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Textures and Inclusions in Chromite from the Ipueira Mine: Contribution to Understanding the Formation of Chromitites in the Jacurici Complex, Bahia

Texturas e inclusões em cromita da Mina Ipueira: contribuição para o entendimento da formação de cromititos no Complexo Jacurici, BA

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Abstract: Chromite is a mineral of the spinel group and constitutes the only source of metallic chromium, being essential in stainless steel production. The formation of chromitites has been a subject of debate. In Brazil, the Jacurici Complex, exploited by Companhia de Ferro Ligas da Bahia – FERBASA, hosts the largest chromium deposit in the country and has been interpreted as a large-scale magmatic system with ore formed in a conduit that was later tectonically disrupted. Previous studies suggest the influence of crustal contamination and volatiles in the exclusive crystallization of chromite, with possible mechanical concentration leading to the formation of the thickest layer. In this study, petrographic analyses supported by Scanning Electron Microscopy and X-ray microtomography were conducted on samples from the Mina Ipueira segment. The results corroborate previous studies and suggest that chromium supersaturation is reflected in the most massive stage of the layer, which exhibits larger volumes of chromite with multiple hydrated inclusions. The abrupt contact between the semi-massive and massive portions, along with compaction in the main layer, suggests a change in the formation process, possibly beginning with in situ crystallization and evolving into a more complex process involving crystal transport and accumulation.
Keywords: Chromites; Inclusions; Jacurici.

Resumo: A cromita é um mineral do grupo dos espinélios e constitui a única fonte de cromo metálico, sendo essencial na produção de aço inoxidável. A formação de cromititos tem sido alvo de debate. No Brasil, o Complexo Jacurici, explorado pela Companhia de Ferro Ligas da Bahia – FERBASA, abriga o maior depósito de cromo do país e tem sido interpretado como um sistema magmático de grandes dimensões com minério formado em um conduto posteriormente rompido tectonicamente. Estudos prévios sugerem influência de contaminação crustal e voláteis na cristalização exclusiva da cromita com possível concentração mecânica na formação da camada mais espessa. Neste trabalho, foram realizadas análises petrográficas com suporte de Microscopia Eletrônica de Varredura e microtomografia de raios-X em amostras do segmento denominado Mina Ipueira. Os resultados corroboram com estudos anteriores e sugerem que a supersaturação em cromo está refletida no estágio mais maciço da camada que apresenta maiores volumes de cromita com múltiplas inclusões hidratadas. O contato abrupto entre as porções semimaciça e maciça, e compactação na camada principal, sugerem uma mudança no processo de formação, possivelmente iniciando com cristalização *in situ* e evoluindo para um processo mais complexo com transporte e acumulação de cristais.
Palavras-chave: Cromita; Inclusões, Jacurici.

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1. Introduction

Chromite is a dark brown cubic mineral belonging to the spinel group. It is the sole source of metallic chromium, an essential metal in the production of high-performance alloys resistant to heat, abrasion, corrosion, and oxidation. A significant portion of chromite production is allocated to stainless steel manufacturing, although it also plays a relevant role in the chemical industry (PAPP and LIPIN, 2010). In Brazil, the largest chromite deposit is located in the Jacurici Complex, in the northeastern portion of the São Francisco Craton, and is currently mined at the Ipueira Mine by Companhia de Ferro Ligas da Bahia S.A. (FERBASA).

The geological mechanisms involved in the formation of chromitites have been a longstanding subject of debate. The formation of thick chromitite layers is particularly problematic when considering mass balance constraints. Mafic and even ultramafic magmas have limited solubility for Cr_2O_3, and the high concentrations observed in many deposits, including large-scale examples such as the Bushveld Complex in South Africa, require magma volumes far exceeding those effectively preserved in ancient magma chambers (see NALDRETT et al., 2012; LATYPOV et al., 2022). In this context, the Jacurici Complex represents an interesting case study, as it hosts a chromitite layer ranging from 5 to 8 meters in thickness within an ultramafic stratified body composed of peridotitic to mafic lithologies, with a relatively restricted total thickness of only 300 meters. To address this issue, the complex has been interpreted as part of a larger magmatic system, where the mineralized bodies are thought to have originally belonged to a conduit that was later tectonically disrupted. A review of this context is provided by Marques et al., (2017), highlighting that much remains to be understood.

Friedrich et al., (2019) conducted a detailed study on one of the segments of the complex, the Monte Alegre Sul body, located in the intermediate portion of the belt. Several inclusions within chromite were described, including various hydrated minerals, suggesting a fundamental role of volatiles in chromite crystallization. To build upon this research, the present study characterizes, through detailed petrography supported by Scanning Electron Microscopy, the textural relationships and inclusions hosted in chromite layers from the Ipueira segment, located further south. The study analyzed the same samples previously investigated by Marques and Ferreira Filho (2003) and Marques et al., (2003) from the current Ipueira Mine area, aiming to draw comparisons with findings from the Monte Alegre Sul segment. Additionally, high-resolution microtomography was employed to provide 3D visualization of relevant textural aspects. The findings corroborate the work of Friedrich et al., (2019) and further strengthen the evidence for a complex genetic history of the deposit.

