**Geological characterization, lithogeochemistry and the metallogenic potential for chromium of the** **Riacho do Mocambo mafic-ultramafic body, northeast of the São Francisco Craton, BA**

**Abstract**

In the north portion of the São Francisco Craton, in the geotectonic context of the Salvador-Curaçá Orogen, it was identified an association of mafic-ultramafic (M-UM) rocks, described in this paper as the Riacho do Mocambo Mafic-Ultramafic Body (RMMUB). Despite being located approximately 60 km from the Vale do Jacurici Complex (VJC), the host of Brazil’s largest reserves of Cr, the RMMUB has never been associated with this Complex in regional geologic mapping projects. When it is mentioned in the bibliography, the M-UM rocks of the RMMUB are genetically related to the São José do Jacuípe Suite (SJJS). While the VJC is described as differentiated sills, associated with a synorogenic to a tardi-orogenic event, the SJJS is interpreted as fragments of an Archean-Paleoproterozoic oceanic crust or as a Gabbro-Anorthosite Stratiform Complex. Such contrasting genesis raised doubts about the RMMUB’s origin and field work along with geochemical analyses were carried out in order to better understand the possible source of the RMMUB. In the field, the RMMUB exhibits an elongated shape of small thickness (7 km of extension by less than 100 m of apparent thickness), displayed concordantly with the Tanque Novo-Ipirá Complex metasediments. In the mapped outcrops it is possible to observe the rhythmic and gradual alternation amid the lithotypes of the RMMUB, varying from serpentinite to metagabbro, suggesting that it is a layered igneous body. The geochemical results support the primitive aspect of the ultramafic rocks of this body (MgO up to 38 wt.%; Ni up to 2972 ppm; Cr up to 7799 ppm) and suggest that the RMMUB shows distinctive characteristics from the SJJS, but similar ones with magma of the VJC such as geochemical signatures, source, depth, and tectonic environment. The discovery of this new M-UM body in an area of great metallogenic fertility opens a potential for the identification of new Cr mineralization and magmatic sulfides of Ni, Cu, and EGP, in the Salvador-Curaçá Orogen, São Francisco Craton, the northeast region of the state of Bahia.

**Keywords**: Metallogenic Potential; Vale do Jacurici Complex; São José do Jacuípe Suite

**1 Introduction**

The Northeast portion of the São Francisco Craton is known for the presence of several mafic-ultramafic rocks (M-UM), such as the São José do Jacuípe Suite – SJJS (Teixeira, 1997; Piaia et al. 2017), the Vale do Jacurici Complex – VJC (Deus & Viana, 1982; Marques et al. 2003a, 2003b; Lord et al. 2004; Silveira et al. 2015), the Caraíba’s M-UM Intrusion (Townsend et al. 1980; Maier & Barnes, 1996; Garcia et al. 2018), the Ultramafic Complex of Campo Formoso (Silva & Misi, 1998; Lord et al. 2004), besides and the M-UM dikes associated to with the Jacobina Group (Couto et al. 1978).

The study area is tectonically located in the São Francisco Craton, specifically, in the northern portion of the orogen Itabuna-Salvador-Curaçá (OISC), which was formed when the Gavião, Serrinha, Jequié, and Itabuna-Salvador-Curaçá paleoplates collided during the Transamazonic (Orosirian) cycle at the end of the Paleoproterozoic (Barbosa and Sabaté, 2003). In the context of the OISC , there are important associations of M-UM rocks around the study area and can be briefly defined, which are represented by the SJJS, unmineralized rocks, and VJC, chrome deposit (Figura 1A and B).

Figure 1: Geological Maps. A. Location map with mafic-ultramafic rocks. Modified from Marinho, 1986. B. São Francisco Craton with location map boundary.

In the study area, M-UM bodies have been currently related to the SJJS. However, the target of this study, called Riacho do Mocambo Mafic-Ultramafic Body (RMMUB), has not been specified in the existing regional mapping. The reason for that might lie in the intense deformation associated with extensive sedimentary covers throughout the area. Doubts with respect to the genesis and the metallogenic potential of the RMMUB were, therefore, raised, since lithological associations of the RMMUB alongside anomalous Cr values ranging from 752 to 7799 ppm in the whole rock indicate a high metallogenetic potential for chromite and other minerals. However, the presence of chromite deposits has been exclusively related to the VJC in the north, while the SJJS has only been associated with non-mineralized mafic-ultramafic rocks, predominantly exposed to the south of the RMMUB.

Pieces of evidence suggesting cogenitivity between RMMUB and VJC chromite deposits implies that the magmatic action that generated the VJC could have had a much wider reach than what was previously assumed, and/or the action of tectonic processes may have placed part of the VJC to the south of its current limits. This correlation could significantly increase the prospective potential for chromite in the north of the São Francisco Craton.

The main goal of this work is to identify and specify the RMMUB in terms of field data, petrographic characterization, and geochemistry, and to compare it with the available data from the SJJS and VJC. This analysis will enable us to discuss and compare topics, such as the source, depth, and tectonic environment of magma. From these data, an evaluation of the metallogenetic potential will be made.

~~The target of this study, called Riacho do Mocambo Mafic-Ultramafic Body (RMMUB) in this paper, was not specified in the existing regional mapping, where this M-UM body has been currently related to with the presence of ultramafic rocks being related to the SJJS.~~

~~Evidences that may suggesting cogenitivity between RMMUB and VJC chromite deposits implicates that the magmatic action that generated the VJC could have had a much wider reach than what was previously assumed, and / or the action of tectonic processes may have placed part of the VJC to the south of its current limits. This correlation could significantly increases the prospective potential for chromite in the north of the São Francisco Craton~~.

