Depositional systems and stratigraphic review proposal of the Rio Preto Fold Belt, northwestern Bahia/southern Piauí

Fabício de Andrade Caxito, Alexandre Uhlein, Júlio Carlos Destro Sanglard, Tatiana Gonçalves Dias, Mônica de Cássia Oliveira Mendes*

Abstract The Rio Preto Fold Belt borders the northwestern São Francisco Craton margin, in northwestern Bahia state. The precursor basin to the fold belt is represented by the km-thick Canabrinha Formation, composed of lithic quartzite, phyllite, sandy-pelitic metarhytmite, metadiamictite, and locally metamarl. Its deposition occurred on a submarine slope-apron dominated by gravitational flows like mud flows and turbidity currents in an east-west trending asymmetric rift or hemi-graben, bounded by a faulted border on the south and a possible flexural border towards the north. The sediment supply came mostly downslope from the São Francisco Craton to the south. In the northern portion of the fold belt, the Formosa Formation probably represents part of the Paleoproterozoic basement, composed of garnet-mica schist, quartzite, iron-manganese metachert, greenschist, and locally orto-amphibolite intercalations. The Formosa Formation was probably deposited in an arc-related basin 1.9 Ga ago. A stratigraphic review proposal is based on two points: 1) Removal of the Canabrinha Formation from the base of the Bambuí Group and its positioning as a chronostratigraphic equivalent to the diamictite-bearing units on the other fold belts that surround the São Francisco Craton; 2) Replacement of the term Rio Preto Group for the term Formosa Formation, once that its rocks can't be individualized into formations. The pre-orogenic sedimentation on the Rio Preto Fold Belt occurred between 850 and 600 Ma ago. During the Brasiliano Orogeny (600 – 540 Ma), the sedimentary basin was metamorphosed at the greenschist facies and inverted, assuming a kilometric doubly-vergent fan structure.

Keywords: Rio Preto Fold Belt; São Francisco Craton; Brasiliano Orogeny.

Resumo *Sistemas deposicionais e proposta de revisão estratigráfica da Faixa Rio Preto, Noroeste da Bahia/Sul do Piauí.* A Faixa Rio Preto bordeja a margem noroeste do Cráton do São Francisco, no noroeste do estado da Bahia. A bacia precursora da faixa dobrada é representada pela Formação Canabrinha, de espessura quilométrica, composta por quartzito lítico, filito, metarritmito areno-pelítico, metadiamictito, e, localmente, metamarga. Sua deposição ocorreu em um ambiente de talude submarino dominado por fluxos gravitacionais tais como fluxos de lama e correntes de turbidez, em um *rift* ou hemi-graben assimétrico de direção leste-oeste, com uma borda falhada a sul e uma possível borda flexural a norte. O aporte sedimentar foi predominantemente talude abaixo, do Cráton do São Francisco a sul, para norte. Na porção norte da faixa dobrada, a Formação Formosa provavelmente representa parte do embasamento Paleoproterozoico, composta por granada-mica xisto, quartzito, metachert ferro-manganesífero, xisto verde, e localmente, intercalações de orto-anfibolito. A Formação Formosa foi provavelmente depositada em uma bacia relacionada a arco magmático 1,9 Ga atrás. Uma proposta de revisão estratigráfica é baseada em dois pontos: 1) Retirada da Formação Canabrinha da base do Grupo Bambuí e seu posicionamento como um equivalente cronoestratigráfico das formações portadoras de diamictitos das outras faixas dobradas que circundam o Cráton do São Francisco; 2) Substituição do termo Grupo Rio Preto pelo termo Formação Formosa, uma vez que suas rochas não podem ser individualizadas em formações. A sedimentação pré-orogênica na Faixa Rio Preto ocorreu entre 850 e 600 Ma atrás. Durante a Orogênese Brasileira (600 – 540 Ma), a bacia sedimentar foi metamorfizada na fácies xisto-verde e invertida, assumindo uma estruturação quilométrica em leque assimétrico de dupla vergência.

Palavras-chave: Faixa Rio Preto; Cráton do São Francisco; Orogênese Brasileira.

INTRODUCTION The São Francisco Craton (Fig. 1) (Almeida 1977, Alkmim 2004) represents a continental fragment involved in the amalgamation of the Western Gondwana paleocontinent during the so-called Brasiliano Orogenic cycle, at the end of the Proterozoic and at the beginning of the Paleozoic (Almeida 1967, 1977, Trompette 1994). During the Neoproterozoic Era, expressive glaciogenic

sedimentation developed in the region, being represented by the Jequitai Formation, in Minas Gerais, and by the Bebedouro Formation, in Bahia. At the same time, in the craton borders, rift basins that evolved into passive margins were developing, with important gravitational sedimentation (debris flow deposits and turbidity currents) and some glacial contribution (Uhlein *et al.* 2004). These sequences were inverted

Departamento de Geologia, Instituto de Geociências, Universidade Federal de Minas Gerais - UFMG, Belo Horizonte (MG), Brasil.
E-mail: boni@ufmg.br, uhlein@dedalus.lcc.ufmg.br, jcsanglard@ymail.com, tatiana.dias@gmail.com, monimendesgeo@yahoo.com.br
*Corresponding author

and metamorphosed during the Brasiliano Orogenic cycle ($\sim 630 - 570$ Ma) and have been preserved in the belts surrounding the craton (Fig. 1). Therefore, the fold belts represent the inversion of sedimentary basins adjacent to the craton, a region that has been relatively spared of deformation and metamorphism.

