Santa Inês. At the end of the day we will return to Jequiriçá, where we will stay for the night.

STOP 5.1 Jequiriçá River right bank, near Lage town
UTM: 0454354/8542536

The outcrop exposes a calc-alkaline, low Ti (Fornari and Barbosa 1994), coarse to medium grained charnoenderbite consisting of antiperthitic plagioclase (An_{25}, 43%), quartz (31%), mesoperthite (17%), orthopyroxene (5%), biotite (2%), clinopyroxene (1%), and brown hornblende (1%). The charnoenderbite is foliated and banded, although it looks massive and green to dark gray in fresh surfaces. Foliation results from the parallelism of mesoperthite grains (0.5-10.0cm) in a finer grained matrix. Banded structure is characterized by alternating feldspar-rich and dark layers. The dark layers are rich in mafic minerals, and may be interpreted as a primary magmatic feature, turned more prominent due to deformation. Mafic enclaves are flattened and stretched into parallelism with the rock banding.

Folds with a low-angle axial-plane schistosity (S_1) and horizontal hinges (B_1) are attributed to the first deformational event (F_1). Kinematic indicators (mesoperthite porphyroclasts) suggest ENE-directed motion.

A Sm-Nd model age (T_{DM}) of 3.0 Ga (Wilson 1987), a Rb-Sr isochron age of 2.89 Ga (Costa and Mascarenhas 1982) and an U-Pb SHRIMP zircon age of ca. 2.8 Ga (Alibert and Barbosa 1992) are the geochronologic data available for this charnoenderbite, thus suggesting a Mesoarchean magmatic age.

Various generations of pegmatite veins composed of quartz, mesoperthite and pyroxene display the following relationships with the host-rock: (i) cutting across the charnoenderbite banding and are affected by the F_1 folds; (ii) parallel to the banding; (iii) not deformed and cut across the rock foliation. Geothermometric analysis of opx-cpx yielded a temperature of ca. 820°C, assumed as the temperature of metamorphic resetting during the Paleoproterozoic collisional event.

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STOP 5.2 Mutuípe town
UTM: 0445688/8537658

The green to gray calc-alkaline, high Ti (Fornari and Barbosa 1994) Mutuípe enderbite is composed of antiperthitic plagioclase (An_{30}, 51%), quartz (22%), clinopyroxene (12%), hornblende (5%) mesoperthite (4%), orthopyroxene (4%), and opaque minerals (2%), with minor biotite, apatite, and zircon.

A foliation attributed to the second deformational event (S_2, N20W/90) is parallel to a banding characterized by alternating light and dark layers of distinct mineral composition.

A magmatic crystallization age of 2.7 Ga was obtained through U-Pb SHRIMP zircon dating for this enderbite (Alibert and Barbosa 1992). In agreement with data for the Lage charnoenderbite, geothermometric analysis of the mineral assemblage opx-cpx yielded a temperature of ca. 820^{o}C, assumed as the temperature of metamorphic reseting.

STOP 5.3 West of Ubaíra town
UTM: 0419979/8535950

The light-green quartzite composed of quartz (90-70%), garnet (10-5%), plagioclase (5-1%), orthopyroxene, and biotite corresponds to one among various supracrustal components of the Jequié Block. Except for boudins of mafic rocks, deformational features are absent. Metamorphic pressures reached 5-6 Kbar, and the presence of an equilibrium mineral assemblage of spinel+quartz points to a temperature close to 1000^{o}C.

STOP 5.4 Lage-Santa Ines road, close to Engenheiro França town
UTM: 0417217/8535273

The outcrop exposes a charnockitic rock (inhomogeneous granulites) of possible anatetic origin with a mineralogical content similar to the charnockites of the low- and high Ti suites from the Lage and Matuípe areas. Blocks and boudins of various sizes, consisting of a granulite of tholeiitic composition are scattered throughout the outcrop. They yielded a Sm-Nd model-age (T_{DM}) of 3.29 Ga. A zircon Pb-Pb evaporation age of ca. 2.9 Ga is reported for this charnockite (Barbosa et al. 2004).

Quartz-feldspar rock veins cut across the charnockite and both veins and host-rock are undeformed.

DAY 6

THRUSDAY, SEPTEMBER 14th
FROM JIQUIRIÇÁ TO JEQUIÉ

Leader: *Johildo Barbosa*[1]

During the 6th day field trip we will keep exploring the rock units and metamorphic features of the Jequié block, including the Paleoproterozoic charnockite domes of its northeastern portion.

Starting from Jequiriçá we will drive northwest on a dirt road up to the town of Brejões. From this town we will head west to reach the route BR 116, where we will make a south turn towards our hotel in Jequié.

STOP 6.1 Ubaíra-Brejões dirt road, SE of Brejões town

UTM: 0419900/8549681

The outcrop consists of alternating layers of green kinzigite and light colored layers of quartz-feldspar-garnet rock, and milky quartz. Also present are anatetic veins of quartz-feldspar composition. The kinzigite layers are composed of quartz, plagioclase, K-feldspar, biotite, sillimanite, graphite, and minor orthopyroxene, besides euhedral red garnet crystals and grayish green cordierite crystals that can reach 2 cm in length.

Metamorphic P-T conditions calculated for the kinzigite yielded 5-6 Kbar and ca. 850^{o}C. Also studied were fluid inclusions of quartz grains from the milky quartz layers; CO_2 carbon isotopes values suggest an organic nature. The kinzigite is probably derived from pelitic sediments, whilst the milky quartz layers are thought to be derived from chert layers.

STOP 6.2 Small quarry near Brejões town

UTM:0413128/8550497

The green charnockite exposed in this outcrop is the main rock type of a series of domes that dominate the structural picture of the northeastern corner of the Jequié Block. The charnockite display large hornblende crystals stretched and oriented parallel to foliation. Its orthopyroxene content is lower than charnockites from previous stops; its REE pattern is also distinct.

STOP 6.3 Access road to Brejões from the route BR-116

UTM: 0413797/8551672

This exposure is made up of alternating quartz-feldspar and mafic granulite (gabbro) layers. These layers are flat-lying and show sharp contacts. Basic granulites are ca. 1m thick and consist of plagioclase (50%), opx+cpx (30%), hornblende (15%), biotite (5%), and opaque minerals. They are medium grained and display a polygonal texture. Quartz-feldspar rock layers are composed of quartz (50%) and mesoperthite (40%), with minor plagioclase and opaque minerals. A penetrative foliation (N60W/25NE) affects both rock-types.

The chemical signature of the basic granulites suggests a tholeiitic protolith. Chemical analyses of quartz-feldspar rock layers have not disclosed their protolith; they could be derived from fine-grained granites, felsic tuffs, or even arkoses.

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STOP 6.4 Access road to Brejões from the route BR-116
UTM:0413478/8551940

The outcrop exposes a rock made up of alternating layers of chert, quartz-feldspar, and banded iron formation, cut by basic to ultrabasic sills. The quartz-feldspar-rich layers display a graphic texture. Fluid inclusions of quartz grains extracted from the milky quartz and quartz-feldspar rock layers yielded carbon isotopes values similar to the values reported for the kinzigites of stop 6.1, suggesting a SEDEX environment for both rock layers.

STOP 6.5 Access road to Brejões from the route BR-116
UTM: 0412486/8551625

Intensively migmatized kinzigite are cut by quartz-feldspar pegmatitic veins, which contain mesoperthite crystals up to 5cm in length and centimetric euhedral garnet crystals. Also present are undeformed veins of a cordierite-garnet bearing charnockite. Both pegmatite and leuco-charnockite were generated during the Paleoproterozoic granulite metamorphic peak. Temperatures close to 1000^{o}C are suggested by the mineral assemblage spinel+quartz of the kinzigites. The presence of biotite crystals with opx rims also corroborates the hypothesis of very high temperatures affecting this sector of the Jequié Block. Metamorphic pressures were estimated at 5-6 Kbar.

STOP 6.6 Route BR 116
UTM: 0391699/8546102

In this outcrop we will examine an augen-charnockite, consisting of large mesoperthite prophyroclasts dispersed in a finer grained matrix consisting of quartz, antiperthitic plagioclase, microcline, and opx remnants.

STOP 6.7 Route BR 116
UTM: 0399761/8535719

The purpose of this outcrop is to observe the tectonic elements of the deformation events D1 and D2 affecting an orthopyroxene-garnet bearing quartzite. This quartzite shows similar chemical and mineralogical composition to the quartzite of stop 5.3. Metamorphic P conditions calculated from the observed paragenese yielded 5-6 Kbar.

STOP 6.8 Route BR 116, locality known as Pedrão
UTM:0390347/8532430

Banded charnockite (inhomogeneous granulite), similar in chemical and mineralogical composition to the charnockite of stop 5.4. The margins of the amphibolite boudins are opx-rich and dehydrated, as a result of progressive metamorphism. Rock-banding is cut by charnockite veins with opx crystals up to 5cm in length. These veins are undeformed and thus assumed to post-date the ductile deformation.

STOP 6.9 Jequié Quarry

Greenish grey, ortho-derived charnockite, displaying a N-S-striking and steeply dipping foliation/ banding. A typical sample of this granulite shows the following composition: quartz (30%), K-feldspar (mesoperthite and a second generation of microcline, 45%), plagioclase (porphyroclasts and recrystallized grains, 15%), orthopyroxene (10%), traces of red biotite, amphibole and iron-oxides. This rock is intruded by two generations of granitic veins, composed of microcline (40-50%), amphibole plus biotite (5-10%), and plagioclase (20-30%). Epidote, chlorite and biotite may also occur. Boudins of basic granulites with biotite alteration can be found as enclaves.

Wilson (1987) obtained ages of 1970±136Ma (Pb/Pb, whole-rock) and 2085±222My (Rb-Sr, whole rock) in samples from this quarry. Sm-Nd TDM model age for the same rocks fall between 2.6 and 2.7 Ga suggesting that their protoliths are much older than 2.0 Ga and the ages obtained by Wilson reflect the Paleoproterozoic metamorphic event.

DAY 7

FRIDAY, SEPTEMBER 15th
FROM JEQUIÉ TO SALVADOR

Leader: *Johildo Barbosa*[1]

The stops of the last field trip day in Bahia will provide a general view of the rock units and structures of the eastern boundary of the Jequié block. In addition, we will be looking at outcrops of the components of the southern segment of the Itabuna-Salvador- Curaçá belt.

From Jequié we will drive southeast on the route BA 330 along the Rio de Contas valley up to the intersection with route BR 101. We will then turn north and drive for ca. 450 km up to Salvador. From Salvador we will fly to Belo Horizonte.

STOP 7.1 Quarry near Jitaúna town, route BA-330

UTM:0393622/8454131

This outcrop display features that result from the action of CO_2 during granulite metamorphism. A calc-alkaline, low Ti charnockite exhibits an interlayering of two phases of centimetric- to metric scale: (*i*) a hornblende-rich light grey granite; (*ii*) green opx-bearing charnockite. Depending on the quality of the exposures, it is possible to observe lateral transitions between this two phases.

STOP 7.2 Road-cut, route BA-330

UTM: 0409138/8450089

The rock in this outcrop, characterized by alternating layers of ampibolite and quartz-feldspar, is affected by the Ipiaú shear zone that marks the boundary between the Jequié Block and the Itabuna-Salvador-Curaçá belt. The gray gneissic layers are 0.30 to 1.5m thick and consist of plagioclase and hornblende. The 1.0 to 10m thick quartz-feldspar-rich layers show granitic composition and consist of quartz, plagioclase, and microcline. The vertical foliation, typical for the Ipiaú shear zone, exhibits a horizontal stretching lineation.

STOP 7.3 Road-cut, route BA-330, near Ipiaú town

UTM: 0416570/8439717

Alternating layers of amphibolite and quartz-feldspar rock within the amphibolite-granulite metamorphic transition zone. The amphibolites are coarse to medium-grained and consist of plagioclase (An_{25-30}, 40%), hornblende (45%), clinopyroxene (5%), quartz (5-1%), and minor orthopyroxene. The felsic layers are composed of quartz (60%), microcline (35%), plagioclase (5%), and opaque minerals. Foliation is flat-lying and possibly associated to the D_1 deformational event.

The amphibolite is tholeiitic in composition and yields Sm-Nd model-ages around 3.1 Ga. In the amphibolite-granulite facies transition zone the following reaction takes place in basic rocks:

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$$Hb + Qz \Leftrightarrow Opx+Cpx+Plag+H_2O$$

An increase in opx content of basic rocks has been reported from this place towards the Atlantic coast, thus implying in an increase of the metamorphic grade from the Ipiaú shear zone to the Itabuna-Salvador-Curaçá belt. The increase in metamorphic grade was not associated to increase in element mobility; the chemical composition remained constant.

STOP 7.4 Oricó Grande river margins
UTM: 0459414/8424697

The shoshonitic monzonite exposed here is another component of the Itabuna-Salvador-Curaçá belt. It contains large plagioclase porphyroclasts and the matrix consists of plagioclase, mesoperthite, opx, cpx, and opaque minerals. Locally, coarse and fine grained opx-cpx assemblages can be observed. The first is probably of magmatic origin and estimated growth temperatures exceed 900°C. The fine grained opx-cpx assemblage must have grown during regional metamorphism under temperatures at ca. 830°C. Available geochronological data for the monzonite (unpublished) is a Sm-Nd model-age (T_{DM}) of 2.4 Ga.

STOP 7.5 Gandu Quarry

This quarry exposes banded granulites showing similar folds marked by a series of continuous mafic layers (plagioclase, pyroxene, amphibole and biotite). These structures, with axial planes oriented at N20E/70-80SE, allow the inference of major shortening during the D2 folding episode. The growth of orthopyroxene on the S_2-foliation surfaces indicates high metamorphic temperatures also acting during the second deformation phase.

The mafic granulites have tholeiitic composition, whereas the light grey bands represent tonalities composed of plagioclase (40-50%), quartz (50%), mesoperthite (1-5%), pyroxene, garnet and opaque minerals. Undeformed pegmatoid veins cut both phases. Metamorphic temperatures around 830°C have been determined for the mafic bands, which yielded Sm-Nd (T_{DM}) ages of ca. 2.6 Ga.

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FIELD TRIP 2

QUADRILÁTERO FERRÍFERO

OUTLINE OF THE GEOLOGY OF THE QUDRILÁTERO FERRÍFERO

Fernando F.Alkmim[1]

Carlos M. Noce[2]

INTRODUCTION

The 15,000 km^2 portion of the Brazilian highlands, just south of the city of Belo Horizonte (Figs. 2.1, 2.2), became known as Quadrilátero Ferrífero (“Iron Quadrangle and abbreviated “QF”) for the fact it is delimited by four almost mutually perpendicular ridges underlain by Paleoproterozoic banded-iron formation and quartzites, which rise above lowlands containing deeply weathered Archean gneisses and schists.

From a geological perspective, the QF is perhaps the most intensively studied region of Brazil, partly because of its mineral resources - the region has hosted significant mining for three centuries, first for gold and more recently for iron ore - and partly because of the puzzling complexity of its rocks and structures. The first publications appeared already in the beginning of 19th century, and the entire region was mapped at a scale of 1:25,000 during the mid-20th century by geologists from the United States Geological Survey (USGS), and the Brazilian Departamento Nacional da Produção Mineral (DNPM). The results of this mapping project have been synthesized by Dorr (1969), and became the most used and referenced publication regarding the QF.

As a whole, the QF lies partially at the southern end of the São Francisco craton, and partially in the southern Araçuaí belt that fringes the craton to the east (Fig. 2.2). Teixeira & Figueiredo (1991) firstly recognized a Paleoproterozoic orogenic belt in the region close to the southern limit of the São Francisco craton. Referred to as the Mineiro belt, it was portrayed by these authors as a manifestation of the 2,1 Ga Transmazonian event. Considering that the adjacent QF also experienced deformation, metamorphism and magmatism around 2,1 Ga (e.g., Endo 1996, Chemale Jr et al. 1997, Alkmim and Marshak 1998, Noce 1995, Machado et al. 1996, Brueckner et al. 2000, Teixeira et al. 2000), Alkmim (2004) expands the original concept of the Mineiro belt in order to incorporate the QF as the foreland domain.

STRATIGRAPHY

The Precambrian section exposed in the QF consists of four major lithostratigraphic units (Fig. 2.3): (*i*) Archean metamorphic complexes, composed of gneisses, migmatites, and granitoids (typical of Archean TTG suites and high-K granites); (*ii*) the Archean Rio das Velhas Supergroup, made up of greenstone and low- to medium-grade meta-sedimentary units; (*iii*) the Paleoproterozoic Minas Supergroup, consisting of low- to medium-grade meta-sedimentary rocks; and (*iv*) the Itacolomi Group, composed of metasandstones and conglomerates. In addition, the district includes two generations of post-Minas Supergroup intrusives. The first consists of

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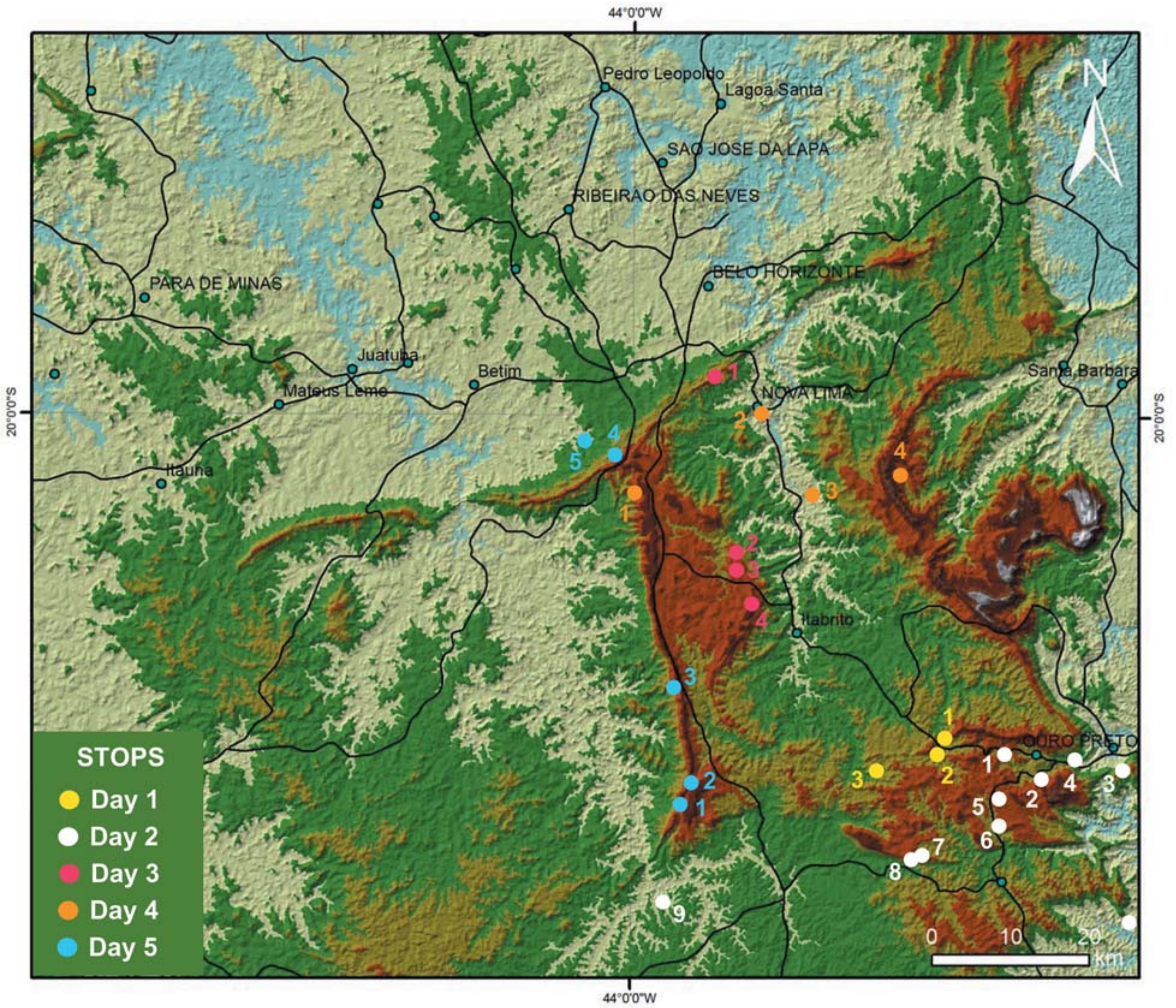

Fig. 2.1 - Topographic map of the QF area, showing the location of the field trip stops.

small granite bodies and pegmatite veins that locally cut the youngest strata of the Minas Supergroup; the second comprises widespread post-Itacolomi mafic dikes and sills. Of note, Silva et al. (1995), using the U-Pb method on badeleyte, obtained an age of 1714 Ma on one of these dikes. The only non-Precambrian rocks of the QF are local deposits of Tertiary coal, clays, sand and gravel (Florália Formation; Dorr 1969) which occur in narrow fault-bounded basins.

Archean Metamorphic Complexes

The metamorphic complexes include 2.9 to 3.2 Ga gneisses and migmatites, and two granitoid suites (Machado and Carneiro 1992; Carneiro et al. 1992, Carneiro et al. 1995). The older generation of granitoids has a calc-alkaline affinity, and yielded U-Pb zircon ages of 2780 and 2.776 Ma, whereas the younger suite is anorogenic and has been dated at 2721 to 2612 Ma (Romano 1989, Carneiro 1992; Machado et al. 1992, Carneiro et al. 1994 Noce 1995). These rocks occur in domal bodies, whose diameters exceed 50 km (Fig. 2.2). TTG-gneisses typically display well developed compositional banding and show various generations of tectonic structures. The granitoids, on the other hand, display both isotropic fabrics and discrete shear zones, which developed especially along the contact with the supracrustal units.

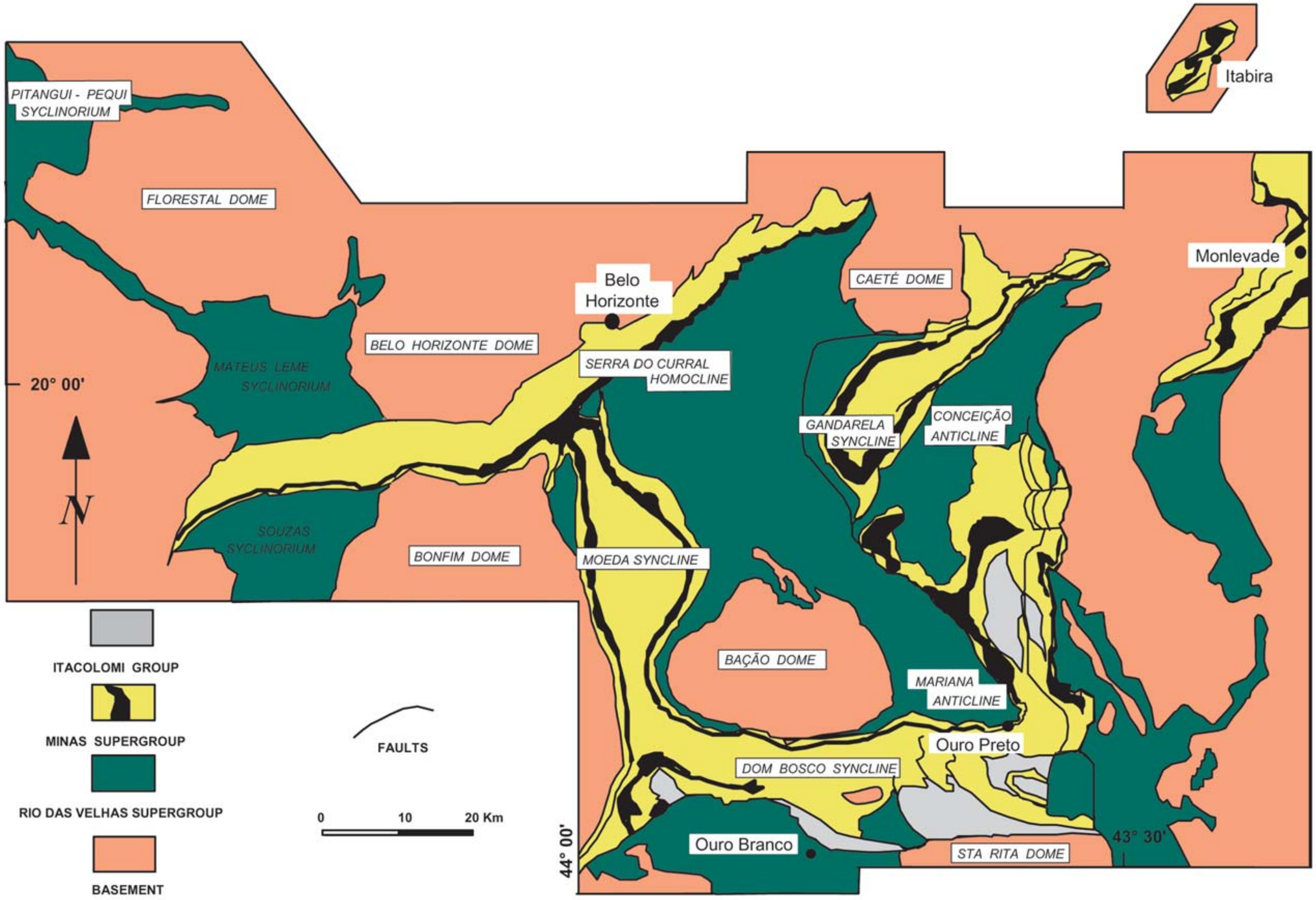

Fig. 2.2 - Simplified geologic map of the QF region, emphasizing the distribution of the Archean basement rocks, Rio das Velhas Supergroup, Minas Supergroup and Itacolomi Group. Based on Dorr (1969) and Romano (1989).

