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Geological Characterization, Lithogeochemistry and the Metallogenic Potential for Chromium of the Riacho do Mocambo Mafic-Ultramafic Body, Northeast of the São Francisco Craton, BA, Brazil

Caracterização Geológica, Litogeoquímica e o Potencial Metalogenético para Cromo do Corpo Máfico-Ultramáfico Riacho do Mocambo, Nordeste do Cráton São Francisco, BA, Brasil

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Abstract

In the geotectonic context of the Salvador-Curaçá Orogen, north portion of the São Francisco Craton, an association of mafic-ultramafic (M-UM) rocks was identified and 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: Salvador-Curaçá Orogen; Vale do Jacurici Complex; São José do Jacuípe Suite

Resumo

No contexto geotectônico do Orógeno Salvador-Curaçá, porção norte do Cráton do São Francisco, foram identificadas rochas intituladas neste trabalho de Corpo Máfico-Ultramáfico Riacho do Mocambo (CMURM). Apesar de situar-se a aproximadamente 60 km do Complexo do Vale do Jacurici (CVJ), hospedeiro das maiores reservas de Cr do Brasil, o CMURM nunca foi associado, em projetos de mapeamento geológico regionais, a este Complexo. Quando citado na bibliografia, as rochas máficas-ultramáficas do CMURM são geneticamente relacionadas à Suíte São José do Jacuípe (SSJJ). Em vista disso, o respectivo trabalho tem como objetivo a caracterização geológica e geoquímica do CMURM afim de compará-lo com o CVJ e a SSJJ. Em campo, o CMURM possui

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forma alongada e pequena espessura (7 km de extensão por menos de 100m de espessura aparente), ocorrendo concordantemente aos metassedimentos do Complexo Tanque Novo-Ipirá. Nos afloramentos mapeados é possível observar a alternância rítmica e gradativa entre os litotipos do CMURM, variando de serpentinito a metagabro, sugerindo tratar-se de um corpo ígneo acamadado. Os resultados químicos reforçam o caráter primitivo das litofácies ultramáficas (MgO até 38%; Ni até 2972 ppm; Cr até 7799 ppm) e indicam que o CMURM apresenta características distintas da SSJJ, mas com assinatura geoquímica semelhante, fonte, profundidade da fonte e ambiente tectônico ao CVJ. A descoberta desse novo corpo M-UM em uma área de grande fertilidade metalogenética abre potencial para a identificação de novas mineralizões de Cr e sulfetos magmáticos de Ni, Cu e EGP, no Orógeno Salvador-Curaçá, Craton São Francisco, nordeste do estado da Bahia.

Palavras-chave: Orógeno Salvador-Curaçá; Complexo Vale do Jacurici; Suíte São José do Jacuípe

1 Introduction

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 & Ferreira Filho 2003a; Marques et al. 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 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 by the collision of the Gavião, Serrinha, Jequié, and Itabuna-Salvador-Curaçá paleoplates during the Transamazonic (Orosirian) cycle at the end of the Paleoproterozoic (Barbosa & Sabaté 2004). 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 (Figures 1A and 1B).

In the study area, M-UM bodies have been currently related to the SJJS. However, the target of this study, called