~~Evidences that may suggest cogenitivity between RMMUB and VJC chromite deposits implicates that the magmatic action that generated the VJC could have had a much wider reach than what was previously assumed, and / or the action of tectonic processes may have placed part of the VJC to the south of its current limits. This correlation could significantly increases the prospective potential for chromite in the north of the São Francisco Craton.~~

**2 Methods and Materials**

This study is part of the project Metallogenetic Map of the State of Bahia II. Methods consist of field work, petrographic characterization of 15 thin sections made in the laboratory of The Geologic Survey of Brazil (CPRM) and 8 lithogeochemical analyses conducted in partnership with Bahia State Mineral Research Company (CBPM). The samples were prepared and analyzed at the SGS- Geosol, in Belo Horizonte – MG, where the major elements were determined by X-ray Fluorescence, trace elements by ICP – OES (Inductively Coupled Plasma Optical Emission Spectrometry) with digestion and use of sodium peroxide (Na2O2), and rare earth analyses by ICP – MS (Plasma Source Mass Spectrometry).

The samples were adjusted for 100% summation, ignoring the percentage of LOI (Loss on Ignition), which presents high values in serpentinites, due to the water content in these rocks. The Fe2O3t was recalculated to FeOt to be used in the selected charts, besides calculating the magnesium number using the formula mg# = 100MgO/ [MgO + FeOt].

**3** **Geological Context**

The area is located in the northeast portion of the São Francisco Craton (SFC; Almeida, 1967; Figure 1A). The SFC was stabilized in the Transamazonic (Orosirian) cycle at the end of the Paleoproterozoic and limited during the Neoprotorozoic and Cambrian era, during the Brazilian cycle that formed the surroundings orogenic belts such as Sergipano, Rio Preto, Riacho do Pontal, Brasília and Araçuaí (Alkmin *et al*. 1993; Barbosa and Sabaté, 2003). In the Transamazonic (Orosirian) cycle period, 2.12-2.02 Ga (Sousa & Oliveira, 2019), the Gavião, Serrinha, Jequié, and Itabuna-Salvador-Curaçá paleoplates collided, originating the Itabuna-Salvador-Curaçá Orogen. This event is also recorded by the emplacement of granitoid bodies and the M-UM rocks from the VJC (Barbosa & Sabaté, 2004; Oliveira et al. 2004). The north portion of the Itabuna-Salvador-Curaçá orogen is basically formed by three lithostratigraphic units: Caraíba Complex, SJJS, and Tanque Novo-Ipirá Complex (TNIC).

s. All these rocks are metamorphosed under the granulite facies, with retrograde metamorphism to the amphibolite facies, and locally to the greenschist facies conditions (Barbosa & Sabaté, 2004). SHRIMP U-Pb dating indicates igneous zircon cores with an average age of 2695 ± 12 Ma (enderbitic orthogneiss), and 2574 ± 6 Ma (tonalitic orthogneiss) for the formation of the protoliths and metamorphic rims with an age of 2072 Ma (Sabate et al. 1994; Silva et al. 1997; Oliveira et al. 2010).

The SJJS is described as a representative of fragments of an Archean-Paleoproterozoic oceanic crust (Teixeira 1997; Melo et al. 1991; Delgado et al. 2003) whereas, Piaia et al. (2017) interpret these rocks as a Gabbro-Anorthosite Stratiform Complex. The U-Pb age in zircon for SHRIMP given to the SJJS, is 2583.7 ± 8 Ma (Oliveira et al. 2010). To the east, it is composed of biotite and hornblende-norite, gabbronorite with cumulate sequences and subordinate leucogabbro, while to the west ferrogabbro, peridotite, and pyroxenite are commonly found (Kosin et al. 2003).

The TNIC is interpreted as a meta-volcanosedimentary sequence developed between the Archean and Paleoproterozoic that experienced a high-grade of metamorphism, under amphibolite to granulite facies (Kosin et al., 2003). It was subdivided into six informal units, based on their lithological assemblages: (i) aluminous biotite gneiss, (ii) calc-silicate rock, quartzite, meta-limestone, amphibolite, and banded iron formation; (iii) migmatized hornblende-biotite gneiss; (iv) graphitic gneiss associated with calc-silicate rocks; (v) banded gneiss, marked by granite-granodiorite, and gabbroicdioritic bands; and (vi) quartz-feldspathic gneiss with rare garnet and biotite.

Within the geotectonic framework junction between the Serrinha block/paleoplate, and the Salvador-Curaçá Orogen, to the west, occurs the VJC situated 60 km to the north of the study area (Silveira et al. 2015). This complex is described as differentiated sills, oriented in the N-S axis, occurring over an extent of 100 km x 10 km, associated with a synorogenic to tardi-orogenic event (Dias et al 2014) with SHRIMP zircon U-Pb age of 2085 ± 5 Ma (Oliveira et al. 2004). The VJC is constituted by 15 mineralized bodies, presenting deposits estimated at 40 Mt of chromite, and its main body, Ipueira-Medrado, has a dimension of 7 km x 500 m x 300 m with its main mineralized layer of massive chromite reaching thicknesses of 5-8 m (Dias et al. 2014).

**4 Field Aspects**

The study area was delimited based on outcrops of M-UM rocks found in the Capim Grosso county (Figure2), which are named in this paper as RMMUB. This M-UM body occurs embedded in calc-silicate rocks (Figure 3A), with verified kinzigite gneisses to the east, and lithotypes associated with the TNIC. The contact is inferred since the expressive presence of Neogene-quaternary detrital covers conceals the identification of contacts in the field it was not possible to identify the contact in the field. The mafic rocks from the SJJS were mapped to the west of the RMMUB and are represented by gabbros metamorphosed under amphibolite facies (Figure 3B).

Figure 2:. Geology of the study area. Modified from Melo et al. 2001.