Rio das Velhas Supergroup

The Rio das Velhas Supergoup, which has been subdivided into the Nova Lima and Maquiné groups (Dorr, 1969), comprises a typical Archean greenstone belt sequence.

Zucchetti et al. (1998) recognized four facies assemblages in the Nova Lima Group, namely (listed in sequence from base to top): *i*) ultramafics and mafic volcanics (including pillowed basalts and komatiites); *ii*) Algoma-type banded-iron formation and associated volcanics and pelites; *iii*) volcaniclastics and turbiditic graywakes; and *iv*) sandy turbidites. Machado et al. (1992) dated zircons extracted from felsic metavolcanics of the Nova Lima Group, and obtained U-Pb ages of 2772 and 2776 Ma. U–Pb zircon dating of vocaniclastic rocks at 2792±11, 2773±7, and 2751±9 Ma suggests a range of about 40 Ma for the eruptive felsic magmatism within the greenstone belt (Noce et al. 2005), which was coeval with the oldest generation of calk-alkaline granitoids of the QF.

The Maquiné Group consists of shallow-marine to alluvial sandstones, conglomerates and pelites, and has been interpreted as a platformal cover sequence that buried the mafic-/ultramafic volcanosedimentary sequence (Baltazar & Pedreira, 1998).

Minas Supergroup

The Paleoproterozoic Minas Supergroup is an 8 km-thick passive-margin to syn-orogenic sedimentary package bounded above and below by angular unconformities (Fig. 2.3) (Barbosa 1968; Dorr 1969; Chemale Jr. 1994; Renger et al. 1994; Alkmim & Marshak 1998). Its oldest units, the Tamanduá and Caraça Groups, which consist of alluvial and subordinate aeolian deposits, grading up into marine strata, represent sediments that accumulated during the early mechanical-subsidence phase of a passive-margin basin. The overlying Itabira Group, divided into Cauê and Gandarela formations, records a regional transgression (Dorr 1969) and probably the development of a broad, thermally subsiding continental margin. The Cauê Formation, the main iron-ore bearing interval of the QF, is made up of a 200 m-thick sequence of Lake Superior-type banded-iron formation, including itabirites, dolomitic marble, and large bodies of high-grade supergene iron ores. The Gandarela Formation is composed predominantly of dolomites. Dolomitic limestones, limestones, pelites, banded iron formation and a breccia containing fragments of chert, carbonates and iron formation also occur in this unit. The Piracicaba Group, a thick sequence of deltaic and shallow-marine strata overlies the Itabira Group rocks on an erosional unconformity.

The youngest unit of the Minas Supergroup, the Sabará Group, unconformably overlies the previously mentioned units. It comprises an up to 3.5 km-thick sequence of metapelites, diamictites, conglomerates, and lithic sandstones. In contrast to older units of the Minas Supergroup, the Sabará contains abundant turbidites, intercalated with submarine fan deposits; in fact, it has been referred to as a “flysch assemblage” (Dorr 1969, Barbosa 1979, Renger et al. 1995, Reis 2001). The Sabará also contrasts with older units in terms of its source. Specifically, sediments of older units in the Minas Supergroup were shed from the north, whereas the Sabará source lays to southeast. Clearly, the Sabará Group reflects both a change in the sediment source and in the character of the basin (Barbosa 1968, 1979, Dorr 1969, Renger et al. 1994, Reis 2001) that occupied the QF region at the time it was part of a convergent-margin setting.

Several authors have attempted to provide constraints on the depositional age of the Minas

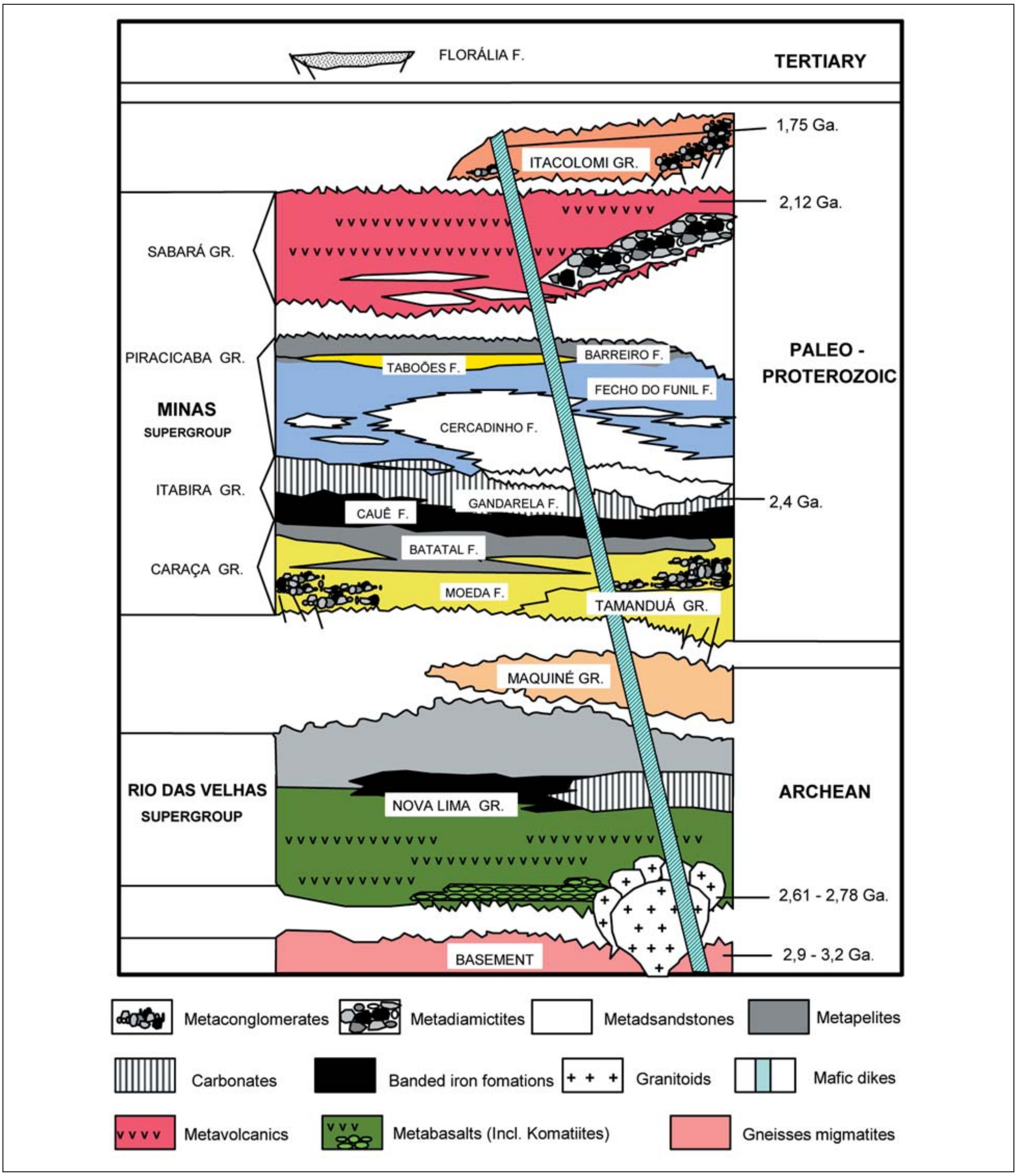

Fig. 2.3 - Stratigraphic column of the QF. Modified from Alkmim & Marshak (1998).

Supergroup. The youngest detrital zircon ages for several samples of the basal Tamanduá and Moeda quartzites are 2606±47 Ma (Machado et al. 1996) and 2584±10 Ma (Hartmann et al. 2006), thus providing a maximum depositional age for these units. Babinski et al. (1995) obtained a depositional age of 2420±19 Ma for carbonates of the Gandarela Formation, using the Pb-Pb method. U-Pb dating of zircons from a greywacke layer of the Sabará Group yielded an age of 2125±4 Ma for the youngest zircon grain (Machado et al. 1992). Dating of monazite grains from pegmatites cutting through basement rocks of the QF yields minimum ages at 2030 Ma (Machado et al. 1992). As the pegmatites are similar to ones that cut the Sabará Group, the age of 2030 Ma provides a minimum age for the Minas Supergroup.. Brueckner et al. (2000) obtained a garnet, whole rock, and feldspar Sm-Nd isochron for a metamorphic aureole developed in pelites of the Sabará Group; this isochron indicates that the Sabará was derived from a Paleoproterozoic source and was metamorphosed at 2095±65 Ma. Summarizing this geochronological data, it appears that the lower part of the Minas Supergroup was deposited between 2.6 and 2.4 Ga, while the Sabará Group accumulated at about 2.12 Ga, at least 300 million years later, and was metamorphosed shortly after deposition.

Itacolomi Group

The Itacolomi Group is an up to 1.8 km-thick succession of sandstones, conglomerates and minor pelites, which represent deposits of an alluvial-fan complex, occasionally submerged by a lake or shallow sea (Alkmim, 1987). Separated from the underlying units by a regional unconformity, the Itacolomi group occurs only in the southern portion of the QF. Barbosa (1968) and Dorr (1969) interpreted the Itacolomi sediments as a “molasse deposit.” Alkmim and Marshak (1998) suggest that the unit was deposited in small intermontane basins during the collapse phase of the Paleoproterozoic Transamazonian orogeny.

Detrital zircon from the Itacolomi Group have yielded U-Pb dates of 2,1 Ga (Machado et al. 1993, 1996) indicating that this unit is of the same age or, more likely, slightly younger than the Sabará Group, indeed significantly younger than other units of the Minas Supergoup.

GEOLOGIC ARCHITECTURE

At first glance, NE-SW-trending structures seem to be dominant fabric of the Mineiro belt (Fig. 1). However, in the QF, besides the NE-SW-trending fabric, two other sets of structures affecting the Minas Supergroup can be recognized in the map: a series of basement domes surrounded by keels containing the supracrustal units (thus forming a dome-and-keel architecture typical of Archean terranes), and a system of NS-trending and W-directed thrusts (Fig.2.2).

Tectonic investigations performed in the QF (eg., Dorr 1969, Drake and Morgan 1980, Endo 1997, Alkmim and Marshak 1998, Chemale Jr. et al 1994; Chauvet et al. 1994) demonstrated that the Minas Supergroup experienced a polyphase tectonic history, which resulted in locally very complex structural pictures. These complexities and the lack on absolute age determinations on tectonic structures gave rise to different, and in many cases conflicting interpretations for the deformation history of the Minas rocks. Here, we follow the interpretation proposed by Alkmim and Marshak (1998), which recognizes three main kinematic phases affecting the Minas rocks:

- NNW-verging thrusting and associated folding, representing the development of the foreland fold-thrust belt of a collisional orogen at ca. 2.1 Ga.
- Formation of domes and associated keels of supracrustal rocks during the extensional collapse of the orogen immediately after 2,1Ga.
- West-verging thrusting, folding, and strike-slip reactivation of preexistent structures during the Neoproteozoic (580-560 Ma) Brasiliano event.

The first and second phases reflect thus the formation of the Mineiro belt.

The action of the west-verging deformation front (probably related to the Neoproterozoic Brasiliano event) upon the older families of tectonic structures result in a rather uncommon structural picture that characterizes the QF:

- Throughout the eastern two thirds of the region, the most prominent small-scale structures are penetrative phyllitic to mylonitic foliations and the associated stretching lineations. The foliations show variable orientations in the area. The stretching lineations, in contrary, display a very strong preferred orientation around 110/35.

- The hinges of small scale to km-size folds are in general parallel to the stretching lineations.

- All together, these outcrop- to mountain-scale fabric elements are kinematically incompatible with the larger scale structure where they occur, i.e., the large keels of the QF.

The Gandarela syncline, the Conceição anticline, the Serra do Curral Homocline, and the Itabira and Monlevade synclinoria belong to the oldest set of structures (Fig. 2.2). The various domes of the second generation of structures share a series of common features. They consist of Archean basement, show tectonic contacts with the surrounding metasedimentary rocks, affect both the Rio das Velhas and Minas supergroups, and depending on the nature of the adjacent rock, are associated with a metamorphic aureole (Marshak et al. 1992; Chemale Jr et al. 1994, Endo 1997; Alkmim & Marshak, 1998). The contacts with the supracrustal units are marked by ductile shear zones of variable sense of displacement. The enveloping shear zones of the Bonfim and Belo Horizonte domes in western QF show normal sense kinematic indicators (Hippertt et al. 1992; Chemale Jr. et al. 1994, Marshak et al 1992, 1996; Alkmim & Marshak 1998), whereas the shear sense observed in the contact zone of the Bação, Caeté, and Santa Rita domes varies between reverse, reverse-oblique and strike-slip (Marshak & Alkmim 1989, Hippertt, 1994, Chemale Jr. et al, 1994, Endo 1996).

PALEOPROTEROZOIC EVOLUTIONARY SYNTHESIS

The following model has been suggested for the Paleoproterozoic history of the QF (Alkmim & Marshak 1998) (Fig. 2.4):

1) Formation of the Minas Passive-Margin Basin

Based on available geochronological data, Noce (1995) and Renger et al. (1995) suggested that the deposition of the Minas Supergroup began around 2.55 Ga. Facies distribution and depositional environments of the Caraça, Itabira, and Piracicaba Groups indicate that the Minas basin initiated as a continental rift that evolved into a passive margin. In the QF, only the continental platform portion of this basin (the portion deposited on the São Francisco craton) has been preserved; the thicker portion presumably lay to south or southeast. Passive-margin conditions prevailed until the development of the unconformity at the base of the Sabará Group.

2) The Paleoproterozoic Transamazonian Orogeny

The Transamazonian orogeny is manifested in the QF by two stages. First, a contractional phase resulted in the formation of a NNW-verging fold-thrust belt. The onset of this phase seems to be marked by the unconformity at the base of the Sabará Group. As noted in the previous section, the Sabará represents a reversal of provenance; older units of the Minas Supergroup were derived from the north, whereas the Sabará sediments were shed from the south or southeast. The character and source of this unit suggests that it was derived from a volcanic arc accreting to the southern margin of the São Francisco craton. Notably, as the Sabará basin grew, it spread out over the adjacent craton (Reis, 2001), as do foreland basins bordering Phanerozoic orogens. Collision of this arc ultimately inverted the Minas

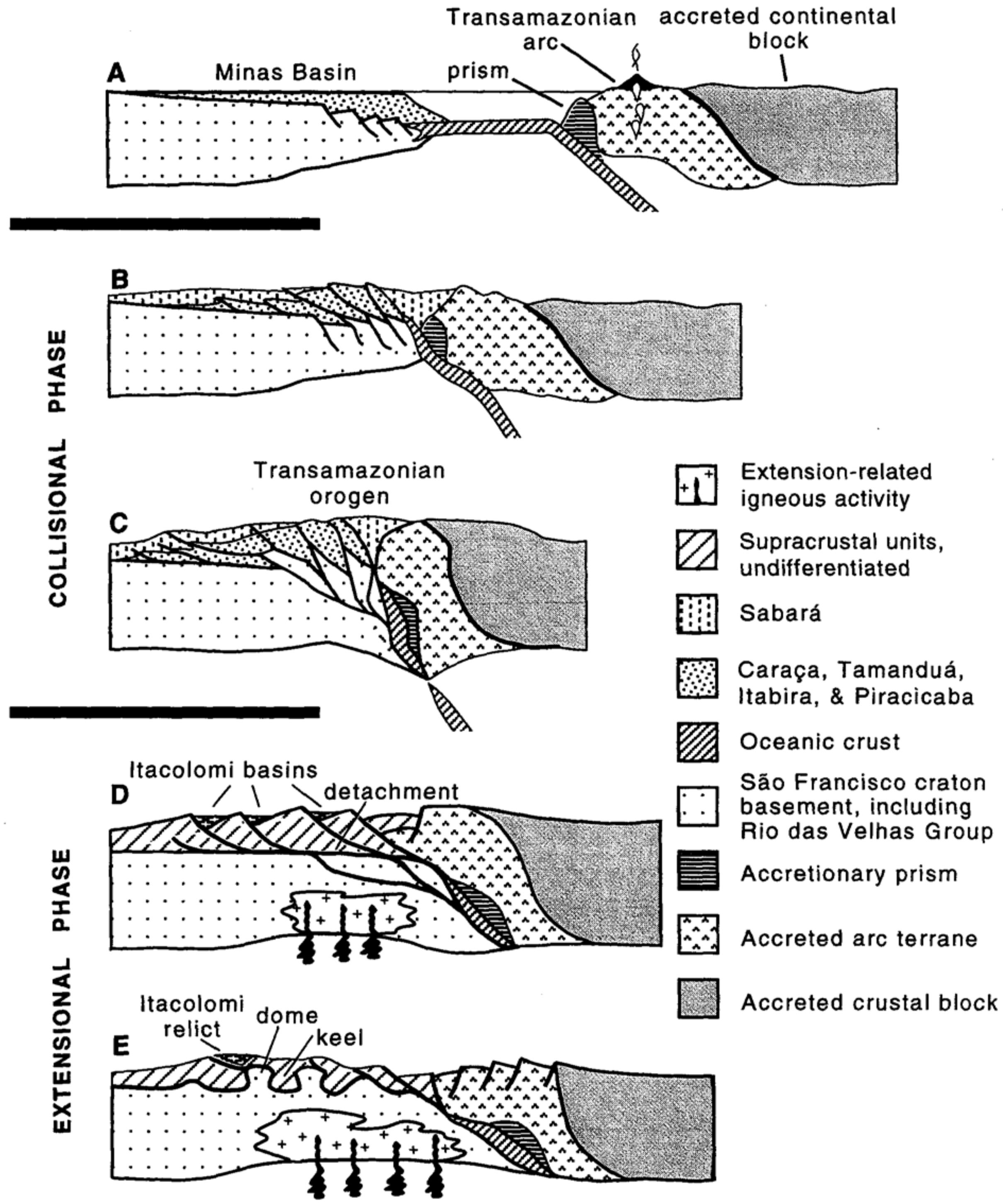

Fig. 2.4 - Cross-sections illustrating a model for evolution of the QF the during the Paleoproterozoic (see text for explanation). Reproduced from Alkmim and Marshak (1998).

basin, and created a NNW-verging fold-thrust belt that involved all supracrustal rocks of the QF. Thus, the QF preserves the foreland margin of an ENE-WSW-trending collisional belt, the Mineiro belt of Teixeira and Figueiredo (1991). The ages of detrital zircons in the Sabará Group indicated that the contractional phase began around 2.12 Ga.

The contractional phase was immediately followed by a process of extensional collapse, whose expression in the QF is the formation of keels containing the Rio das Velhas and Minas supergroup strata between domes cored by Archean TTG's and granitoids. Normal-sense shear along the boundaries of the keels juxtaposed Rio das Velhas and Minas strata against hot basement, and thus led to the development of metamorphic aureoles. The age of this metamorphism (2095±60 Ma), indicates that orogenic collapse occurred very soon after the formation of the Sabará basin and the contractional event. The deposition of the Itacolomi Group may record the generation of small extensional basins at this time; these basins were filled with an intermontane molasse.

3) The Espinhaço rifting event

Around 1.75 Ga, the continental masses that assembled during the Transamazonian orogenies experienced a major episode of rifting associated with bimodal magmatism (Brito Neves et al. 1996). In the northern São Francisco craton and along its eastern margin this rifting event resulted in a basin filled by the Espinhaço Supergroup, a thick package of continental to marine sandstones and pelites (Uhlein et al. 1998, Martins-Neto 2000). In the QF area the Espinhaço rifting event is represented only by mafic dikes, dated by Silva et al. (1995) and Carneiro et al. (2005) at around 1.75 Ga.

DAY 1

SUNDAY, SEPTEMBER 17th
FROM OURO PRETO TO CACHOEIRA DO CAMPO

Leaders: *Fernando F.Alkmim*[1]

Carlos M. Noce[2]

The stops planned for this afternoon (Fig. 2.1) focus the stratigraphy of the lower portion of Paleoproterozoic Minas Supergroup, and the deformation history of the southern QF. The lower and middle portions of the Minas Supergroup (Caraça, Itabira and Piracicaba groups) (Fig. 2.3), currently interpreted as a passive margin section developed between 2,6 and 2,4 Ga, may also contain the record of a glacial event, as we will discuss during the field trips.

Starting from Ouro Preto we drive west, following the E-W- trending Ouro Preto ridge, which corresponds to the northern limb of the Dom Bosco syncline, the dominant structure of the southern QF (Figs. 2.2 and 2.5). At the locality known as Funil bridge (or Funil creek) the roads crosses the Ouro Preto ridge. At this point we will examine exposures of the basal units of the Minas Supergroup, including the Lake Superior type Cauê Banded Iron Formation and the carbonates of the Gandarela Formation. We then will head north, to the Cachoeira do Campo, where we will take a dirt road to the Cumbi quarry, located 10 km to the southwest of the village. At this abandoned quarry will be looking at exposures of the youngest carbonate unit of the Minas Supergroup, and discussing its stratigraphic significance.

STOP 1.1 Railroad cut, Vitória-Minas Railway, km 131, Funil bridge.
UTM 0643543 - 7747136

The cut exposes the unconformity between the Archean Nova Lima Schist and the Paleoproterozoic Moeda Quartzite, the basal unit of the Minas Supergroup, which in its turn is overlained by the Batatal Phyllite and Cauê Banded Iron Formation. All units are strongly deformed and attenuated within a layer-parallel shear zone developed on the northern limb of the Dom Bosco syncline during the E-W shortening event (probably the Neoproterozoic Brasiliano event) that affected the eastern QF.

The Archean Nova Lima group is represented by a coarse grained biotite-quartz-plagioclase-sericite-chlorite schist. Sericite replaces porphyroclasts of plagioclase and other minerals, probably $AlSi_2O_5$ polymorphs. Granitoids and pegmatite veins (also deformed) cut the schist. One of these pegmatites intruded along the schistosity of the Nova Lima rocks and contains monazite that is 4.4% discordant with a $^{207}Pb/^{206}Pb$ age of 2022 Ma (Machado et al. 1992). This is in agreement with ages ranging from 2030 to 2059 Ma yielded by monazite and sphene from another pegmatite body and an amphibolite enclave, sampled at a gneiss quarry a few kilometers from this stop.

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The Moeda Formation consists of a quartz-sericite ultramilonite, with thin layers of a grey phylonite. The Batatal Formation a grey phyllite, composed essentially of sericite, hematite, calcite, and quartz, contains large hematite-rich nodules. The Cauê Formation is made up of itabirites and amphibole-rich itabirites in this locality.

The most prominent fabric element in the outcrop is a layer-parallel foliation, the south-dipping Sm_1-foliation, which pervasively affects all units. The Lm_1-stretching lineation on the Sm_1 surface plunges 35º to SE (108/35). S-C structures and a variety of other asymmetrical fabric elements indicate an overall reverse-dextral sense of shear. A second generation of structures, including open folds and a crenulation cleavage (S_2), overprint the previously mentioned fabric elements. The S_2-crenulation is the most expressive fabric in the Nova Lima-schist. In the Moeda Mylonite the crenulation is weak or absent.