The Rio Preto fold belt (Figs. 1 and 2) is the least studied region in the context of the São Francisco Craton and its marginal fold belts. The objective of this paper is to describe the geology of this area with emphasis on the sedimentary evolution of the precursor basin to the fold belt, besides presenting a proposal of a stratigraphic review based on the Brazilian standards of stratigraphic nomenclature (*Código Brasileiro e Guia de Nomenclatura Estratigráfica*; Petri *et al.* 1986). The Rio Preto fold belt is located at the northwest of the state of Bahia, bordering the state of Piauí, where the main urban center is the city of Barreiras (Fig. 1), about 150 km to the south of Formosa do Rio Preto, on the central portion of the belt.

PREVIOUS STUDIES Compared to other fold belts surrounding the São Francisco Craton,

few studies have addressed the geology of the region. In the 1970's, with the mapping resulting from LETOS Project (Moutinho da Costa *et al.* 1971) and the study from Santos, Meneses & Santos (1977), the metasedimentary rocks of Preto river valley were grouped in the Rio Preto Group and stratigraphically placed above the Chapada Diamantina Group, of the mesoproterozoic, and below the Bambuí Group, a neoproterozoic cratonic cover of the São Francisco Craton (Fig. 1). After the disclosure of the geological map to the millionth of the State of Bahia (Inda & Barbosa 1978), the main geological and tectonic environments of northwestern Bahia were defined, in a geosynclinal context.

Jardim de Sá & Hackspacher (1980) made a structural pattern recognition on the northwestern margin of the craton, identifying four phases of deformation. These authors placed the Rio Preto Group in the Early Proterozoic because of their correlation with the supracrustal rocks of the Riacho do Pontal fold belt (Fig. 1) that, back then, were considered to be older than those from the Chapada Diamantina Group.

Barbosa (1982) analyzed manganese deposits in the west of Bahia and proposed a Neoproterozoic age for the Rio Preto Group, with almost contemporary deposition with the Bambuí Group. The project RADAMBRASIL also adopts this interpretation (Montes, Monteiro & Silva 1986).

Egydio-Silva (1987) carried out an important study in the region of Rio Preto Fold Belt and the adjacent cover of the craton, identifying the main lithostratigraphic, structural and tectonic aspects of northwestern Bahia. This author reallocated a major portion of the Rio Preto Group to the base of the Bambuí Group (Canabrinha Formation), thus considering the rest of the group to be correlated to the Chapada Diamantina Group, of Mesoproterozoic age. This interpretation was further adopted by the CPRM — Geological Service of Brazil —, during its basic geological mapping program (Andrade Filho, Neves & Guimarães 1994, Arcanjo & Braz Filho 1999).

Figure 1 – São Francisco Craton and surrounding belts. Adapted from Alkmim (2004).

STRATIGRAPHIC REVIEW PROPOSAL

The stratigraphic aspects of the Rio Preto fold belt presented in this paper (Fig. 3) are the results from stratigraphic, sedimentological and lithochemical studies, besides being supported by geochronological and isotopic data gathered in the past few years (Uhlein *et al.* 2008, Sanglard *et al.* 2008, Gonçalves Dias & Mendes 2008, Caxito 2010, Caxito *et al.*

Figure 2 – Geological map of the Rio Preto belt, northwestern Bahia and southern Piauí. See Fig. 1 for location.

2011a, b). The stratigraphy herein proposed differs from that proposed by Egydio-Silva, Karmann & Trompette (1989), suggesting the removal of the Canabrinha Formation from the Bambuí Group, and the change of denomination of the Rio Preto Group into Formosa Formation, of Paleoproterozoic instead of Mesoproterozoic age, as previously suggested (Tab. 1). Next, we will present the main lines of reasoning and argumentation in which this proposal of stratigraphic review is based on.

Cristalândia do Piauí Complex

The tectonic-stratigraphic basement of the Rio Preto fold belt is represented by the Cristalândia do Piauí Complex, in the northern part of the fold belt (Fig. 2) (Arcanjo & Braz Filho 1994), which comprises intercalations of biotite gneiss and amphibolite. These rocks are aged 2.1 Ga (Rb-Sr whole rock isochron), with biotites dating around 540 Ma (K-Ar) (Egydio-Silva 1987). Sm-Nd model ages (T_{DM}) in between 2.8 and 2.6 Ga suggest that Archean crust is the main component of this segment (Caxito 2010 and new data), with the impression of a paleoproterozoic cycle and rework during the Brasiliano cycle. The geology of this complex is relatively unknown and requires further studies, especially regarding petrography and lithochemistry.

Formosa Formation The Formosa Formation corresponds to the Rio Preto Group according to Egydio-Silva, Karmann & Trompette (1989). The name Rio Preto Group was informally proposed by Santos, Meneses & Santos (1977) to denominate the metasedimentary rocks of the Preto river valley. However, as Fuck *et al.* (1993) states, the Rio Preto unity should not be considered as a group, for its rocks are not naturally subdivided in formations. According to the Brazilian Code of Stratigraphic Nomenclature, “the formations are fundamental units in the description and interpretation of a region’s geology, especially regarding the spatial distribution of

successions and deposition in areas that are proximal and distal within the basin.” (Petri *et al.* 1986, p. 377, § 1). Thus, Uhlein *et al.* (2008) and Caxito (2010) suggest a redefinition of this group based on genetic criteria and according to the limitations of stratigraphic studies on Precambrian regions, comprising the Canabrinha and Formosa Formations. However, recent geochronological and isotopic data suggest that the two formations developed in different contexts and ages, so they should not be included in the same group (Caxito *et al.* 2011a, b). Hence, the term “Rio Preto Group” is no longer used.

