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

Abstract

In the geotectonic context of the Salvador-Curaçá orogen, in the north portion of the São Francisco Craton, there were identified rocks, which are named in this present paper as The Riacho do Mocambo Mafic-Ultramafic Body (RMMUB). Despite of being located approximately 60 km from the Vale do Jacurici Complex (VJC), host of Brazil's largest reserves of Cr, described as differentiated sills, associated to a synorogenic to tardi-orogenic event. The RMMUB has never been associated, in regional geologic mapping projects, to this Complex. When it is mentioned in the bibliography, just the ultramafic rocks from the RMMUB were mapped and associated with the São José do Jacuípe Suite (SJJS) described as fragments of an Archean-Paleoproterozoic oceanic crust or interpreted as a Gabbro-Anorthosite Stratiform Complex. 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 gabbro, 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 geochemical signatures as the source, depth, and tectonic environment of magma with the VJC. 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, in the northeast region of the state of Bahia.~~revealing a high metallogenic potential~~.

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

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1 Introduction

In the Northeast of the São Francisco Craton, the presence of mafic-ultramafic rocks (M-UM) is recorded, ~~being related specially to the Precambrian period~~. The main ~~lithologic types~~ lithostratigraphic units are: São José do Jacuípe Suite – ~~SSJJ~~SJJS (Teixeira, 1997; Piaia et al. 2017) Vale do Jacurici Complex – ~~CVJ~~VJC (Deus & Viana, 1982; Marques et al. 2003a, 2003b; Lord *et al*. 2004; Silveira et al. 2015 ~~Oliveira et al. 2004~~); Caraíba's M-UM Intrusion (Townsend *et al*. 1980; Maier & Barnes, 1996; Garcia et al. 2018) Ultramafic Complex of Campo Formoso (Silva & Misi, 1998; Lord et al. 2004), besides the M-UM dikes associated to the Jacobina Group (Couto *et al*. 1978).

In the study area, the important associations of M-UM rocks can be briefly defined, which are represented by the ~~SSJJ~~SJJS and ~~CVJ~~VJC. The ~~SSJJ~~SJJS is described as a representative of fragments of an Archean-Paleoproterozoic oceanic crust (Teixeira 1997; Melo et al. 1991; Delgado et al. 2003); or interprets these rocks as a Gabbro-Anorthosite Stratiform Complex Piaia et al. 2017. The U-Pb age in zircon for SHRIMP given to the ~~SSJJ~~SJJS, is of 2583.7 ± 8 Ma (Oliveira et al. 2010)

The ~~CVJ~~VJC is described as differentiated sills, oriented in the N-S axis, occurring over an extent of 100 km x 10 km, associated to a~~n~~ synorogenic to tardi-orogenic event (Dias et al 2014) with SHRIMP zircon U-Pb age of 2085 ± 5 Ma (Oliveira et al. 2004). The ~~CVJ~~VJC is constituted by 15 mineralized bodies, presenting deposits estimated in 40 Mt of chromite, having as its main body Ipueira-Medrado, which has a dimension of 7km x 500m x 300m and presents its main mineralized layer of 5-8 m of thickness composed by massive chromite (Dias et al. 2014).

~~The target of the study was named in this work as Riacho do Mocambo's mafic-ultramafic body (CMURM), and in this article the field, petrographic and geochemical characteristics are investigated, as well as their metallogenic potential, in order to observe if there are similarities with the SSJJ or with the CVJ, this last one being the host of the biggest deposits of chromite in Brazil.~~

The target of this study was called Riacho do Mocambo Mafic-Ultramafic Body (RMMUB)~~CMURM~~) in this article, as it was not specified in the existing regional mapping, with the presence of ultramafic rocks being related to the ~~SSJJ~~ SJJS. The presence of mineralized ultramafic rocks of the VJC ~~CVJ~~ to the north, and non-mineralized of the SSJJ, predominantly to the south of the RMMUB ~~CMURM~~ pose doubts

Comentado [A1]: Detalhar: Arqueano? Paleoproterozoico?Meso? Neo?????

Comentado [A2R1]: Revisão feita, irei cortar pois as rcohas vairam desde do neoproterozoico ao paleoproteroico, além de algumas dessas rochas não terem datação.

Comentado [A3]: Não são tipos litológicos. Tipos litológicos são rochas específicas. complexo, Suite Grupo consistem em unidades litoestratigráficas.

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Comentado [A5]: **Silveira et al 2015 tem datação do Complexo Vale do Jacurici, inserir no texto. U-Pb zircon geochronology of intrusive and basement rocks in the Jacurici Valley region, São Francisco Craton, Bahia**

Comentado [A6R5]: Revisão feita

Comentado [A7]: Por que e para que?
O que é esse corpo? Por que estuda-lo?
Qual a motivação da pesquisa? Quais contribuições científicas essas comparações irão trazer????
Dentro de uma pesquisa científica, algumas questões são colocadas. E o motivo pelo qual é importante responde-las.

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in relation to the genetic connection to the RMMUB ~~CMURM~~ and, the consequent definition of the metallogenic potential of these rocks.

The main goal of this work is to identify and specify the RMMUB~~CMURM~~ from field data, petrographic characterization and the analysis of the geochemical patterns related to the SJJS ~~SSJJ~~ and VJC ~~CVJ~~ patterns. This analysis will cover topics as the source, depth, and tectonic environment of magma. From these data an evaluation of the metallogenetic potential will be made.