2. Geological Context

The Jacurici Complex, located in the northeastern portion of the São Francisco Craton (Figure 1) in the state of Bahia, hosts the largest chromium deposit in Brazil. It comprises 15 mineralized bodies aligned in a north-south direction over a belt extending more than 70 km in length and 20 km in width, exploited by FERBASA since 1973. Currently, FERBASA operates an underground mine in the municipality of Andorinhas (Ipueira Mine).

The Jacurici Complex is part of the remnants of a large igneous province that was deformed and metamorphosed during the Paleoproterozoic (BARBOSA et al., 2012). However, its precise age and tectonic setting remain poorly constrained. It is located at the boundary between two major terranes: the Serrinha Block (to the east, Archean) and the Salvador-Curaçá Belt (to the west, Paleoproterozoic). The complex crops out to the east, parallel to the Itiúba Syenite, a north-south–oriented Paleoproterozoic alkaline massif extending for approximately 150 km. The mafic-ultramafic intrusions are hosted within Archean basement rocks composed of quartz-feldspathic gneisses, marbles, metacherts, and calc-silicate rocks (DE DEUS and VIANA, 1982; SILVEIRA et al., 2015; DIAS et al., 2022). The minimum age for the complex is approximately 2.1 Ga (DIAS et al., 2022), although this age is also associated with the regional metamorphic peak.

The Jacurici Complex underwent deformation and metamorphism under amphibolite- to granulite-facies conditions (CUNHA et al., 2012; MARQUES et al., 2017), with structural evolution involving the formation of synforms followed by boudinage (ALMEIDA et al., 2017), leading to tectonically inverted segments. Despite serpentinization, the texture, mineralogy, and chemical variations of the cumulate rocks remain locally well-preserved (DE DEUS and VIANA, 1982; MARQUES and FERREIRA FILHO, 2003; DIAS et al., 2014; MARQUES et al., 2017).

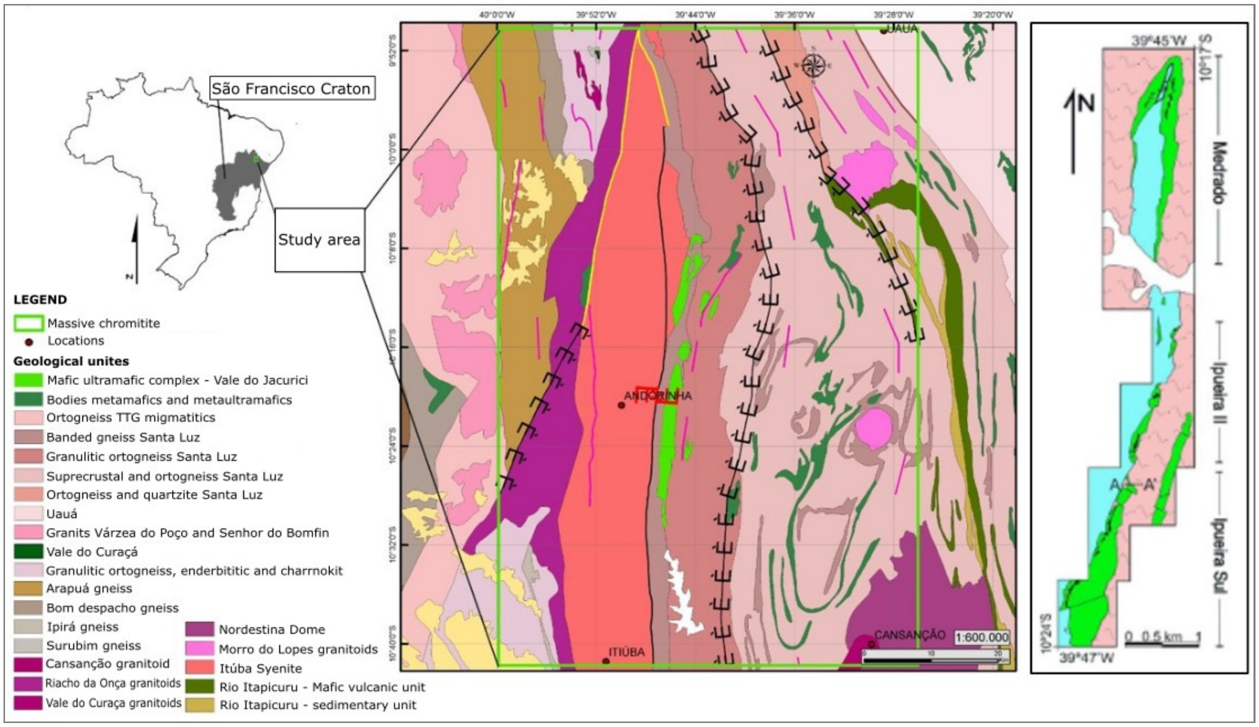

Figure 1 – A. Delimitation of the São Francisco Craton; B. Regional geological map; C. Ipueira Sul, Ipueira I, and Medrado sections.
Source: A. modified from CPRM (2003) and B. adapted from the Geology Division of FERBASA (internal report), modified from Marques et al., (2017).