The Formosa Formation (named after the city of Formosa do Rio Preto) originates in the setentrional portion of the Rio Preto fold belt, alongside Preto river, and extends 20 km to the north, towards the Bahia and Piauí boundary (Fig. 2). It is composed of muscovite schist, often with abundant garnet, with intercalations of micaceous quartzite, sandy metarhythmite, iron-manganese metachert, chlorite-actinolite-epidote schist (greenschist), and, locally, orthoamphibolite (Figs. 3 and 4). The stratotype can be observed on BR-135 road, between Formosa do Rio Preto and the borderline of Bahia and Piauí (Figs. 2 and 4B). Subsidiary reference sections in which the intercalations of metachert and greenschist may be easily observed are indicated at Vereda Jatobá and in the region of Arroz Village, to the east and northwest of Formosa do Rio Preto, respectively. Metric intercalations of micaceous quartzite are seen in the road to Coaceral (Portal do Jalapão) near the limits of Bahia-Piauí (Fig. 4A). The lithotypes in Formosa Formation present a metamorphism of greenschist to epidote-amphibolite facies (~ 500°C, 2 – 5 Kbar, 10 – 20 km depth; Caxito, 2010). Due to the tectonism of the Formosa Formation, with frontal and lateral low-angle thrusts (Fig. 4B), it is virtually impossible to estimate its thickness; however, constant intercalations of gneiss slivers from the basement suggest preserved low thickness.

Table 1 – Proposal of stratigraphic review of the Rio Preto fold belt

Egydio-Silva <i>et al.</i> (1989)			This study	
Neoproterozoic	Bambuí Group	Riachão das Neves Fm.	Bambuí Group (craton)	Riachão das Neves Fm.
		Serra da Mamona Fm.		Serra da Mamona Fm.
		São Desidério Fm.		São Desidério Fm.
		Canabrinha Fm.		Canabrinha Fm. (fold belt)
Mesoproterozoic	Rio Preto Group		Paleoproterozoic Orosirian (~ 1.9 Ga)	Formosa Fm.
Archean/Paleoproterozoic	Cristalândia do Piauí Complex		Archean/Paleoproterozoic	Cristalândia do Piauí Complex

Good occurrences of iron-manganese metachert can be found in the Jataí region, 20 km to the east of Formosa do Rio Preto (Figs. 4C and D), on the road to Santa Rita de Cássia, and in the Lagoa Farm, on the old BR-135 road, which is accessed through the wooden bridge crossing Preto river in Formosa do Rio Preto, towards the southeast. This rock constitutes a

guide-layer for the Formosa Formation that has been previously described as itabirite (Egydio-Silva 1987, Andrade Filho, Neves & Guimarães 1994). Recently, Gonçalves Dias & Mendes (2008) and Mendes *et al.* (2008) carried out petrographic and lithochemical studies, aided by scanning electron and optical microscopy (Fig. 4D), indicating its classification as metachert,

Figure 3 – Stratigraphic relations in the Rio Preto fold belt according to the proposal of our study. Note the change in scale between the columns of Canabravinha and Formosa formations.

with SiO₂ between 90.49 and 99%, Mn between 0.04 and 3.54%, and Fe between 0.4 and 2.4%.

Metric to decimetric intercalations of green-schist with nematoblastic texture are common in the Formosa Formation. These are mainly composed of chlorite, actinolite, epidote and plagioclase strongly oriented in the main foliation. The most important accessory mineral is titanite. Tectonic intercalations of gneiss slivers of the Cristalândia do Piauí Complex are also found in the Formosa Formation, especially in Arroz Village and near the BR-135, to the north of Formosa do Rio Preto.

In the Angico Farm, to the west of Formosa do Rio Preto, a 200 meters thick epidote-amphibolite layer intercalates between garnet-mica schist and sandy meta-rhyolite of the Formosa Formation. These rocks have long been considered as essential for the understanding of the geodynamic evolution in Rio Preto belt (Egydio-Silva 1987, Fuck *et al.* 1993, Uhlein *et al.* 2008). The amphibolites present lithochemistry of tholeiitic basalts, with flat chondrite-normalized rare earth elements (REE) patterns and slight enrichment of light REE compared to heavy REE (La_N/Yb_N: 1.35 – 2.97; Eu/Eu*: 0.94 – 1.14),

negative Nb and positive Sr anomalies, and high LIL/HFS ratio (Caxito 2010, Caxito *et al.* 2011b). In most tectonic discrimination diagrams, the samples plot within island-arc tholeiites, back-arc basalt or Mid Ocean Ridge Basalt (MORB) fields. U-Pb analyses of magmatic zircons (Th/U: 0.11 – 1.56) yield a homogeneous population aging $1,961 \pm 11$ Ma, with $\epsilon_{\text{Nd}}(1.96)$ ranging from slightly negative to positive (-0.3 to +1.0). Thus, these rocks probably represent oceanic crust remnants, derived from a mantle wedge above a subduction zone that may be related to a paleoproterozoic volcanic arc (Caxito 2010, Caxito *et al.* 2011b).