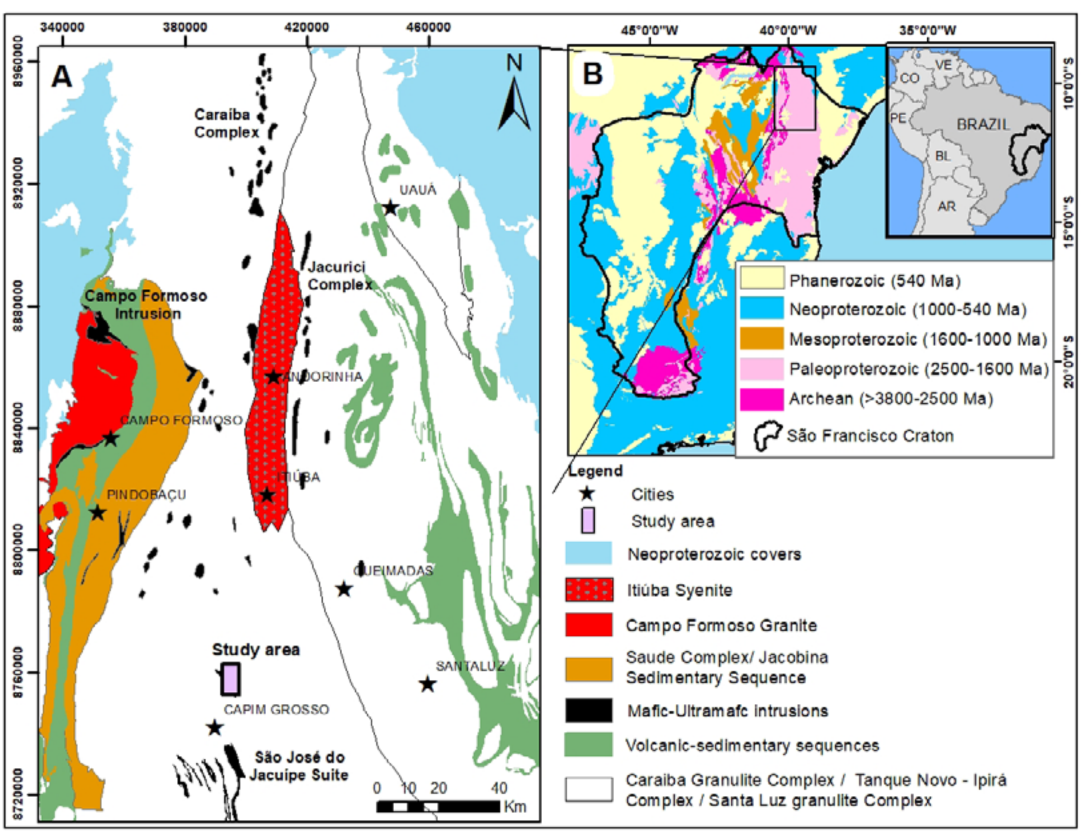

Figure 1 Geological maps: A. Location map with mafic-ultramafic rocks. Modified from Marinho et al. (1986); B. São Francisco Craton with location map boundary.

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.

Evidence suggesting cogent relationship 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.

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 (Na_2O_2), 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 Fe_2O_{3t} was recalculated to FeO_t 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 (Alkmim, Neves & Alves 1993; Barbosa & Sabaté 2004). 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).

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 (Sabaté 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 (Figure 2), 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).

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 (S_0) 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 (S_n), S_0//S_n (Figure 3E), having a trend N330°, with a sub-vertical dip, varying from 70° to 90° to NE. (Figure 3F).