The RMMUB represents a metamorphosed cumulate of layered M-UM rocks and is formed from west to east by serpentinites, metapyroxenites, and metagabbro (Figure 3C). In these rocks, it is possible to observe the suggested igneous layering (S0) in the serpentinites and pyroxenites, marked by compositional change or variation in the color of the rock (Figure 3D). The primary layering is parallel to the deformational foliation (Sn), S0//Sn (Figure 3E), having a trendN330°, with a sub-vertical dip, varying from 70° to 90° to NE. (Figure 3F).

|  |
| --- |
|  |
| Figure 3: Field aspects of local geology. A. Outcrop of the calc-silicate of the TNIC dipping to N330°/75NE. B. Amphibolite outcrop from SJJS; C. Samples from the RMMUB, from left to right: serpentinite, pyroxenite, and gabbro. D. Pyroxenite from RMMUB with white plagioclase bands locally setting up a gabbro, possible igneous layering; E. Contact between dunite and pyroxenite from the RMMUB where no shear is observed, suggesting the igneous layering. F. Dunite from the RMMUB exhibiting cleavage fracture.  |

**5 Petrography**

The petrographic characterization of the RMMUB has enabled the classification of the lithologies described in the field as serpentinite, metapyroxenite, and metagabbro..The serpentinite is composed mostly of serpentine, making up 75 to 90% of the modal composition (Figures 4A and C), under an advanced stage of hydrothermal alteration. However, it is still possible to identify the cumulate texture since the serpentinized minerals retain the primary shape of the olivine and orthopyroxene grains (Figure 4A). Other minerals of alteration are represented by amphibole, talc, biotite, and bowlingite (saponite). Spinels occur with a brownish coloration, possibly due to the picotite; the presence of opaques as accessory minerals is also recorded. It is possible to observe the texture in mesh formed by the serpentine and opaque minerals, which are a result of the alteration of olivine and orthopyroxene (Figures 4B and C).

The metapyroxenite is mainly composed of three phases: amphibole, orthopyroxene, and clinopyroxene, but there is an occurrence, although in a less expressive way, of plagioclase. The minerals are moderately oriented and show habits, in their majority, prismatic and granular (Figure 4D). The rock is inequigranular with fine to medium grain size, showing amphibole and clinopyroxene phenocrysts up to 2 mm. The texture of the minerals suggests a cumulate characteristic for this lithotype, and it can be classified as a mesocumulus. The orthopyroxene and clinopyroxene occur as cumulus phases (Figure 4E), while the intercumulus phase minerals are represented by clinopyroxene and plagioclase (Figure 4F).

The retrometamorphic minerals in the metapyroxenite are the amphiboles, alteration of the pyroxenes, occurring as clinoamphibole (possibly hornblende or cummingonite) and orthoamphibole (anthophyllite). The grains of plagioclase are almost completely altered to sericite and epidote. There are also other minerals of alteration, such as talc, biotite, and opaques.

The metagabbro is formed by amphibole, orthopyroxene, clinopyroxene, and labradorite, where the last mineral occurs poorly preserved. It is an inequigranular rock, fine to medium grained, with amphibole crystals reaching 3mm. The texture of the minerals also suggests a cumulate characteristic for this lithotype, representing a mesocumulate, which is partially obliterated by the effects of metamorphism (Figure 4G). The retrometamorphic minerals that occur in this lithotype are: ortho and clinoamphiboles, biotite, sericite, and epidote created by the effects of sericitization and saussuritization, respectively (Figure 4H).

|  |
| --- |
|  |
| Figure 4: Petrographic aspects of the RMMUB. A. Note ~~Notice~~ that the relict outline of the olivine grains (Ol) altered to serpentine (Srp) retrometamorphic in addition to spinels (Spl); B. Orthopyroxene (Opx) and clinopyroxene (Cpx) relicts in a serpentinite matrix C. Mesh texture, showing relicts of Ol; D. Cumulate texture, having Opx and Cpx as cumulus minerals; and amphibole (Am) as a retrometamorphic mineral. E. Opx of the cumulus phase being altered at the edges to Am. F. Plagioclase occurring as intercumulus wrapped by Am of alteration; G. Cumulate texture with phenocrysts of Am and Cpx, note ~~notice~~ that the biggest deformation occurs in the metagabbro; H. Twinned Cpx altering to retrometamorphic Am in the metagrabbo |

**6 Lithogeochemistry**

**6.1 Preservation of the lithogeochemical igneous signature**

The eight analyzed samples from the RMMUB (Table 1) are partly preserved as metagabbro, and metapyroxenite, while serpentinite has shown the highest percentage of hydrothermal alteration minerals. All samples of serpentinite have high contents of MgO (32.4 to 37.5 %); Cr (1915 to 7799 ppm); Ni (> 2000 ppm), and lower values of Al2O3 (2.26 to 3.78%). It suggests a refractory nature of the mantle. In addition, the peridotites from mantle wedges are generally highly refractory and serpentinites deriving from these rocks preserve the depleted REE signature of their protoliths (Deschamps et al. 2010; Saha et al. 2018). Therefore, it is possible that its refractory nature allowed the analysis of the primary mineral signature after serpentinization.