STOP 1.2 BEMIL Quarry, route BR 356, 18 km west of Ouro Preto

UTM 0643512 - 7746009

In this quarry, located just a few hundred meters to the south of the last outcrop (Fig.2.5), the mining activities exposed the upper portion of the 2,4 Ga old Gandarela Formation and the contact with the overlaying Cercadinho Formation. The lower portion of the Gandarela Formation crops out in the road cuts in front of the quarry and under the adjacent Funil bridge.

As a whole, Gandarela Formation comprises in this area a ca. 120m thick package of carbonates (metamorphosed dolomites, dolomitic limestones and limestones) with intercalations of banded iron formations at the base, pelites in middle portion and a breccia in the upper part of the section. All these rocks are intensively deformed, so that no sedimentary structures are preserved.

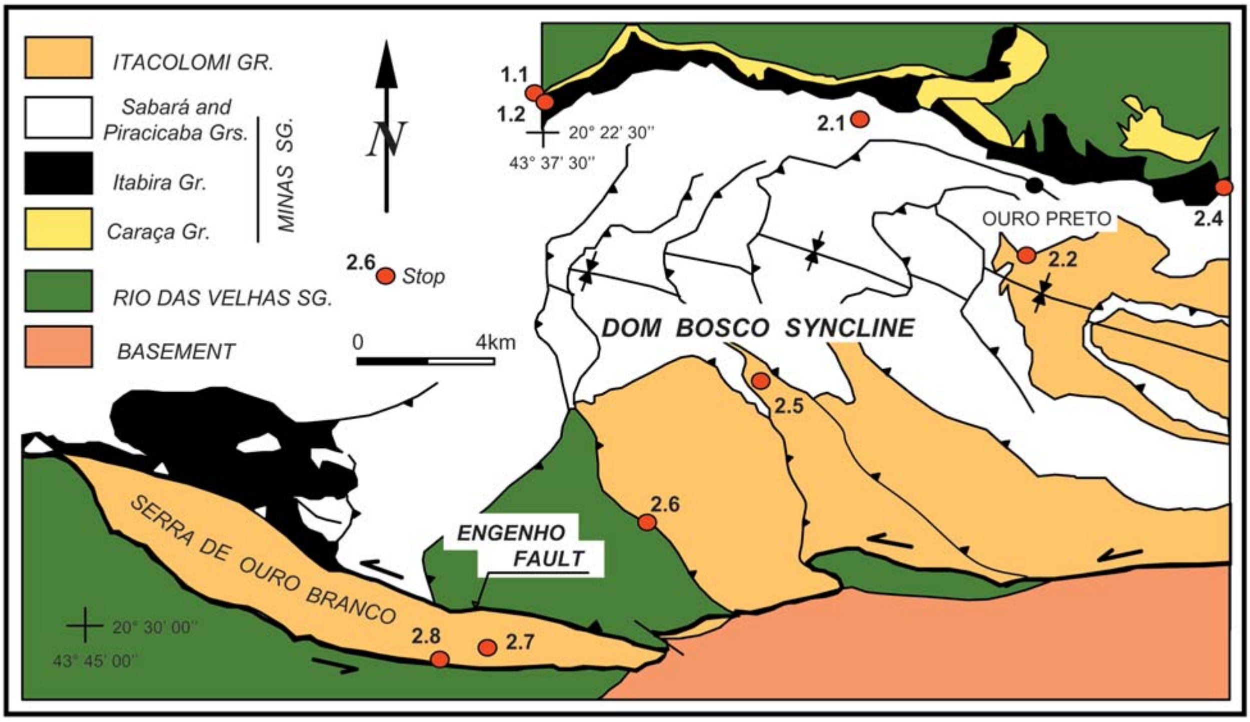

Fig. 2.5 - Simplified geologic map of the eastern Dom Bosco syncline, showing the location of the field trip stops of the first and second days field trips. Based on Dorr (1969).

The breccia layer contains fragments of quartzite, chert, and carbonate dispersed in a hematite-rich pelitic matrix. In other exposures of the Gandarela Formation these breccias also occur in the upper portion of the Gandarela Formation, as we will see in the next field trips.

The Gandarela carbonates are overlain by the Cercadinho Formation, which is composed of coarse grained, hematite-rich metasandstone, interbedded with layers of a silver phyllite, consisting of quartz, sericite and very fine grained hematite.

The rock section exposed in the quarry was involved in a W directed deformation front, represented by a penetrative bedding parallel and E-dipping foliation, which contains a down-dip stretching lineation. Ductile, E-dipping shear zones and large scale boudinage are also present in the quarry.

STOP 1.3 CUMBI quarry, 10 km to the southwest of Cachoeira do Campo
UTM 0636697 - 7742155

The purpose of this out crop is to examine a section of the Fecho Funil carbonates and discuss its stratigraphic significance. The Fecho do Funil Formation is composed of dolomitic phyllite and phyllite, with lenses of dolomitic marble. According to Dorr (1969), although in some places the carbonate lenses tend to be near the base of the formation, they may occur anywhere in the unit. In the Cumbi quarry, dolomite make up three lenses intercalated within carbonatic phyllites and gray phyllites, and the sequence is capped by carbonaceous phyllites of the Barreiro Formation (Fig. 2.6). The two larger lenses are about 100-120 m in length and 30-50 m thick. Both contain layers with well-preserved stromatolites.

Pb/Pb analyses of dolomites yielded an isochron age of 2110±110 Ma (Babinski et al. 1995) assumed as the age of a metamorphic event that caused loss or re-equilibration of radiogenic Pb in most samples. $\delta^{13}C$ values for the dolomite lenses range from +5.6 to +7.4 (Fig. 2.6). According to Bekker et al. (2003) these values must record the global ca. 2.2 Ga carbon isotope excursion in Brazil and are correlative with the Paleoproterozoic $\delta^{13}C$-enriched carbonates worldwide.

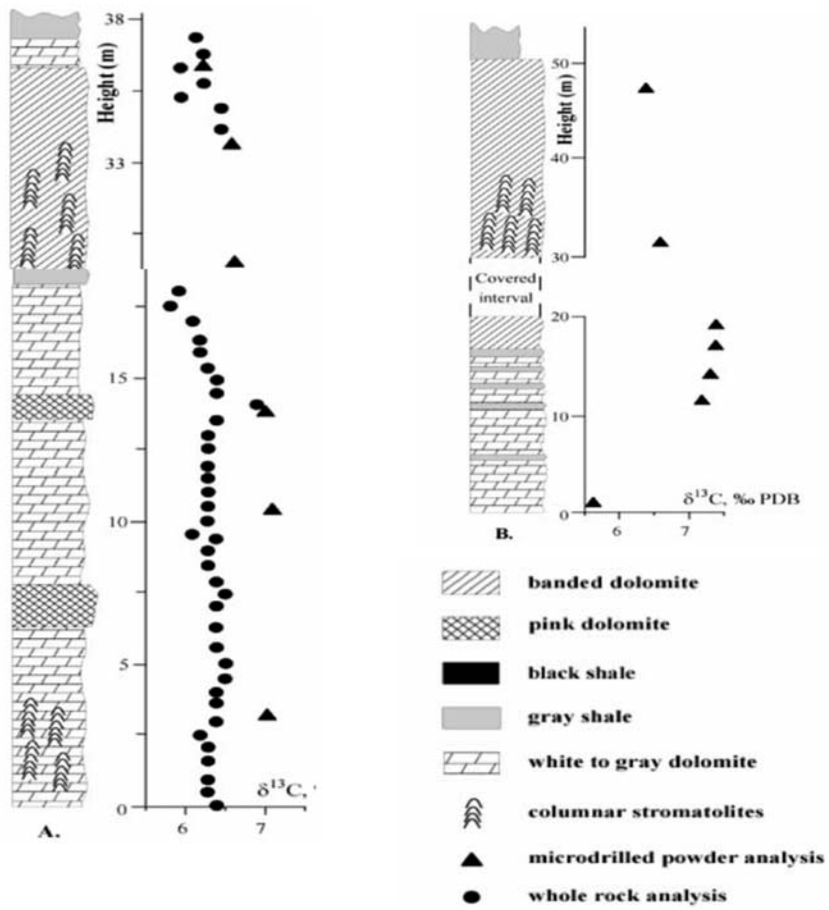

Fig. 2.6 - Stratigraphic columns of the dolomitic lenses of the Fecho do Funil Formation, Cumbi quarry, with $\delta^{13}C$ values. Reproduced from Bekker et al. (2003).

DAY 2

MONDAY, SEPTEMBER 18th
FROM OURO PRETO TO OURO BRANCO AND JECEABA

Leaders: *Fernando F.Alkmim*[1]

Carlos M. Noce[2]

This day will be devoted to aspects of the stratigraphy of the upper section of the Minas Supergroup and Itacolomi Group, as well as to other structural features of the southern QF. In addition, we will examine the gold deposits hosted in the basal units of Minas Supergroup, and as last stop of the day, the Alto Maranhão Tonalite, a component of the magmatic arc of the Paleoproterozoic Mineiro belt.

The route of the field trip, the historical Estrada Real, traverses through the Dom Bosco syncline (Fig. 2.5), a major keel of the QF dome-and-keel province that has been strongly affected by W-directed thrusting. Details of the resulting geometries and kinematic picture will be addressed during the trip.

We will start at an outcrop located at the western entrance to Ouro Preto. We then move eastwards, stopping at the Itacolomi Natural Park, to reach later the very southeastern corner of the Iron Quadrangle, close to the town of Mariana. After visiting the Passagem gold mine, we will take the Estrada Real and drive southwest, through the rough topography of the southern QF. Having crossed the Ouro Branco ridge that marks the southern boundary of the QF, we enter a different landscape, characterize by lower relief energy developed on the Archean basement rocks of the southern São Francisco craton. We keep driving southwest up to a quarry in the vicinity of the town of Jeceaba. From this place we take the route BR 040 and head north to Belo Horizonte.

STOP 2.1 Road cut, MG 262 1km from the intersection with route BR 356
UTM: 7745 580/ 652 884

The Sabará Group is represented in this outcrop by deeply weathered schists interbedded with meta-diamictite layers. The diamictites contain pebble to boulder sized fragments of quartz, ferruginous quartzites, grey and silver phyllites, banded iron formation and granitoids dispersed in a pelitic matrix.

The layer parallel foliation dips 30^{o} to ESE and is associated with a down-dip stretching lineation. Asymmetric tails around the clasts, foliation sigmoids and other small scale features indicate an overall top-to-the-west motion.

STOP 2.2 Itacolomi Natural Park, Ouro Preto
UTM: 7742 368/ 656 235

The Itacolomi Group in its type locality, the Itacolomi ridge in the central portion of the Dom Bosco

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syncline (Fig. 2.5), comprises a ca. 1800m thick package of alluvial sandstones and conglomerates. Proximal alluvial fan deposits, represented by a conglomerate dominated succession, are exposed in the eastern portion of Itacolomi ridge. Towards west, the succession becomes dominated by distal braided plain deposits, as we will observe in the outcrops.

The cuts along the access trail to the Itacolomi peak expose the unconformable contact (locally sheared) of the Itacolomi Group with the underlying Sabará phyllites and a ca. 40m thick sandstone bed, caped by a 4m thick conglomerate layer. The basal quartz-rich meta-sandstones are very coarse grained, poorly sorted and show small-scale trough cross-bedding. The pebble conglomerates are grain supported and contain clasts of quartz vein?, ferruginous quartzites, phyllites and tourmalinite. Bedding surfaces dip 35^{o} to ENE, and are cut by a weakly developed foliation.

Detrital zircons extracted from a sample collect in this outcrop yielded the age spectrum shown in the diagram of Fig. 2.7. New U-Pb SHRIMP obtained by Hartmann et al. (2006) for the Itacolomi Group are also shown on Fig. 2.7.

STOP 2.3 Road side, route MG 262, Km 198,6
UTM 7745 041 /667 494

From this point looking west we see the nose of the E-SE-plunging Mariana anticline (Figs. 2.2 and 2.5), delineated by the outcrops of the Cauê Iron Formation of the Minas Supergroup. A laterite crust developed on the itabirites of the Cauê Iron Formation makes this unit resistant to erosion. The "scars" in the landscape resulted from gold mining during the colonial times.

The QF region has been reached by pioneers only by the end of the 17th century, i.e., ca. 170 years

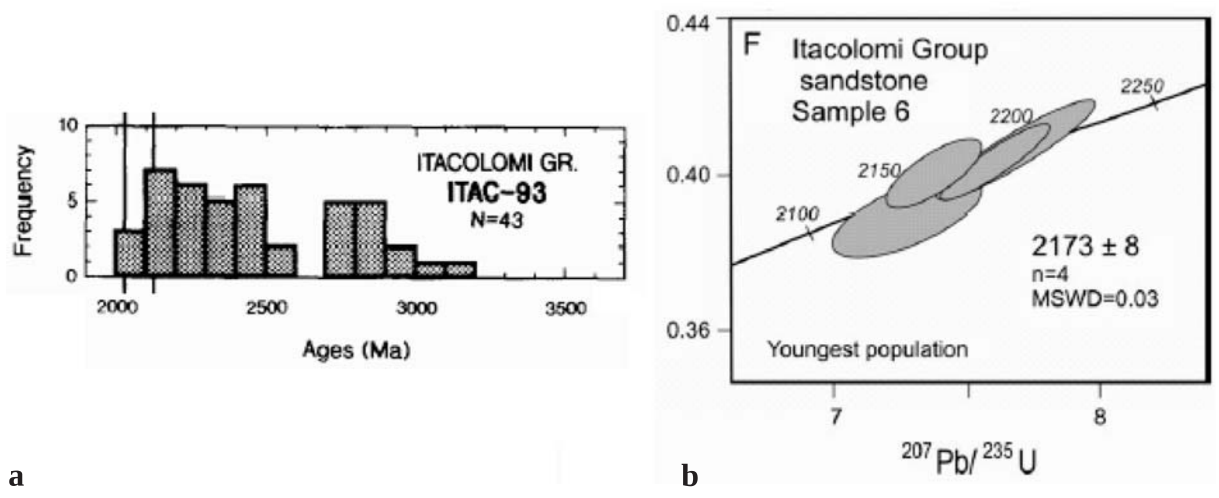

Fig. 2.7a Histogram for ages of detrital zircon of a Itacolomi quartzite sample from the type locality at Serra do Itacolomi (Laser ablation-ICPMS $^{207}Pb/^{206}Pb$ ages, Machado et al. 1996). Detrital zircon ages display a well defined mode at 2.7-2.9 Ga. an irregular distribution of ages younger than 2500 Ma, and a minimum age of 2059±58 Ma. **b** U-Pb SHRIMP ages of detrital zircons of a quartzite from the Itacolomi Group (Hartmann et al. 2006). Reconnaissance dating of six zircon crystals (seven spots) yields three Archean ages (3236±18, 3046±9 and 2812±13 Ma) and four Paleoproterozoic ages pooled at 2173±8 Ma.

after the arrival of the Portuguese in South America. The towns of Ouro Preto (former Villa Rica) and Mariana (former Villa do Carmo) were born in the aftermath of the gold discovery by the pioneer Antônio Dias in 1698. A fast succession of many other discoveries triggered a gold rush that resulted in a production of ca. 10 metric tons of gold per year between 1735 and 1744. The population of Villa Rica and its surroundings may have reached 80.000 inhabitants around 1750. However, after 1760, the production progressively decreased, being reduced down to 3 tons/year by the end of the century. The total production of the so called gold cycle (18^{th} century) is estimated in ca. 640 metric tons. Due to the depletion of the rich deposits and the lack on mining technology, the 19^{th} century is characterized by the decline of the gold cycle.

In the first years of the gold rush, the mining activities were concentrated in the river beds. Gold nuggets found in the alluvial deposits of the region show a typical dark coating of hematite, hence the name Ouro Preto ("black gold"). Afterwards, terraces and colluvial deposits were accessed, and only later, as the production started to decline, source ore bodies have been discovered. Along the Ouro Preto ridge, originally referred to as the Golden ridge, hydrothermal deposits are hosted by a thick, south-dipping shear zone, developed along the contact between the Archean Rio das Velhas and Paleoproterozoic Minas supergroups.

The Mariana anticline (Fig. 2.2), one of the few large scale antiformal structures of the Q.F., connects two keels: the Santa Rita and Dom Bosco synclines, respectively, to north and to south. The Mariana anticline is probably a Paleoproterozoic (Transamazonian) structure, which pre-dates the west-vergent Brasiliano deformation, causing a very pronounced strain partitioning during the westward propagation of the thrust sheets.

STOP 2.4 Passagem gold Mine in Passagem de Mariana

UTM 7744 372/ 662 986

The Passagem mine is located in the southeastern corner of the QF, between Ouro Preto and Mariana. The deposit lies in the nose zone of the Mariana anticline, within the major shear zone developed along the contact between the Nova schist of Rio das Velhas Supergroup and basal units of the Minas Supergroup. With a maximal extension of 4 km, the mineralized zone dips 18^{o}-20^{o} to SE and shows thickness between 2 and 15m. It corresponds to a hydrothermal alteration front, marked by the occurrence of abundant quartz and carbonate veins, tourmalinites, and sulfides. Gold occurs in association with arsenopyrite and bismuthinite, as inclusions or filling intergranular and fracture spaces. The mineralization took place after the peak of the syn-kinematic amphibolite facies metamorphism (Duarte 1991). According to Chauvet et al (1993), the intensive hydrothermal activity responsible for the mineralization was associated to the gravity collapse that followed the Brasiliano contractional event. Previous models for the development of the Passagem deposit postulated a Paleoproterozoic syngenetic origin for the mineralization (Fleisher and Routhier 1973, Vial 1988).

Gold mining in Passagem started immediately after the first discoveries in the region. The German naturalist and mining engineer Wilhem Ludwig von Eschwege founded the company *Sociedade Mineralógica de Passagem* in 1819 and introduced the mining technology in the region. The underground activities persisted, with some interruptions, until the beginning of the 70's of the last century. The total production of the mine is estimated in ca. 6 metric tons of gold.

STOP 2.5 Road cut, access road to the Lavras Novas village from the Estrada Real
UTM 7738 454/ 658 321

This plateau area known as "Chapada" is underlain by a thick sequence of metasandstones and conglomerates of the Itacolomi Group (Fig. 2.5). The purpose of this stop is twofold. First, we will examine trough cross beds in a distal sandstone facies of the Itacolomi Group, which indicate a sediment input from the east. Second, we will observe in the landscape the morphological expression of the system of curved thrust that affects the Itacolomi and older units within the Dom Bosco syncline (Fig. 2.5).

In a recently published paper, Almeida et al. (2005) postulated an alternative interpretation for the stratigraphy and internal structure of this portion of the Dom Bosco syncline. These authors portrayed the observed intercalations between phyllites and quartzites as part of a south-verging fold nappe. Furthermore, they correlate the quartzites exposed here with the Sabará Group.

STOP 2.6 Calixto bridge, Estrada Real
UTM 7734 379/ 646 482

Very coarse, matrix supported conglomerates of the basal Itacolomi Group were here catch by the lateral ramp of one of the major thrusts that affect the eastern Dom Bosco syncline (Fig. 2.5).

The conglomerates contain cobbles and boulders of quartzite, phyllite, vein-quartz vein and banded iron formation. They are underlain by a sandstone layer, represented by a sericite-hematite-quartz mylonite. The S-C and ECC mylonitic foliations dip NE. The associated stretching lineation plunges 35^o to S80E. The sense of shear deduced from the kinematic indicators is reverse-sinistral.

STOP 2.7 South escarpment of the Ouro Branco ridge, Estrada Real
UTM 7731 761/ 642 237

The E-W-trending Ouro Branco ridge extends for ca. 17 km along the southern border of the QF (Figs. 2.2, 2.5). It is underlain by a 1350m thick package of metasandstones and metaconglomerates of the Itacolomi Group. A diagram showing the distribution of lithofacies units along the ridge is shown on Fig. 2.8. A sediment source located to the east can be inferred from this diagram, reproducing the observations we made in the previous outcrops. The lithofacies units mapped in the area can be easily recognized in the landscape of the ridge, for they have very distinct morphological expressions.

Detrital zircons extracted from the Ouro Branco ridge quartzites yielded an age spectrum comparable with pattern obtained for the Itacolomi Group at its type locality (Machado et al. 1996) (Fig.2.9).

As a whole, the Ouro Branco ridge corresponds to a large-scale, left-lateral oblique-slip duplex, bounded on both the south and north sides by splays of the so called Engenho fault (Alkmim and Ribeiro 1997) (Figs. 2.5, 2.10). Within the duplex, a series of reverse-sinistral faults connects the sole and roof splays of the Engenho fault and cause a N-direct, clockwise rotation of the strata involved. The amount of rotation increases towards east, as shown by the block-diagram of Fig. 2.10.

Coarse grained pebbly metasandstones with large trough cross-beds strike E-W and dip steeply to the north in this outcrop. A penetrative ENE-dipping foliation cuts the bedding at high angle.

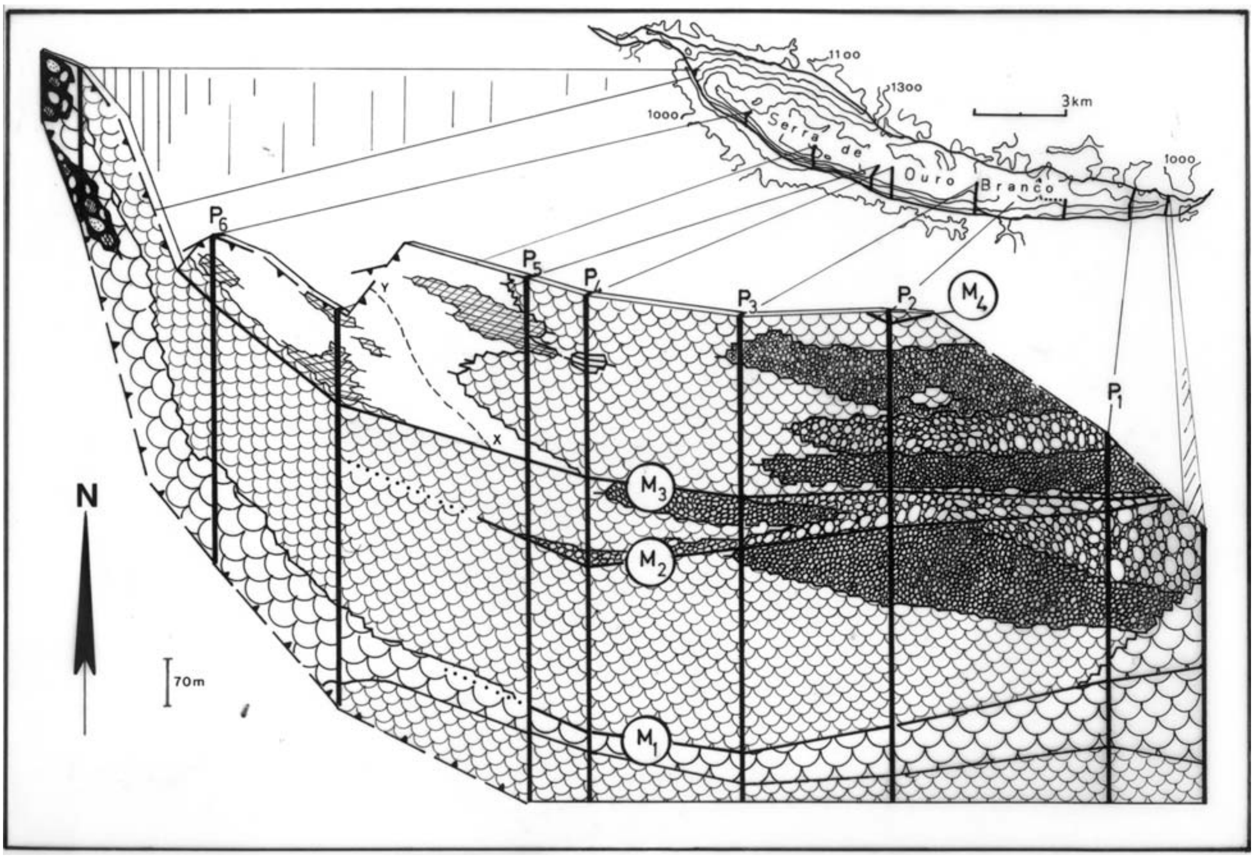

Fig. 2.8 Facies diagram for the Itacolomi sequence exposed in the Serra de Ouro Branco. M1 to M4 are conglomerate guide-horizons. From Alkmim (1987).