This study indicates that the RMMUB ~~CMURM~~ represents a paleo cumulate of layered M-UM rocks with anomalous values of Cr, going from 752 to 7799 ppm. Apart from evidence that suggest similar sources between the RMMUB ~~CMURM~~ and the chromite deposits of the~~-~~ VJC ~~CVJ~~. The correlation between RMMUB ~~CMURM~~ and VJC ~~CVJ~~ implicates that the magmatic action that generated the VJC ~~CVJ~~ has a much bigger reach than what was mapped before, and / or the action of tectonic processes may have placed part of the VJC ~~CVJ~~ to the south of its current limits. This correlation significantly increases the prospective potential for chromite in the north of the São Francisco craton.

2 Methods and Materials

This study was included in the ~~Project~~ project~~-~~Metallogenetic Map~~-~~of the State of Bahia II.~~,~~ To carry out the work, a field stage took place ~~for carrying out the work was done~~ ~~The study was conducted with field stage~~, . 15 thin sections made in the laboratory of The Geologic Survey of Brazil (CPRM) and 8 lithogeochemical analyses conducted in a 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~~s~~ elements were determined by X-ray Fluorescence, trace by ICP – OES (Inductively Coupled Plasma Optical Emission Spectrometry) with digestion and use of sodium peroxide (Na_2O_2) and rare earths by ICP – MS (Plasma Source Mass Spectrometry).

Comentado [A9]: Necessita de uma melhor redação. Uma redação mais técnica, mais científica.
Um estudo conduzido COM seções delgada????

Comentado [A10R9]: Revisão Feita!

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]. ~~The samples were normalized by the chondrite C1 obtained in Sun & McDonough, (1989).~~

~~The bibliographical data used were from 9 mafic-ultramafic rock samples from the SSJJ~~SJJS ~~of the work of Teixeira, (1997); 11 samples from the CVJ~~VJC ~~used for trace element/rare earth charts by Marques et al. (2003b); and 9 samples from the CVJ~~VJC ~~used for charts with bigger elements from the work of Lord et al. 2004.~~

3 Geological Context

The area is located in the northeast portion of the São Francisco Craton (SFC;~~Figure 1A), tectonic compartment defined by~~ Almeida, ~~(~~1967~~);~~ Figure 1A) ~~and redelimited by subsequent studies (Alkmin *et al*. 1993)~~. The SFC ~~São Francisco Craton~~ corresponds to an area stabilized in the Transamazonic (Orosirian) cycle at the end of the Paleoproterozoic and limited during the N~~n~~eoproterozoic and Cambrian era, during the Brazilian cycle, that formed the orogen~~sy~~ ~~by~~ ~~the~~ Sergipano, Rio Preto, Riacho do Pontal, Brasília and Araçuaí ~~Neoproterozoic Orogens~~ (Alkmin *et al*. 1993; Barbosa and Sabaté, 2003).

~~This area stabilized~~ In the Transamazonic (Orosirian) cycle, period 2.12-2.02 Ga (Sousa & Oliveira, 2019)~~after the event in the Paleoproterozoic (Riacian-Orosirian)~~, when the Gavião, Serrinha, Jequié and Itabuna-Salvador-Curaçá paleoplates collided, originating the Itabuna-Salvador-Curaçá Orogen. In this event occurred the emplacement of granitoid bodies and the M-UM rocks from the ~~CVJ~~VJC (Barbosa & Sabaté, 2004; Oliveira et al. 2004). ~~Citar os dados geocronológicos de Souza & Oliveira 2019; Oliveira et al 2019~~ The north portion of the Itabuna-Salvador-Curaçá orogen is basically formed by three lithostratigraphic units: Caraíba Complex, SJJS, Tanque Novo-Ipirá Complex.

The Caraíba Complex is formed of felsic rocks as enderbite, charnoenderbite and charnockitic gneiss; and mafic rocks composed of gabbro-diorite lenses. All these rocks are metamorphosed to the granulite facies, with retrograde metamorphism to the amphibolite facies, locally to the greenschist facies conditions (Barbosa & Sabaté, 2004). SHRIMP U-Pb dating indicates igneous zircon cores with an average ages of 2695 ± 12 Ma (enderbitic orthogneiss) and 2574 ± 6 Ma (tonalitic orthogneiss) for the formation of

Comentado [A11]: Desnecessario em um artigo científico. As referências vão sendo citadas ao longo do texto.

Comentado [A12R11]: Revisão feita

Comentado [A13]: Isso deve constar apenas no item Litogeoquímica quando referir-se aos padrões normalizados. Importante: amostras não são normaizadas, os resultados analíticos obtidos, sim.

Comentado [A14R13]: Revisão feita!

Comentado [A15]: Este parágrafo necessita ser reescrito. Por exemplo:
The area is located in the northeast portion of the São Francisco Craton (SCF, Almeida (1967; Figure 1A), tectonic compartment stabilized after the event (QUAL EVENTO? TEM UMA DESIGNAÇÂO PARA ESSE EVENTO??) in the Paleoproterozoic (Riacian-Orosirian TEM IDADE ABSOLUTA????), when the Gavião, Serrinha, Jequié and Itabuna-Salvador-Curaçá paleoplates collided, originating the Itabuna-Salvador-Curaçá Orogen (Alkimin, 1993). The CSF is limited by the Sergipano Rio Preto, Riacho do Pontal, Brasília and Araçuaí Neoproterozoic Orogens (Alkmin *et al*. 1993). During this event occurred the emplacement of granitoid bodies and the M-UM rocks from the CVJ (Barbosa & Sabaté, 2004; Oliveira et al. 2004).

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Comentado [A18R17]: Revisão feita!

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the protoliths and metamorphic rims with an ~~na~~ age of 2072 Ma (Sabate et al. 1994; Silva et al. 1997; Oliveira et al. 2010).