Table 1: Chemical analysis of the RMMUB. Serpentinite (Serp.) Pyroxenite (Px).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample | SSJ-03A | MV-13 | SSJ-13 | SSJ-15A | SSJ-16A | SSJ-16B | SSJ-03B | SSJ-03C |
| Rock | Serp | Serp | Serp | Serp | Serp | Px | Px | Gabbro |
| Major Elements (%) |
| SiO2 | 38.7 | 41.6 | 39.4 | 39 | 41.3 | 49.3 | 50.5 | 45.4 |
| TiO2 | 0.08 | 0.07 | 0.09 | 0.09 | 0.17 | 0.38 | 0.27 | 0.63 |
| Al2O3 | 2.48 | 2.26 | 2.98 | 2.38 | 3.78 | 8.18 | 7.06 | 13.3 |
| Fe2O3 | 8.35 | 6.77 | 9.65 | 7.83 | 9.35 | 11.1 | 12.6 | 14.4 |
| MnO | 0.11 | 0.09 | 0.2 | 0.06 | 0.14 | 0.2 | 0.26 | 0.27 |
| MgO | 36.1 | 36.5 | 34 | 37.5 | 32.4 | 20.1 | 23.9 | 14.1 |
| CaO | 0.9 | 0.74 | 0.86 | 0.2 | 2.9 | 8.91 | 5.06 | 9.13 |
| Na2O | 0.15 | 0.05 | 0.21 | 0.12 | 0.17 | 1.23 | 0.8 | 1.7 |
| K2O | 0.02 | 0.02 | 0.03 | 0.01 | 0.04 | 0.38 | 0.09 | 1.08 |
| P2O5 | 0.018 | 0.01 | 0.019 | 0.017 | 0.018 | 0.029 | 0.037 | 0.022 |
| V2O5 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 | 0.04 | 0.03 | 0.06 |
| LOI | 12.18 | 12.83 | 11.86 | 12.66 | 9.3 | 0.57 | 0.03 | 0.64 |
| Trace Elements (ppm) |
| Cr | 1915 | 1642 | 7799 | 1915 | 3284 | 2942 | 2805 | 752 |
| Co | 110.9 | 98.6 | 131.2 | 95.7 | 113.3 | 87.2 | 91.6 | 234.1 |
| Ni | 2972 | 2549 | 2207 | 2484 | 2125 | 1028 | 1206 | 434 |
| Cu | <5 | <5 | <5 | <5 | 73 | 23 | 8 | 13 |
| Ga | <0.1 | 2.4 | <0.1 | <0.1 | <0.1 | 4.8 | 3 | 10.2 |
| Rb | <0.2 | 0.7 | 0.3 | <0.2 | <0.2 | 3.2 | 0.2 | 13.7 |
| Sr | 24 | 17 | 20 | 14 | 45 | 51 | 33 | 48 |
| Y | 2.78 | 2.35 | 15.21 | 2.93 | 5.8 | 13.47 | 6.6 | 19.2 |
| Zr | 13 | <10 | 12 | 20 | 21 | 42 | 23 | 37 |
| Nb | 2.76 | 2.25 | 0.81 | 1.95 | 1 | 5.39 | 2.55 | 2.28 |
| Ba | 121 | 355 | 289 | 139 | 95 | 97 | 184 | 233 |
| Hf | 0.46 | <0.05 | 0.28 | 0.49 | 0.48 | 1.08 | 0.68 | 1.32 |
| Ta | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Th | 1.8 | <0.1 | 0.4 | 0.4 | 1.5 | 0.3 | 1.4 | 1.5 |
| U | 0.09 | <0.05 | 0.12 | 0.13 | 0.25 | 0.16 | 0.22 | 0.35 |
| Rare Earth Elements (ppm) |
| La | 2.9 | 0.3 | 14.5 | 2.8 | 9.3 | 9.5 | 4 | 7.3 |
| Ce | 3.1 | 1.9 | 5.4 | 3.1 | 11.3 | 13.8 | 4.2 | 11.5 |
| Nd | 1.1 | 0.5 | 9.6 | 1.8 | 4.7 | 8.5 | 2.6 | 7.4 |
| Sm | 0.2 | 0.3 | 1.8 | 0.3 | 0.8 | 1.8 | 0.6 | 1.8 |
| Eu | 0.07 | 0.06 | 0.2 | 0.09 | 0.24 | 0.86 | 0.19 | 0.71 |
| Gd | 0.33 | 0.32 | 1.87 | 0.5 | 0.96 | 2.09 | 0.81 | 2.42 |
| Dy | 0.38 | 0.4 | 1.91 | 0.51 | 0.94 | 2.26 | 1.04 | 2.88 |
| Ho | 0.09 | 0.08 | 0.41 | 0.12 | 0.2 | 0.46 | 0.23 | 0.63 |
| Tm | 0.05 | 0.05 | 0.05 | 0.29 | 0.18 | 0.06 | 0.08 | 0.20 |
| Yb | 0.3 | 0.3 | 1 | 0.3 | 0.5 | 1.3 | 0.7 | 2 |
| Lu | <0.05 | <0.05 | 0.13 | 0.06 | 0.08 | 0.19 | 0.09 | 0.29 |
| Eu/Eu\* | 0.83 | 0.59 | 0.33 | 0.71 | 0.84 | 1.36 | 0.83 | 1.04 |
| mg# | 82.79 | 85.71 | 79.67 | 84.20 | 79.40 | 66.82 | 67.84 | 52.13 |
| LaN/LuN |  - |  - | 11.95 | 5.00 | 12.46 | 5.36 | 4.76 | 2.70 |
| LaN/YbN | 6.93 | 0.72 | 10.40 | 6.69 | 13.34 | 5.24 | 4.10 | 2.62 |
| SmN/YbN | 0.74 | 1.11 | 2.00 | 1.11 | 1.78 | 1.54 | 0.95 | 1.00 |
| LaN/SmN | 9.30 | 0.64 | 5.17 | 5.99 | 7.46 | 3.38 | 4.28 | 2.60 |

With the intent of observing a possible effect of hydrothermal or metamorphic alteration, the Ratio in Molecular Proportion Method (Beswick & Soucie, 1978) was used. It revealed sharply detailed trends in the samples from the RMMUB, indicating the absence of significant mobility for most of the major elements (Figures 5A, 5C, 5D, and 5F). Only in the diagram of Log(SiO2/K2O) x Log(CaO/K2O) dispersion in the samples is registered, suggesting the presence of some alteration degree (Figure 5B). In order to confirm the results, the diagram proposed by Myashiro (1975) was used, corroborating that there was no significant alteration of the elements Na2O e K2O during the hydrothermal processes (Figure 5F). This fact reinforces that the lithogeochemical signature of the RMMUB is preserved as well as the data obtained from the SJJS and the VJC. The presence of secondary carbonate was registered sporadically in only one sample and the anomalies of Eu vary from 0.33 (serpentinite) to 1.35 (gabbro).

Figure 5: Charts used for identification of sample preservation proposed by Beswick, (1978) and Myashiro (1975). A-C. Molecular ratio diagrams proposed by Beswick, (1978). D. Diagram proposed by Myashiro (1975) indicating that the samples are preserved. The bibliographical data used were from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 9 samples from the VJC (Lord et al. 2004).