Studies of detrital zircon and Nd isotopes suggests a relative simple sedimentary provenance for the Formosa Formation, with a bimodal distribution of detrital zircon U-Pb ages in between 1.9 – 2.2 and 2.5 – 2.6 Ga, and T_{DM} model ages between 1.9 and 2.6 Ga (Caxito 2010, Caxito *et al.* 2011a). These data seem to indicate the Cristalândia do Piauí Complex as the main source of the Formosa Formation. The absence of meso – to neoproterozoic zircons and the intercalation of paleoproterozoic mafic rocks suggest that at least part of the Formosa Formation was formed in

hbl: hornblende; ol: oligoclase; cz: clinozoisite; cl: chlorite; ap: apatite.

Figure 4 – Lithotypes of Formosa formation. (A) Intercalations of garnet-mica schist (x) and micaceous quartzite (q), road to Coaceral (Portal do Jalapão); (B) Mica schist in the BR-135 road, north of Formosa do Rio Preto, with deformation characterized by low angle thrusts; (C) Iron-manganese Metachert, Primavera farm, east of Formosa do Rio Preto; dark iron and manganese oxide rich layers alternate with quartz-rich layers; (D) aspect of dark metachert layer at the scanning electron microscope, formed mainly by espessartite and manganese oxides. (E) Ortho-amphibolite at Angico farm, west of Formosa do Rio Preto; clear plagioclase-rich layers (albite and oligoclase) alternate with mafic amphibole-rich layers (mainly hornblende); (F) microscopic aspect of ortho-amphibolite from Angico farm.

the Paleoproterozoic Era, probably in a basin related to a magmatic arc, hence composing the basement to the Rio Preto fold belt alongside the Cristalândia do Piauí Complex. The Formosa Formation contacts the Canabrinha Formation in the south through an oblique reverse dextral shear zone (Malhadinha-Rio Preto Shear Zone, Gonçalves Dias & Mendes 2008, Caxito *et al.* 2010), and in the north it thrusts in low-angle the gneisses of the Cristalândia do Piauí Complex. To the east, the Formosa formation is thrust upon the quartzites of the Santo Onofre Group, in Serra do Boqueirão (Egydio-Silva 1987). The high degree of transposition of older structures by crenulation cleavage (S_2) dating from the Brasiliano cycle (600 – 540 Ma, K-Ar in muscovite, Egydio-Silva 1987) makes it hard to recognize possible paleoproterozoic-related deformational structures.

Canabrinha Formation The Canabrinha Formation was defined by Egydio-Silva, Karmann & Trompette (1989) as the basal unity of the Bambuí Group in the region, being related to the Bebedouro Formation, base of the Una Group, in Bahia. The nomenclature refers to the Canabrinha stream, which runs next to the homonymous farm, in the municipality of Monte Alegre dos Cardosos, where the authors made the schematic section of the formation.

Uhlein *et al.* (2008) and Caxito (2010) suggest the removal of the Canabrinha Formation from the Bambuí Group, due to its kilometric thickness, greenschist facies metamorphism, and significant deformation, which are characteristics of deposition and structural evolution in the context of a fold belt, in contrast to the Bebedouro Formation, which presents a thickness of hundreds of meters and low to null deformation and metamorphism, which suggest evolution in a cratonic context. Although both unities could present chronostratigraphic correlation, the tectonic and sedimentary contexts are quite different. The Canabrinha Formation thrusts the Bambuí Group in the southern portion of the fold belt (Cariparé shear zone), so the original contact relations between these two units are not recognized. Therefore, it is more coherent that the Canabrinha Formation be correlated to the diamictite-bearing formations from the other Brasiliano fold belts (i.e. basal formations of the Macaúbas Group, in Araçuaí belt, Capitão-Palestina Formation, in the Sergipana belt, and the Ibiá Group, in the Brasília belt).

The Canabrinha Formation occurs in the southern portion of the Rio Preto belt, from north of Cariparé towards north for almost 40 km (Fig. 2). It is composed of lithic, conglomeratic, feldspathic, carbonatic or micaceous quartzite with graded, plain or cross stratification; meta-graywacke, carbonaceous phyllite and mica schist; sandy metarhytmite; metadiamicctite, and metamarl (Fig. 5). Millimetric to centimetric euhedral limonite is profusely disseminated. Besides the section of Canabrinha stream, in the BR-135 road, between Cariparé and Formosa do Rio Preto, metarhytmites are easily seen. The Canabrinha formation presents a lateral and vertical variation with coarse lithofacies to the south, progressively gradating to lithofacies presenting a higher proportion of pelitic material towards the north.

The spectrum of U-Pb ages in detrital zircon of the Canabrinha Formation differs from that of the Formosa Formation, varying from 3,000 to 850 Ma. The Nd isotopes also indicate a larger variety of sources, with T_{DM} model ages in between 1.5 and 2.7 Ga (Caxito 2010, Caxito *et al.* 2011a). These data suggest that the Canabrinha and Formosa formations present geological evolution in different contexts, i.e. they are probably not chronologically correlated. So, geochronological data do not support the allocation of both formations in the same group, as previously proposed (Rio Preto Group, Uhlein *et al.* 2008, Caxito 2010). We assume the hypothesis that the Formosa Formation represents part of the paleoproterozoic basement of the Rio Preto belt, while the Canabrinha Formation represents the neoproterozoic sedimentation in the fold belt precursor basin.