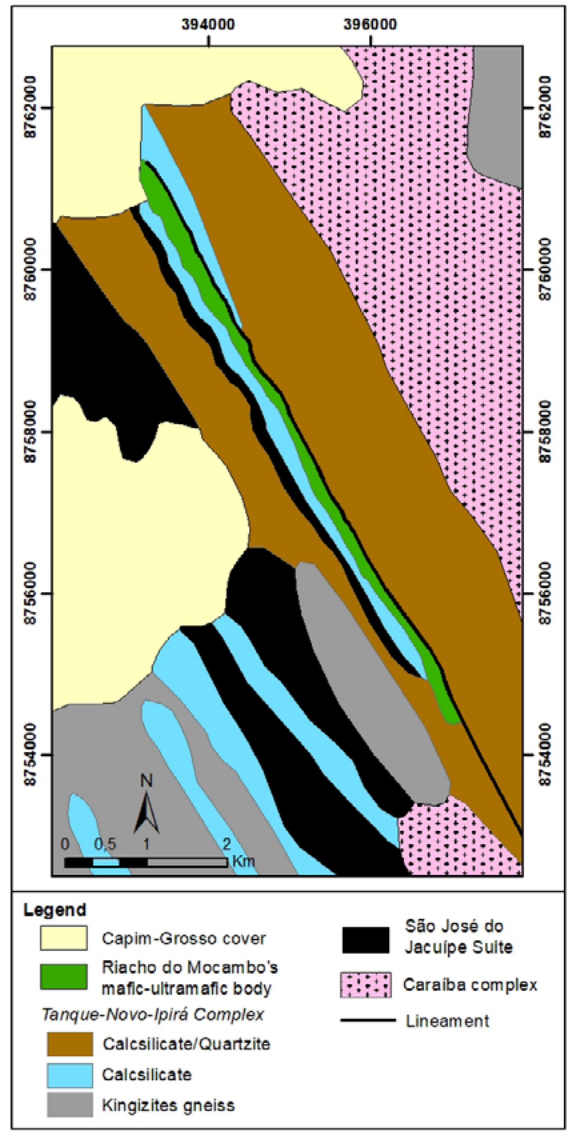

Figure 2 Geology of the study area. Modified from Melo et al. 2001.

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 4C), 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 4C).

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

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.

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).