The Ipueira segment extends approximately 6 km in length, 500 meters in width, and 300 meters in thickness. Marques and Ferreira Filho (2003) proposed two main zones from base to top: (1) the Ultramafic Zone (up to 250 m thick), composed mainly of dunites, harzburgites, and pyroxenites, and (2) the Mafic Zone (up to 40 m thick), in the upper portion, represented by norites. The ultramafic zone is subdivided into three units: the Lower Ultramafic Unit (LUU), the Main Chromitite Layer (MCL), and the Upper Ultramafic Unit (UUU) (Figure 2).

The Lower and Upper Ultramafic Units host semi-massive chromitite layers, 0.5 to 1 m thick, characterized by a network texture with olivine/orthopyroxene crystals—now fully serpentinized—surrounded by euhedral chromite. The Main Chromitite Layer (MCL) reaches up to 7 m in thickness, with a basal semi-massive chromitite layer (~1 m thick) followed by a massive chromitite (lump ore). The semi-massive ore exhibits a network texture with fully serpentinized olivine/orthopyroxene, whereas the massive ore contains interstitial or poikilitic orthopyroxene, also serpentinized.

The cryptic variation of olivine and orthopyroxene along the stratigraphy suggests a petrological shift associated with the main interval of single crystallization of spinel (MCL). Below the main chromitite layer, a continuous evolution in Fo (89–92) and En (88–91) contents is observed, suggesting crystallization concurrent with magma injections in an open system. Above the MCL, there is a rapid evolution with Fo decreasing from 90 to 82 and En from 90 to 84 towards the top, indicative of normal fractionation. Marques and Ferreira Filho (2003) interpreted the magmatic system as a conduit.

Marques et al. (2003) conducted a petrological study using Os and Nd isotopes and suggested an ancient subcontinental lithosphere as the source of the magmatism. The primitive magma is thought to have undergone crustal contamination near the MCL interval. Mineral inclusions in chromite, described by Friedrich et al., (2019) in the Monte Alegre Sul segment, provide evidence of magma enriched in H_2O and CO_2, leading to the hypothesis of contamination through the assimilation of carbonate wall rocks (marbles). This process would have increased fO_2, triggering chromite crystallization. The crystallization likely began in situ, followed by crystal accumulation due to slurry-like gravitational flux, a process facilitated by the presence of volatiles.