The Canabrinha Formation is characterized by a low to medium-grade metamorphism and complex structural geology related to the Brasiliano Orogeny, as indicated by K-Ar ages in muscovite around 590 Ma, obtained by Egydio-Silva (1987). To the south, it is thrust upon the Serra da Mamona Formation of the Bambuí Group by a frontal reverse shear zone (Cariparé shear zone) (Figs. 2 and 7), and to the north it contacts the Formosa formation through an oblique dextral shear zone (Malhadinha-Rio Preto Shear Zone) (Figs. 2 and 7). Based on gravimetric data, Egydio-Silva (1987) estimates a thickness of almost 7,500 meters for the Canabrinha Formation. However, this data must be carefully interpreted, due to the high ductile deformation of these rocks, presenting isoclinal folds in the central portion of the fold belt (Fig. 2 and 7).

BambuÍ Group The Bambuí Group in the western part of Bahia has been subdivided into three formations by Egydio-Silva, Karmann & Trompette (1989), including, from the bottom up:

1) São Desidério Formation. Dark gray limestones with intercalations of marls and siltstones, with estimated thickness of 450 meters. The basal contact is not observed; however, if we admit a correlation to the Sete Lagoas Formation, to the south, nearby Correntina, the latter settles by erosive discordance over gneisses of the Archean/Paleoproterozoic basement of the São Francisco Craton. The superior contact is gradational, with progressive increase in the proportion of clastic material in carbonates,

grading to the metamarls and carbonaceous slates of the Serra da Mamona Formation.

2) Serra da Mamona Formation. It can be correlated to the Serra da Saudade Formation, and it is marked by the intercalation of metacarbonate and metapelite layers with incipient to low metamorphic grade. Thickness, according to the geological profile, is estimated in 3,000 meters (Egydio-Silva, Karmann & Trompette 1989), but these authors call the attention to the fact that it is a region of intense tectonic deformation, thus this estimate must be carefully considered.

3) Riachão das Neves Formation. On top of Serra da Mamona Formation, the lithotypes show a

(A, B): Column A, Chapada da Boa Vista; (C–G): Column B, Canabravinha stream; (H): Column C, BR-135 between Malhadinha and Formosa do Rio Preto.

Q: quartz; P: plagioclase; C: carbonate; M: muscovite.

Figure 5 – Lithotypes of Canabravinha formation. (A) Graded stratification in lithic quartzite; (B) Photomicrograph under crossed polarizers of lithic quartzite. (C) Decimetric layer of metadiamicctite intercalated within carbonatic phyllite. Note the absence of isolated clasts in the phyllite layer; (D) Detail of granite boulder in the metadiamicctite layer; (E) carbonate pebble and quartzite clasts in the metadiamicctite layer; (F) Climbing laminations in the quartzite layer; (G) phyllite clast in the quartzite layer; (H) low-density metaturbidites. Centimetric sandy layers, in clear grey, intercalated within dark grey pelitic layers. The arrow indicates graded stratification in the quartzite layer.

gradual increase of sedimentary granulometry, presenting a great amount of feldspar and lithic fragments in its composition, thus characterizing meta-arkoses and metagraywackes of the Riachão das Neves formation. This formation can be correlated to the Três Marias Formation, with estimated thickness of 4,000 meters.

Phanerozoic covers Above the Precambrian units of the region, lies the Urucuia Group upon an erosive and angular discordance, which is constituted by fluvial/aeolian sandstones and conglomerates of the Cretaceous period. All of the units are covered by unconsolidated sedimentary deposits from the Cenozoic Era, mostly sand and clay, often lateritized.

DESCRIPTION OF STRATIGRAPHIC COLUMNS Aiming at a stratigraphic and sedimentological study of the Rio Preto belt, three schematic columns were raised at the Canabravinha Formation, looking to recognize the main lithofacies and depositional systems in key-areas of the region (Figs. 2 and 3). It is worth emphasizing the schematic character of such columns, inherent to studies of this type in fold belts. The column correlation method was chosen due to the visual practicality of stratigraphic and sedimentological relations in time and space.

Column A (Fig. 3) was raised in Chapada Boa Vista, near the tectonic contact with Serra da Mamona Formation (UTM 512249E/8738285N; Datum SAD69 Zone 23S, being the same for all other columns). One can observe a sequence dominated by coarse grained lithofacies, mainly psamopsephitic deposits. The basal metadiamicite in this column is found on road BR-135 and is estimated to be 10-meter thick (Fig. 3). The metadiamicite presents a metapelitic matrix that sustains clasts of granule to block size of orthoquartzite, limonitic micaceous quartzite, carbonates, quartz, gneiss, and granite. The original geometry of the clasts is currently obliterated by their stretching in the S_2 foliation, due to the proximity to the Cariparé shear zone, the limitation between the craton and the fold belt (Egydio-Silva 1987) (Fig. 2).

In the intermediate portion of Column A, granodecrescent sequences of granule to pebble sandy metabreccia, lithic quartzite with coarse to fine graded stratification, and sandy-pelitic metarhytmite with plain-parallel stratification are found (Fig. 5A). The quartzite is usually poorly selected and presents

low textural and mineralogical maturity, thus angular to sub-angular grains predominating (Fig. 5A). Microscopic analyses (Fig. 5B) showed quartzite is composed of quartz, muscovite, carbonate, plagioclase, gneiss, feldspar, granite, limonite and opaques, so it can be classified as coarse lithic to conglomeratic or carbonatic quartzite. On the top of the scarp, metadiamicite with block-sized clasts is found again, which characterizes the cyclicity of the sedimentation processes.