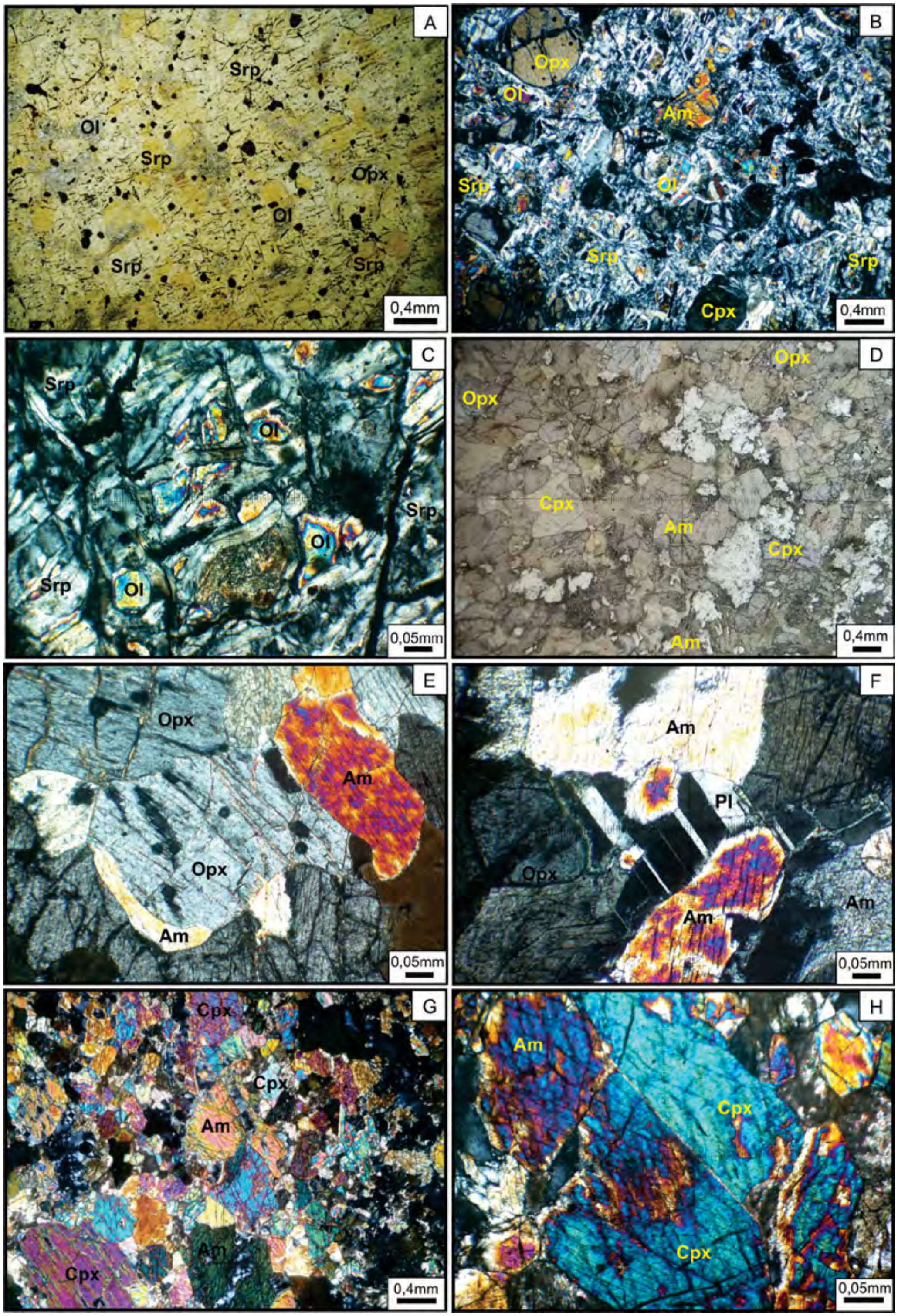

Figure 4 Petrographic aspects of the RMMUB: A. Note that the relict outline of the olivine grains (Ol) altered to serpentine (Srp) retrometamorphic in addition to spinels (Spl); B. Orthopyroxene (Opx) and clinopyroxene (Cpx) relicts in a serpentinite matrix; C. Mesh texture showing relicts of Ol; D. 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 that the more intense 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 Al_2O_3 (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.

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(SiO_2/K_2O) x Log(CaO/K_2O) 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 Miyashiro (1975) was used, corroborating that there was no significant alteration of the elements Na_2O e K_2O 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).

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).

The RMMUB results indicate similar characteristics to primary magmas such as high MgO (14.1% a 37.5%) and low SiO_2 (38.7% a 50.5%), low alkali sum $Na_2O + K_2O < 0.24$ (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 TiO_2 values are low, ranging from 0.08% (serpentinite) to 0.63 (gabbro), and the CaO /Al_2O_3 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 Al_2O_3, CaO, Fe_2O_3 e TiO_2 diagrams, indicating fractional crystallization process (Figures 7B, 7E, 7G, and 7H) whereas in the SiO_2, P_2O_5, Na_2O, and K_2O diagrams, it is possible to notice turning points that suggest that the crystallization of pyroxene, apatite and the alkalis are attributed to plagioclase (Figures 7A, 7C, 7D, and 7F).

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 8B), 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 La_N/Lu_N (11.95 – 2.70), La_N/Yb_N (13.34 – 0.72), Sm_N/Yb_N (10.97 – 0.74) e La_N/Sm_N (9.30 – 0.64) indicate that there were varying degrees of LREEs fractionation relative to the HREEs.

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

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 (%)								
SiO_2	38.7	41.6	39.4	39	41.3	49.3	50.5	45.4
TiO_2	0.08	0.07	0.09	0.09	0.17	0.38	0.27	0.63
Al_2O_3	2.48	2.26	2.98	2.38	3.78	8.18	7.06	13.3
Fe_2O_3	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
Na_2O	0.15	0.05	0.21	0.12	0.17	1.23	0.8	1.7
K_2O	0.02	0.02	0.03	0.01	0.04	0.38	0.09	1.08
P_2O_5	0.018	0.01	0.019	0.017	0.018	0.029	0.037	0.022
V_2O_5	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
La_N/Lu_N	–	–	11.95	5.00	12.46	5.36	4.76	2.70
La_N/Yb_N	6.93	0.72	10.40	6.69	13.34	5.24	4.10	2.62
Sm_N/Yb_N	0.74	1.11	2.00	1.11	1.78	1.54	0.95	1.00
La_N/Sm_N	9.30	0.64	5.17	5.99	7.46	3.38	4.28	2.60