STOP 2.8 Base of the south escarpment of the Ouro Branco ridge, Estrada Real

At this point (Fig. 2.5 and 2. 10), the south splay of Engenho fault juxtaposes the Archean Nova Lima Schists and the Itacolomi Quartzites. The fault zone is marked here and along the whole length of the Ouro Branco ridge by a quartz-ultramylonite band, whose thickness can reach more than 100m. The mylonitic foliation dips NE; the stretching lineation plunges 20-30^{o} to ESE. A sinistral-reverse sense of shear can be deduced from various categories of indicators.

STOP 2.9 Alto Maranhão Pluton, small quarry near the town of Jeceaba

UTM 7726 615/ 621 325

The Alto Maranhão pluton is part of a Paleoproterozoic plutonic arc that crops out along the southern border of the São Francisco craton, to the

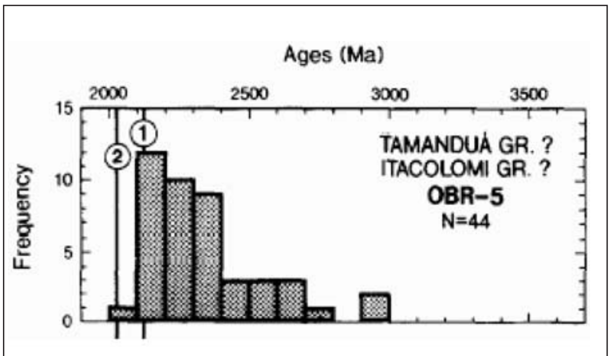

Fig. 2.9 - Histogram for ages of detrital zircon of a quartzite sample from Serra do Ouro Branco (Laser ablation-ICPMS $^{207}Pb/^{206}Pb$ ages, Machado et al. 1996). The age pattern of 44 zircon grains reveals a high concentration of ages in the 2.1-2.4 Ga range, a mode at 2.1-2.2 Ga and a minor Archean component. The age pattern and the minimum age of 2066±60 Ma is similar to that obtained for the Itacolomi Group at the type locality.

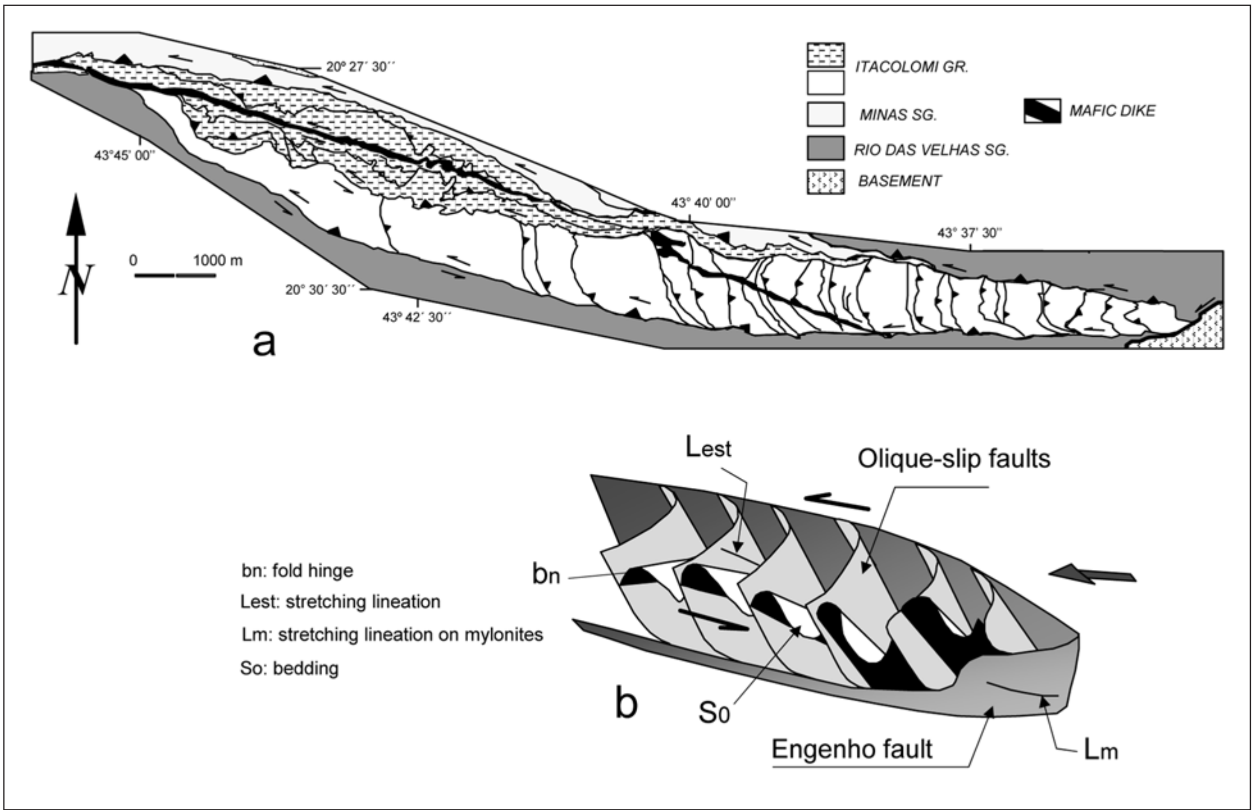

Fig. 2.10 - a Structural map of the Serra de Ouro Branco. The geometry and kinematics of the fault system affecting the Itacolomi quartzites along the Ouro Branco ridge characterizes an oblique-slip duplex (Alkmim and Ribeiro 1997). **b** Block-diagram illustrating the internal structure of the Serra de Ouro Branco oblique-slip duplex. See the text for explanation.

south and southwest of the QF (Fig. 2.11). The components of the arc intrude the Archean crust composed of TTG gneiss and migmatite, granulites and greenstone belts. The Paleoproterozoic plutonic rocks display a wide range of compositions, varying from gabro-diorite, TTG (tonalite-trondhjemite-granodiorite) to granite. These plutons do not follow any clear evolutionary trend, as mantle-derived tonalites and highly fractionated S-type granites may show a close spatial/temporal relationship (Noce et al. 2002). Available U-Pb ages points to at least two major magmatic episodes at ca. 2.24-2.18 Ga and 2.13-2.05 Ga (Noce et al. 2002).

The Alto Maranhão tonalite belongs to the younger generation of granitoid plutons. In the small quarry of this stop, the rock is foliated, tonalitic in composition, and consists of plagioclase, quartz, biotite, and hornblende, with minor sphene, zircon, apatite, and allanite. A mafic dike cutting across the tonalite can be seen at the right side of the quarry.

This calc-alkaline tonalitic intrusion contains in average 66.3% of SiO_2, 4.2%, of CaO, 4.6% of Na_2O, 1,8% of K_2O, and high FeO_t+MgO amounts (3.92 to 6.93%). Rb/Sr values are very low (around 0.06). Its spidergram shows a strong Nb depletion, Ba enrichment and no Sr depletion (Fig.2.12a). REE data yield fractionated patterns with HREE depletion and no Eu/Eu* anomalies (Fig.211a).

U-Pb zircon and sphene analyses yielded an intrusion age of 2124±1 Ma (Fig. 2.12b). Sm-Nd analyses yielded a model-age (T_{DM}) of 2.27 Ga. $\varepsilon_{Nd(2.1)}$ value is +1.3, and initial $^{87}Sr/^{86}Sr$ values are low, ranging from 0.70191 to 0.70266. Geochemical and isotopic signatures suggest a mantle-source for the tonalitic magma. Seixas et al. (2002) proposed for the tonalitic magma a hybrid mantle source produced by the interaction of the mantle wedge with “adakitic” LILE rich and HFSE poor slab melts; the residues would probably involve garnet and no plagioclase.

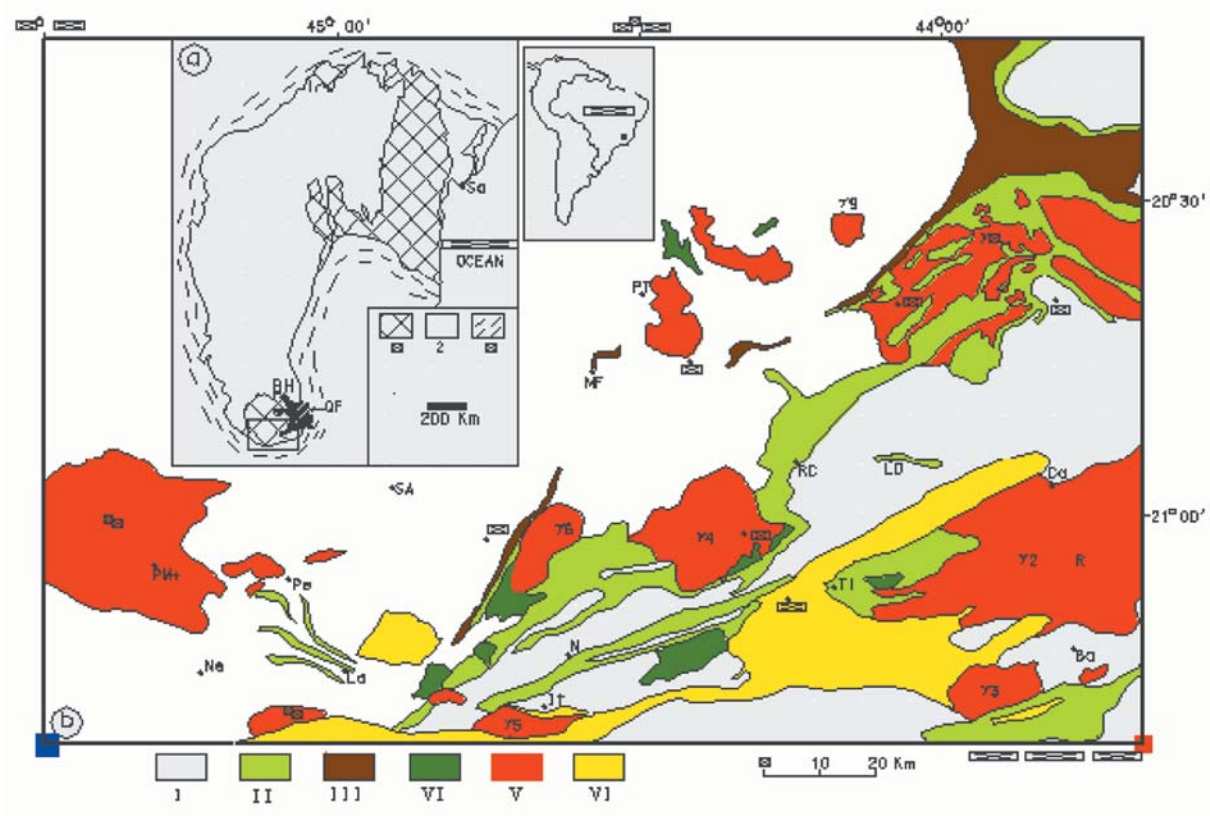

Fig. 2.11 - Geologic map of the Southern São Francisco craton region showing the distribution of Paleoproterozoic granitoid plutons (in red) that intrude the Archean basement southwest of the QF. (Modified from Noce et al. (2000).

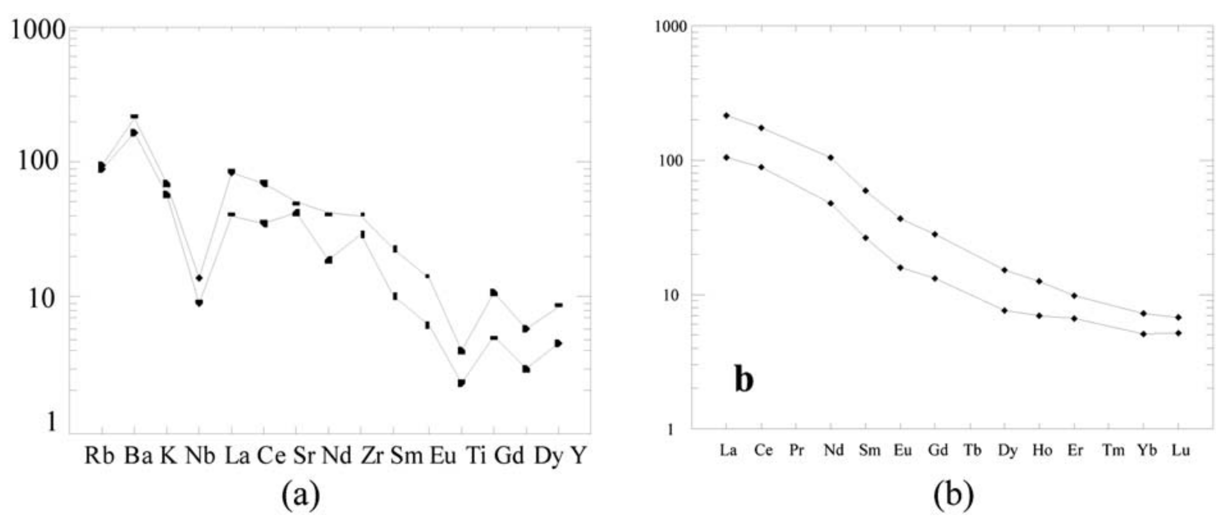

Fig. 2.12 - a Primitive mantle-normalized spidergram fot the Alto Maranhão pluton. **b** Chondrite-normalized REE patterns for the Alto Maranhão Pluton.

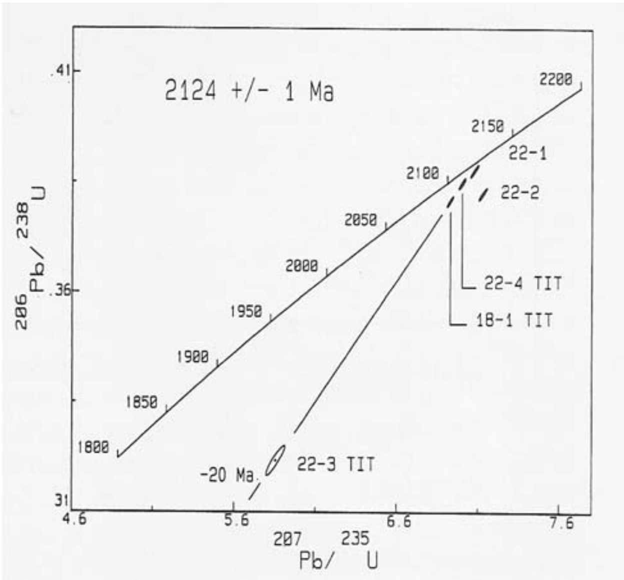

Fig. 2.13 - Concordia diagram for the Alto Maranhão tonalite (Noce et al. 1998).

DAY 3

TUESDAY, SEPTEMBER 19th IRON ORE DEPOSITS SOUTH OF BELO HORIONTE

Leaders: *Leandro Q. Amorim*[1]

Victor Suckau[1]

The third field trip day will be spent in the iron ore mining complex of the Minerações Brasileiras Reunidas – MBR in the northern QF (Fig. 2.14). We will have an opportunity to look at outcrops of various components of the Cauê Banded Iron Formation and to discuss its significance in terms of global processes operating in Paleoproterozic Earth. The MBR geologists leading the trip will also address topics related to iron ore genesis in the QF and its importance for the past and present-day Brazilian economy. In addition, we will stop at an outcrop located in the MBR property, which exposes the contact between Gandarela Formation breccias (candidate for the record of a glacial event) and the overlaying Cercadinho Quartzite.

Departing from Belo Horizonte we drive to the Águas Claras Mine, located in the Serra do Curral (Figs. 2.1 and 2.14), the prominent WSW-ESE-oriented ridge that bounds the Iron Quadrangle to the north. From this locality, we keep driving south along the Moeda plateau on the route BR 040, until the entrance to the Capitão do Mato Mine. After looking outcrops of the basal portion of Cauê Formation in the mine pit, we will take the route known as Green Line, that connects the Capitão do Mato and Pico Mines. Halfway between these two mines we will stop to look at the Gandarela Breccias. After visiting the Pico Mine we drive back to our hotel near Belo Horizonte.

STOP 3.1 Águas Claras Mine, Serra do Curral, south of Belo Horizonte

Águas Claras, a former iron ore mine, is located 7 km south of Belo Horizonte , in the central part of the Serra do Curral (Fig. 2.14). The mined ore body was ca. 1600m long, 250m wide and 500m thick, and consisted of soft hemtatite, a supergene enriched ore corresponding to a finely laminated leached BIF, with local pockets of hard hematite (mylonitized and/or thickly laminated BIF) derived from the Cauê Formation. The boundaries of the ore body were determined by facies transitions between dolomitic and silica-rich iron formations. The depth of leaching that produced the soft ore increases from NE to SW along the strike of the iron formation. The contact between the soft ore and the hard dolomitic itabirite is now exposed at the NE limit of the mine, as well as in its central part. The stratigraphic sequence is overturned along the Serra do Curral and because of that, quartzite and phyllite of the Moeda and Batatal formations lay over the dolomitic and the siliceous itabirites of the Cauê Formation.

[1]*MBR - Minerações Brasileiras Reunidas.*

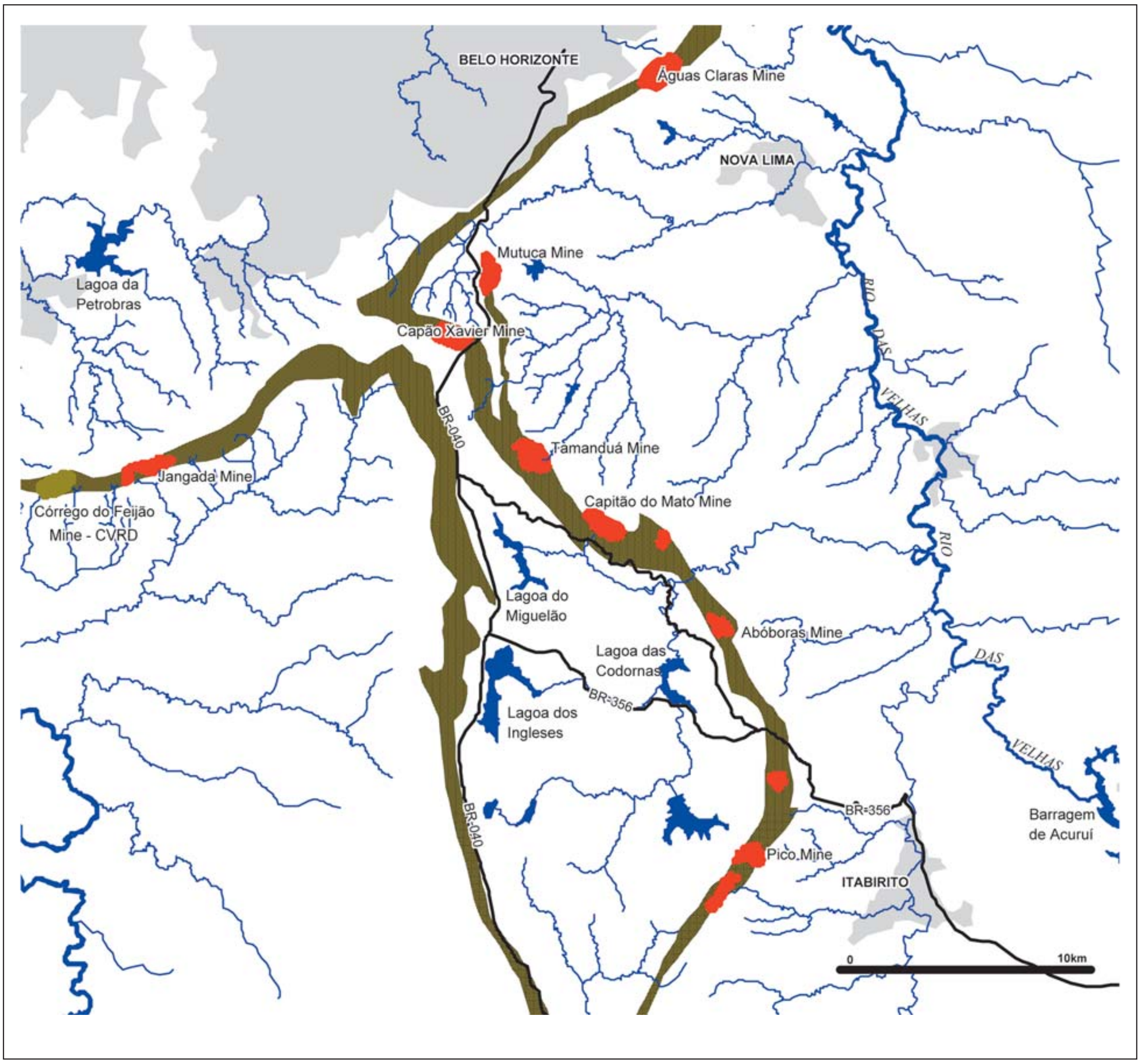

Fig. 2.14 - Map showing the outcrop belts of the Cauê Iron Formation in the Moeda syncline and the location of the iron mines of the northern QF.

The mine started in 1973 and closed in 2003. The mining operation involved the removal of about 250 million tons of waste in order to exploit 300 million tons of "run of mine", thereby generating 270 million tons of products (iron ore) and 30 million tons of tailings. The ore was of very high grade, averaging 67-68 % Fe, so that no concentration was required. Due to the completeness of the supergene enrichment, less than 20% of the total ore volume corresponded to lump ore (i.e., blocks of hard hematite dispersed in the soft-ore matrix). The soft ore reserve was made up of 50% "sinter-feed" (i.e., can be used directly in sinterization smelting) and 30% pellet-feed.

STOP 3.2 Capitão do Mato Mine

The Capitão do Mato mine is located on the eastern limb of the Moeda Syncline (Fig. 2.14). The ore body strikes N70°W and is composed mainly of hipogene hematite. Developed in the interior of a large-scale fold, the 2400 m long ore body has a rather complex internal structure, in which discontinuous and irregular shaped masses of hard hematite are surrounded by bands of supergene soft hematite and itabirites. Bounded to the NE by the phyllites of the Batatal Formation, the ore body forms a narrow and sub vertical belt (50 - 100 m wide) in the northwest part of the deposit, becoming quite broad (up to 300 m wide) in the extreme southeast, as a consequence of folding and supergene events combined. The proto-ore in this deposit is a siliceous itabirite.

The main foliation, N-S striking and dipping 80°E, is strongly developed in the adjacent units and in the iron formation as well. It represents the axial surface foliation of the small-scale folds frequently observed in the area, which in turn are parasitic to the large fold that defines the general architecture of the deposit.

The proportion of coarse material (>6,3 mm) is about 40%. The reason for that is the high proportion of hipogene ore in this deposit. The Capitão do Mato lump ore is also suitable for direct reduction.

The mine started production in 1996 and it is scheduled to produce 14 million tons of iron ore in 2006.

STOP 3.3 Green line, at the intersection with the access road to Rio do Peixe village
UTM 616558/7770756

In a few exposures of the upper portion of the Gandarela Formation located along the hinge zone of the Moeda syncline, a thick breccia lies on an irregular surface developed on top of pink dolomites and is caped by the ferruginous quartzites of the Cercadinho Formation. This outcrop (Fig. 2.14) shows such a breccia in contact with the Cercadinho Quartzites. Angular fragments consisting of chert, and rare carbonate are dispersed in a brown matriz, made up of fine grained carbonate~~s~~, hematite, and quartz.

STOP 3.4 Pico Mine, Itabirito Peak

The Pico Mine is also located on the eastern limb of the Moeda Syncline (Fig. 2.14). In the vicinity of the mine, the iron formation is 700 m thick, and strikes N25°E. It is bounded to the SE by phyllites of the Batatal Formation and to the NW, by dolomites of the Gandarela Formation. Due to its high ductibility, the itabirite has been intensely folded and shows dips that can vary from 20° to 85° either to SE and NW. On the other hand, the more competent quartzites of the Moeda Formation that crop out continuously to the southeast of the area show a very consistent sub vertical dip.

Lithologically, the Cauê Formation is represented by ordinary (siliceous) itabirites and hematites of variable consistency. No dolomitic itabirite has been found in the area so far. Within the Cauê Formation, there are two major hematite ore bodies surrounded by soft and hard itabirite with quite irregular shapes. They are located on the southwest and northeast parts of the mine.