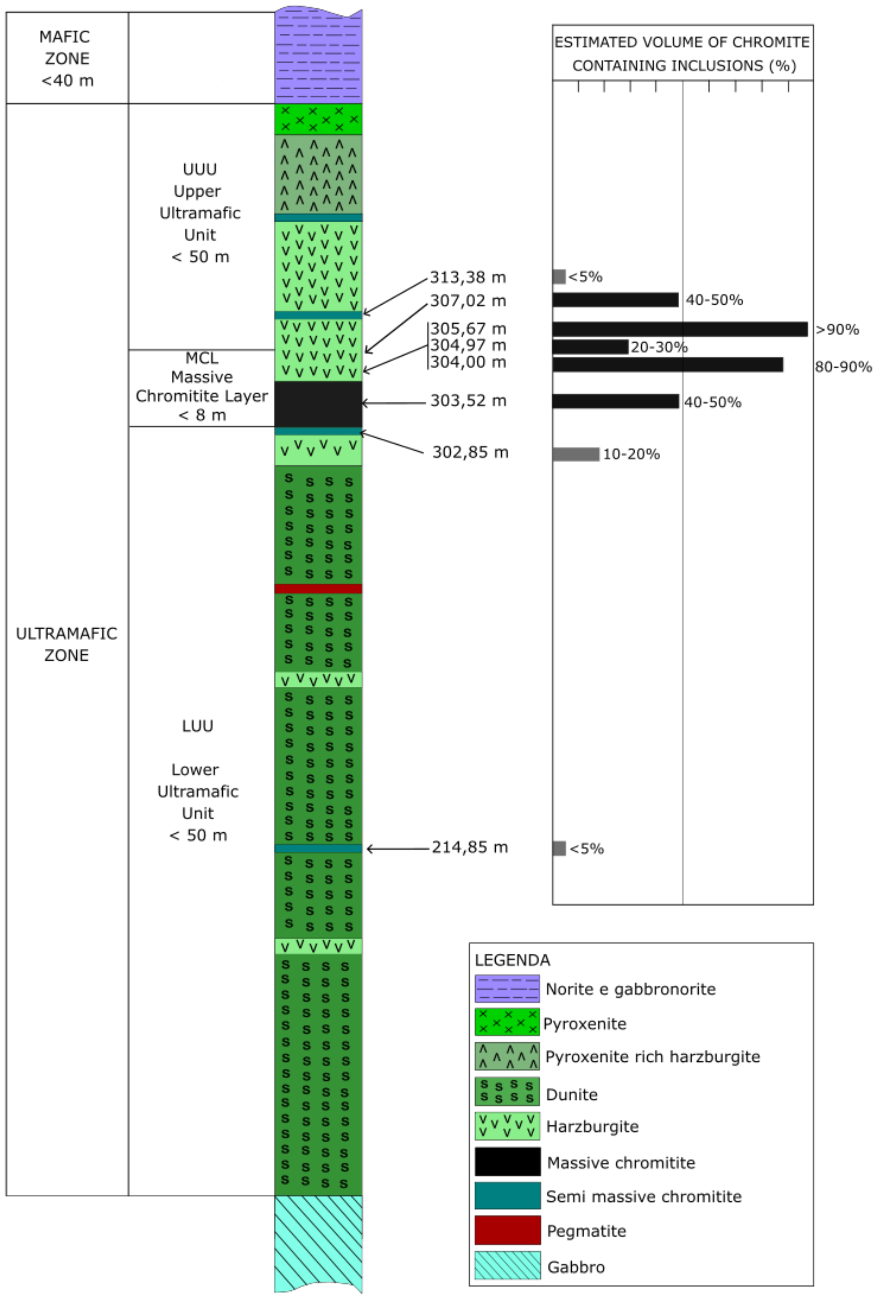

Figure 2 – Schematic section of the Ipueira Sul segment, illustrating the stratigraphic succession from borehole I-328-55°. The intervals utilized in this study are indicated. The right column represents the estimated percentage volume of chromite crystals containing inclusions for each analyzed sample, as determined in this study.
Source: Modified from Marques et al., (2017).

3. Sampling and Analytical Procedures

Eight polished thin sections were prepared from samples previously studied by Marques and Ferreira Filho (2003) — borehole I-328-55°. The selection aimed to evaluate the texture of chromite and the presence of inclusions along the stratigraphy in samples with existing data. Samples from three different layers were chosen: two from semi-massive layers occurring below and above the Main Chromitite Layer (MCL), respectively, in the Lower Ultramafic Unit (LUU) and Upper Ultramafic Unit (UUU), and five samples from the MCL (Figure 2).

Petrographic analysis of chromite crystals and mineral inclusions was conducted using a JEOL 6610-LV Scanning Electron Microscope (SEM) equipped with an Energy Dispersive Spectrometer (EDS) and a Bruker Nano Xflash 5030 Detector at the Isotopic Geology Laboratory of the Federal University of Rio Grande do Sul (LGI/UFRGS). The equipment operated with an acceleration voltage of 15 kV and a working distance of 11 mm, utilizing gold coating. Systematic observations focused on textural characteristics, morphology, and contacts between chromite grains, as well as the form and distribution of inclusions. An estimation of the volume of inclusion-bearing crystals relative to non-bearing ones was also performed.

High-resolution X-ray micro-computed tomography (μCT) aimed to obtain a three-dimensional digital model of sample 310.63 — borehole I-765-90° — Ipueira. The sample was cut to dimensions of 2×4×10 cm. Analyses were performed using a Bruker Skyscan 1173 microtomograph at the Institute of Petroleum and Natural Resources of the Pontifical Catholic University of Rio Grande do Sul (IPR/PUCRS). Analytical conditions were set at 130 kV, 61 μA, with a resolution of 15 μm, a step size of 0.20°, and a 0.25 mm brass filter. Density peaks for silicates and chromite were delineated, isolating the chromite density peak by excluding silicates. To refine the model, Data Viewer and MeshLab software were utilized; in Data Viewer, the model was sectioned along the (X, Y, Z) axes to visualize the sample's interior. MeshLab was employed to enhance the resolution and coloration of the solid, culminating in the final model.