The SJJS briefly described in the introduction of the pa~~p~~per is ~~a~~ mafic-ultramafic, to the east it is composed of biotite and hornblende-norite, gabbronorite with cumulate sequences and subordinate leucogabbro, while to the west it is ~~are~~ more common to find ferrogabbro, peridotite, and pyroxenite (Kosin et al. 2003).

Kosin et al. (2003) interpreted the Tanque Novo-Ipirá Complex as a meta-volcanosedimentary sequence developed between the Archean and Paleoproterozoic that experienced high-grade amphibolite to granulite facies metamorphism. 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.

INCOMPLETO

4 Field Aspects

The study area was delimited based on outcrops ~~with the main idea of the identification~~ of M-UM rocks found in the region of Capim Grosso city (Figure 1B), which are named in this article as ~~CMURM~~RMMUB. This body occurs embedded between calc silicate rocks (Figure 2A), with verified kinzigite gn~~a~~eisses to the east, lithotypes associated to the Tanque Novo-Ipirá Complex ~~(CTNI)~~. The contact is inferred, because due to the expressive presence of Neogene-quaternary detrital cover it was not possible to identify the contact in the field. The mafic rocks from the ~~SSJJ~~SJJS were mapped to the west of the ~~CMURM~~RMMUB and are represented by amphibolitized gabbros (Figure 2B).

Figure 1: Geological Maps. A. Localization Map Modified from Marinho, 1986. B. Geology of the study area. Modified from Melo et al. 2001.

~~During the field phase it was possible to observe rock outcrops from the SSJJ~~SJJS, ~~which were represented mainly by typical amphibolites or mafic granulites, occurring in large outcrops mainly near the city of the same name or in the form of enclaves, lenses~~

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Comentado [A19]: Textos adicionados.

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Comentado [A20]: não se delimita uma área com a ideia de identificação de corpos geológicos.
Os corpos aflorantes é que delimitam a área a ser estudada.

Por exemplo: os corpos máficos e ultramáficos do Complexo Riacho do Mocambo aflram em uma área geográfica com cerca de..km2 nas vizinhanças do município de Capim Grosso _Ba (fig..).

Por que esse Complexo Tanque Novo não consta na Introdução?????

Comentado [A21R20]: Revisões feitas

~~and bands embedded in rocks of the Caraíba Complex, being highly deformed and metamorphosed rocks in the in the granulite facies with a retrograde metamorphism to the amphibolite facies (Barbosa & Sabaté, 2004).~~

The RMMUB represents a paleo cumulate of layered M-UM rocks and is formed from west to east by serpentinites, pyroxenites and gabbro (Figure 2C). In ~~this rocks~~ these rocks, ~~locally~~, 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 2D). The primary layering is parallel to the deformational foliation (S_n), $S_0//S_n$ (Figure 2E), having trend N330°, with a subvertical dive, varying from 70° to 90° to NE. The S_n is characterized by a cleavage fracture, marked by a set of centimeter-spaced microfractures (Figure 2F~~E~~).

Comentado [A22]: O que isso se associa com o restante. Está dentro da área estudada?????
Descreva o mapa apresentado corretamente, que se terá os aspectos de campo de forma clara e bem redigida.

Comentado [A23R22]: Reviões feitas, Irei cortar esse trecho, pois realmente é uma informação de campo, desnecessária para o artigo.

Comentado [A24]: Em que consiste o CMURM??? Colocar de forma clara as suas litologias com respectivas estruturas.