.

**6.2 Major Elements**

In the silica vs. alkali sum diagram, proposed by Middlemost (1994), the samples from the RMMUB and the VJC are classified as peridotites and gabbros, while the samples from SJJS are classified as gabbroic and gabbroic diorite (Figure 6A). In the AFM diagram, proposed by Irvine and Baragar (1971), the samples show a similar trend to the fractional crystallization pattern of tholeiitic primary magmas (Figure 6B).

Figure 6: Classification Diagrams. A. Diagram proposed by Middlemost, naming the rocks from the RMMUB as peridotites and gabbros; (B) AFM Diagram, suggesting the similarity of the RMMUB with primitive magmas and showing a tholeiitic trend. The bibliographical data used were from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 9 samples from the VJC (Lord et al. 2004).

The RMMUB results indicate similar characteristics to primary magmas such as high MgO (14.1% a 37.5%) and low SiO2 (38.7% a 50.5%), low alkali sum Na2O + K2O < 0.24 (except from two samples, SSJ-16B and SSJ -03C, which presented value >1), as well as high Cr (752 to 7799 ppm) and Ni (434 to 2972 ppm). High levels of magnesium were found, #mg, ranging between 85.71% and 79.40 in the serpentinites, 67.84 to 66.82% in the pyroxenites, and 52.13% in the gabbro. In the serpentinites, the values found are below the values proposed by McDonough (1990) for rocks from the mantle (#mg > 85%) and from the primitive mantle (#mg = 89.76%). The gabbro, on the other hand, represents an evolved basaltic magma, since early basaltic magmas have mg# values between 74 and 80% (Jacques & Green, 1979).

The TiO2 values are low, ranging from 0.08% (serpentinite) to 0.63 (gabbro), and the CaO /Al2O3 ratio ranges from 0.08 (serpentinite) to 1.09 (pyroxenite). In binary diagrams of major elements *versus* MgO it can be observed well-marked correlation trends in the Al2O3, CaO, Fe2O3 e TiO2 diagrams, indicating fractional crystallization process (Figures 7B, E, G, and H) whereas in the SiO2, P2O5, Na2O, and K2Odiagrams, it is possible to notice turning points that suggest that the crystallization of pyroxene, apatite and the alkalis are attributed to plagioclase (Figures 7A, C, D, and F).

Figure 7: Diagrams of chemical variation of MgO versus major elements, samples from SJJS and VJC were plotted for comparison. The bibliographical data used came from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997), and 9 samples from the VJC (Lord et al. 2004).

**6.3 Trace and Rare Earth Elements**

In binary diagrams of Cr and Ni versus MgO,well-marked negative correlation trends are observed (Figures 8A and B), whereas in the Cr diagram, the serpentinite samples from the RMMUB reach 7799 ppm (Figure 8A). In the normalized multi-element diagrams (Sun & McDonough, 1989) are observed among the samples, showing slight fractionation between LILE and HFSE, Rb, U, Th spikes and strong depletions Nb-Ta, Sr, and Ti in relation to the Primitive Mantle (Figure 8C).

In the multielemental diagram, normalized by Chondrite (Figure 8D), there is a slight fractioning between Light Rare Earth Elements (LREEs) and Heavy Rare Earth Elements (HREEs), with a slight enrichment in the LREEs and a small depletion in the HREEs. It is also noted that the ratios of LaN/LuN (11.95 – 2.70), LaN/YbN (13.34 – 0.72), SmN/YbN (10.97 – 0.74) e LaN/SmN (9.30 – 0.64) indicate that there were varying degrees of LREEs fractionation relative to the HREEs.

Figure 8: A Diagram of MgO versus Cr and the SJJS and VJC samples were also plotted for comparison. B. Diagrams of MgO versus Ni. C. Diagram with the Primitive Mantle as the normalizer, according to McDonough and Sun (1995) data from the Cascades (Barnes, 1992) and Kurila (Schmidt & Grunder, 2011) arc were also plotted. D. Diagram with the Chondrite as normalizer according to Boynton (1984). The bibliographical data used came from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 11 samples from the VJC (Marques et al. 2003b).

**7 Discussion**

**7.1 Lithogeochemical correlation**

In the Diagrams of MgOversus major elements it is possible to notice that the RMMUB samples are plotted in similar regions as the VJC samples, showing trends with similar differentiation. On the other hand, the mafic-ultramafic rocks from the SJJS are more differentiated, with lower MgO contents, do not present well-marked trends, and are plotted in different regions of the RMMUB. In the diagrams using SiO2, Al2O3, CaO, Na2O e TiO2, the SJJS samples are in more evolved rock positions, in contrast to the other two groups (Figures 7A, B, E, F, and H). In the MgO diagrams versus Cr and Ni, it can be observed that the samples from the RMMUB and the VJC demonstrate the same degrees of enrichment in these elements, with similar trends, while SJJS is depleted of these elements (Figures 8A and B).

In the study of the tectonic ambiance of the rock groups, we used the diagrams based on the content of the elements Ti, Nb, V, Y, and Zr proposed by Verma et al. (2006), aiming the study of basic-ultramafic rocks in the classification of tectonic ambiance. It can be noticed that RMMUB and VJC are plotted in different fields when compared to the SJJS rocks. The RMMUB and VJC occur associated with the IAT (Island Arc Tholeiitic) (Figures 9B to E) and as CRB (Continental Rift Basalt) in one diagram (Figure 9F) whereas the SJJS plots in the MORB field (Mid Ocean Ridge Basalt) (Figures 9B, D, and F), and in a diagram as OIB (Ocean Island Basalt) (Figure 9C).

In the multielemental diagrams (Figures 8C and 8D) it is possible to notice a similar pattern among the samples from the RMMUB, indicating they may be related to the same primary magma (Winter, 2014). The anomalies of Nb and Ta can be interpreted as a reflection of magma generation from a depleted/metasomatized source such as a subduction environment. In general, the enrichment of LREEs relative to the Primitive Mantle (Figure 8C) can be attributed to the enrichment by metasomatic processes (Pearce, 1983; Pearce & Peat, 1995; Hawkesworth *et al*. 1997). .