Column B was raised throughout the draining of the Canabravinha stream, near Monte Alegre dos Cardosos (504030E / 8744592N). The sequence is similar to that of Column A, although the metadiamicite layers are less thick and decimetric, and the phyllites and quartzites are more common (Figs. 5C–G). In the metadiamicite layers, clasts of carbonate, gneiss, quartz, quartzite, and granite (*sensu lato*) are found (Figs. 5D and E). Clasts of metadiamicite within the metadiamicite layers are rare. Clasts of granite, gneiss and quartzite present granulometry of granule to boulder, while the carbonate clasts occur mostly on granule to pebble granulometry. The original geometry of these clasts remains well preserved, without a dominant pattern, commonly varying from sub-angular to sub-rounded types (Figs. 5C–E); however, rounded and angular clasts, presenting low sphericity, are also common. The matrix is mainly formed by carbonates and oriented phyllosilicates (white mica), and stretched quartz according to the main foliation (S_2). Metadiamicite layers intercalate with phyllite and quartzite layers, which do not present isolated clasts (Fig. 5C). The proportion of carbonate is sometimes very expressive, constituting layers of metamarl.

In the quartzite layers, centimetric climbing laminations are found (Fig. 5F), as well as phyllite clasts (Fig. 5G) with irregular geometry, highly angular, chaotically disseminating within the quartzite.

Column C was raised on BR-135 road, between Malhadinha and Formosa do Rio Preto (488396E/8771374N). In this region, we observe a predominance of metarhythmites formed by centimetric to decimetric intercalations between metagraywackes with graded coarse-fine stratification and phyllites/schists (Fig. 5H), mostly carbonaceous and manganeseiferous, with local layers of quartzite. It is interesting to note the rhythmic occurrence of manganese low-thickness crusts intercalated within the lithotypes, parallel to the bedding plane (Fig. 5H).

FACIES, SEDIMENTARY ENVIRONMENTS AND DEPOSITIONAL SYSTEMS OF THE CANABRAVINHA FORMATION

Fig. 3 presents a correlation of the three graphic-sedimentary profiles raised in the study, representing the main lithofacies associations throughout the Canabravinha Formation. Coarse facies (metadiamicrites) are prevalent in the south portion, becoming thinner to the north. Tab. 2 shows the main facies, processes and products interpreted on the stratigraphic columns. Based on this data, one can identify the depositional environments and propose a model of evolution for the precursor basin to the fold belt.

The decimetric to metric layers of metadiamicrite suggest the periodic action of mud and debris flows that occasionally grades to high-density turbidity currents (granule and pebble metabreccia) (Lowe 1982), and these to low-density currents, with Tabc intervals of Bouma (1962), represented by conglomeratic to coarse lithic quartzite with graded, plane and crossed stratification, according to the velocity of the current flow. The intercalated phyllite layers are the product of decantation of fines in suspension, which is generated after each mudflow. The presence of climbing laminations (Tc) and phyllite clasts within quartzite intercalating with metadiamicrite layers also indicate the action of turbidity currents during the sedimentation of such layers. The climbing laminations are formed when tractive sedimentary processes compete with sedimentation by decantation, as in the case of decelerating flows such as turbidity currents; Phyllite clasts are widely disseminated in sand layers of turbidity sequences, being formed mainly by erosive processes of the clayey soil during gravitational flows (Johannson & Stow 1995).

In general, the disposition of the facies of metarhythmites in Column C follows the classic scheme of low-density turbidites, of Bouma (1962).

Metaturbidites are formed by centimetric layers of metagraywacke with coarse-fine graded stratification (Ta), followed by metagraywacke with plane stratification/lamination (Tb), rarely crossed stratification (Tc), followed by phyllite/schist layers (Tde). These are superimposed by another metagraywacke layer followed by another phyllite layer, and so on. Similar outcrops are common on road BR-135, between Malhadinha and Formosa do Rio Preto, which suggest a predominance of diluted turbidity currents in this portion of the precursor basin.

The sedimentary/stratigraphic analysis showed no direct evidence of glacial influence on the sedimentation of the Rio Preto belt. Although diamictites have been recognized for over 50 years as important facies in depositional systems that are not related to glacial sedimentation, the distinction between glacial and non-glacial diamictites is still neglected. Some good reviews on the theme and distinction criteria between glacial and non-glacial diamictites can be found in the works of Schermerhorn (1974), Boulton & Deynoux (1981), Dreimanis & Schucluter (1985), Moncrieff (1989), Eyles (1993), Miller (1996) and Uhlein *et al.* (2004). The intercalation of thin layers (decimeters to meters) of diamictites with sandstones and pelites, deposited in submarine conditions, and the association with turbidites, do not allow defining these rocks as tillites (glacio-terrestrial rock). Glacio-marine sedimentation is not supported either, for in such case one would expect to find isolated clasts in rhythmites and pelites away from the mud flows of Columns A and B, i.e., in Column C. The hypothesis of reworking glacial deposits by gravitational submarine flows cannot be excluded; however, the lack of identification of striated, faceted or pentagonal clasts makes it only conjectural. Nevertheless, times of low sea level stand, such as glacial periods, strongly favor the development of slope-aprons and

Table 2 – Lithofacies identified in the stratigraphic columns of Canabravinha Formation, with the interpretation of the main products and sedimentation processes