Comentado [A25R24]: Revisões feitas

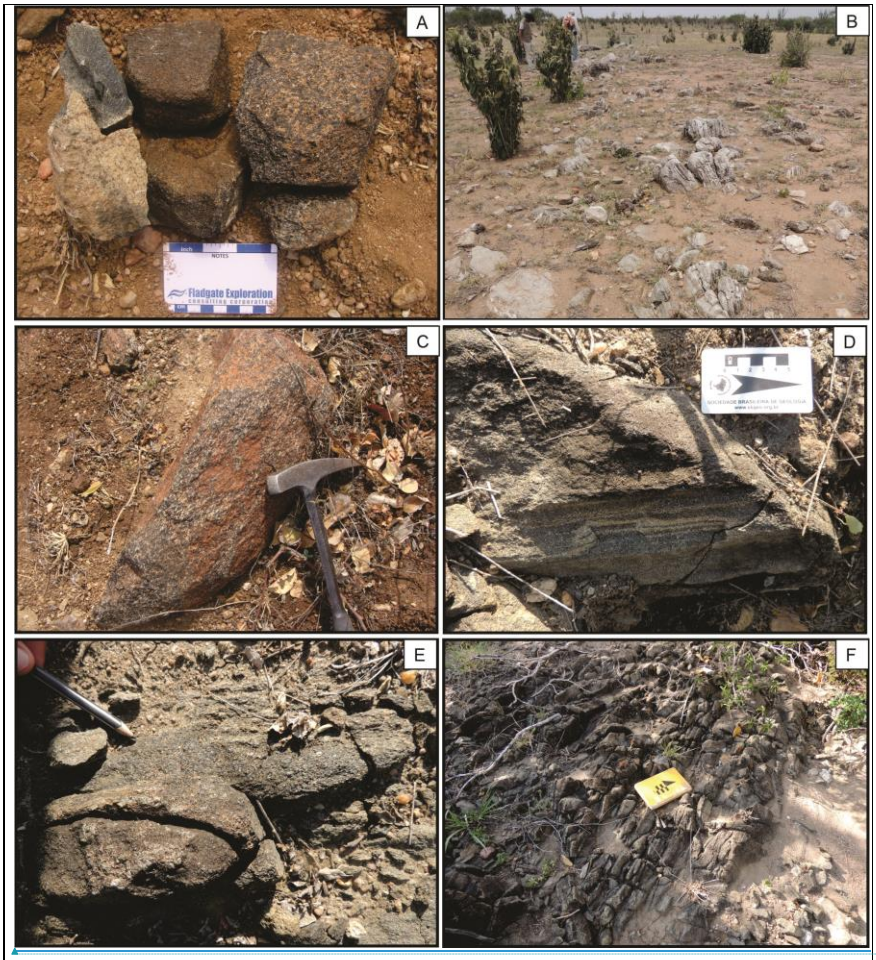

Figure 2: Field aspects of local geology. A. Outcrop of the calc silicate of the CTNI diving to N330°/75NE. B. Amphibolite outcrop from ~~SSJJ~~SJJS; C. Samples from the ~~CMURM~~RMMUB, being from left to right, serpentinite, pyroxenite and gabbro. D. Pyroxenite from ~~CMURM~~RMMUB, note white plagioclase bands, locally setting up a gabbro, possble igeneous layering; E. Contact between dunite and pyroxenite, from the ~~CMURM~~RMMUB, where no shear is observed, being an indication of the igneous layering. F. Dunite from the ~~CMURM~~RMMUB exhibiting ~~-~~cleavage fracture;

5 Petrographic Characterization

The petrographic characterization of the ~~CMURM~~RMMUB has enabled the classification of the lithologies described in the field as serpentinite, metapyroxenite and metagabbro. The rocks have ~~your~~ their igneous texture ~~are~~ partly preserved due ~~from~~ to

Formatado: Fonte: (Padrão) Times New Roman, 12 pt

~~the~~ hydrothermal/metamorphism events to which they were submitted, ~~with the exception of the serpentinites~~.

The serpentinite is composed mostly of serpentine, making up 75 to 90% of the modal composition (Figures 3A and C) representing an advanced stage of alteration, but it is still possible to identify the cumulate texture due to the serpentinized minerals retain the primary shape of the olivine and orthopyroxene grains (Figure 3A). Other minerals of alteration are represented by amphibole, talc, biotite and bowlingite (saponite). Spinels occur with a brownish coloration, possibly due to the picotite~~r~~; 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 3B 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, the plagioclase. The minerals are moderately oriented and show habits, in their majority prismatic and granular (Figure 3D). The rock is inequigranular with fine to medium grain size, showing amphibole and clinopyroxene phenocrysts up to 2 mm. The texture ~~setting~~ 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 phase (Figure 3E), while the intercumulus phase minerals are represented by clinopyroxene and plagioclase (Figure 3F).

The main secondary minerals in the metapyroxenite are the amphiboles, alteration of the pyroxenes, occurring as clinoamphibole (possibly hornblende or cummingonite) and ortho-amphibole (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, the last mineral being poorly preserved. It is an inequigranular rock, fine to medium grained, with amphibole crystals reaching 3mm. The ~~setting~~ 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 3G). The ~~alteration~~ retrometamorphic minerals that occur in this lithotype are: ortho and clino

Código de campo alterado

Comentado [A26]: Serpentinito é uma rocha metamórfica.

Comentado [A27R26]: Concordo, texto modificado.

Comentado [A28]: Or texture???????

Comentado [A29R28]: Texture, erro de tradução!

Comentado [A30]: Facies granulito de baixa pressão????

Comentado [A31R30]: Minha hipótese é que são rochas ígneas M-UM que foram intrudidas durante o metamorfismo regional e que torna-se difícil identificação se o mineral é ígneo ou metamórfico, mas os minerais de retrometamorfismo ficam evidentes durante a descrição petrogarfica

Comentado [A32]: Ou textura?????

Comentado [A33R32]: Revisão feita, textura

Formatado: Realce

amphiboles, biotite, sericite and epidote created by the effects of sericitization and saussuritization, respectively (Figure 3H).

Figure 3: Petrographic aspects of the ~~CMURM~~RMMUB. A. Notice that the relict outline of the olivine grains (Ol) altered to serpentine (Srp) 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 an alteration 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, notice that the biggest deformation occurs in the metagabbro; H. Twinned Cpx altering to Am in the metagrabbo

Comentado [A34]: Anfibólio não é o resultado de metamorfismo progressivo na fácies granulito de baixa pressão??
Por que mineral de alteração ou seja, retrometmórifco?
Qual a textura sugestiva para essa interpretação??????

Comentado [A35R34]: O anfibólio é produto de retrometamorfismo.

Comentado [A36]: Ou de retrometamorfismo?
Processo de alteração em rocha ígnea é uma coisa; metamorfismo é outra.
Se a rocha é designada como METAgabro não é um gabro alterado, é um gabro metamorfizado e tem que descrever conforme textura e paragêneses metamórficas.
A descrição apresentada é de uma rocha ígnea.

Comentado [A37R36]: As rochas apresentam textura ígnea preservada, com minerais de retrometamorfismo bem marcados, o anfibólio nos Metapiroxenito e metagabro e a serpentina nos serpentinitos, onde houve um metamorfismo mais pervasivo. Apesar de ainda ser possível se observar o formato dos critais de olivina.

6 Lithogeochemistry

6.1 Preservation of the lithogeochemical signature

The eight analyzed samples from the ~~CMURM~~RMMUB (Table 1) are partly preserved as metagabbro and the metapyroxenite, while the serpentinite has shown the highest percentage of alteration minerals. The preservation of the lithogeochemical signature in dunites that were serpentinized due to the action of metasomatism is possible because of its refractory nature, allowing the analysis of the primary mineral signature after serpentinization (Deschamps et al. 2010; Saha et al. 2018).