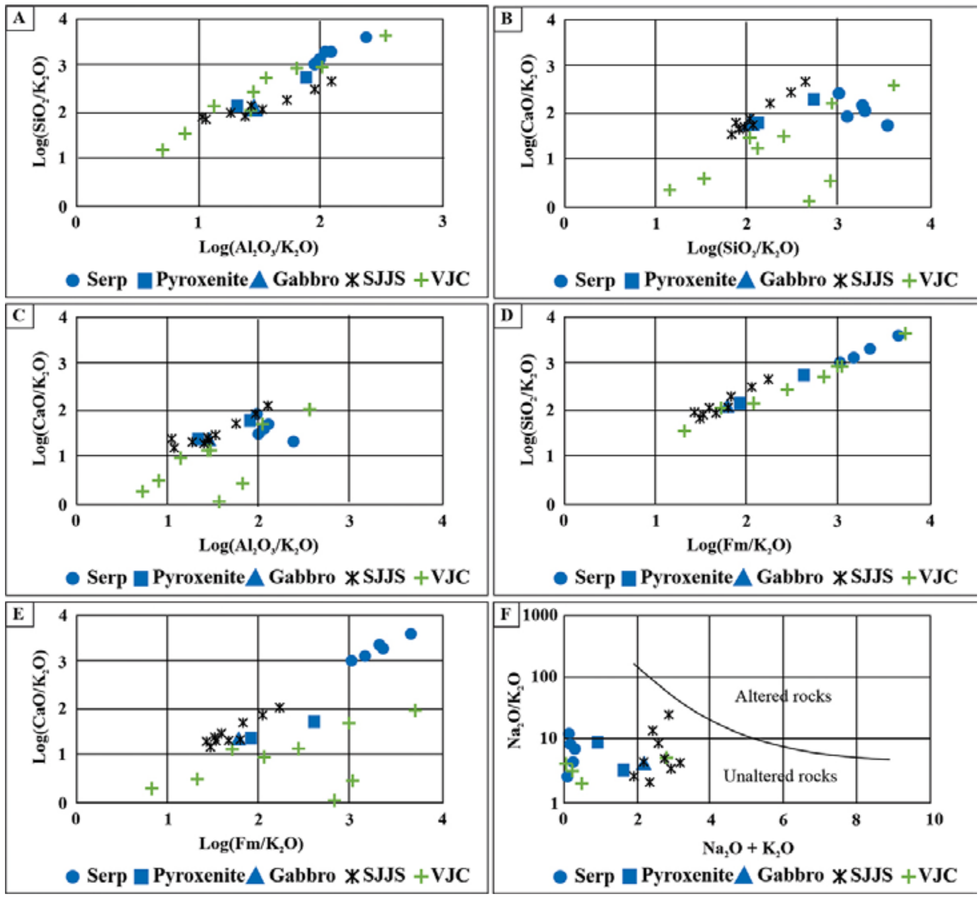

Figure 5 Charts used for identification of sample preservation proposed by Beswick and Soucie (1978) and Miyashiro (1975): A-C. Molecular ratio diagrams proposed by Beswick and Soucie (1978); D. Diagram proposed by Miyashiro (1975) indicating that the samples are preserved. The bibliographical data used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