Facies	Products	Processes	Columns
Dm	Massive diamictite with pelite-carbonatic matrix, containing carbonate, gneiss, quartzite, quartz and granite clasts.	Mud flows	A and B
Alm Alg Alp Alcx	Lithic sandstone composed of quartz, carbonate, gneiss, feldspar and muscovite grains, massive (m), with coarse-fine graded stratification (g), plane-parallel stratification (p) or crossed stratification (cx), locally with climbing laminations and shale clasts.	Low to high density turbidity currents (Tabc)	A, B and C
M	Marl	Reworking of carbonate debris, precipitation	B
Rap	Sandy-pelitic rhythmite, formed by centimetric to decimetric plane-parallel layers of sandstone and pelite, often carbonaceous and/or manganeseiferous.	Low density turbidity currents (Tabcde)	B and C

fans, because a great portion of the platform may be exposed, thus tapering the sediments through canyons and fans towards the slope. In high sea level stand periods, on the other hand, sediments tend to concentrate in lagoons and estuaries, or in environments near the coast, not reaching the platform and the feeding canyons (Stow, Howell & Nelson 1985).

According to the lithofacies that have been identified and the sedimentary processes interpreted for the Canabrinha Formation (Tab. 2), a model of deep marine environment for the deposition of its protholits may be proposed. The deep marine sedimentation involves mainly gravitational sedimentation processes on a continuum of high density flows (blocks fall, drags, slides, mud and debris flows) to low-density turbidity currents. These flows interact directly with processes of pelagic and hemipelagic sedimentation (Stow, Reading & Collinson 1996, Stow & Mayall 2000).

The lithofacies of Columns A and B were probably deposited by gravitational sedimentary flows in the proximal portion of a gravel-rich slope-apron system (Reading & Richards 1994, Richards, Bowman & Reading 1998, Stow & Mayall 2000). The slope-aprons form when there is a multiple linear source feeding the basin through a non-canalized system, directly into the slope. The fans form inter-related turbidity systems, so sheet or apron geometry is formed, making individual fan morphology unrecognizable. This type of sedimentation is well developed in fault-bounded margins such as submarine rifts in tectonically active basins, where a considerable amount of sediments is thrown through a steep slope to the adjacent basin, which is rapidly subsident (Fig. 6) (Reading & Richards 1994). The turbidities of Column C represent the dilution of gravitational flows in the distal portion of the basin (Fig. 6).

TECTONIC CONTEXT OF THE RIO PRETO BASIN The deposition of the sediments that compose the Canabrinha Formation probably occurred in a rift basin (Rio Preto basin), where the movements in normal faults favored the episodic origin of mud/debris flows that evolved to turbidity currents (Fig. 6). The mudflows were responsible for the deposition of diamictites, while their dilution resulted in high and low-density turbidity currents that caused sand and pelite layers to be deposited in proximal to distal turbidity sequences, from south to north (Fig. 6).

The association of lithofacies of the Canabrinha Formation and the predominance of coarse and immature sediments to the south, and of finer-grained sediments to the north, indicate that the sedimentary supply was mostly from south to north, therefore the main source area was the São Francisco Craton. The lithic content found in quartzite and clasts of diamictites support this hypothesis. The abundant occurrence of carbonate and granite fragments exempts the Rio Preto belt of being one of the source areas, for none of these rocks is found in the fold belt. It is thus difficult to conciliate a model of provenience exclusively from north towards south by erosion of the mountain chains that formed in the region, either by gravitational processes or by mountain glaciation (i.e. Gonzaga & Walde 2007). On the other hand, the São Francisco Craton is full of granite and carbonaceous proterozoic covers that may have served as a source for the Canabrinha Formation debris.

STRUCTURAL GEOLOGY AND TECTONICS OF THE RIO PRETO BELT The Rio Preto belt represents a quilometric asymmetric divergent fan structure (Figs. 2 and 7), with a well-developed south portion with clear vergence to the São Francisco Craton, and a shorter north portion showing vergence to the north, where the Formosa Formation thrusts the Cristalândia do Piauí gneisses in low angle (Egydio-Silva 1987). This structure is the result of a complex evolution that took place during the Brasiliano Orogeny, which generated three different secondary foliations associated with folds and oblique to transcurrent shear zone systems.

Egydio-Silva (1987) recognized the Cariparé shear zone (Figs. 2 and 7) as the boundary between the craton and the fold belt in the northwest region of Bahia, almost 60 km to the south of the previously proposed limit (Almeida 1977). Despite that, images of the craton in the scientific literature often ignore such limit in its northwest portion, and this fact should be considered in further publications.

The Cariparé shear zone constitutes an inverse fault with SW-NE orientation, 330-350/45 attitude and frontal kinematics, where the rocks of the Canabrinha Formation, in the north-northwest, are pushed onto the rocks belonging to the Bambuí Group, in the south-southeast. The main S_2 foliation, in the Canabrinha Formation, is parallel to the slate cleavage in the cratonic cover of the

Bambu Group, in the transitional craton — fold belt region. The K-Ar ages in between 547 Ma and Ma 595 obtained by Egydio-Silva (1987) in muscovite of the Canabravinha and Formosa Formations reinforce the hypothesis of this deformation having been originated during the Brasiliano Orogeny.

Three different deformation phases, possibly progressive, may be distinguished in the structural and tectonic evolution of the Rio Preto belt (Egydio-Silva 1987, Caxito 2010):

The D_1 phase generated the S_1 penetrating foliation, which is generally parallel to S_0 . Little can be stated about the structures and the tectonic meaning of such phase due to the lack of data and posterior generalized transposition.