Table 1: Chemical analysis of the ~~CMURM~~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 (%)								
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

With the intent of observing a possible effect of hydrothermal or metamorphic alteration, the Ratio in Molecular Proportion Method (Beswick & Soucie, 1978) was used, which revealed sharp detailed trends to the samples from the ~~CMURM~~RMMUB, indicating that there was no significant mobility for most of the major elements (Figures 4A, 4C, 4D and 4F). Only in the diagram of $Log(SiO_2/K_2O)$ x $Log(CaO/K_2O)$ a dispersion in the samples is registered, suggesting the presence of some alteration degree (Figure 4B). In order to confirm the results, the diagram proposed by Myashiro (1975) was used, corroborating that there was no significant alteration of the elements Na_2O e K_2O during the hydrothermal processes (Figure 4F). This fact reinforces that the lithogeochemical signature of the ~~CMURM~~RMMUB is preserved, as well as the data obtained from the ~~SSJJ~~SJJS and the ~~CVJ~~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).

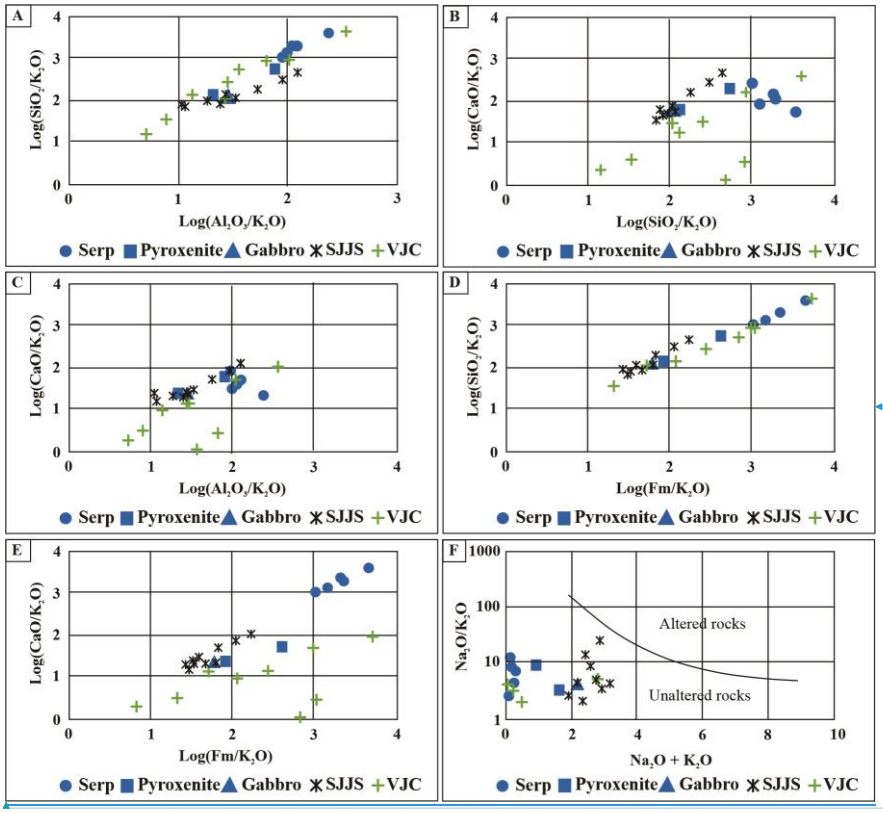

Figure 4: Charts used for identification of sample preservation proposed by Beswick, (1978) and Myashiro (1975). A-C. Molecular ratio diagrams proposed by Beswick, (1978). D. Diagram proposed by Myashiro (1975) indicating that the samples are preserved. The bibliographical data used were from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 9 samples from the VJC (Lord et al. 2004).

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Colocar as referências dessas análises. Não são suas.
Colocar no texto.

Comentado [A39R38]: Revisão feita:
The bibliographical data used were from 9 mafic-ultramafic rock samples from the SSJJ (Teixeira, 1997);; and 9 samples from the CVJ (Lord et al. 2004).

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6.2 Major Elements

In the silica vs. alkali sum diagram proposed by Middlemost (1994) the samples from the ~~CMURM~~RMMUB and the ~~CVJ~~VJC are classified as peridotites and gabbros, while the samples from ~~SSJJ~~SJJS are classified as gabbroic and gabbroic diorite (Figure 5A). 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 5B).

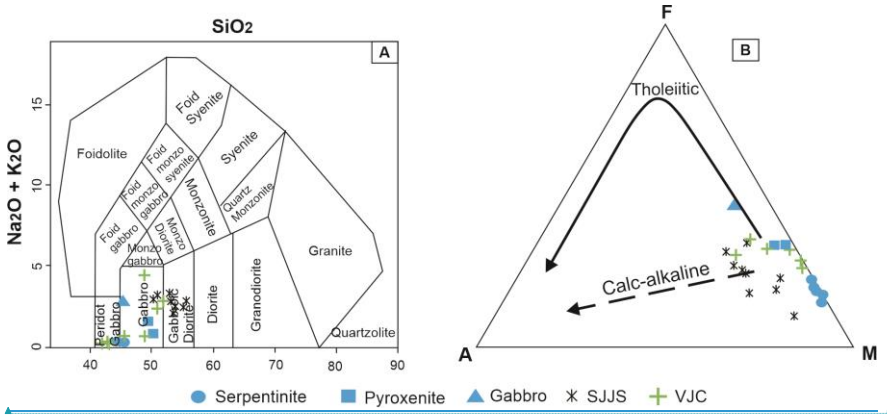

Figure 5: Classification Diagrams. A. Diagram proposed by Middlemost, naming the rocks from the ~~CMURM~~RMMUB as peridotites and gabbros; (B) AFM Diagram, suggesting the similarity of the ~~CMURM~~RMMUB with primitive magmas and showing a tholeiitic trend. The bibliographical data used were from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 9 samples from the VJC (Lord et al. 2004).