The southwest hematite ore body is composed of a massive core of hipogene hard ore (the Pico Monument), surrounded by soft ore and itabirites. The northeast hematite body consists mainly of soft ore, surrounded by soft and hard itabirites. This ore body is bounded to the northeast by a dike of mafic rock and to the southwest by phyllites of Batatal Formation. The mineralization goes as deep as 400m from the surface.

Notwithstanding the iron formation appearing folded, faulted and sheared, no shear zones cut through the adjacent quartzites of the Moeda Formation, where the main foliation is very weakly developed, as opposed as what occurs at Capitão do Mato mine. Probably as a consequence of the large strains experienced by the iron formation, the lump ore of this mine is not porous, being not suitable for direct reduction processes.

The Pico mine is the oldest operation unit of MBR. Exploitation started in the 40‘s with a small production that persisted until the beginning of the 90‘s, when an expansion program was carried out. The exploitation is developed in three pits, named Galinheiro (to the north); Sapecado (to the south) and Pico Mine itself. The total production scheduled for 2006 is around 20 million tones. The reserves of high grade hematite ore are to be depleted by the year 2008. Because of that, a new project involving the mining of low grade itabirite ore is being carried out. With investments in the order US$ 760 million, the project considers the expansion of the mining areas, the construction of a concentration plant, as well as the implementation of a pelletizing plant.

DAY 4

WEDNESDAY, SEPTEMBER 20th
FROM BELO HORIZONTE TO THE GANDARELA FARM VIA NOVA LIMA

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The onset of the Minas basin development, recorded by the proximal facies of the Moeda Formation, and the paleo-environmental significance of the Gandarela Carbonates are the focus of the fourth day field trip. Additionally, we will visit a museum devoted to the history of gold mining in the Nova Lima district and look at one outcrop of the Archean Rio das Velhas Supergroup, the host unit of the largest gold deposits in the Quadrilátero Ferrífero.

From Belo Horizonte we first drive southwest using on the route BR 040 up to the entrance of the Retiro das Pedras village, where we turn west on a dirt road. Our first stop will be on the edge of the Moeda plateau (Fig. 2.1). From this place we return to Belo Horizonte and drive south, to the town of Nova Lima, where we will visit the Morro Velho Memorial Centre. From Nova Lima we will travel across the Rio das Velhas valley to reach the Gandarela farm in the eastern QF.

STOP 4.1 Serra da Moeda, western edge of the Moeda plateau

UTM 605562/7775166

This point, located in the western limb of the N-S trending Moeda syncline, allows a scenic view of the landscape of western QF. Looking west and southwest, we see the low lands underlain by the Archean basement gneisses and granitoids of the Bonfim Complex; looking NW, the western segment of the Curral range. The Serra do Curral, which corresponds to an WSW-ENE-trending overturned homocline interferes with Moeda syncline in a rather complex structure that will be discussed in the following day.

Looking at the slope's base we can see the Moeda Formation lower contact. At this place the Moeda conglomerates and quartzites lay on top of phyllites of the Nova Lima Group (Rio das Velhas Greenstone Belt). Moeda basal conglomerates were mined for gold in the XVIII century. The old pit and ruins of a fortified house still stand.

Besides the scenic view, the purpose of this outcrop is to examine proximal alluvial deposits of the basal and upper Moeda Formation, which are separated by transgressive marine pelites.

The subdivision of the Moeda Formation into three members (Wallace 1965, Dorr 1969) is also clearly seen from this viewing point. Member 1 makes up the steep slope above the basal contact.

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The slope changes eastward into a flat area with a smooth surface, where member 2 is exposed, and then again into a rugged surface due to the presence of member 3. Member 1 consists of lenticular beds of basal conglomerate and a thick pile of medium- to coarse grained, pure or sericitic quartzite; Member 2 of very fine-grained quartzite, gray quartz-sericite phyllite, and phyllite. Member 3 is made up of medium- to coarse-grained quartzite and conglomerate lenses.

We will make a short W-E cross-section from the top of member 1 to the base of member 3. A striking feature is the sharp contact between the basal conglomerate of Member 3 and the pelitic rocks of Member 2. The conglomerate has well rounded clasts of smoky quartz in a matrix of medium- to coarse-grained quartzite.

Following the contact between members 2 and 3 we will cross a E-W left-handed strike-slip fault that displaced the contact for ca. 30 m.

STOP 4.2 Morro Velho Memorial Centre, Nova Lima

The Morro Velho gold mine in Nova Lima mirrors the history of gold mining in central Minas Gerais. The deposit consists of several gold/sulfide bearing quartz lodes hosted in the Archean Rio das Velhas Greenstone Belt. In the beginning of the mining activities, the near surface portion of the deposit, enriched by deep tropical weathering, was mined by Portuguese settlers with primitive methods. A British company bought the mine in 1834 and proceeded with systematic underground operations. During the 1920's it became the deepest mine of the world, reaching about 2000 m below surface. Now owned by the South-African company Anglogold-Ashanti, it was closed down in 2003. During nearly 170 years, the company produced about 500 metric tons of gold from Morro Velho and other mines that have been incorporated over the years.

STOP 4.3 Rio Acima town

The Rio das Velhas Greenstone belt records a felsic eruptive event dated from 2792±11 to 2751±9 Ma that was coeval with the intrusion of tonalite and granodiorite plutons. Although no direct age of komatiite and tholeiitic volcanism is available, there are field indications of some overlapping with the felsic event. As the original stratigraphy of the belt was disrupted by polyphase tectonism, its successive evolutionary stages cannot be determined with precision, and the felsic magmatism spanning a range of about 40 Ma may also have encompassed the whole magmatism within the belt.

The outcrop consists of an approximately 50m thick body of a slightly schistose greenish-gray metagraywacke, containing lithic fragments, quartz and plagioclase crystals of volcanic origin. A U–Pb SHRIMP analysis was carried out on a sample from this outcrop (Noce et al. 2005). Analysed crystals display varied morphological aspects, and yield a complex age pattern due to the combination of different crystallization ages and recent and/or episodic lead loss. The concordant or near concordant data within the youngest age distribution are represented by magmatic-textured euhedral crystals numbered 11 and 12 on Fig. 2.15. Analyses 11.1 and 12.1 on magmatic overgrowths (Fig. 2.15) yield a mean $^{207}Pb/^{206}Pb$ age of 2792±11 Ma. This can be assumed as the maximum age of the graywacke deposition, and also as the probable age of the volcanic source, considering that a dacitic lava has been dated at 2772±6Ma (Machado et al., 1992). The presence of older zircon grains with distinct morphological types

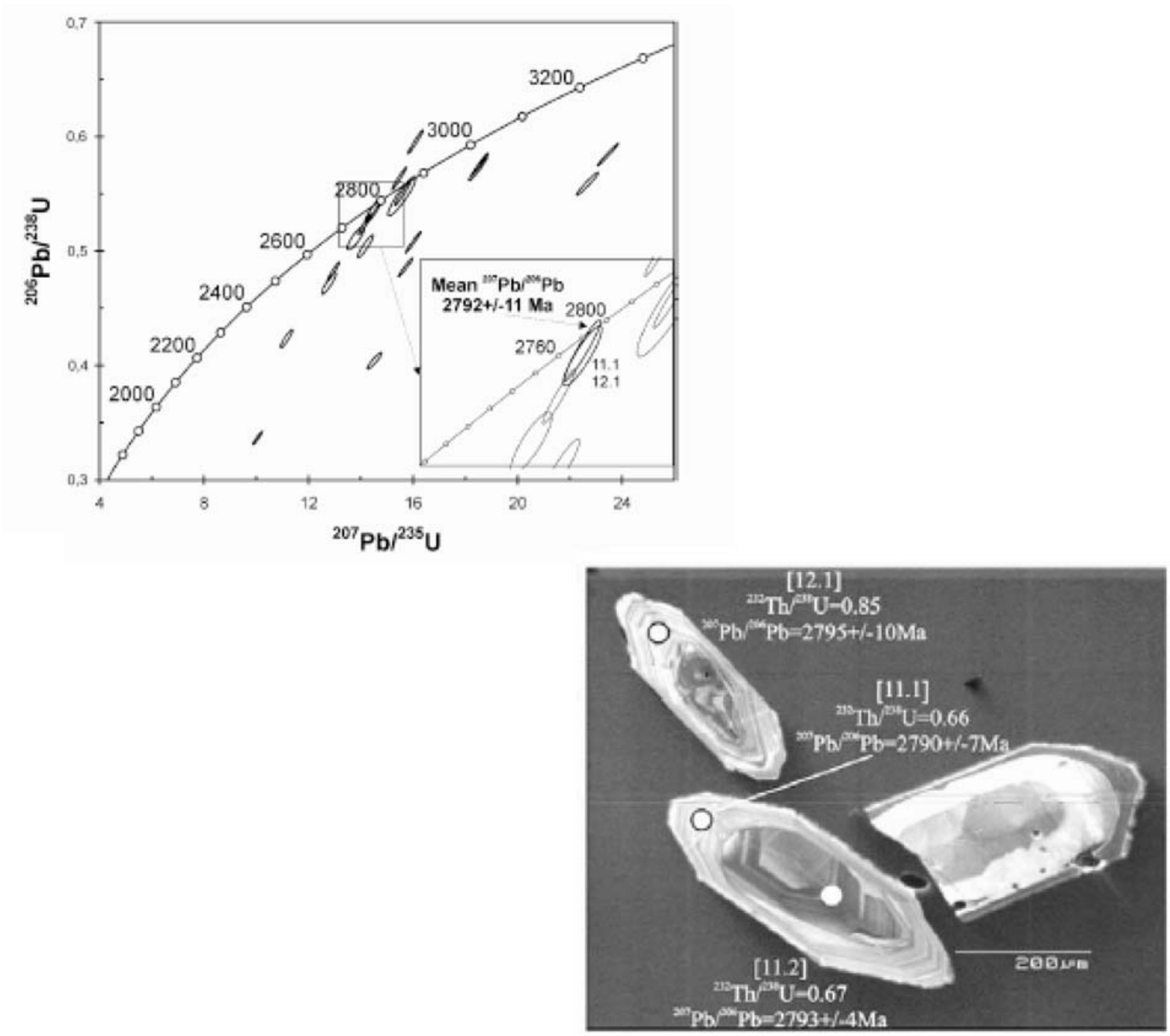

Fig. 2.15 Concordia diagram for sample FR-38 and CL images of zircon grains. Insert display analyses of magmatic overgrows 11.1 and 12.1, which mean $^{207}Pb/^{206}Pb$ age of 2792±11 Ma is assumed as the best estimate of felsic volcanism.

and $^{207}Pb/^{206}Pb$ ages as old as 3454 Ma suggests that this graywacke sample may have a dual source, that is, the felsic detritus came from the volcanic/ volcaniclastic piles and from an older continental source.

STOP 4.4 EXTRAMIL quarry at the Gandarela Farm

UTM 638968/7781061

Two outcrops of Gandarela carbonates will be visited in this area. The first outcrop is a light gray limestone displaying laminated stromatolitic structures and oncolites. It corresponds to the middle portion of the Gandarela Formation, which in this locality (the type section) also comprises white laminated limestone at the base and red dolomites in the upper portion (Souza and Müller 1984). A 2420±19 Ma Pb-Pb isochron age (Babinski et al. 1995) was determined on samples from this outcrop, and interpreted as the depositional age.

The second exposure is located in the EXTRAMIL quarry, where the red laminated dolomites of the upper portion contains a ca.1.5m-thick breccia horizon. The breccia contains fragments of carbonates, chert and pelites floating in hematite and dolomite-rich matrix.

Carbon isotopes were analyzed at those two outcrops and a third one, encompassing most of the Gandarela stratigraphic column in this area (Fig. 2.16). $\delta^{13}C$ values range from -1.6 to +0.4 permil. The red dolomite at the top of the formation displays the most negative $\delta^{13}C$ values ranging from -1 to -1.3 permil. According to Bekker et al. (2003) $\delta^{13}C$ data from the carbonates of the Gandarela Formation may provide a record of the carbon isotope composition of the seawater prior to any of the Paleoproterozoic ice ages, and also of the fact that seawater preceding the ice ages was not significantly enriched in ^{13}C.

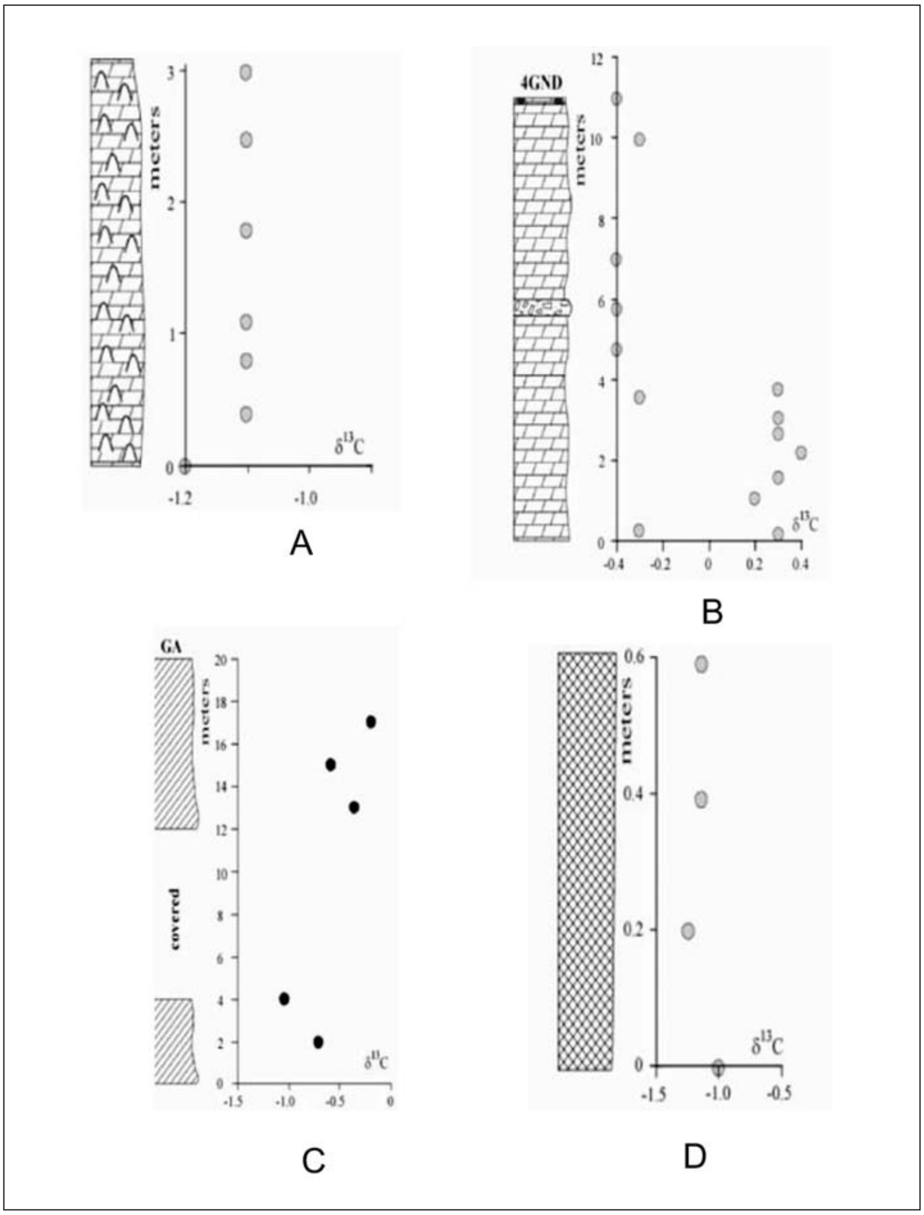

Fig. 2.16 - Stratigraphic sections of the Gandarela Formation from the Gandarela farm with d13C values (from Bekker et al. 2003). Sections A and B are from medium and upper basal white dolomites; section C from intermediate gray limestones; section D from upper red dolomites.

DAY 5

THURSDAY, SEPTEMBER 21th CROSSING THE MOEDA AND ROLA MOÇA RIDGES

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For the last day of field trip we selected outcrops that show a whole series of features related to the development of the dome-and-keel architecture that dominates the structural panorama of the QF. These outcrops are located in the western QF (Fig. 2.1), beyond of the Neoproterozoic Brasiliano deformation front.

We will start the day by driving southward on route BR 040 up to the access road to Belo Vale. We make a west turn and drive on the road to Belo Vale for more 10km, up to the escarpment of the Serra da Moeda, location of our first stop. From this point we will drive back to BR 040, stopping near the Bandeira peak on the Mascate ridge for a scenic view of the southern QF. On route BR 040 we will head north and make another west turn at the intersection with the access road to Moeda. Driving southwestwards on this road, we reach again the escarpment of the Moeda ridge for one more stop. We will then drive back, and head north to the Rola Moça Park, located on the Serra do Curral, south of Belo Horizonte. After a quick stop in the park, we drive down to the town of Ibirité for the last stop.

STOP 5.1 Moeda ridge, access road to Belo Vale, km 10

UTM 609945/7739102

The large exposure along the escarpment of the Moeda ridge preserves a major shear zone that marks the contact between the basement gneisses and the supracrustal units. In this particular place, the shear zone affects the basement, a ca. 40m-thick lenses of pelitic schist of the Archean Nova Lima Group and Moeda Quartzites.

First we will examine the Moeda mylonites, which display a series of kinematic indicators attesting normal-dextral sense of shear. The mylonitic foliation is oriented at 110/45; the stretching lineation plunges 30^{o} to S20E.

Walking down the road we will observe weathered outcrops of the Nova Lima schists and phyllonites, also exhibiting top-down-to-SSE shear sense indicators. A waterfall located ca. 200m down the road exposes a fresh piece of the Nova Lima schist. This schist, consisting essentially of chlorite, sericite, quartz, and plagioclase, contains cm-size nodules of a dark material. As we will see in the last outcrop, these nodules probably represent large crystals of Al_2SiO_5 polymorphs, here deformed and replaced by sericite and chlorite. These minerals characterize metamorphic aureoles that developed especially in pelitic rocks around the gneiss domes.

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The Batatal phyllite and the Cauê Iron Formation above the Moeda mylonites in the upper part of the road cut show fabric elements compatible with a west-direct tectonic transport, i.e., the same structural assemblage we observed in the various stops of the previous days.

STOP 5.2 Mascate ridge, access road to Belo Vale, km 7
UTM 612200/7739663

A quick stop at this point was planned, primarily, for a scenic view of the southern QF. From here looking west we can also observe the morphological expression of west-directed thrust that brings the Cauê Iron Formation on top of the Piracicaba Group. In other words, the Mascate ridge corresponds to a second occurrence of the Cauê Formation along the E-W section of the Moeda syncline we are traversing.

STOP 5.3 Moeda Ridge, access road to Moeda, km 7
UTM 608807/7756478

Along this road we will examine a second exposure of the same shear zone we observed in the last stop, here juxtaposing the Archean Mamona Granitoid (Carneiro 1992) and the quartzites of the Moeda Formation.

The Mamona granitoid, dated at 2721± 3 Ma (Machado et al. 1992) (Fig. 2.17) is composed of equal proportions of quartz, plagioclase, and microcline, containing smaller amounts of biotite and secondary white mica. Accessory minerals are zircon, apatite, opaque minerals surrounded by titanite, allanite, and fluorite (Jordt-Evangelista et al. 1993a). Away from the shear zone the granitoid still preserves hypidiomorphic textures typical of igneous crystallization.

The mylonitic foliation affecting the granitoid and the Moeda Quatzite dips 50-60° to ENE and displays a down-dip lineation. A variety of small-scale asymmetric features indicates a systematic hanging-wall down motion along the shear zone.

According to Jordt-Evangelista et al. (1993a) the deformation of the granitoid was accompanied by strong hydrothermal alteration that causes intense sericitization and generation of the phyllonite bands we can observe in the outcrops. The main syn-kinematic reaction observed was the conversion of feldspars in quartz + white mica. Mass balance calculations carried out by Jordt-Evangelista (1993b) show Ca and Na depletion, combined with K and Mg enrichment along the shear zone.

Age spectra of detrital zircons extracted from the Moeda Formation are shown on Fig. 2.18.

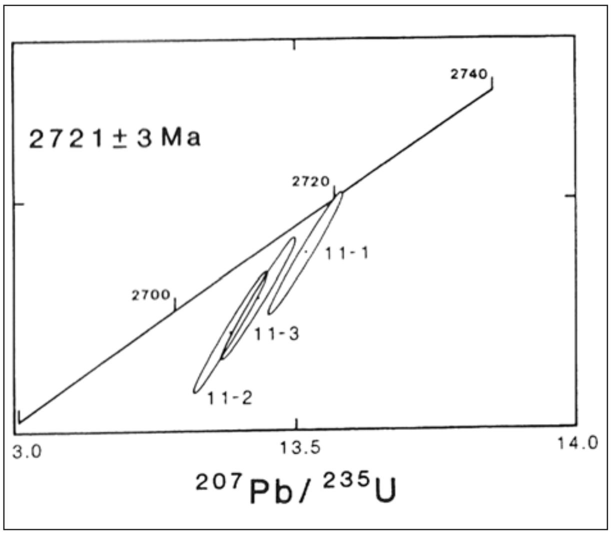

Fig. 2.17 Concordia diagram for the Mamona Granite (Machado et al. 1992). Two zircon analyses are 0.6% and 0.7% discordant with $^{207}Pb/^{206}Pb$ ages of 2717 and 2715 Ma. A third zircon fraction (11.1) is concordant at 2721±3 Ma, the best estimate for the age of crystallization of the pluton.

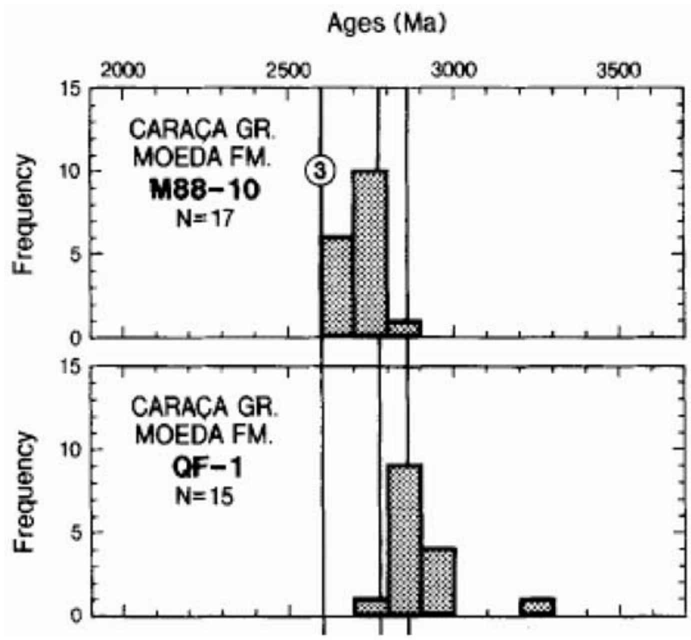

Fig. 2.18 Histograms for ages of detrital zircon from basal quartzites of the Moeda Formation (Laser ablation-ICPMS $^{207}Pb/^{206}Pb$ ages, Machado et al. 1996). Youngest age obtained is 2651±33 Ma.

STOP 5.4 Rola Moça ridge and natural park, near Belo Horizonte

Besides the scenic view of the Rola Moça ('rolling girl") ridge (local name of the Curral ridge), the purpose of this stop is to summarize the observations we made so far and discuss the generation of the dome-and-keel architecture of the QF.

This stop is located in the junction of two large scale and almost perpendicular structures of the QF. The NS-trending Moeda syncline, the keel between the Bofim and Bação domes (Fig. 2.2), interferes with the ENE-WSW-oriented Serra do Curral overturned homocline. The junction resulted primarily from the refolding of a NW-verging anticline – the Serra do Curral anticline – by the Moeda Syncline, thereby creating an interference saddle fold. West-directed thrusts and strike-slip faults (probably related to the Brasiliano event) overprint the already complex junction (Fig. 2.19) (Alkmim and Marshak 1998).