4. Results

4.1 Petrography of Semi-Massive Chromitites in the Lower and Upper Ultramafic Units

The semi-massive chromitite layers hosted in dunites within the Lower Ultramafic Unit (LUU; sample at 214.85 m) and in harzburgites within the Upper Ultramafic Unit (UUU; sample at 313.38 m) exhibit similar textures (Figure 3A, C). Chromite constitutes approximately 30 to 40% of the volume. A network texture is observable even on the surface of drill cores, characterized by serpentinized orthopyroxene/olivine crystals surrounded by finer chromite grains. The chromite tends to be subhedral, minimally fractured, with rounded to straight, occasionally irregular edges (Figure 3B, D). Chromite crystals containing at least one inclusion represent less than 5% of the total volume of this mineral. The inclusions are rounded to elongated and are randomly distributed within the crystals (Figure 3B, D). A single petrographic difference was observed between these layers—the presence of magnetite at the contacts between some chromite crystals in the upper layer sample (Figure 3B). This magnetite is interpreted as a late-stage feature, possibly related to metamorphism or serpentinization. Regarding the types of inclusions, only orthopyroxene was identified.

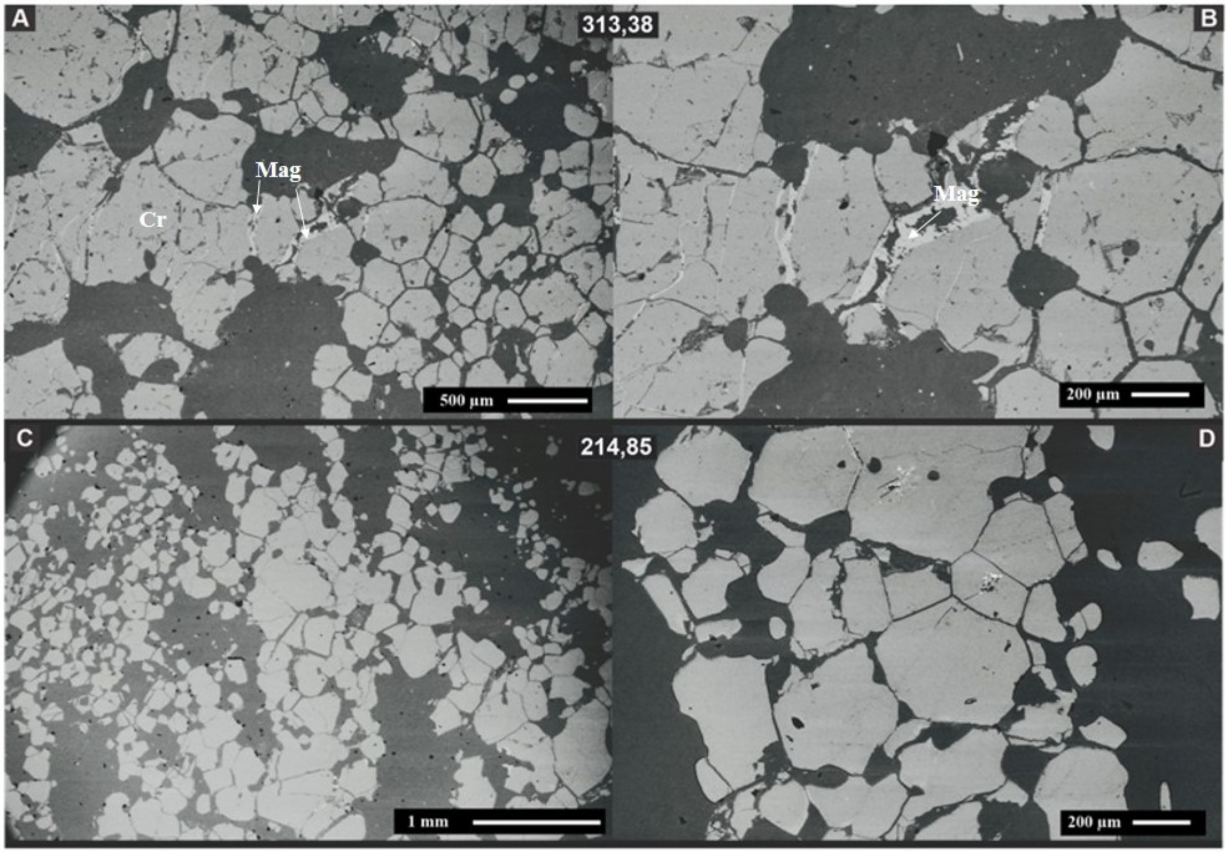

Figure 3 – Backscattered electron (BSE) images illustrating the textural characteristics of chromite (Cr) crystals. A and B: Sample at 313.38 m, representing semi-massive chromitite from the layer above the main chromitite in the Upper Ultramafic Unit (UUU), exhibiting a network texture and the occurrence of late-stage magnetite (Mag). C and D: Sample at 214.85 m, representing semi-massive chromitite from the layer below the main chromitite in the Lower Ultramafic Unit (LUU), also displaying a network texture.
Source: Authors (2022).