The ~~CMURM~~RMMUB results indicate characteristics similar 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,

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67,84 to 66,82% in the pyroxenites and 52,13% in the gabbro. In the serpentinites the values found are ~~a little~~ below of 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), 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 ~~negative~~ correlation trends in the Al_2O_3, CaO, Fe_2O_3 e TiO_2 diagrams indicating fractional crystallization process (Figures 6B, E, G and H) and 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 6A, C, D and F).

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Comentado [A41]: O contrário.
Não use esses termos de correlação quando utiliza o MgO como ID, pode te levar a interpretações totalmente ao inverso. Os teores de CaO, al2O3 aumentam, sugerindo o não fracionamento de plagioclásio, como é esperado em magmas ultrabásicos.
Quanto menor os teores de MgO mais evoluído é o magma. Veja o sentido dos teores de MgO nos diagraas de variação.
CUIDADO!!!!!!!!!!Entre 42-25% MgO parece que apenas olivina, opx e cpx está sendo fracionada (ver MgO x Cr e Ni); em 25% Mgo ponto de inflexão e mudança na assembleia fracionante; início do fracionamento de plagioclásio, óxidos de Fe e ti.
Ver a variação dos elementos traços para corroborar.

Comentado [A42R41]: Estou de acordo com o texto, mas não quis dizer que por estar ocorrendo o processo de cristalização fracionada marcada pela variação desses elementos, eles estariam sendo utilizados para formar plagioclásio e óxidos de ferro. Entendo que mesmo durante a cristalização de oliviona opx e cpx também existe uma variação no valor do MgO em relação a esses elementos.

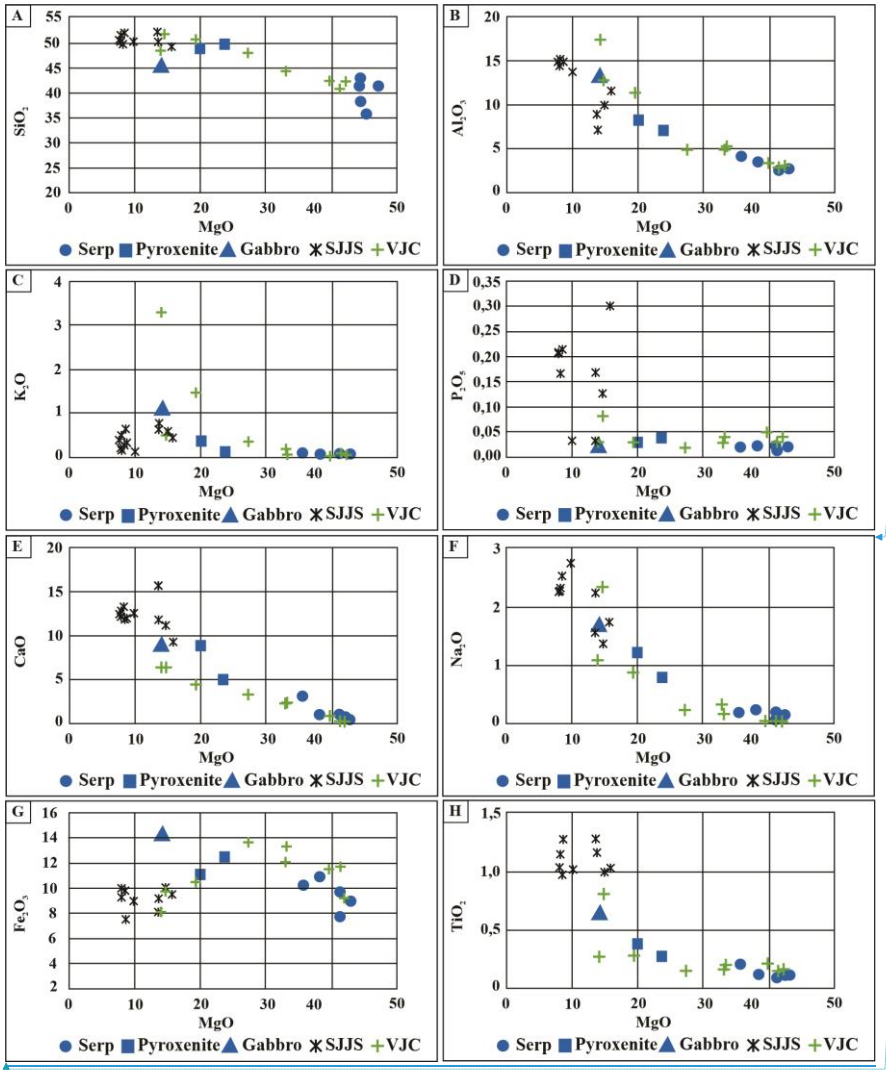

Figure 6 Diagrams of chemical variation of MgO versus major elements, samples from ~~SSJ~~SJJS and ~~CVJ~~VJC were plotted for comparison. The bibliographical data used were from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 9 samples from the VJC (Lord et al. 2004).

6.3 Trace and Rare Earth Elements

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In binary diagrams of Cr and Ni versus MgO well marked negative correlation trends are observed in the diagrams (Figures 7A and B), where in the Cr diagram, the serpentinite samples from the ~~CMURM~~RMMUB reach 7799 ppm (Figure 7A). In the normalized multi-element diagrams (Sun & McDonough, 1989) are observed among the samples, ~~with a similar pattern to the modern arch boulders like Cascades and Kurila~~, showing slight fractionation between LILE and HFSE, Rb, U, Th spikes and strong depletions Nb-Ta, Sr and Ti in relation to the ~~Early~~ Primitive Mantle (Figure 7C). ~~The REE normalized diagram (references), etc, etc and etc.~~

In the multielemental diagram normalized by Chondrite (Figure 7D), there is ~~a addition to~~ 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.