STOP 5.6 Rail road cut, Ibirité town
UTM 599145/7785552

We came to this place to observe outcrop evidence for a metamorphic aureole developed in the pelitic schists of the Sabará Group. This stop is located ca. 2km to the south of the contact between the Sabará schists and the TTG gneisses of the Belo Horizonte complex. The normal sense shear zone that marks this contact involves a ca. 4km wide aureole, which comprises form north to south sillimanite, cordierite, andalusite and biotite zones (Jordt-Evangelista et al. 1992, Marshak et al. 1992). The blastesis of the alumino-silicate polymorphs is syn- to post-kinematic in respect to the shear zone development. A Sm-Nd garnet-whole rock-muscovite isochron obtained by Brueckner et al. (2000) from samples collected in this aureole yielded an age of 2095± 65Ma, regarded as the age of the aureole formation. Furthermore, a mafic dike that cuts the aureole was dated at 1714 Ma by Silva et al. (1995).

The Sabará Schists in this exposure show large andalusite porphyroblasts in a fine grained matriz composed of staurolite, biotite, quartz, feldspar and white mica.

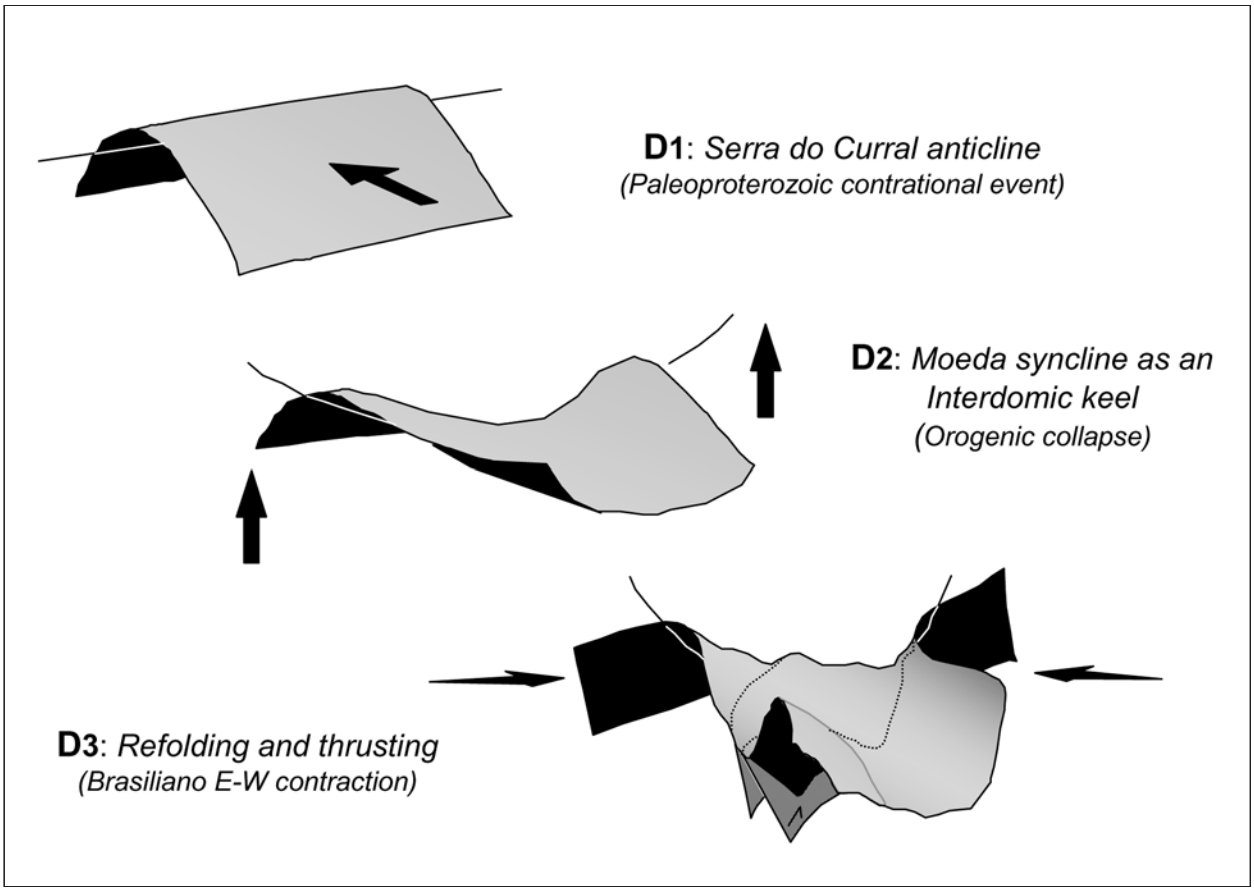

Fig. 2.19 Evolutionary model for the development of the junction between the Serra do Curral homocline and the Moeda Syncline. The surface took as reference in the figure represents the base of the Cauê Iron Fromation (Modified from Alkmim and Marshak 1998).

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Abstracts

The quest for Paleoproterozoic supercontinents and links to global evolution

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The 900 million-year-long Paleoproterozoic Era embraces a substantial segment of Earth's "middle age," a time of important and irreversible global changes from the core to the surface. As geochronological resolution advances at satisfying pace and with novel techniques, we are poised to attain breakthroughs in understanding possible causal relationships among: growth of the geomagnetic field, development of modern-style plate tectonics, atmospheric oxygenation, changing ocean chemistry and paleoclimate (including low-latitude ice ages), the two largest known terrestrial impact events, and biological evolution. Supercontinents are created and destroyed by mantle flow, and they may strongly influence globally averaged geochemical fluxes to alter the surface environment; as such, they occupy a central position in the long-term Earth system, imposing quasi-cyclical variations (10^8 year) that are superimposed on the longer-term (10^9 year) secular trends in planetary evolution.

The geological record contains ample evidence for globally widespread amalgamation of cratons into one or more supercratons, or a supercontinent, at 1.9 Ga. The precise paleogeography of this supercontinent, most commonly named Nuna or Columbia, is unknown; thus it is presently undetermined how much reshuffling of cratons occurred during the Mesoproterozoic, prior to the formation of Rodinia. Even less certain are the global tectonic regimes that led to assembly of Nuna, as some have interpreted the widespread juvenile 2.3–2.1 Ga accretionary orogens (e.g., Birimian) as manifesting an early stage of supercontinental accretion, whereas others have emphasized the abundant mafic dyke swarms through the same interval of time as representing worldwide continental disaggregation. Phanerozoic assembly of Asia via northward motions of detached fragments from Gondwanaland informs us that both processes can occur simultaneously, and this may constitute a useful model for future considerations of mid-Paleoproterozoic global tectonics. The dawn of the Paleoproterozoic Era, at 2.5 Ga, may have included an earlier supercontinent Kenorland, but efforts to reconstruct global paleogeography from this and earlier times are severely hampered by the limited low-grade rock record amenable to paleomagnetic studies.

The International Geological Correlation Programme (IGCP) Project 509, "Paleoproterozoic Supercontinents and Global Evolution," has brought together nearly 200 scientists from more than 20 countries, to address these issues. Our project seeks to generate three global-scale products. First, we aim to summarize the current state of knowledge of the Paleoproterozoic rock record by way of comprehensive stratigraphic correlation charts, in the form of those recently produced for various sectors of Laurentia (Wardle et al., 2002, Can. J. Earth Sci., v.39, p.895). Second, the geological units depicted on those charts will be included in a global stratigraphic database, expanding that which already exists for southern Africa (Eglington and Armstrong, 2004, S. Afr. J. Geol., v.107, p.13-32). Third, aided by the globally integrated stratigraphic correlations, various trends in planetary secular evolution and environment (e.g., isotopic composition of seawater, ice ages, peaks in large-igneous-province activity, microfossils and biomarkers) can be compiled and displayed together on a timeline that accompanies each regional stratigraphic chart. These graphs will be useful for selection of global stratotype sections and points (GSSPs) in the developing Precambrian chronostratigraphic timescale mandated by the International Commission on Stratigraphy (Gradstein et al., 2004, Episodes, v.27, p.83-100). Fourth, preliminary paleogeographic maps of the Paleoproterozoic world, based on paleomagnetic data and tectonic correlations among pre-Rodinian cratons and orogens, will serve as a guide for future research into the assemblies and fragmentations of Proterozoic supercontinents—centerpieces of the Earth system as it evolved through its middle age.

Paleoproterozoic framework of the South American continent reviewed

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Paleoproterozoic rocks are widespread in the Amazonian/West Africa, São Francisco/Congo and Rio de la Plata cratons, and are also present within the Neoproterozoic framework of Western Gondwanaland. The major recognized Paleoproterozoic features are: *i*) extensive platform basins with quartz-sandstones, carbonate rocks, bifs and volcanics (2.4 - 2.1 Ga); ii) diachronic intercontinental orogenies (2.30 Ga; 2.25 - 2.15 Ga; 2.08 – 2.00 Ga; 1.90 – 1.8 Ga; 1.80 -1.55 Ga), iii) crustal rifting and tectonic basins (1.8 - 1.6 Ga; Statherian taphrogenesis) with sedimentary assemblages and anorogenic igneous activities (e.g., mafic dike swarms, bimodal volcano-plutonic magmatism), as part of larger intercontinental systems. Such a geodynamic process is a result from tectonic convergence of crustal fragments, their agglutination and partial reworking, combined with a further tendency of dispersion of the newly formed lithosphere due to the asthenospheric thermal regime at that period of time.

The orogenic scenarios include accretionary (with greenstone belts and calc-alkaline plutonism) and collisional (ensialic) belts showing multiple deformation and metamorphism, recurrent mafic-felsic and alkaline magmatism, as well as volcanic-sedimentary successions. In contrast, the deep eroded Paleoproterozoic belts exhibit dominantly high grade rocks, mafic-ultramafic layered intrusions and granitoid suites. Large shear zones and faults may be also present, reflecting collision of the terranes, blocks and orogens.

From the isotopic point of view, the Paleoproterozoic blocks of the South America continent includes large amount of material accreted from the mantle with subordinate reworking of the pre-existing continental crust, as deduced from the major juvenile-like Nd signatures of the parental magmas of granitoid rocks, in coherence with the usually slightly older U-Pb ages and Sm-Nd model ages. The petrogenetic signatures of the anorogenic plutons are consistent with usually multiple origins, but sources of material are predominantly mantle-derived. From the above evidences the concept of significant juvenile crustal growth can be envisaged for most of the Paleoproterozoic domains, marked by the evolution of intra-oceanic arcs in a tectonic environment of ongoing plate convergence, but also containing in places, collisional type belts, microcontinents, Cordilleran type granites, volcano-sedimentary basins**,** and anorogenic-type complexes.

Three exemples of such a Paleoproterozoic framework in the Amazonian, São Francisco and Rio de la Plata Cratons) are summarized here:

1) The SW Amazonian Craton comprises Archean (Central Amazonian) and five Proterozoic provinces [Maroni-Itaicaiunas (2.25 – 1.95 Ga); Ventuari-Tapajós (VT; 1.95-1.80 Ga); Rio Negro-Juruena (RN; 1.80-1.55 Ga); Rondonian-San Ignacio (1.55 – 1.30 Ga) and Sunsas-Aguapeí (1.30-1.10 Ga)]. Evaluation of the available information suggests that the most important mantle differentiation/ accretion event took place between 2.25 and 2.00 Ga (Transamazonian cycle) during which the Maroni-Itaicaiunas belt and the Eburnean (West African) counterpart were formed. Tectonomagmatic evolution of the VT and RN marginal belts is consistent with predominant mantle differentiation processes, succeeded by progressive agglutination of the younger belts to the more stable crustal block, as suggested by the Nd isotopic evidence and U-Pb age constraints.

2) The São Francisco-Congo Craton encompasses Archean domains surrounded by Paleoproterozoic mobile belts with some intervening blocks. These belts contain voluminous felsic-mafic plutonism and extensive supracrustal rocks, whereas mafic dike swarms and remnants of greenstone sequences may also occur. Interpretation of the isotopic, geochemical and structural information and lithostratigraphical correlations are consistent

with the existence of Neoarchean/ Paleoproterozoic crustal rifting succeeded by development of orogenic belts (2.25 to 2.00 Ga). The Itabuna-Salvador-Curaçá belt represents a high grade domain which preserves in places foreland basins (e.g., Jacobina) and greenstone belt sequence. It originated from a tectonic collage of the three Archean blocks due to crustal shortening, melting with late to post collisional plutonism, as suggested by structural data and related tectonic features (e.g., faults and shear zones). The roughly contemporary Mineiro belt in Minas Gerais is an eroded calc-alkaline plutonic arc system, chiefly ensialic in nature. However, the central and eastern parts of the belt contain mafic and felsic plutonism of arc affinity (2.24-2.10; 2.04 Ga). Isotopic inferences suggest the following orogenic evolution: *i*) rifting of the Neoarchean lithosphere with passive margin to foreland basin sequence (Minas Supergroup); *ii*) arc development and oceanic closure; *iii*) tectonic juxtaposition of the magmatic phases by crustal shortening along major structures of the belt. Tectonic stability (ca. 1.9-1.8 Ga), following structural exhumation, fault reactivation and regional cooling.

3) The Tandilia system (Rio de la Plata Craton, Argentina), is intruded by two Paleoproterozoic unmetamorphosed, calc-alkaline and tholeiitic dikes swarms, dated at 2.02 – 2.07 Ga, and 1.59 Ga, respectively. The calc-alkaline dikes were emplaced during the transtensional stage of a Paleoproterozoic orogenic system during which the Tandilia plutonic rocks were formed. Such a tectonic scenario has similarities with the evolution of the Richtersveld plutonic arc complex of the Southern Africa that faces the Rio de la Plata Craton in the West Gondwana reconstruction. The significant younger tholeiitic dikes are part of diachronous extensional episodes which initiated shortly after the tectonic stabilization of the Tandilia system. The existence of such a extensional ectonic setting is supported by occurrence of the large 1.73 Ga Florida tholeiitic dike swarm and coeval, anorogenic granitoids, in the Uruguayan shield. Similar intraplate, features (Statherian) occur most of the Paleoproterozoic domains in the Brazilian shield (the exception is the 1.75 Ga Rio Negro-Juruena mobile belt in the Amazonian Craton), such as fault block-basins with bimodal magmatism (e.g, Espinhaço Supergroup; Borrachudos and São Timóteo granites; São Francisco/Congo plate) and coeval igneous activities (e.g, Iriri felsic volcanism; Amazonian Craton).

Finally, some of the recognized Paleoproterozoic features are still open questions and need further investigation, such as: *i*) the precise spatial, temporal and genetic nature of the terranes and orogens, including the geologic significance of the Transamazonian cycle; and *ii*) the age of deposition of the supracrustal rocks (within both mobile belts and rift systems).

Conceptual Framework of the ICDP Fennoscandian Arctic Russia – Drilling Early Earth Project (FAR-DEEP)

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The development of new analytical techniques, and improved models for planetary evolution, has intensified research into the evolution of the Earth System and targeted several critical intervals in Earth history when the biota, hydrosphere and atmosphere were experiencing global-scale changes. It is common knowledge that the Archaean Earth System (> 2.5 Ga) functioned differently from that in the recent past because of the absence of an oxygen-rich atmosphere. Oxygen-rich habitats were restricted to microbial mats or perhaps ephemeral oxygen oases in the surface ocean or in lakes, and so biogeochemical recycling of buried organic matter in the Archaean largely depended on fermentative decomposition. Given the lack of oxidative weathering, it remains unclear how organic matter preserved in marine sediments was recycled upon uplift and exposure. The first 500 million years of the early Palaeoproterozoic was a time of environmental upheaval that heralded the emergence of the modern, aerobic Earth System. Global intracontinental rifting and associated mafic volcanism accompanied by widespread deposition of banded iron formation was followed by the oldest known world-wide glaciation(s), a rise in atmospheric oxygen, the largest ever positive excursion of $d^{13}C_{carb}$ (Lomagundi-Jatulian Paradox), and then, enigmatically, abundant deposition of anomalously organic-carbon-rich sediments forming the oldest known significant petroleum deposits (Shunga Event). The remaining 1500 Myr of the Proterozoic exhibits evidence that the Earth operated much as it does today, with most biogeochemical recycling, in the oceans and on land, dependent on highly energetic aerobic pathways. The available data provide only a relative chronology of these major Archaean-Palaeoproterozoic events and several fundamental questions remain unanswered. Why is the oldest known significant accumulation of organic-carbon-rich sediments and petroleum deposits only at 2000 Ma when microbial life is known to have persisted through the Archaean? Why did an oxygen-rich atmosphere appear around 2300 Ma even though oxygen-rich habitats existed since 2700 Ma? Why, given an oxygen-rich atmosphere at 2300 Ma, was there a 300 Myr lag in the development of deep biosphere and aerobic pathways in biogeochemical recycling of organic matter at around 2000 Ma? Why did the first global glaciations occur at around 2400 Ma and why do the first-order features of the marine carbon isotope record indicate that global carbon cycle operated in the Archaean much as it does today? Other key unresolved problems at the Archaean-Proterozic transition include: (***i***) the nature and timescales of the Proterozoic carbon cycle; (***ii***) the sulphur, phosphorous and nitrogen cycles; (***iii***) the redox-state of the mantle and its possible impact on oxidation state of the hydrosphere-atmosphere; (***iv***) the origins and timing of the rise in atmospheric oxygen; (***v***) seawater composition and marine sulphate reservoir.

What is required now is new data as the basis for self-consistent models to explain the genesis and timing of the abrupt establishment of the aerobic Earth System. In order to address some of these fundamental questions in Earth System evolution, a multi-disciplinary, international research group has been awarded a new research initiative within the framework of the International Continental Scientific Drilling Program. The ultimate goal of this initiative is to develop a scientific drilling project on the Fennoscandian Shield and create a self-consistent model explaining the establishment of the aerobic Earth system out of the biogeochemical paroxysms of Palaeoproterozoic time. We welcome the participation and collaboration of our colleagues (many of whom are now organised around the new IGCP project 509 “Palaeoproterozoic Supercontinents and Global Evolution”) as we explore this critical interval of Earth history as its recorded on the Fennoscandian Shield.

Paleoproterozoic (2.5-2.0 Ga) Event and Chemostratigraphy: a Powerful Tool for Interbasinal Correlation

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Correlation of Precambrian sedimentary successions is still hindered by poor age constraints. Event and chemostratigraphy overcome this limitation by utilization of marker beds and changes in chemical composition that represent stratigraphic expression of global events. This approach might be particularly useful for Paleoproterozoic sedimentary successions since the 2.5-2.0 Ga surface environment was affected by a number of distinctive tectonic, climatic, and biogeochemical perturbations that are unambiguously recorded in the sedimentary record. These events, in the ascending order, are: 1) the 2.48-2.45 Ga plume breakout events expressed in the rock record by large igneous provinces with bimodal volcanic and plutonic rocks, associated with the supercontinent assembly and deposition of Banded Iron Formations (BIFs), 2) the glacial epoch (ca. 2.42-2.3 Ga) with three glacial events accompanied by carbon isotope excursions in seawater composition [1, 2] and the rise of atmospheric oxygen [3], 3) the following period of enhanced weathering [4, 5] expressed in the rock record by mature quartz sandstones and Al-rich shales, 4) the ca. 2.25-2.2 Ga plume breakout event that formed extensive plateau basalts and dikes and led to the second stage of rifting and the breakup along some rift systems; 6) the positive carbon isotope excursion in seawater composition between >2.22 and ca. 2.1 Ga not associated with a known glaciation [6], 6) the increase in ocean sulphate content during the ca. 2.22-2.1 Ga carbon isotope excursion [7], 7) episodic mafic events at 2.17, 2.12-2.10, and 2.08 Ga likely related to protracted rifting [7], and 7) the final breakup of the Kenorland supercontinent at 2.1-2.0 Ga [8].

Sedimentary rift successions associated with the final stage of the supercontinent assembly contain detrital uraninite and pyrite [9]. Atmospheric pO_2 most likely changed episodically during the glacial epoch in response to fluctuations in the exogenic carbon cycle and long-lasting ice ages. Worldwide, the end of the Paleoproterozoic glacial epoch was followed by deposition of mature, Al-rich shales and quartz sandstones suggesting a climate change to greenhouse conditions favouring chemical weathering. The >2.22 – ca. 2.1 Ga carbon isotope excursion also succeeded the glacial epoch but the temporal and stratigraphic relationship between the beginning of the carbon isotope excursion and deposition of mature quartz sandstones is poorly constrained. The carbon isotope excursion is thought to have lasted more than 100 Ma and was likely accompanied by an increase in atmospheric oxygen [6]. Carbonate successions deposited during the carbon isotope excursion contain pseudomorphs of anhydrite and gypsum suggesting warm and arid climates and increase in the ocean sulphate content. The end of the carbon isotope excursion between 2062 ± 2 Ma and 2113 ± 4 Ma was accompanied by voluminous mafic volcanism which has been related to the supercontinent breakup. Mn-rich sediments were deposited during the ca. 2.22-2.1 Ga carbon isotope excursion in upwelling zones, while BIFs, phosphorites, and organic-rich shales with high organic carbon contents and with some carbon isotope values of organic matter as low as -40 - -45‰ coincides in age with the end of the carbon isotope excursion and are likely related to the change in the ocean redox state due to the enhanced delivery of oxidants to the deep ocean. Transition to more vigorously circulating ocean is ultimately related to the supercontinent breakup through the change in land mass distribution and volcanic activity. Recognition of these events combined with high precision geochronology and sequence stratigraphy has a great potential for interbasinal correlation and the understanding of the evolution of the Paleoproterozoic exosphere.

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Paleoproterozoic Continent-Arc/Continent Collision Zones –A Secular Change In The Archean to Neoproterozoic Tectonic Style

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The Earth has cooled from Archean to Present by the loss of original heat and by decreasing production of radiogenic heat. This has led to secular evolution from depleted low-density Archean lithospheric mantle (SCLM) to more fertile denser Phanerozoic lithospheric mantle beneath continents. It is controversial whether modern subduction-type tectonics begun during Archean, Paleoproterozoic or during Neoproterozoic era when first abundant eclogites occur.

The Svecofennian Orogen is one of the largest Paleoproterozoic orogens in the world covering over 1 mill. km2. It is atypically non-linear and is suggested to have formed in four partly overlapping orogenies (1.9-1.8 Ga) and to form the core or one of the cores of a 1.8 Ga supercontinent [1]. Seismic reflection data reveal a crocodile structure within the thickened Archean-Proterozoic continent-arc/continent collision zone; rigid Karelian passive margin wedge has split the young and hot island arc to an upper part, thrust on the Karelian plate, and a lower part, buried under the stacked continental edge. Similar structures are found at many 1.9-1.7 Ga Archean-Proterozoic boundaries. This type of collision prevents the exhumation of subduction-related eclogites characteristic to modern collision zones. A net result of collision is thickened lithosphere that is often attenuated during subsequent extension. During long-lived convergence and associated cooling the thick crust and the lithospheric mantle may be stabilized (e.g. Svecofennian Orogen and Yavapai province, USA).

Subduction-related processes operated in the Paleoproterozoic but the buoyant nature of the Archean lithosphere in combination with denser Paleoproterozoic lithosphere may cause the differences between Paleoproterozoic and Neoproterozoic-Phanerozoic continent-arc/continent collision zones.

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A Review of The Banded Iron Formation From The East Moesian Basement, Romania: Mineralogy, Genetic Significance and Paleocontinental Models

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South Dobrogea is the only place in Romania where a banded iron formation is known. South Dobrogea is a tectonic block of East Moesia, a small continental fragment with disputed paleocontinental affinities. Following a localized magnetic anomaly north of Constantza, boreholes in Palazu Mare – Cocoºu area SE of the Capidava-Ovidiu Fault pierced the cratonic basement of South Dobrogea at depths between 430 and 600 m. The Palazu Group consists of two main lithological types, amphibolites and magnetite-bearing quartzites. Interbeds of carbonate and quartzitic rocks, as well as of graphitic micaschists, are interpreted to suggest sedimentary bedding. Previous detailed mineralogical and chemical studies revealed that the banding is produced by alternating layers including various amounts of quartz, magnetite, hornblende, cummingtonite, almandine, biotite, dolomite and ankerite. The carbonate beds consist of tremolite, ferrosalite and/or diopside. The protolith of these rocks is a banded chert sequence, which includes cherts, as well as clayey and shaly muds. This protolith type represents abyssal oceanic sediments related to sea-floor spreading. Associated hornblende and cummingtonite schists resulted from siderite and carbonate cherts, respectively; the high initial content of Ni, Cr and V was interpreted to indicate the presence of initial clayey fraction, mixed with the iron-rich sediments. The associated clastic rocks include micaschists, quartzites and microcline gneisses, with frequent graphite and seldom thin amphibolite interlayers. Based on lithological resemblance, the Palazu Group was correlated to the Paleoproterozoic Krivoi Rog series from the Ukrainian shield.