4.2 Petrography of the Main Chromitite Layer

In the studied core, the Main Chromitite Layer (MCL) comprises a basal sublayer of semi-massive chromitite with a network texture, approximately 0.6 meters thick, followed by massive chromite ore—also referred to as "lumpy" in the Vale do Jacurici Mining operations—about 5 meters thick. The semi-massive layer contains up to 60% chromite by volume, while the massive portion can exceed 90% chromite by volume. Figure 4 presents representative backscattered electron images illustrating the textural variations and inclusion volumes throughout the layer. Table 1 summarizes this information, including data from the LUU and UUU layers.

Table 1 – Depths and positions of samples along the lithological profile.

Zone	Unit	Depths (m)	Type	Estimated volume of chromites containing inclusions. (%)
Ultramafic	LUU	313,38	Sem-massive	<5
	MCL	307,02	Massive	15 - 25
		305,67		> 90 (some with many)
		304,97		20 - 30
		304,00		80-90 (some with many)

		303,52		40 – 50
		302,85	Semi-massive	10 - 20
	UUU	214,85	Semi-massive	< 5

Source: Authors (2023).

Sample 302.85 m represents the semi-massive portion (Figure 4J, L). Generally, its texture is similar to other semi-massive layers. Chromite occurs as relatively fine aggregates (0.2 to 0.8 mm) surrounding serpentinized olivine/orthopyroxene crystals larger than 1 mm. The chromite crystals have edges ranging from straight to rounded, occasionally irregular. They may appear isolated or connected with straight contacts, showing no signs of compaction (Figure 4L). Regarding inclusion volume, crystals containing at least one inclusion constitute about 10% to 20%. Inclusions exhibit irregular to elongated shapes and are randomly distributed within the crystals**.**

Sample 303.52 m is the first from the massive portion (Figure 4H, I). Chromite crystals are subhedral, ranging from 0.01 to 0.05 mm, with at least one face in contact with another, and show no compaction. Fractures are present but not abundant. The estimated chromite volume is approximately 80%, with inclusions occurring in about 40% to 50% of the chromite crystals, randomly distributed and sometimes concentrated at the edges of larger crystals. Within the same thin section, areas with crystals containing few or no inclusions (Figure 4H) and areas with crystals containing dozens of inclusions (Figure 4I) are observed.

Sample 304.00 m shows a slightly lower chromite volume, around 70%. The crystals tend to be euhedral to subhedral, ranging from 0.01 to 0.04 mm, and exhibit a flattened network-like arrangement. Some fractures and irregular edges are present, though straight edges predominate. Notably, in this sample, up to 80% to 90% of the crystals contain inclusions. Some crystals have dozens of small inclusions, which may be concentrated in the core, form rings at the edges, or be distributed throughout the crystal (Figure 4G). Some crystals contain larger, globular to prismatic inclusions, typically located centrally. When near the edges, inclusions may align parallel to the crystallographic axis.

Sample 304.97 m, from the mid-upper portion of the MCL, exhibits a higher chromite volume, up to 90%, with areas showing significant compaction and annealing features (Figure 4G), which are not uncommon in massive chromitite layers. Individually, crystals range from 0.2 to 0.6 mm and, in less compacted areas, retain euhedral to subhedral shapes. A lower volume of crystals with inclusions is noted, only 20% to 30%. When present, inclusions are randomly distributed, few per crystal, with rounded or prismatic shapes.

Sample 305.67 m, representing the upper intermediate portion of the MCL, contains approximately 70% to 80% chromite, without signs of compaction. Crystals tend to be more isolated or in straight contact on one or two faces (Figure 4D), ranging from 0.1 to 0.4 mm, and are generally euhedral to subhedral. Almost all crystals contain inclusions, with many having dozens of small inclusions. Inclusions vary in shape, from prismatic and elongated to ovoid, and are preferably located in the center of the grains or aligned parallel to the crystallographic axes (Figure 4E).

Sample 307.02 m, near the top of the MCL and close to the contact with harzburgite of the UUU, has a chromite volume around 80%. Crystals are isolated or in contact on up to three faces, without signs of compaction. They are subhedral to euhedral, ranging from 0.1 to 0.5 mm, with few fractures and straight or occasionally irregular edges. The inclusion volume is lower, with about 15% to 25% of the crystals containing one or more inclusions. Inclusions are elongated to ovoid, of varying size, and randomly distributed. Rare crystals show a relatively higher number (>10) of small prismatic inclusions along the crystallographic axes.