~~The presence of anomalies is registered by the depletion of HFSE, as Nb and Ta in relation to the Early Primitive Mantle (Figure 7C). In the multielemental diagram normalized by Chondrite (Figure 7D), an enrichment in the LREEs relative to the HREEs, negative Ce, Eu and Tm anomalies are observed in two samples.~~

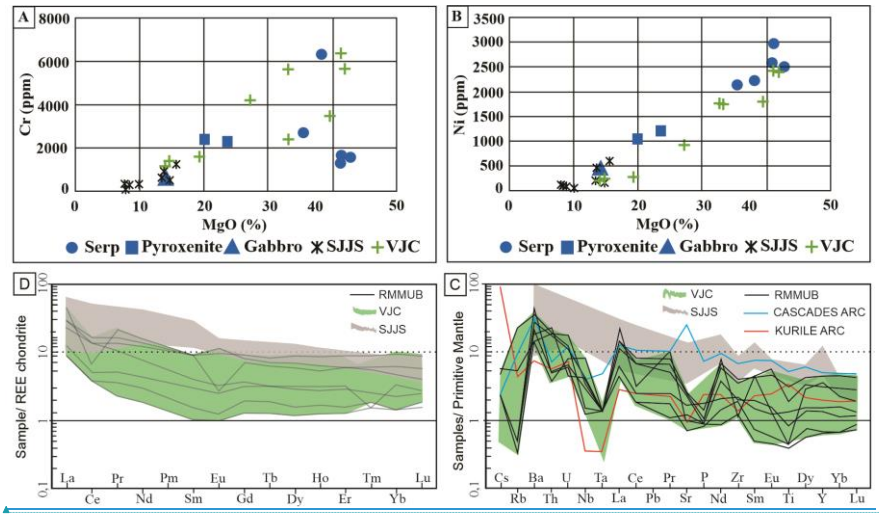

Figure 7 . A Diagram of ~~(~~MgO~~)~~$_{adj}$ versus Cr and the ~~SSJJ~~SJJS and VJC ~~FJC~~ samples were also plotted for comparison. B. Diagrams of ~~(~~MgO~~)~~$_{adj}$ versus Ni. C.Diagram with the ~~Early~~ Primitive

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Comentado [A44R43]: Ok!

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Comentado [A46R45]: Obrigado. Revisão feita

Comentado [A47]: Primitive mantle

Comentado [A48R47]: Revisão feita

Comentado [A49]: Separar as descrições de diagramas multielementares para elementos traço (LILE and HFSE) de padrões noramizados de ETR (LREE and HREE).

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Comentado [A51]: Primitive mantle

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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 were 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 (MgO)adj versus major elements it is possible to notice that the RMMUBMCURM samples are plotted in similar regions as the CVJVJC samples, showing trends with similar differentiation. While the mafic-ultramafic rocks from the SSJJSJJS are more differentiated, with lower MgO contents, do not present well marked trends and are plotted in different regions of the CMURMRMMUB. In the diagrams using ($(SiO_2)_{adj}$, $(Al_2O_3)_{adj}$, $(CaO)_{adj}$, $(Na_2O)_{adj}$ e $(TiO_2)_{adj}$ the SSJJSJJS samples are in more evolved rock positions, in contrast to the other two groups (Figures 6A, B, E, F and H). In the (MgO)adj diagrams versus Cr and Ni, it can be observed that the samples from the CMURMRMMUB and the CVJVJC demonstrate the same degrees of enrichment in these elements, with similar trends, while SSJJSJJS is depleted of these elements (Figures 7A and B).

In the study of the tectonic ambience 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), for the study of basic-ultramafic rocks in the classification of tectonic ambience. It can be noticed that CMURMRMMUB and CVJVJC are plotted in different fields than the SSJJSJJS rocks, with CMURMRMMUB and CVJVJC associate to the being classified as IAT (Island Arc Tholeiitic) in 4 diagrams (Figures 8B to E) and as CRB (Continental Rift Basalt) in one diagram (Figure 8F). However, While the SSJJSJJS ploting is classified as in MORB field (Mid Ocean Ridge Basalt) in 4 diagrams (Figures 8B, D and F) and in a diagram as OIB (Ocean Island Basalt) (Figure 8C).

In the multielementalr diagrams (Figures 7C and 67D) it is possible to notice a similar pattern among the samples from the CMURMRMMUB indicating they may be related to the same primary magma (Winter, 2014), the anomalies of REE fractionation

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Comentado [A54R53]: Entendi, concordo com a mudança de ordem

~~pattern with the strong depletion of high force field elements (~~HFSE~~), as~~ 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 ~~Early~~ Primitive Mantle (Figure 7C) can be attributed to the enrichment by metasomatic processes (Pearce, 1983; Pearce & Peat, 1995; Hawkesworth *et al*. 1997). However, the participation of fluids, subsequent to magma crystallization, responsible for serpentinization, sericitization and saussuritization is not discarded.