The regional tectonic history of the study area indicates that the regional metamorphism under the amphibolite to granulite facies has had an effect on the RMMUB rocks. The hydrothermal fluids from intrusive granitoid bodies followed by many deformational phases might have had responsibility for the hydrothermal alterations of those rocks, generating the hydration reactions shown by serpentinization, sericitization, and saussuritization.

The La/Yb x Sm/Yb diagram is used to classify magmatic sources as spinel peridotite, pure peridotite with garnet, and carbonated peridotite with garnet (Yu *et al*. 2015). It is observed that the RMMUB is plotted in the same region as the VJC, corresponding to the peridotite spinel, a material that would represent a shallower possible source of arch boulders (Pearce & Stern, 2006) or by a primitive metasomatized lithospheric mantle, as discussed by Marques et al. (2003b). By contrast, the SJJS is plotted closer to the Sm/Yb ratio axis, in the peridotite line with garnet, which is a material representing a deeper source with a garnet signature, similar to the source of the MORBs (Hirschmann & Stolper, 1996). (Figure 9A)

**Figure 9.** The tectonic ambiance and magmatic source diagrams. A. In the diagram of La/Yb versus Sm/Yb ratios for magmatic sources (Yu *et al*. 2015), the RMMUB and VJC samples are plotted near the Peridotite spinel field, while the SJJS is plotted between the field of peridotite with garnet and peridotite with carbonate and garnet. 8B-F. Diagrams proposed by Verma et al. (2006), for the study of basic-ultramafic rocks. It can be noticed that the RMMUB and VJC samples (circled in purple) are mostly plotted in the IAT field, while SJJS is plotted in the MORB field. The bibliographical data used came from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 11 samples from the VJC (Marques et al. 2003b).

In the literature, it is proposed that the SJJS would represent a Neoarchean ophiolite (Teixeira, 1997), generated in an extensional environment, similar to the MORB, as the classification indicated. On the other hand, the geotectonic setting for the Paleoproterozoic age rocks of the VJC is not well understood but it is discussed by Marques et al. (2003b). These authors discuss several hypotheses for the petrogenesis of the VJC. Among them, the VJC could be derived from a previously depleted, but metasomatically enriched mantle, representing, then, an old metasomatized subcontinental lithospheric mantle formed by the roots of the Archean craton.

**7.2 Metallogenic Potential**

In the metallogenic chart of the Serrinha sheet (Neves & Delgado, 1995), current sediment anomalies are recorded with Cr (5000 ppm), Ni (5000 ppm), and Cu (100 ppm) located in the referred area. Total rock analytical results corroborate these anomalies, with maximum values of 7799 ppm Cr and 2972 ppm Ni being found in serpentinites. These values are similar to the bedrock of the VJC chromium mineralization (Lord *et al*. 2004; Marques et al. 2003b).

It is also pointed out that both the RMMUB and the VJC are embedded in the same lithotypes, metasediments of marine/plataformal origin, metamorphosed into high amphibolite to granulite facies, composed of olivine - serpentine - marbles, diopside and calc-silicate granulites, and belonging to the TNIC. (Gama, 2019; Ribeiro, 2016). The RMMUB is located around 60km from a mineralized body in Cr, in the region of Laje Nova associated with the VJC. Therefore, the results suggest an extension of the Cr prospecting area, where the fertility of prospects in the Vale of Jacurici could be extended to the south, up to Capim Grosso county, totalizing an extension of about 160 km for the occurrence of mafic-ultramafic bodies with high chromium contents.

**8 Conclusions**

The field and petrographic analyses revealed that the RMMUB represents paleocumulates of layered M-UM rocks consisting of gabbros, pyroxenites, and dunites, with preserved lithogeochemical characteristics even with petrographic evidence of metamorphic action, registered mainly by the serpentinized dunites. The lithogeochemical results indicate similarities with the VJC rocks and differences with the SJJS counterpart. We suggest that, due to the scale of mapping, the RMMUB may not have been mapped in existing regional works as a result of the complex tecnonic arrangement of the region of study. Thus, the discovery of this new M-UM body in an area of great metallogenic fertility opens a potential for the discovery of new Cr mineralization and magmatic sulfides of Ni, Cu, and EGP, in the Salvador-Curaçá Orogen, São Francisco Craton, northeast of the state of Bahia.

**9 Acknowledgements**

This scientific work was generated within the project Metalogeographic Map of the State of Bahia II, as a result of an agreement between the National Council for Scientific and Technological Development (CNPQ), Bahia State Mineral Research Company (CBPM), and the Federal University of Bahia (UFBA). This work is also dedicated to professor Márcio Mattos Paim, *in memoriam*.

**10 References**

Almeida, F.F. M. 1967. Origin and evolution of the Brazilian platform. DNPM. Div. Geol. Min., bol. v. 241, 36 p.

Alkmim, F.F., Brito neves, B.B., & Castro Alves, J.A. 1993. Tectonic framework of the São Francisco Craton - A review. In: Dominguez, J. M. L.; Misi, A. (Eds.). The São Francisco Craton. Salvador: SBG/SGM/CNPq. 45–62 p.

Barbosa, J.S.F. & Sabaté, P. 2004. Archean and Paleoproterozoic crust of the São Francisco Craton, Bahia, Brazil: geodynamic features.Precambrian Research, v. 133, 1-27 p.

Barnes, C.G. 1992. Petrology of monogenetic volcanoes, Mount Bailey area, Cascade Range, Oregon. Journal of Volcanology and Geothermal Research, v. 52, 141-156 p.

Beswick, A.E., Soucie, G. 1978. A correction procedure for metasomatism in an Archaean greenstone belt. Precambrian Research, 6(2), 235-248. https://doi. org/10.1016/0301-9268(78)90015-3.