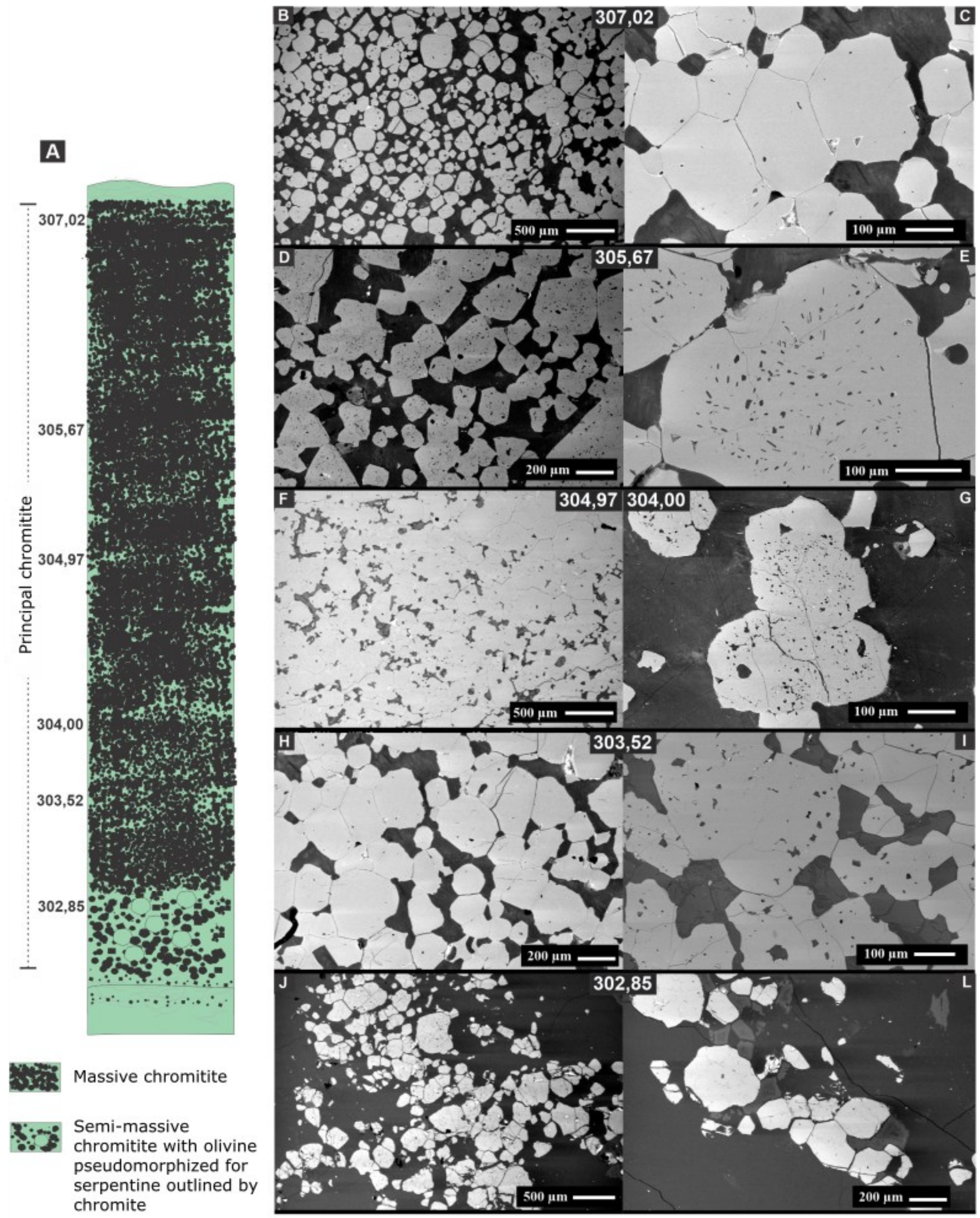

Figure 4 – Backscattered electron (BSE) images illustrating the general appearance of chromite crystals along the Main Chromitite Layer (MCL). A. Schematic profile showing the base with semi-massive chromitite transitioning abruptly to massive chromitite. B and C. Sample at 307.02 m, top of the layer, with chromite containing few inclusions and no compaction. D and E. Sample at 305.67 m, interval where over 90% of the crystals contain numerous inclusions with varied distributions. F. General aspect of sample 304.97 m showing compaction; some crystals have inclusions, but they

are not abundant. G. Detail of sample 304.00 m showing an interval with less compaction and crystals with abundant inclusions, although many are inclusion-free. H and I. Sample at 303.52 m, general view and detail, showing crystals with inclusions, but not abundant. J and L. Sample at 302.85 m representing the semi-massive basal interval, showing crystal distribution and near absence of inclusions.
Source: Authors (2022).

Regarding the typology of inclusions, a variation similar to that reported by Friedrich et al., (2019) in the Main Chromitite Layer (MCL) was observed, with the presence of non-hydrated silicates such as olivine and orthopyroxene, generally forming ovoid to elongated inclusions, usually isolated (Figure 5A, B, D), ranging in size from 5 to 40 µm. Less commonly, clinopyroxene occurs in small crystals. Hydrated silicate inclusions are common and are generally represented by prismatic or elongated ovoid amphibole (hornblende) ranging in size, reaching up to 20 µm. The crystallographic axes can host both hydrated and non-hydrated silicate inclusions (Fig. 5A and C). The chromite from Ipueira, although less commonly than reported for the Monte Alegre Sul segment, also presents carbonate (dolomite) inclusions and may have rare Fe and Ni sulfides.