The D_2 phase is responsible for the developing of the S_2 penetrating foliation, besides the remarkable structure in form of a double-vergence fan in the Rio Preto belt (Figs. 2 and 7).

In this phase, folds were formed in a gradient of style that vary from smooth and concentric, in the cratonic Bambu Group, becoming progressively tighter towards the craton/fold belt boundary, with tight to isoclinal similar folds in the core of the Rio Preto belt. This phase also generated the ductile-brittle structures in the region, such as the Caripar and Malhadinha shear zones. This phase of deformation is the closest to the metamorphic peak of the Brasiliano Orogeny in the Rio Preto belt, with the main metamorphic minerals oriented according to S_2 .

The D_3 phase is characterized by the S_3 spaced crenulation cleavage or fracture cleavage (modal maximum: 187/32, n: 184), axial plan of smooth folds in S_2 , and possibly represents a final compressive phase comprising structures verging to the northwest, from the craton to the fold belt. Thrust faults sub-parallel to S_3 may be found on BR-135

Figure 6 – Stratigraphic relations accross the So Francisco paleocontinent and neoproterozoic Rio Preto rift in a schematic S-N section.

road between Formosa and Malhadinha, with associated sigmoidal structures indicating frontal movement with top-to-northwest kinematics.

Fig. 7 shows S_2 and L_2 stereograms for the south, central and north portions of the Rio Preto belt (Caxito 2010, Caxito *et al.* 2010). From Cariparé to Malhadinha, S_2 dips northwest (modal maximum: 334/29) (Fig. 7A), inclining progressively towards north until it reaches high angle to sub-vertical values in the region of Malhadinha (170/72) (Fig. 7B) and, from Formosa towards north, its inclination inverts to the southeast (139/15) (Fig. 7C).

The field study shows that the region of Malhadinha corresponds to a shear zone some kilometers thick by 80 km in outcropping extension, named Malhadinha-Rio Preto shear zone (Figs. 2 and 7) (Gonçalves Dias & Mendes 2008, Caxito 2010, Caxito *et al.* 2010). This zone is composed of quartzite mylonites with subvertical S_2 foliation and oblique-directional L_2 lineation. The direction of reverse oblique dextral shear is indicated by a rounded geometry with S-deflection patterns, by structures in the field, and by microstructures in thin section such as S-C pairs, mica-fish and mantled porphyroclasts, and also by quartz crystalline structure orientation (Caxito 2010, Caxito *et al.* 2010).

A model of geotectonic evolution proposed for the Rio Preto belt involves crustal stretching during the Neoproterozoic Era (~ 850 – 600 Ma), with deposition of the Canabrinha Formation in a hemi-graben basin located within the Archean/Paleoproterozoic basement of the region, that is, the Cristalândia do Piauí Complex and the Formosa Formation (Egydio-Silva 1987, Caxito 2010). Posteriorly, this basin was inverted during the Brasiliano Orogeny (~ 600 – 540 Ma), with the development of three phases of progressive deformation. The main phase, D_2 , generated a structure in the form of a quite peculiar asymmetric fan, whose possible causes are discussed by Egydio-Silva, Karmann & Trompette (1990), Caxito (2010) and Caxito *et al.* (2010).

FINAL CONSIDERATIONS The Rio Preto belt has developed onto an Archean/Paleoproterozoic substrate (~ 2.8 – 2.0 Ga) of the Cristalândia do Piauí Complex. During the Orosirian period (~ 1.9 Ga), the deposition of the protholites of the Formosa Formation took place, with predominantly pelitic sedimentation and local chemical precipitation (iron-manganese metachert) possibly associated with basic magmatic activity (greenschist and ortho-amphibolite). The Formosa Formation was probably formed on a

Figure 7 – Geological section and stereograms for S_2 and L_2 in the Rio Preto Belt. For section localization, see Fig. 2.

basin related to a magmatic arc. The crustal block represented by the Formosa Formation and by the Cristalândia do Piauí Complex may have been through deformation and metamorphism of a paleoproterozoic orogenic cycle, as indicated by Rb-Sr ages of the Cristalândia do Piauí Complex (Egydio-Silva 1987); this issue requires further detailed studies. A depositional hiatus marked by a unconformity of over one billion years separates the Formosa and Canabrinha Formations, the latter being formed during the Cryogenian to Ediacaran periods (~ 850 – 600 Ma).

The deposition of the Canabrinha Formation was caused by the opening of a rift with hemi-graben geometry, with a fault-bounded margin to the south and a possible flexural margin to the north. In the faulted margin, gravitational flows predominated in an submarine slope-apron, where mud flows graded to turbidity currents progressively more diluted to the north. There is no direct evidence for glacial sedimentation processes at the Rio Preto belt; however the possibility of reworking of glacial deposits by gravitational flows should not be excluded. During the Brasiliano Orogeny, in the Ediacaran Period (~ 600 – 540 Ma), the Rio Preto

rift and its substrate went through structural inversion and metamorphism in the greenschist facies.

The ductile-brittle doubly-vergent asymmetric fan structure, with oblique to directional movement in the central portion of the fold belt, suggests destructive interaction in clockwise direction between the Cristalândia do Piauí block, to the north, and the São Francisco Craton, to the south. The total absence of orogenic magmatic rocks and oceanic reminiscences of Neoproterozoic age suggest evolution of the outcrop portion of the Rio Preto belt in an ensialic context, as a typical example of an intracontinental orogenic belt (Egydio-Silva 1987, Caxito 2010).

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