Boynton, W.V. 1984. Geochemistry of the rare earth elements: meteorite studies. In: Henderson P. (ed.). Rare earth element geochemistry. Elseviers, 63-114 p.

Couto P.A., Sampaio, A.R., Gil, C.A.A.; Loureiro, H.C., Arcanjo, J.B., Filho, J.F., Guimarães, J.T., Campelo, R., Mascarenhas, J.F., Bruni, D.C., & Toledo, L.A.A. 1978. Serra de Jacobina Project: Geology and geochemical prospection – Final Report – text. Salvador: CPRM. 346 p., v. 1. Convênio DNPM-CPRM, v. 1, 346 p.

Delgado, I.M., Souza, J.D., Silva, L.C., Silveira Filho, N.C., Santos, R.A., Pedreira, A.J., Guimarães, J.T., Angelim, L.A.A., Vasconcelos, A.M., Gomes, I.P., Lacerda Filho, J.V., Valente, C.R., Perrota, M.M., Heineck, C.A. 2003. Geotectônica do Escudo Atlântico. In: Bizzi, L.A., Schobbenhaus, C., Vidotti, R.M., & Gonçalves, J.H. (Eds.), Geology, Tectonics and Mineral Resources of Brazil. CPRM, pp. 227 e 334.

Deus, P.B., Viana, J.S. 1982. Jacurici Valley Chromite District. In: International symposium on archean and early proterozoic geologic evolutions and metallogenesis, Salvador. Abstract Excursions. Salvador: SME, 97-107 p.

Dias, J.R.V.P., Marques, J.C., Queiroz, W.J.A., Frantz, J.C., Giusti, R. 2014. The Várzea do Macaco body and the chromium, nickel and copper mineralizations, Jacurici Mafic-Ultramafic Complex Máfico-ultramáfico, São Francisco Craton, Bahia.*Braz. J. Geol.* vol.44, n.2, pp.289-308.

Deschamps, F., Guillot, S., Godard, M., Chauvel, C., Andreani, M., Hattori, & K., 2010. In situ characterization of serpentinites from forearc mantle wedges: timing of serpentinization and behavior of fluid-mobile elements in subduction zones. Chemical Geology 269, 262 e 277.

Gama, M.A. Petrographic and lithogeochemical characterization of the metacarbonate and calc silicate rocks of Vale do Rio Jacurici, Bahia. Geosciences Institute. Monograph. Federal University of Bahia. Salvador. 114 p., 2014.

Garcia, P. M.P., Teixeira, J.B.G., Misi, A., Sá, J.H.S., & Silva, M.G. 2018. Tectonic and metallogenic evolution of the Curaçá Valley Copper Province, Bahia, Brazil: A review based on new SHRIMP zircon U-Pb dating and sulfur isotope geochemistry. Ore geology reviews, v. 93, 361-381 p.

Hawkesworth, C., Turner, S., Peate, D., McDermott, F., & Calsteren, P. 1997. Elemental U and Th variations in island arc rocks: implications for U-series isotopes. Chemical Geology, v. 139, 207-221 p.

Hirschmann, M.M. & Stolper, E.M. 1996. A possible role for garnet pyroxenite in the origin of the ‘‘garnet signature’’ in MORB. Contrib Mineral Petrol, Springer-Verlag, v. 124, 185-208p.

Irvine, T.N., & Baragar, W.R.A. 1971. A Guide to the Chemical Classification of the Common Volcanic Rocks. Canadian Journal of Earth Science, v. 8, 523-548 p.

Jacques, A. L., Green, D. H. (1979). Determination of liquid compositions in high-pressure melting of peridotite. American Mineralogist, 64(11-12), 1312-1321.

Kosin M., Melo R.C., Souza J.D., Oliveira E.P., Carvalho M.J., Leite C.M.M. 2003. Geologia do segmento norte do Orógeno Itabuna-Salvador-Curaçá e Guia de Excursão. Revista Brasileira de Geociências, 33:15-26.

Lord, R.A.; Princhard, H.M.; Sá, J.H.S.; Neary, C.R. 2004. Chromite Geochemistry and PGE Fractionation in the Campo Formoso Complex and Ipueira-Medrado Sill, Bahia State, Brazil. Economic Geology. v. 99, n. 2, 339-364 p.

Maier, W.D. & Barnes, S.J. 1996. Unusually high concentrations of magnetite at Caraíba and other Cu-sulfide deposits in the Curaçá Valley, Bahia, Brazil. Canadian Mineralogist, v. 34. 717–731 p.

Marinho, M.M., Rocha, G.F., Deus, P.B., & Viana, J.S. 1986. Geology and chromitiferous potential of the Jacurici-Bahia Valley. 24th Brazilian Congress of Geology, Goiânia, Anais 5, 2074-2088.

Marques, J.C., Ferreira filho, C.F. 2003a. The chromite deposit of the Ipueira-Medrado sill, São Francisco craton, Bahia State, Brazil. Economic Geology, v. 98, 87–108 p.

Marques, J.C., Ferreira filho, C.F., Carlson, R. W., & Pimentel, M. M. 2003b. Re-Os and Sm-nd isotope and trace elements Constraints on the Origin of the Chromite Deposit of the Ipueira-Medrado Sill, Bahia, Brazil. Journal of petrology, v. 44, n. 4, 659-678 p.

McDonough, W.F, 1990. Constraints on the composition of the continental lithospheric mantle. Earth Planetary Science Letters, 101: 1 – 18.

McDonough, W.F. & Sun, S.S. 1995. The Composition of the Earth. Chemical Geology, v. 120, 223-253 p.

Melo, R.C., Souza, J.D., Silva, L.C., Fernandes, P.C.D., Padilha, A.V., Motta, A.C., Metello, M.J., Teixeira, L.R., & Neves, J.P. 1991. Pintadas – Sheet SC.24-Y-D-V. State of Bahia. Explanatory Text. Geological Survey of Brazil – PLGB. Brasília: DNPM/CPRM. It includes 2 folded maps. 192 p.