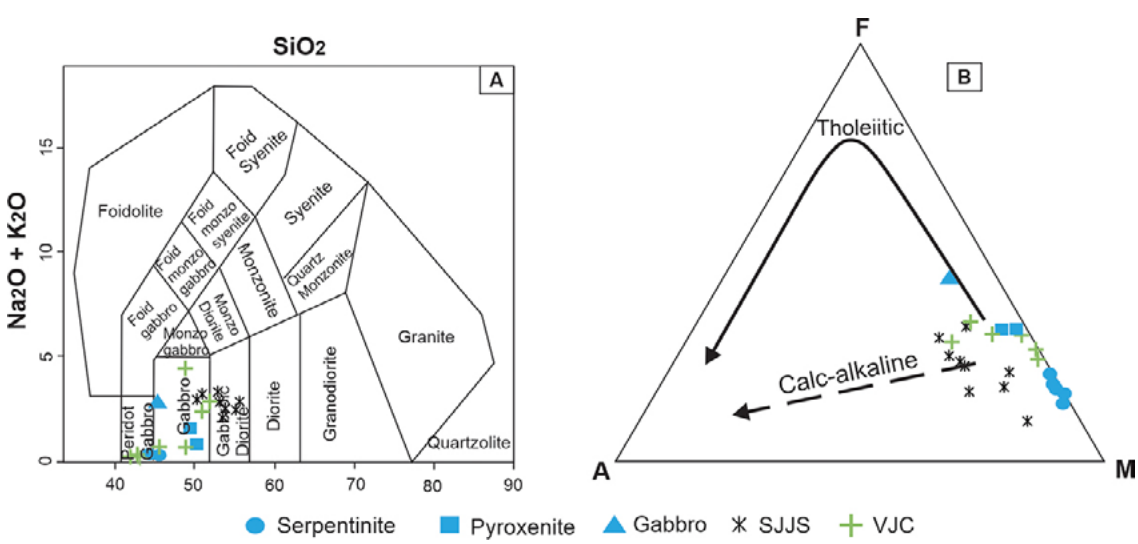

Figure 6 Classification diagrams: A. Diagram proposed by Middlemost naming the rocks from the RMMUB as peridotites and gabbros; B. AFM Diagram suggesting the similarity of the RMMUB with primitive magmas and showing a tholeiitic trend. The bibliographical data used were from 9 mafic-ultramafic rock samples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