Beneath the Palazu Group borholes intercepted an assemblage of migmatic gneisses, granite gneisses and pegmatites designated as the Ovidiu Group. Based on geometric relations in boreholes, where the BIF shows a gradual transition to massive, feldspar rich and coarse grained gneisses, the Ovidiu gneisses were interpreted as a pre-Karelian (Archaean) basement.

The oldest K-Ar ages yielded by the Ovidiu orthogneisses range between 1777 Ma (on K feldspar) and 1620 Ma (on muscovite). These ages were interpreted as the overprint of the Karelian amphibolite facies metamorphism of the overlying Palazu BIF, a LP-HT event which produced assemblages with andalusite + sillimanite (600^{o}C and 4-5 kbar). A second age group includes Neoproterozoic ages (867 Ma whole-rock on micaschist and 729-644 Ma on K-feldspar from granite gneiss). A later, greenschist facies retrogression of the older basement rocks was correlated with the very low grade, late Cadomian metamorphism of the overlying Neoproterozoic Cocoºu Formation.

Detailed studies of borehole cores revealed that the Ovidiu gneisses and the Palazu Group are involved in northward directed thrusts. Because beneath strongly mylonitic Ovidiu gneisses three boreholes intercepted pelitic-psammitic rocks ascribed to the Vendian Histria Formation exposed in Central Dobrogea, the age of thrusting was interpreted as Late Proterozoic.

If the oldest Moesian crust correlates to the Ukrainian shield, as previously suggested based on lithology, then it might represent a small sliver of Baltica, detached and displaced on strike-slip faults along the Trans-European Suture Zone. However, mineralogical assemblages are distinct from those in the Ukrainian shield. Clear evidence for provenance of this older Proterozoic basement is still missing and needs to be solved by accurate geochronology.

Paleoproterozoic amphybolites from the Rio Grande do Norte terrane: Constraints from Sm-Nd isotopes and U-P geochronology

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The Rio Grande do Norte Terrane (RGNT, [1]) is one of several basement inliers in the Borborema Province, northeastern South America. With an extent of more than 150,000 km^2, it is characterized by calc-alkaline arc affinity magmatism dated around 2.15-2.2 Ga (U-Pb zircon ages) and constitutes a continental lithospheric fragment consolidated in the Paleoproterozoic. T_{DM} model ages of these granitoid rocks cluster around 2.6 Ga, and their Nd isotopic signature is characterized by negative ε_{Nd}(t) values at 2200 Ma, ranging from –4 to –1. Different types of amphibolites occur associated with the granitoids in the basement terranes of Caicó and São Vicente-Florânia. The most common occurrence is as a swarm of dykes of banded and foliated fine-grained elongated bodies of biotite-bearing amphibolite, accompanying the domic shape of the granitoid rocks. Coarse-grained hornblendite form circular bodies, occur close to São Vicente. Clinopyroxene-bearing coarse-grained amphibolites occur as xenoliths and dykes in the granitoid host rocks. Epidote is common in mylonitic shear zones.

Geochemistry data suggest distinct groups. The majority are calc-alkaline basalt with an island arc signature, characteristic of destructive margins setting. However, low K_2O tholeiitic basalts are also present. U-Pb geochronology of banded amphibolites in the Caicó region suggest a concordant age of 2.16 Ga, interpreted as crystallization age of the igneous protolith. An inherited component of c. 2.2 Ga is considered as derived from the granitoid host rock. The São Vicente hornblendite yielded an upper intercept age of 2.18 Ga and positive ε_{Nd}(t) values. The last event of mafic magmatism is recorded in Florânia, where amphibolite samples yield an age c. 1.96 Ga and ε_{Nd}(t) values close to zero.

T_{DM} model ages vary from 2.3 to more than 3.0Ga, and ε_{Nd}(t) values are positive to negative, characterizing different degrees of crustal contamination of the basaltic magmas.

Associated with the cooling process at the end of Paleoproterozoic, there was a period of taphrogenesis developed during the Statherian (1.8–1.7 Ga) and represented by the Orós-Jaguaribe, São José, Peixe Gordo, Alencar, and Pio IX intracontinental basins in this part of the Borborema Province [2]. We would like to stress the importance of considering the Borborema Province crustal fragments in Atlantica and Rodinia supercontinent models, in addition to and between the commonly represented São Francisco–Congo and West Africa–São Luiz cratons (e.g. [3]; [4]).

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A Paleoproterozoic Mafic Layered Complex Deformed By Neoproterozoic Low Angle Thrusts in the Southern Limit of the São Francisco Craton, Southeastern Brazil.

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In the southeastern portion of Minas Gerais State, in the region situated between the cities of Santos Dumont and Piau, lies an important boundary between the southern border of São Francisco craton and the central segment of the Ribeira belt which could be connected to the Araçuaí belt through the Dom Silvério shear zone. In this area, the granitic to tonalitic orthogneissic basement rocks, correlated with the Mantiqueira Complex, are interlayered with supracrustal sequences of unknown ages that certainly were submitted to a sequence of geologic processes during times previous to the Brasiliano orogeny (ca. 580-520 Ma) that generated this belt.

The large occurrence of an extremely homogenous fine grained (hornblende)-(muscovite)-biotite leucogneiss with amphibolite layers and minor amounts of intercalated quartzites and (sillimanite)-(garnet)-biotite gneisses, suggests the hypothesis for a volcanic and sedimentary origin of these sequences. Near to the locality of São João da Serra and associated to the basement rocks, occurs an extensive mafic layered complex [1; 2] composed of centimetric to decametric banded (leuco)gabbroic, quartz diorite and tonalitic gneisses, locally with centimetric piroxenite lenses. From multi-element and tectonic setting diagrams it is possible to point to an intraplate origin for these tholeiitic rocks. Preliminary U-Pb zircon geocronological data of the gabroic intrusions points to paleoproterozoic crystallization ages, around 1.95 Ga, with paleoproterozoic to archean inheritance [3]

The observed structures present low-angle sheets indicating NW-vergence, which represent the outer parts of the Brasiliano orogen. Associated with these sheets there are frontal shear zones with a NE–SW preferred orientation, corresponding to the main deformation phase (D_{1+2}) of the Ribeira Belt [1; 4]. Based on field observations (1:25.000 and 1:50.000), and structural and petrological data, it is possible to postulate that the shear zones are responsible for the interference of the previously formed structures and also for mineralogical and textural changes in these rocks [5]. Thus, opx-bearing gabbros are gradually transformed into garnet-cpx metagabbros and finally into biotite amphibolites as they approach these shear zones. Similarly, in the country orthogneisses, an enderbitic garnet leucogneiss is retrogressed to a migmatitic biotite-hornblende gneiss. Frequently all these rocks present mylonitic recrystallization textures, locally forming L-tectonite fabrics, indicating the higher deformation intensity.

Geochemical data for the enderbitic rocks [6] indicate the removal of Pb and Ba due to the hydrothermal action of the Neoproterozoic shear zones, and the migmatization is more intense in the orthogneisses country rocks. In relation to the mafic rocks, the shear zones are responsible for higher contents of Cr, Ni, Cu and Co, where the gabbros are transformed into amphibolites.

The geological evolution can be subdivided in three different episodes. First, before the mafic intrusions (pré-1.95Ga.), the rocks were composed by orthogneisses (Mantiqueira Complex) and supracrustal rocks, with low angle dipping to NE and SW, metamorphosed under lower amphibolite facies conditions. In a second event, around 1.95Ga., large intrusions of sub-ofitic textured basic rocks generated the São João da Serra mafic layered complex. Evidence shows that the tholeiitic mafic intrusions had an important role in the development of metamorphic enderbitic portions in the orthogneissic country rocks near the contact region. Finally, during the collisional orogeny, the influence of low-angle shear zones associated to the D_{1+2} phase (596-565 Ma.; [7]) generated a number of textural and mineralogical changes in these rocks. This tectonic event caused partial melting on pelitic rocks, in the presence of muscovite, indicating a prograde metamorphism. In other hand, for basic rocks, this neoproterozoic metamorphism caused retrograde metamorphism with the formation of hydrated minerals biotite and hornblende from orthopyroxene and clinopyroxene.

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U-Pb Geochronology of Zircons from Orthogneisses of the Campos Gerais Complex South of Alpinópolis Town (Minas Gerais, SE-Brazil) Using the LA-MC-ICPMS Technique: Reconstructing Archean Nuclei in the Southwestern Margin of the São Francisco Craton

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A geochronological reconnaissance on the orthogneisses of the Campos Gerais complex south of Alpinópolis town was carried out using the Laser Ablation Multi-Collection Inductively Coupled Mass Spectrometry (LA-MC-ICPMS) technique, with the determination of U-Pb ages of zircons from six rock samples. The basement of the southern part of the São Francisco craton displays two contrasting tectonic settings: a) Archean nuclei typically composed of granite-greenstone rock assemblages dating ca. 3.2 to 2.7 Ga or TTG orthogneiss complexes of Neoarchean age; and b) Paleoproterozoic orogenic belt composed either of reworked Archean rocks or more juvenile crust such as magmatic arc and associated supracrustal rocks. Radiometric ages of Paleoproterozoic metamorphism and syn-tectonic granitogenesis concentrate between 2.2 and 2.0 Ga in the southern São Francisco craton. Late- and post-orogenic (ca. 1.9 Ga) intrusive complexes are abundant in the southernmost São Francisco craton with compositions ranging from gabbroic to granitic. Remnants of both the Archean nuclei and the Paleoproterozoic belt also occur as variably reworked basement inliers within the surrounding Neoproterozoic (Brasiliano or Pan-African) orogenic belts. The Campos Gerais complex is an example of basement complex within the southern Brasilia Belt in SW Minas Gerais state. The complex crops out along a WNW-oriented antiformal window between (beneath) the Passos and Varginha-Guaxupé east-verging nappe systems, respectively to the north and south. This basement complex shows lateral continuity to the east with the major exposure of the basement of the southern São Francisco craton, which is elsewhere covered by the Neoproterozoic metasedimetary strata of the Bambuí group. The granitoid rocks in the Campos Gerais complex display a pervasive SSW-dipping foliation and contains several mylonite zones with kinematic features indicatiing sinistral movement. The mineralogic and chemical compositions observed in the Campos Gerais orthogneisses characterise a tonalite-trondhjemite-granodiorite (TTG) association. This predominantly plutonic complex contains keels and tectonic intercalations of greenstone belts such as those of Alpinópolis and Morro do Ferro localities, and other supracrustal rock associations. Numerous NW-striking mafic dikes are present and probably belong to more than one generation of recurring mafic magmatism episodes in the southern São Francisco craton. Between 10 and 20 zircons from each of the 6 granitoid samples were analysed using a laser beam with diameter of 40 microns. These zircons yielded mostly discordant U-Pb ages owing to the polycyclic tectonic evolution of the Campos Gerais complex. This isotopic behaviour resulted from the superposition of Archean, Paleoproterozoic and Neoproterozoic orogenic events. Variably discordant analytical points in the concordia diagram define discordia lines that point to lower intercepts of Brasiliano (c. 0.60 Ga) age, indicating that the zircons suffered lead loss related to the Neoproterozoic collisional history of the Brasilia belt. Zircons from a tonalitic gneiss define a discordia line with an upper intercept of 2953 ± 20Ma, interpreted as crystallisation age. Older, inherited zircons have minimum ages of 3.23, 3.27 and 3.32Ga. Four samples of monzogranitic orthogneisses yielded discordia lines with the following upper intercepts, also interpreted as crystallisation age: 2820 ± 69 Ma, with inherited zircons at 3.3 and 3.6 Ga; 2812 ± 15Ma, with inherited zircons at 3.1 and 3.6 Ga; 2842 ± 15Ma, with inherited zircons between 3.2 and 3.6 Ga, and

one sample that zircons define two discordia lines with upper intercepts of 2766 ± 36 Ma and of 2244 ± 72 Ma. One sample from an intrusive tonalite complex of several plutons yields an upper intercept of 2778 ± 21 Ma. One discordant zircon from this sample dates 2060 ± 18 Ma. The analytical data, interpreted in the contex of the tectonic framework of the southern São Francisco craton, indicates that the studied samples crystallised between 2.98 and 2.77 Ga, during a significant Neoarchean episode of granitogenesis observed elsewhere in the southern São Francisco craton. The significant number of inherited zircons indicate some extent of much older crust dating 3.6 to 3.2 Ga. It can be inferred thus that the studied sector of the São Francisco basement shows tectonic affinity with other Archean cratonic nuclei, in opposition to Paleoproterozoic orogenic terranes. Subordinate U-Pb ages found between 2.2 and 2.0 Ga indicate that some igneous or metamorphic activity must have taken place in the Campos Gerais complex during the Paleoproterozoic but with limited extent.

Paleoproterozoic Crust Forming Events in the Basement of the Brasília Belt, SE Tocantins- NE Goiás, Central Brazil: Constraints From U-Pb and Sm-Nd Isotopic Data

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The external zone of the Neoproterozoic Brasília Belt, in SE Tocantins-NE Goiás, central Brazil is underlain by granite-gneiss terrain, minor volcano-sedimentary sequences, felsic and mafic-ultramafic intrusions. The orthogneiss terrain comprises a ca. 6,000 km^2 crustal block, limited westward by Neoproterozoic arc rocks, and southward by late Paleoproterozoic rift-related bimodal volcanic and sedimentary rocks (Araí Group) and intraplate A-type granites. These, in turn, are covered by younger Neoproterozoic metasedimentary and sedimentary sequences, the Paranoá Group southward, and the Bambuí Group eastward. To the north, the basement is unconformably overlain by the Natividade Group, an admittedly equivalent unit of the Araí Group, and by Phanerozoic sedimentary rocks of the Parnaíba Basin.

Despite the large outcropping area, the orthogneiss basement and associated rocks are poorly known. Available geological maps, usually of small scale, have failed to discriminate different domains within this large crustal block. Exceptions are the Almas-Dianópolis and Arraias-Cavalcante areas, where, aside from the dominant orthogneiss, large-scale mapping allowed to discriminate several rock associations, including volcano-sedimentary sequences and granite, diorite and gabbro intrusions. Two deformed granitoid suites were recognized in Almas-Dianópolis (Cruz and Kuyumjian 1998, Cruz 2001). The oldest suite comprises hornblende-bearing tonalite gneiss, with minor trondhjemite, granodiorite and quartz diorite. These rocks were intruded by younger oval-shaped biotite-bearing tonalite, trondhjemite and granodiorite plutons. Both suites display low-K calc-alkaline affinity, the younger being more Al-rich. Both were dated at c. 2.2 Ga, using U-Pb SHRIMP dating on zircon (Cruz et al. 2000, Cruz 2001). Titanite from an orthogneiss sampled close to Almas yielded a c. 2.4 Ga age (Cruz et al. 2000, Cruz 2001).

The Arraias-Cavalcante area is dominated by peraluminous felsic plutonic rocks, varying in composition from granite to tonalite and less common quartz diorite. The most striking feature of many of these rocks is the presence of sub-centimetre magmatic muscovite crystals. Most of these rocks were strongly to moderately deformed, but some of the plutons are undeformed. They intrude the Ticunzal Formation, a metasedimentary sequence characterized by graphite-rich micaschist, probably Early Paleoproterozoic in age. Our data (see Nilson et al., this Symposium) reveal Sm-Nd T_{DM} model ages between 2473 Ma and 2578 Ma, and $e_{Nd(t)}$ values between –1 and –3 for the peraluminous gneiss. U-Pb zircon ages vary between 2166±10 Ma and 2120±2 Ma.

The large area between Paranã, São Valério, Natividade, Conceição do Tocantins and Arraias is dominated by orthogneiss ranging in composition from tonalite through granite. The majority of orthogneiss sampled in this area displays T_{DM} model ages between 2.24 Ga and 2.5 Ga. U-Pb zircon ages indicate two groups of orthogneiss samples, one with ages c. 2.3-2.4 Ga, and a younger group with ages between 2.1 Ga and 2.18 Ga. Positive $\varepsilon_{Nd(t)}$ values suggest that the older group of samples, collected in the Conceição do Tocantins area, represents a fragment of Early Paleoproterozoic juvenile continental crust in the Tocantins Province. However, available geological maps do not allow to acertain the extent of this crustal fragment and separate it from younger adjoning terrains. The younger group of ages, c. 2.1-2.18 Ga, has been found in samples from all over the sudy area. Their $\varepsilon_{Nd(t)}$ values are slighly positive or negative, suggesting depleted mantle and older continental sources. Larger negative $\varepsilon_{Nd(t)}$ values have been determined in several samples, with T_{DM} model ages ranging between 2.6 Ga and 3.0 Ga, suggesting derivation from continental Archean sources. Again, there is no indication, so far, for specific domains with older T_{DM} model ages that can be discriminated from domains with younger model ages.

From the available isotopic data, we infer that the orthogneiss rocks from the basement of the Brasília Belt, Tocantins Province, central Brazil, were formed during several crust-forming events: *i)* c. 2.3-2.4 Ga Conceição do Tocantins; *ii)* c. 2.2 Ga Almas-Dianópolis; *iii)* c. 2.09-2.19 Ga Cavalcante-Paranã-São Valério.

The architecture of the orthogneiss basement terrain is not yet understood. Foliation is mostly close to vertical, with dominant NS and NW-SE directions, cut across by younger NE-SW strike-slip shear zones, which are related to Brasiliano orogeny deformation and provide the main tectonic framework of the study area. Folds and compressional structures are common at the borders of the Paleoproterozoic orthogneiss basement, suggesting that it behaved as a coherent and rather cool block during the Brasiliano Orogeny. Geophysical data indicate that this block could represent the westernmost exposure of the former São Francisco continental plate.

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The Paleoproterozoic peraluminous Aurumina granite suite, Goiás and Tocantins, Brazil: geological, whole rock geochemistry and U-Pb and Sm-Nd isotopic constraints

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The Aurumina suite comprises an extensive granite terrain of peraluminous nature in central Brazil, close to the boundary between Goiás and Tocantins states. It is part of the basement of the Brasília Fold Belt, previously known as Granite-gneiss Complex. From the oldest to the youngest, the granitic rocks are muscovite monzogranite, muscovite–biotite monzogranite, tonalite, biotite syenogranite and tourmaline-bearing leucogranites and pegmatites. The Aurumina suite hosts many occurrences and some deposits of gold, tin, tantalum and uranium, and, aside from its metallogenic importance, it is relevant to understanding the geological evolution of central Brazil.

Granites of the Aurumina suite are intrusive in graphite-bearing schist and paragneiss of the Paleoproterozoic Ticunzal Formation. Syn- to late-tectonic intrusion relationships are indicated by lit-par-lit type structures and imprint of the same pervasive N10–N30E mylonitic foliation in granites and country rocks. Another striking feature in Aurumina suite rocks is the common presence of fine-grained graphite lamellae and centimeter-sized graphite-rich nodules interpreted as probable restites. Migmatite features were observed in the granite terrain, mainly related with metasedimentary inclusions and along the contact with the Ticunzal Formation. The biotite enriched granite facies, bearing monazite, and less frequently thorite, as accessory minerals, are characterized by strong gamaspectrometric anomalies.

All petrographic facies of the Aurumina suite display mineral and chemical features, such as igneous muscovite with 0.8-1.5 % TiO_2 in equilibrium with biotite, and ASI>1.1, indicating peraluminous granites and tonalites, interpreted as sin- to post-collisional or simply sin- to post-tectonic, derived from crustal melting. Granites bearing dominant muscovite are typically sin-tectonic, concordantly deformed with their country rock. In both tonalites and biotite granite, deformation is weak and field relations indicate that these are late intrusions, with clearly late- to post-tectonic characteristics. The crustal origin of the Aurumina suite granites is supported by the occurrence of igneous muscovite and garnet, the presence of graphite restite, the peraluminous nature of the rocks, the enrichment in P, Th, Rb, Li and Ta and the strong fractionation of rare earth elements $(La/Yb)_N>50$.

U-Pb zircon data provide ages between 2,12 and 2,17 Ga for the Aurumina suite rocks. The younger ages are comparable with the c. 2.1 Ga U-Pb ages of cassiterite from the Monte Alegre de Goiás tin deposits and with the c. 2.1 Ga K-Ar ages of muscovite from Sn-pegmatites, related with tourmaline-albite granite, suggesting coeval relationships between crystallization of magmas and tin-bearing hydrothermal systems.

Granites and tonalites display $\varepsilon_{Nd}(T)$ values between -1 and –3 and T_{DM} between 2,4 and 2,6 Ga. It is inferred, therefore, that the peraluminous magmas of the Aurumina suite were sourced in reworked Archean to Paleoproterozoic crust. In the geological context of the Aurumina suite, the Ticunzal Formation is the oldest sequence (> 2.2 Ga) recognized so far, probably related to an Archean source, as indicated by T_{DM} model ages between 2.5 and 2.8 Ga.

The peraluminous nature of the Aurumina suite, its geological and geotectonic relationships with the Ticunzal Formation, the occurrence of migmatites and residual graphite or graphite-bearing xenoliths, and U-Pb and Sm-Nd data, allow suggesting that this metasedimentary sequence could be a possible source for the Aurumina granite magmas. The Aurumina suite represents the most important peraluminous granitogenesis described so far in the basement of the Brasília Fold Belt. These granites are interpreted as an indicator of a Paleoproterozoic collisional event in central Brazil.

Paleoproterozoic record in the Campinorte-Mara Rosa region, Goiás, Brazil

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The Paleoproterozoic era represents the most important event of crustal genesis in the South America Plataform, where two distinct episodes of juvenile accretion are observed. Between 2,3 Ga and 2,1 Ga, volcano-sedimentary sequences were formed, and in the 2,1-1,8 Ga interval the development of several magmatic arcs generated c. 35% of today's continental crust.

The Campinorte volcano-sedimentary sequence recently mapped in northwestern Goiás represents this Paleoproterozoic scenario. The sequence outcrops between the Neoproterozoic Mara Rosa magmatic arc and the mafic-ultramafic complexes of Barro Alto and Niquelandia, and is covered by metasedimentary rocks of the Serra da Mesa Group.

The Campinorte sequence consists of metapsamites and metapelites, eventually with interbedded lens-shaped gondites and metacherts. Rhyolite to rhyodacite metavolcanic rocks and pyroclastic deposits, and subordinate metabasic rocks also occur. Tonalites, granodiorites and granites intruded the sequence, some of which were deformed during a Paleoproterozoic orogenic event, which also lead to greenschist to amphibolite facies metamorphism in the sequence.

U-Pb analyses of zircon from four deformed granitoids from the Campinorte sequence reveal crystallization ages of c. 2,15 Ma. Lower intercepts of the discordias show age values close to 580 Ma, which coincides with the last tectono-metamorphic event recorded in the Brasília Fold Belt. Sm-Nd T_{DM} model ages obtained for the same granitoids vary between 2,2 Ga and 2,4Ga, with slightly positive ε_{Nd} values (from +1,8 to +2,4), indicating a juvenile accrescionary event with short crustal residence.

The U-Pb and Sm-Nd isotopic data of the Campinorte sequence are equivalent to the Silvania volcano-sedimentary sequence and the Aurumina granitoids, described in southern and northern Goiás, respectively. Therefore, these Paleoproterozoic terrains may represent a larger crustal domain in the Tocantins Province than previously recognized.

A Paleoproterozoic Orogen Hidden Within The Neoproterozoic Ribeira Belt, Southeastern Brazil

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The external segment of the Paleoproterozoic Mineiro belt is well constrained at border of the SFC. As previously described, at the cratonic region the orogen is characterized by a passive margin sequence (Minas Supergroup) that began deposition at ca. 2.5 Ga along the Archaean continental margin. Both sequences were deformed as a thrust and fold belt vergent to west, between ca. 2.13-2.0 Ga. Pre-collisional rocks have ca. 2.2 Ga and late granitoids ca. 1.9 Ga. Dome-and-keel structures have been described as the effects of the orogenic collapse at 2.095 Ga, at the Iron Quadrangle region. A molasse succession (Sabara formation) overlays the passive margin sequence and is supposed to be deposited within a foreland tectonic setting, with contribution of the orogen at that time.