Melo, R.C., Pereira, L.H.M., Loureiro, H.S.C., Neves, J.P., & Teixeira, L.R. 2001. Serrinha – Folha SC.24-Y-D. State of Bahia. Explanatory Text. Geological Survey of Brazil – PLGB. Brasília: CPRM/DIEDIG/DEPAT. It contains 1 CD-ROM. 80 p.

Middlemost, E.A. 1994. Naming materials in the magma/igneous rock system Earth-Science Reviews, 37 (3–4), p. 215-224.

Miyashiro, A. (1975). Classification, characteristics, and origin of ophiolites. Journal of Geology, 83(2), 249-281. https://www.jstor.org/stable/30060218.

Neves, 1995. Metallogenic/Previsional Map, Serrinha Sheet, SC.24-Y-D. CPRM. Escala 1:250.000.

Oliveira, E.P., Carvalho, M.J., & McNaughton, N.J. 2004. Evolution of the Northern Segment of the Itabuna-Salvador-Curaçá Orogen: Chronology of arc accretion, continental collision, and terrain escape. Geology Bulletin USP, Scientific Series, v. 4, 41-53 p.

Oliveira, E.P., McNaughton, N.J., Armstrong, R. 2010. Mesoarchaean to Paleoproterozoic growth of the northern segment of the Itabuna–Salvador–Curaçá orogen, São Francisco craton, Brazil. Geological Society, London, Special Publications, v. 338, 263-286 p.

Pearce, J.A., Peate, D.W. 1995. Tectonic implications of the composition of volcanic arc magmas. Annual Review of Earth and Planetary Sciences 23, p. 251-285 p.

Pearce, J.A. & Stern, R.J. 2006. Origin of Back-Arc Basin Magmas: Trace Element and Isotope Perspectives. Back-Arc Spreading Systems: Geological, Biological, Chemical, and Physical Interactions. Geophysical Monograph Series 166, American Geophysical Union.

Piaia, P., Oliveira, E.P., & Valeriano, C.M. 2017. The 2.58 Ga São Jose do Jacuípe gabbro-anorthosite stratiform complex, Itabuna-Salvador-Curaçá Orogen, São Francisco Craton, Brazil: Root of the Neoarchaean Caraíba continental arc? Journal of South American Earth Sciences, v. 79, 326 – 341 p.

Ribeiro, T.S. 2016. Geological characterization of the Tanque novo -Ipirá Complex calc silicate and metacarbonate rocks in the Pintadas sheet - BA: Metallogenic Potential for phosphate. Geosciences Institute. Master's Dissertation. Federal University of Bahia. Salvador. 181 p.

Sabaté P., Peucat J.J., Melo R.C., Pereira L.H. 1994. Datação por Pb-evaporação de monozircão em ortognaisse do Complexo Caraíba: expressão do acrescimento crustal transamazônico do Cinturão Salvador-Curaçá (Cráton do São Francisco, Bahia, Brasil). In: 38º Congresso Brasileiro de Geologia. Camboriú, p. 219.

Saha, A., Santosh, M., Ganguly, S., Manikyamba, C., Ray, J., & Dutta, J. 2018. Geochemical cycling during subduction initiation: Evidence from serpentinized mantle wedge peridotite in the south Andaman ophiolite suite. Geoscience Frontiers, v. 9, 1755-1775 p.

Schmidt, M.E. & Grunder, A. 2011. Deep Mafic Roots to Arc Volcanoes: Mafic Recharge and Differentiation of Basaltic Andesite at North Sister Volcano, Oregon Cascades. Journal of Petrology, v. 32, 603 -641 p.

Silva L.C., McNaughton N.J., Melo R.C., Fletcher I.R. 1997. U-Pb SHRIMP ages in the Itabuna-Caraíba TTG high-grade Complex: the first window beyond the Paleoproterozoic overprinting of the eastern Jequié Craton, NE Brazil. In: International Symposium on Granites and Associates Mineralizations. Salvador, p. 282-283.

Silva, M.G.; Misi, A. 1998. Archean - lower Proterozoic basement of the São Francisco Craton, northeastern Bahia. Geology and mineral deposits. (Geological Tours) Salvador: SGM, 164 p.

Silveira, C.J.S., Frantz, J.C., Marques, J.C., Queiroz, W.J.A., Roos, S., Peixoto, V.M. 2015. Geocronologia U-Pb em zircão de rochas intrusivas e de embasamento na região do Vale do Jacurici, Cráton do São Francisco, Bahia. Brazilian Journal of Geology, 45(3): 453-474.

Sun, S.S. & McDonough, W.F. 1989 Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. Geological Society, London, Special Publications, v. 42, p. 313-345.

Sousa, D.F.M., & Oliveira, E.P. 2019. Geocronologia e evolução tectônica do magmatismo granítico 2,12-2,02 Ga, pré- a pós-colisional, segmento norte Orógeno Itabuna-Salvador-Curaçá, Bahia. Anais do 4° Simpósio sobre o Cráton do São Francisco e Orógenos Marginais. Aracaju – SE. 110 p.

Teixeira, L. R. 1997. The Caraíba Complex and the São José do Jacuípe Suite in the Salvador-Curaçá Belt (Bahia, Brazil): petrology, geochemistry and metallogenic potential. Doctoral Thesis – Geosciences Institute, Federal University of Bahia, Salvador, 208 p.

Townend, R., Ferreira, P.M., & Frake, N.D., 1980. Caraíba, a new copper deposit in Brazil. Inst. Miner. Metal, v. 89, 159–164 p.

Verma S.P., Guevara, M., & Agrawal, S. 2006. Discriminating four tectonic settings: Five new geochemical diagrams for basic and ultrabasic volcanic rocks based on log-ratio transformation of major-element data. Journal of Earth System Science, v. 115, 485–528p.

Yu, X., Chen, L.H., & Zeng, G. 2015. Growing magma chambers control the distribution of small-scale flood basalts. *Sci. Rep,* v. 5.