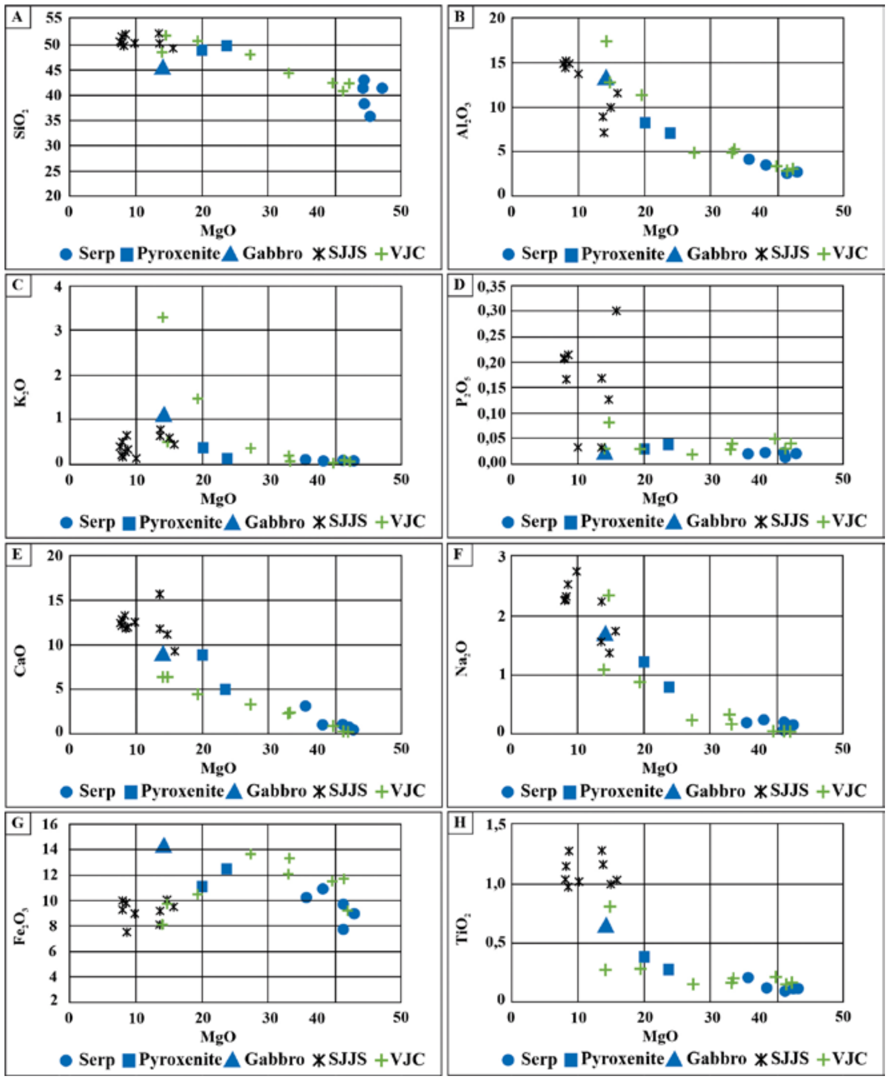

Figure 7 Diagrams of chemical variation of MgO versus major elements and samples from SJJS and VJC were plotted for comparison: A. MgO versus SiO; B. MgO versus Al_2O_3; C. MgO versus K_2O; D. MgO versus P_2O_5; E. MgO versus CaO; F. MgO versus Na_2O; G. MgO versus Fe_2O_3; H. MgO versus TiO_2. The bibliographical data used came from 9 mafic-ultramafic rock samples from the SJJS (Teixeira 1997), and 9 samples from the VJC (Lord et al. 2004).

7 Discussion

7.1 Lithogeochemical Correlation

In the Diagrams of MgO versus 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 SiO_2, Al_2O_3, CaO, Na_2O e TiO_2, the SJJS samples are in more evolved rock positions, in contrast to the other two groups (Figures 7A, 7B, 7E, 7F, and 7H). 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 8B).

For the tectonic ambiance discrimination, 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 9E) 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, 9D, and 9F), 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 & Peate 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).

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.