On the other hand, the internal domain of the Paleoproterozoic belt is exposed as tectonic slices disrupted and reworked during the Neoproterozoic Collage at the Central Ribeira belt. In spite of the high metamorphic grade and deformation, the combination of detailed geological mapping and geochronology allow the distinction between of basement and cover within the high grade gneisses and granulites that outcrop at the Occidental Terrane of the Central Ribeira. Two major lithological units were mapped in detailed: a) the Mantiqueira complex and b) The Juiz de Fora complex

The Mantiqueira complex comprises four calc-alkaline suites and one very heterogeneous tholeiitic group, listed from the older to the youngest unit: A) tonalite to granodiorite banded orthogneisses with amphibolites; b) tonalite to granodiorite weakly foliated orthogneisses; c) tabular sheets and dikes of amphibolites; d) intrusive leucogneisses; and e) Augen gneisses of granite composition clearly intrusive in al above mentioned units. All of the four groups of calc-alkaline orthogneisses are compatible with continental-arc and collision settings of active tectonic margins. The tholeiitic rocks comprise E-MORB ($[La/Yb]_N$ ca. 1,0 - 3,0) and intraplate continental basalts subdivided in those with lower ($[La/Yb]_N$ ratios ca. 3,5 - 5,0 and higher $[La/Yb]_N$ ca. 13 - 18)

The Juiz de Fora Complex comprises orthogranulites of a wide compositional range, with a predominance of enderbitic and charno-enderbitic over charnockitic and basic rocks. The felsic granulites are subdivided in two calc-alkaline geochemical groups. One is a medium K group that comprises a wide range composition, from diorites to granodiorite; and the other is a high-K group (K_2O up to 4.1%) represented only by acid rocks (granites and subordinated granodiorites). The field relationships indicate that that the charnockitic group is younger than the other one. The chemical composition of both groups also indicates convergent tectonic settings with the suggestion of a progressive chemical maturity, as observed in modern magmatic arcs, with enrichment in Alk and in the total LILE from medium to high-K calcalkaline groups. The most abundant basic granulites of the Juiz de Fora complex are low-TiO_2-P_2O_5 tholeiitic basic rocks. The second basic group comprises alkaline to transitional basic rocks enriched in TiO_2 > 3.3%; K_2O 1.1-1.7%; FeO* > 10%; P_2O_5 > 0.58% and in all incompatible elements the chemical composition signature is consistent with an intracontinental tectonic setting.

The new LA-ICPMS and ID-TIMS U/Pb obtained data reccord the following geochronological episodes

a) The Mantiqueira complex includes calc-alkaline arc-related rocks (c.a 2,2 Ga) and collisonal granitoids (ca. 2,15 Ga). Isotopic data indicate an Archaean crustal component suggesting a cordilleran tectonic setting. A metamorphic episode at ca. 2.04 Ga is also detected. Both units are cut by bimodal composite dikes still undated.

b) To the east, the Juiz de Fora complex comprises two distinct arc-related calc-alkaline suites (ca.2,1) with juvenile isotopic signature, and minor tholeiitic basic rocks (ca.2,4Ga) with both ocean floor and island arc signatures. The data suggest a juvenile terrane accreted to the Tranzamazonian belt.

c) The Juiz de Fora association is also intruded by basic rocks (ca. 1.7 Ga) related to subsequent rifting of the São Francisco paleocontinent that resulted in the development of the São João del Rei and Espinhaço rift basins.

d) The Neoproterozoic orogenic overprint is characterized by amphibolite facies metamorphism and by several folding phases identified at the Mantiqueira complex at ca. 590 Ma. Granulite facies metamorphism and a pervasive mylonitic foliation indicate relatively more intense Neoproterozoic reworking of the Juiz de Fora complex.

The new data suggest that the basement exposed at the Occidental Terrane of Ribeira belt is the extension of the São Francisco paleocontinent amalgamated during Tranzamazonian orogeny. The Mantiqueira complex represents the reworked margin of the Archaean paleocontinent in a cordilleran tectonic setting, while the arc(s)-ocean floor (plateau??) associations of the Juiz de Fora complex indicate juvenile component and probably developed within an oceanic setting. This unit was probably accreted to the the active margin of the SF-paleocontinent during the latest stages of the Transamazonian Orogeny around ca. 2.05 Ma causing the deformation and metamorphism of the Mantiqueira complex. At this time and to the west on the cratonic foreland, the deformation of the Minas passive margin and the development of the Sabará basin were in course.

After the Transamazonian Orogeny, the basement associations were intruded by alkaline and basic rocks related with the distinct extensional phases that result on the opening of the intracratonic Paleo and Mesoproterozoic basins at ca, 1.7 and 1.3 Ga, and at ca. 1.0/ 0.9 Ga related with the development of the Neoproterozoic Andrelândia Passive margin. As suggested before by our research group the Transamazonian suture located between the Mantiqueira and Juiz de Fora Paleoproterozoic terranes could have controlled the Neoproterozoic passive margin tectonics and also the development of a major thrust during the Neoproterozoic/Cambrian Brasiliano convergence.

Palaeoproterozoic basement units reworked within central Ribeira belt: lithological, geochemical and structural constraints outlining two distinct continental blocks

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The Ribeira belt, located on the southeast coast of Brazil, is interpreted as the result of the Neoproterozoic/Cambrian convergence among the São Fracisco, Congo and a third cratonic block on the south. Four distinct tectono-stratigraphic terranes (named Occidental, Oriental, Paraíba do Sul and Cabo Frio) integrate the central segment of this belt [1] and a main Brasiliano suture is recognized between the formers [2]. Pre-1.7 Ga basement units are identified within all terranes with the exception of the Oriental one. The Occidental terrane, which is interpreted as the result of reworking of the São Francisco paleocontinent, comprises two allochthonous (Andrelândia an Juiz de Fora) domains in which basement units are composed of a complex group of high-grade metamorphic rocks. The Mantiqueira Complex (basement within the Andrelândia domain) comprises a great variety of well-foliated, migmatitic, tonalitic to granitic orthogneisses and minor orthoamphibolites, whereas the Juiz de Fora Complex (basement within the homonimous domain) is composed of granulite facies quartz-dioritic to granitic orthogneisses and orthopyroxene-bearing metabasites. Both complexes comprise: intermediate to acid calcalkaline rocks; and transitional basic rocks with either tholeitic or alkaline affinities. The calcalkaline rocks of the Mantiqueira Complex comprise four different petrogenetic groups, characterised by limited silica variation and generated by partial melting of crustal material [3]. U-Pb zircon ages of 2.2 Ga and 2.15 Ga and inherited zircon Archaean ages were obtained for two of these groups [4]. A heterogeneous group of basic rocks includes REE patterns of E-MORB and intracontinental (tholeitic and alkaline) basalts. The four calcalkaline groups of the Mantiqueira Complex are taken as having evolved within a cordilleran magmatic arc setting. The calcalkaline rocks of Juiz de Fora Complex (2.1 Ga; [5]) comprise a relatively expanded suite of co-genetic rocks, related to fractional crystallization and bulk assimilation processes [6], and interpreted as having evolved within an oceanic or thin continental magmatic arc setting. Sm-Nd signatures and T_{DM} ages [7] support a palaeoproterozoic juvenile origin for this unit. A heterogeneous group of basic rocks includes N-MORB, E-MORB and intracontinental signatures. Crystallization ages of 2.4 Ga and 1.7 Ga were yielded, respectively, by N-MORB type basalts and intracontinental alkaline rocks [4]. On the other hand, basement units within the Paraíba do Sul and Cabo Frio terranes are less complex either in litho-geochemical terms and in structural ones. Within the former, basement unit is represented by the Quirino Complex which comprises weakly foliated tonalitic/granodioritic and granitic orthogneisses with metamafic and calcsilicate enclaves. This Complex comprises two distinct calcalkaline magmatic suites [8]: a medium-K calcalkaline suite which includes orthogneisses of tonalitic and granodioritic compositions of 2.15 Ga; and a high-K calcalkaline suite which includes granitic ortogneisses of 2.20 Ga. Inherited zircons yield Archaean ages of 2.8-2.9 Ga [8]. Isotropic to weakly-foliated orthogneisses with diorite and amphibolite enclaves of Região dos Lagos Complex constitute the basement unit within the Cabo Frio terrane (*c.* 1.9 Ga; [9]). These orthogneisses comprise two distinct magmatic suites: a medium-K suite which includes intermediate rocks ($[La/Yb]_N$: 7-15); and a high-K suite composed of acid rocks ($[La/Yb]_N$: 55-104; [10]). T_{DM} Sm-Nd model ages (2.3 - 2.6 Ga) and e_{Nd} values of *c.* -6,0 indicate, at least, some contribution of continental older sources [11].

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Geology of the Palaeoproterozoic Basement (2.03-1.95 Ga) from the Cabo Frio Tectonic Domain, SE Brazil, and its correlation with coeval South American and African blocks

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The Cabo Frio Tectonic Domain is part of the Neoproterozoic-Eo-Paleozoic NE-SW trending Ribeira Belt, cropping out at the eastern portion of Rio de Janeiro state (SE-Brazil). It is limited to the NW by a major NE-SW thrust fault, which separates it from the Neoproterozoic Oriental Terrane, and to the SE it is covered by the Atlantic Ocean.

The predominant lithostratigraphic unit is a Palaeoproterozoic basement tectonically interleaved with a Neoproterozoic amphibolite-paragneiss association. Both lithotectonic units show metamorphic mineral assemblages from upper amphibolite to granulite facies related to low-angle ductile structures, attributed to a Brasiliano tectono-metamorphic event that affected the area in the Mid-Cambrian [1].

This Palaeoproterozoic basement is not connected geographically to any other tectonic basement sheet or even cratonic domain. The detailed study of these allochtonous paleoproterozoic rocks is crucial to the understanding of the tectonic evolution and paleogeography of a 2 Ga continent involving circum Atlantic provinces [2]. In addition, the establishment of a link with other tectonic domains will provide important information upon the final amalgamation of Gondwana during the Paleozoic [1].

The studied basement is subdivided in two main lithostratigraphic units: a felsic unit, named Região dos Lagos, and a mafic unit, named Forte de São Mateus. The first one comprises metagranitoids, metaquartz-diorites and metatonalites. In the low strain domains, the igneous protoliths and primary structures can easily be identified, whereas in strongly deformed domains, the metagranitoids become banded gneisses with migmatitic structures. The metagranitoids are mainly monzogranites, with subordinate syenogranite, quartz-monzonite and granodiorite varieties. The metaquartz-diorites and metatonalites present amphibole and biotite as varietal and accessory minerals. The Forte de São Mateus Unit is constituted by two main lithotypes: a massive-garnet orthoamphibolite and an amphibole-garnet-diopside banded gneiss. Both lithotypes are interleaved and occur as megaboudins with mylonitic contacts with the felsic unit. There are also tabular amphibolites, 2 to 5 meters thick, that clearly cross-cut the felsic orthogneisses, and are interpreted as paleodykes.

The lithogeochemistry analysis in the felsic lithotypes presented a calci-alkaline, subalkaline high-K trend with metaluminous to peraluminous character (Schmitt et al., in prep). This could be indicative of an I-type granitoid protolith, confirmed by presence of the corindon (lower 1%) and diopside in the CIPW normative. Based on the multi-element diagrams, it is suggested that the probable source is a crustal granite with light fractionation of Eu, indicated by the cristallization of plagioclase and a positive anomaly of Ho. Moreover, the Sr fractionation confirms the presence de plagioclase in the source. In the tectonic discriminating diagrams the samples plot in the field of a volcanic arc setting. The orthoamphibolitic unit featured a transitional serie, with tholeiitic affinities. These rocks are enriched in light REE with positive anomaly of Sm. The enrichment in Rb, K and La, and the La/Y and La/Yb ratios higher than 1, suggest that the source for this magma probably had contribution of the enriched lithospheric mantle. Tectonic discriminating diagrams indicate that the protoliths would correspond to island arc basalts.

The metagranitoids present U/Pb ages from single-grain analysis in zircons ranging between 2030 and 1960 Ma (upper intercepts) ([1]; Schmitt et al., in prep). The metatonalite yielded the oldest age, 2029 Ma. These ages are interpreted as the time of crystallization. The T_{DM} model ages vary from 2.6 to 2.4 Ga (similar to data from [3]), which indicates that the original magma was not juvenile. The orthoamphibolites from the Forte de São Mateus Unit presented also an age of 1.96 Ma [1]. The Nd evolution curves are parallel to the depleted mantle. Two samples presented T_{DM} model ages of 2.6 Ga. This isotope geochemistry data points out that the felsic and mafic gneisses could be related to the same tectono-magmatic event in the period of 2.03 to 1.96Ga.

This period is slightly younger than the time range of basement rocks within the Ribeira Belt and the São Francisco Craton (2.2 – 2.0 Ga) [4]. Moreover the 2.0 Ga age is interpreted as the orogenic collapse, which do not fit in the tectonic setting suggested here for the Cabo Frio basement. On the other hand, in the western coast of Namibia (Africa), it is recognized a granitic basement with crystallization ages between 1.98 -1.96 Ga within the Neoproterozoic Kaoko Belt [5]. In the coastal area of Angola, there is also an orthogneissic unit geologically similar to this basement [6]. This preliminary correlation would imply that the Cabo Frio basement could have been part of the Congo Craton before 650 Ma. Nevertheless the hypotheses that the Cabo Frio basement was connected to Curitiba Terrane, in the Dom Feliciano Belt [7], or even was part of a microcontinent, should not be discarded yet.

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The Proterozoic Rocks of Southeeastern Nigeria and their Relationship with Central African Fold Belt

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The Oban massif and the Obudu Plateau form the basement rocks of southeastern Nigeria. They are giant spurs forming the western prolongation of the Cameroon Mountains into the Cross River plains of southeastern Nigeria.

The rocks in the region are schists, gneisses, amphibolites, migmatities, and granulites intruded by rocks of granitic and basaltic composition. The rocks are dominantly Proterozoic in age. Ages obtained range from Pan-African to early Proterozoic. The schists in the region gave zircon evaporation ages between 600-1789 Ma but a xenocrystic zircon that gave an age of 2.5Ga has been recovered from the Obudu schists. The gneisses yielded ages between 600 and 1800Ma whilst the granulites gave zircon ages of 2062 ± 0.4Ma. The charnockites are Pan-African in age yielding zircon age of 574.1 ± 1.0Ma. An amphibolite in the Oban area has given a mesoproterozoic age of 1313 ± 37Ma (Rb-Sr)

The metamorphism of the area was Barrovian type and ranged from middle greenschist to granulite facies. The Pan-African high-grade event was coeval with the formation of granulites in northern Cameroon, Togo and Ghana and resulted from collision of the West African craton and the Benin-Nigerian plate during continental amalgmation to form the supercentinent Gondwana. Inherited xenocrystic zircons upto 2.5Ga in age attest to the presence of Archaean relicts in the region. It is suggested that at least part of the basement rocks of southeastern Nigeria belongs to the Central African Fold belt and contains tectonically interlayered Palaeoproterozoic and Neoproterozoic supracrustal sequences.

SHRIMP U-Pb zircon age evidence for Paleoproterozoic sedimentation and 2.05 Ga syntectonic plutonism in the Nyong Group, south-western Cameroon: consequences for the Eburnian-Transamazonian belt of NE Brazil and Central Africa

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The Nyong Group of the NW corner of the Congo craton is a metasedimentary and metaplutonic rock unit that underwent a high-grade tectono-metamorphic event at ~ 2050 Ma associated with charnockite formation. However, the age of the sedimentation and associated plutonism was not known. In view of this, the unit was considered to be part of the Archean Congo craton reactivated during a Paleoproterozoic or a Pan-African orogeny. Such interpretation was widely supported by the persistance of Archean inheritance revealed by Nd isotope data on whole rocks and U-Pb on zircons. New SHRIMP analyses on detrital zircons from metasediments (BIF, orthopyroxene gneiss and garnet gneiss) yield Mesoarchean to Paleoproterozoic ages, with the youngest zircon at 2423±4 Ma, thus giving the maximum deposition age for the Nyong Group. Data on a metagranodiorite at Bonguen and a metasyenite at Lolodorf yield emplacement ages of 2066±4 Ma and 2055±5 Ma respectively, with Archean inheritance (2836±11 Ma) for the metasyenite. The syntectonic emplacement of these plutonic rocks is supported by the age of 2044±9 Ma obtained on the Bienkop charnockite, associated with Eburnean high-grade metamorphism which continued probably up to 1985±8 Ma. These new data and those from previous works permit correlation of the Nyong rocks with the Paleoproterozoic of NE Brazil and the discussion of the source provenance of detritus for the Nyong Group. Finally, it is proposed that the West Central African Belt (WCAB) in southern Cameroon, Gabon, Congo and Angola represents a segment of the Eburnean-Transamazonian orogeny that resulted from the convergence and collision between the São Francisco-Nigerian Shield block and a former Congo megacraton.

Paleoproterozoic subduction zones at the margins of the Tanzania and Congo Cratons: Evidence from eclogites with MORB-type chemistry in the Usagaran - Ubendian Belts of Tanzania and the Nyong complex of Cameroon

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Subduction of oceanic crust produces blueschists and eclogites, which are stable only under the low geothermal gradients of subduction zones. The recognition of such rocks in Precambrian orogenic belts is evidence that plate tectonic processes similar to those in the modern plate tectonic regime already operated. Since eclogite occurrences mark the sites of suture zones, they are also crucial for reconstructions of former continent configurations. Most known Precambrian eclogites are of Neoproterozoic age, but Paleoproterozoic and even Archean eclogites have increasingly been recognized during the last ten years. Up to 2005 the only known Paleoproterozoic eclogites were those exposed at Yalumba Hill in the Usagaran Belt of central Tanzania [1]. For the eclogites mapped in the Ubendian belt along the southwestern margin of the Tanzania Craton [2] a similar age was assumed [3].

In search of the Paleoproterozoic suture, we studied the Ubendian eclogites at the known localities, in the Ubende Block (Karema-Ikola and Kungwe Bay) and in the Ufipa Block (Chisi) of the Ubendian Belt, in terms of petrology, geochemistry and U-Pb SHRIMP II dating of zircons. Dating of the zircons reveals a metamorphic age of 1863±28 Ma for the Karema and Kungwe Bay eclogites. Major and trace element concentrations point to a formation of the magmatic precursors in a MOR-type setting. HREE are 10-20 times chondritic, whereas LREE are depleted similar to those of MORB (low (La/Sm)N ratios (<1) at variable Nb/La. Our data indicate that the Paleoproterozoic eclogites may represent former ocean floor, which became metamorphosed during a Paleoproterozoic subduction process. However, the mylonitic texture, which characterizes all the eclogites of the Ubende Block, has been attained under high-pressure granulite-facies conditions during the Kibaran orogeny (1086±21 Ma), as indicated by zircon rims overgrown on the eclogitic zircons as well as partial breakdown and recrystallisation of omphacitic pyroxenes to diopside and plagioclase. In contrast, the eclogites of the Ufipa Block, further southeast, are coarse grained and preserved their eclogite-facies mineralogy and texture. SHRIMP II dating of zircons of these eclogites revealed a Pan-African age (593±20Ma). Consequently, the Paleoproterozoic Ubendian Belt, situated between the Tanzania Craton and the Bangweulu Block, contains two suture zones: one is of Paleoproterozoic and the other one of Pan-African age. So far , the eclogites of both localities in the Ubendian Belt were thought to have been formed during the same Paleoproterozoic orogenic cycle [3].

Along the north-eastern border of the Congo Craton in Cameroon another remnant of a Paleoproterozoic belt is outcropping, which was in part overprinted by Pan-African tectonism and metamorphism in the Central African Fold Belt (CAFB). The latter stretches East-West along the northern border of the Congo Craton. The Paleoproterozoic Nyong Complex at the SW corner of the CAFB locally includes strongly retrogressed eclogites. Omphacitic clinopyroxene (up to 23% jd) contains numerous plagioclase "exsolutions" pointing to a former significantly higher jadeite component during subduction at maximum depth. Thermobarometry gives a minimum pressure of 16 kbar at 750-800 °C. HREE are 10-19 times chondritic, whereas LREE are depleted similar to those of MORB (low (La/Sm)N ratios (<1) at variable Nb/La (0.7-1.4). SHRIMP II dating of zircons from two eclogite samples revealed metamorphic ages of 2095±70 Ma and 2093±45 Ma.

The investigated eclogites occurring at the margins of the Congo- and Tanzania Cratons are among the oldest subduction rocks exposed in orogenic belts and their MORB-type chemistry indicates subduction of oceanic lithosphere during the Paleoproterozoic. Due to later (Pan-African or Kibaran) reworking the direction of subduction at the different locations is obscured. However, at the south-eastern margin of the Tanzania Craton (Yalumba Hill) the eclogites are associated with synchronously formed cordierite-bearing granulites, which may be interpreted to represent a low-pressure metamorphic belt above a subduction zone. In this case it would imply subduction to the East, below a now reworked Archean Block within the East African Orogen and not below the craton in the West.

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Proterozoic evolution of southern São Francisco Craton based on $^{40}Ar/^{39}Ar$ isotopic data

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The geological evolution of the continental crust of Southern São Francisco Craton records a polyphase crustal history ranging from Meso- to Neoarchaean. After the first substantial sialic crust and supracrustal sequences were generated, successive accretion and differentiation stages associated with crustal reworking affected this area during the Archaean and Proterozoic. Usually, the continental crust of the Southern São Francisco Craton comprises Archaean medium to high-grade metamorphic rocks (gneisses) and granite-greenstone associations. The gneisses and relict of greenstone sequence are crosscut by mafic dykes swarm that are positioned into NW-SE structures and constituted by a distinctive group of not deformed neither metamorphosed rocks, which can be classified as gabbronorite and gabbro. In order to investigate the evolution of this continental crust, we will present $^{40}Ar/^{39}Ar$ step-heating analyses for biotites and amphiboles from different rock-type (gneisses and its amphibolites enclaves; amphibolites from the greenstone sequence; gabbronorite and gabbros from the mafic dyke swarm). The $^{40}Ar/^{39}Ar$ data obtained from biotite and hornblende, extracted from gneisses, amphibolite enclaves, amphibolite from supracrustal rocks, gabbronorite and gabbro, display imperative information related at three events, around 2.0-1.9 Ga; 1.7 Ga and 0.9 Ga, occurred on the southern São Francisco Craton. The 2.0-1.9 Ga event is correlated to the exhumation and retrograde metamorphic processes from the high-grade metamorphic event. Around 1.7 Ca an emplacement and crystallization of the gabbronorite occurred under a mafic dykes swarm. The NW-SE structures into which these swarm dykes were emplaced can be correlated with the Staterian continental rift scenario (1.8-1.6 Ga). The latest thermal evidence in the Campo Belo Metamorphic Complex is the emplacement of the ~0.9 Ma gabbros, into preexisting NW-SE structures and might be coupled to the Macaubas rift. The results point out in this study stand for the final stabilization of the Campo Belo Metamorphic Complex that happened in the Mesoproterozoic and not in the Achaean.

The Espinhaço rift-sag basin, eastern Brazil, and the end of the Paleoproterozoic Era

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Sedimentologic, paleogeographic, stratigraphic, structural and tectonic studies in the Late Paleoproterozoic to Early Mesoproterozoic Espinhaço 1st-order sequence, eastern Brazil, indicates deposition in a rift-sag (steer's head) basin. The Espinhaço basin belongs to a continental-scale rift network, which marks the installation of sedimentary basins controlled by fully-developed, Phanerozoic-style plate-tectonics.

Four basin evolution stages are recognized (pre-rift, rift, transitional and flexural), which are represented by four unconformity-bounded 2nd-order sequences. The unconformities are recognized in the field and mappable even on a regional scale. The pre-rift and rift stage of the Espinhaço basin were filled by products of continental depositional systems. The pre-rift stage probably represents the first product of the rifting process, before the development of the half-grabens that characterize the rift stage. During the rift stage, mechanical subsidence due to lithospheric stretching was predominant and led to episodic rising of the depositional base level. As a result, the basin fill is characterized by three 3rd-order sequences arranged in coarsening-upward. Structural mapping and paleocurrent patterns indicate that block tilting and half-graben subsidence/uplift controlled sediment dispersion. The first marine incursion within the Espinhaço basin marks the change in the subsidence regime of the basin. The evolution of the transitional and flexural stages was probably controlled by thermal subsidence due to thermal contraction of the lithosphere during cooling. The transitional stage was characterized by relatively low subsidence rates. Higher subsidence rates and a consequent sea-level rise characterize the flexural stage of the Espinhaço basin, in which three 3rd-order transgressive-progradational sequences can be recognized.

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