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 ~~CMURM~~RMMUB is plotted in the same region as the ~~CVJ~~VJC, corresponding to the peridotite spinel, material that would represent a shallower, possible source of arch boulders (Pearce & Stern, 2006) or by a~~n~~ ~~ancient~~ primitive metasomatized lithospheric mantle as discussed by Marques et al. (2003b). While the ~~SSJJ~~SJJS is plotted closer to the Sm/Yb ratio axis, in the peridotite line with garnet, material representing a deeper source with garnet signature, similar to the source of the MORBs (Hirschmann & Stolper, 1996). (Figure 8A)

~~In the study of the tectonic ambience 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), for the study of basic-ultramafic rocks in the classification of tectonic ambience. It can be noticed that CMURM~~RMMUB ~~and CVJ~~VJC ~~are plotted in different fields than the SSJJ~~SJJS ~~rocks, with CMURM~~RMMUB ~~and CVJ~~VJC ~~being classified as IAT (Island Arc Tholeiitic) in 4 diagrams (Figures 8B to E) and as CRB (Continental Rift Basalt) in one diagram (Figure 8F). While the SSJJ~~SJJS ~~is classified as MORB (Mid Ocean Ridge Basalt) in 4 diagrams (Figures 8B, D and F) and in a diagram as OIB (Ocean Island Basalt) (Figure 8C).~~

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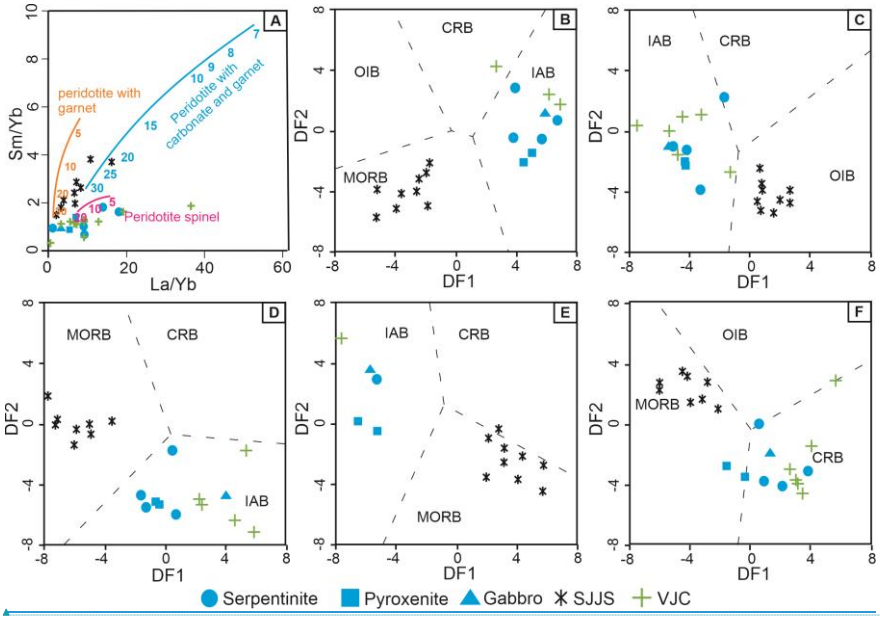

Figure 8. Tectonic ambience and magmatic source diagrams. A. In the diagram of La/Yb versus Sm/Yb ratios for magmatic sources (Yu *et al*. 2015), the ~~CMURM~~RMMUB and ~~CVJ~~VJC samples are plotted near the Peridotite spinel field, while the ~~SSJJ~~SJJS is plotted between the field of peridotite with 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 ~~CMURM~~RMMUB and ~~CVJ~~VJC samples (circled in purple) are mostly plotted in the IAT field, while ~~SSJJ~~SJJS is plotted in the MORB field. The bibliographical data used were from 9 mafic-ultramafic rock samples from the SJJS (Teixeira, 1997); and 11 samples from the VJC (Marques et al. 2003b).

In literature it is proposed that the ~~SSJJ~~SJJS would represent a ~~neoarchean~~Neoarchean ophiolite (Teixeira, 1997), then generated in an extensional environment, similar to the MORB, as the classification indicated. On the other hand, ~~T~~the geotectonic setting ~~placement environment~~ for the Paleoproterozoic age rocks of the ~~CVJ~~VJC, ~~on the other hand,~~ is not well understood, but is discussed by Marques ET AL. (2003b). This author discusses several hypotheses for the petrogenesis of the ~~CVJ~~VJC, among them that the ~~CVJ~~VJC may be derived from a previously depleted, but metasomatically enriched mantle, representing then an ~~ancient~~ old metasomatized subcontinental lithospheric mantle formed by the roots of the Archean craton.

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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) e 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 bedrocks of the ~~CVJ~~VJC chromium mineralization (Lord *et al.* 2004; Marques et al. 2003b).

It is also pointed out that both the ~~CMURM~~RMMUB and the ~~CVJ~~VJC are embedded in the same lithotypes, being metasediments of marine/plataformal origin, metamorphosed into high amphibolite to granulite facies, composed of olivine - serpentine - marbles, diopside and calcisilitic granulites and belonging to the Tanque Novo-Ipirá Complex. (Gama, 2019; Ribeiro, 2016). The ~~CMURM~~RMMUB is located around 60km from a mineralized body in Cr, in the region of Laje Nova associated to the ~~CVJ~~VJC, so, the results suggest an extension of the Cr prospecting area, where the fertility of prospects in Vale do Jacurici could be extended to the south, up to Capim Grosso, 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 reveal that the ~~CMURM~~RMMUB represents paleocumulates of layered M-UM rocks, consisting of gabbros, pyroxenites and dunites, with preserved lithogeochemical characteristics even with petrographic evidence of ~~metasedimentary~~ metamorphic action, registered mainly by the serpentinized dunites. The lithogeochemical results indicate similarities with the ~~CVJ~~VJC rocks and differences with the ~~SSJJ~~SJJS ones, suggesting that due to the scale of mapping the ~~CMURM~~RMMUB may not have been mapped in existing regional works due to the complex tectono-structural arrangement of the region of study. So, 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 ~~e~~state of Bahia.

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9 Acknowledgements

This scientific work was generated within the project Metalogeographic Map of the State of Bahia II, 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*.

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