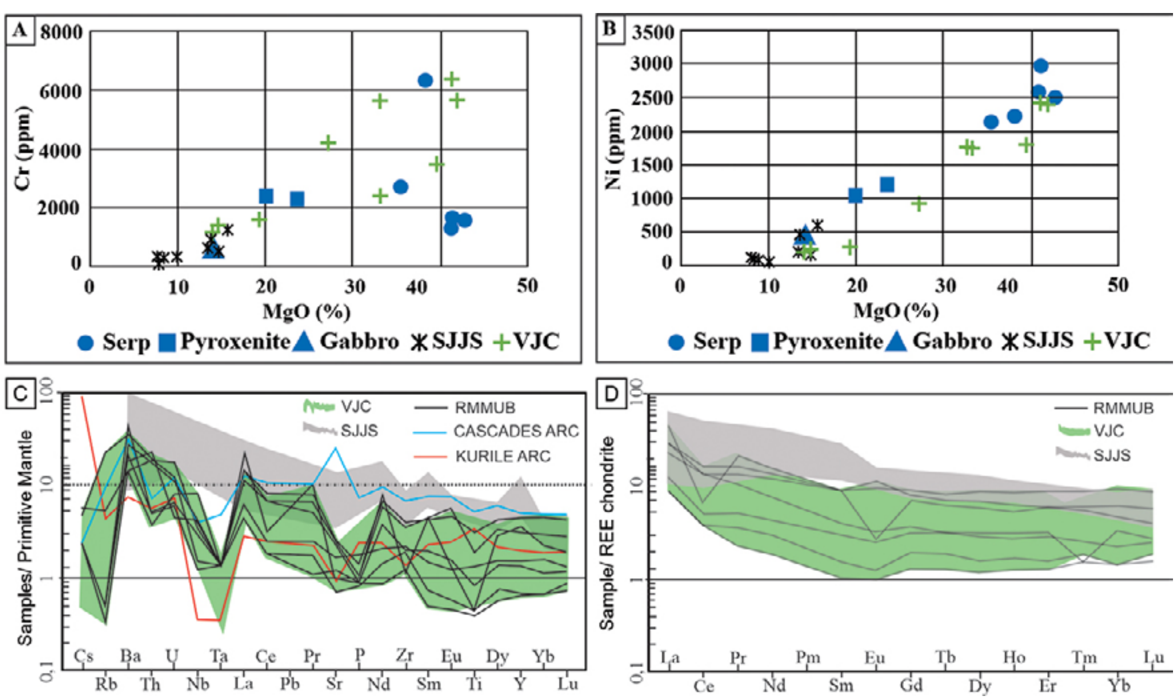

Figure 8 Diagrams using trace and rare earth elements: A. Diagram of MgO versus Cr and the SJJS and VJC samples were also plotted for comparison; B. Diagrams of MgO versus Ni; C. Diagram with the Primitive Mantle as the normalizer, according to McDonough and Sun (1995) data from the Cascades (Barnes 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).

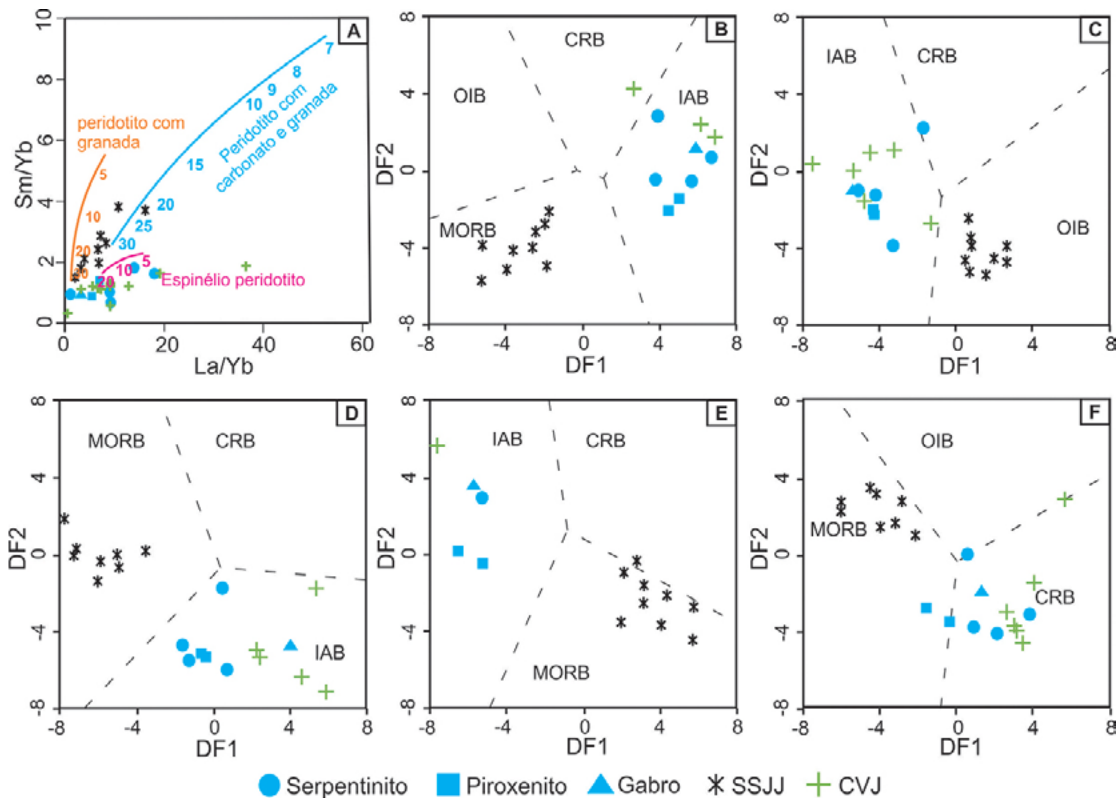

Figure 9 The tectonic ambiance and magmatic source diagrams: A. In the diagram of La/Yb versus Sm/Yb ratios for magmatic sources (Yu et al. 2015), the RMMUB and VJC samples are plotted near the Peridotite spinel field, while the SJJS is plotted between the field of peridotite with garnet and peridotite with carbonate and garnet; B-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).

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 2014; 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.

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Conflict of interest
The authors declare no conflict of interest.

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