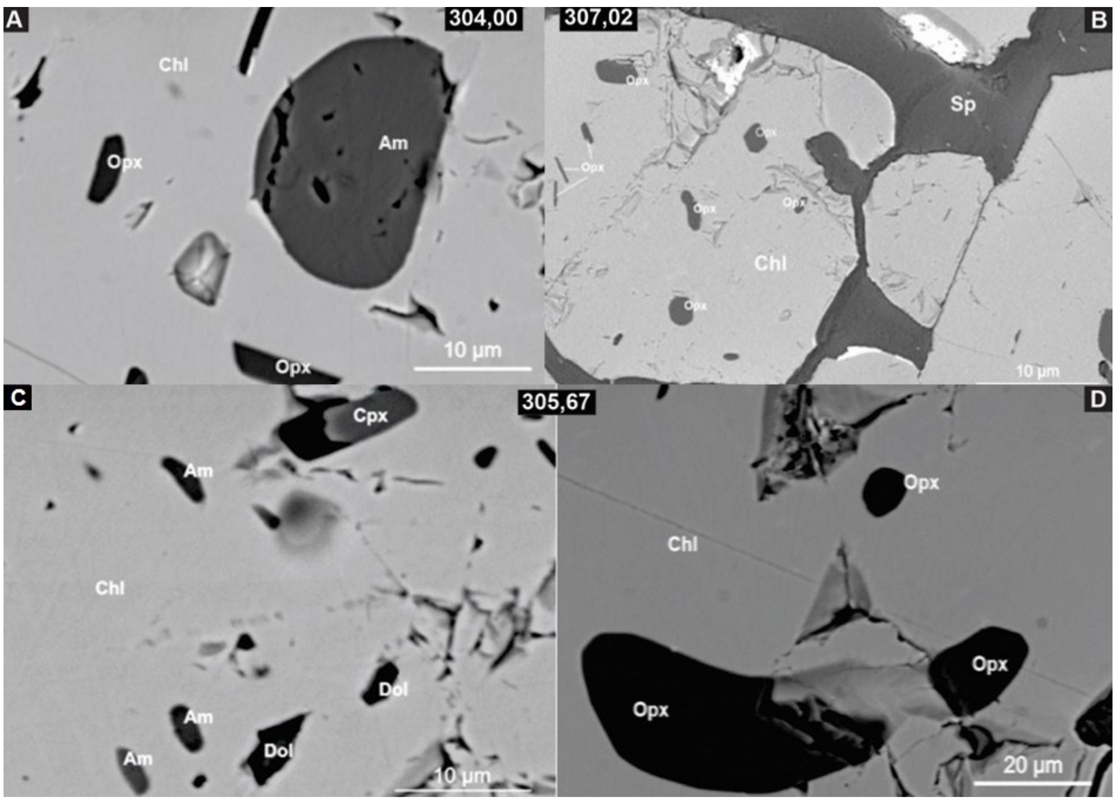

Figure 5 – Backscattered electron (BSE) images showing the most frequent inclusions found in chromite within the massive layer of the Ipueira body. A. Sample 304.00 m exhibits a relatively large amphibole (am) inclusion and also an elongated orthopyroxene (opx) inclusion along the crystallographic axis of chromite. B. Sample 307.02 m shows a crystal with a random distribution of orthopyroxene inclusions. C and D. Sample 305.67 m displays different included minerals within the same chromite crystal (C), including orthopyroxene, amphibole, clinopyroxene, and dolomite (dol), and a relatively large orthopyroxene inclusion (D). Chl – chlorite; Cpx – clinopyroxene; Sp – serpentine.
Source: Authors (2022).

4.3 Results of X-ray Computed Microtomography (µCT)

High-resolution X-ray computed microtomography (µCT) was performed on sample 310.63 m from borehole I-765-90° of the Ipueira body, a different geological section, to observe the transition from the semi-massive to the massive portion in the Main Chromitite Layer (MCL) (Figure 6). This transitional interval was not available in borehole I-328-55°. The three-dimensional digital model highlights chromite crystals in dark gray (Figure 6A, B). It is possible to observe that in the semi-massive portion, the crystals are distributed either in isolation or connected by two or more faces, forming a texture resembling the "chicken-wire" texture described by Barnes (1998), where chromite forms a structure similar to a chain of crystals (Figure 6B, D). A striking feature is the abrupt contact between this portion of more dispersed crystals and the massive portion with compaction features. The contact between these portions is irregular. Towards the top of the massive layer, compaction decreases, although the crystals remain in contact with each other on more than two faces (Figure 6C). The observed fracturing is interpreted as a late-stage feature.

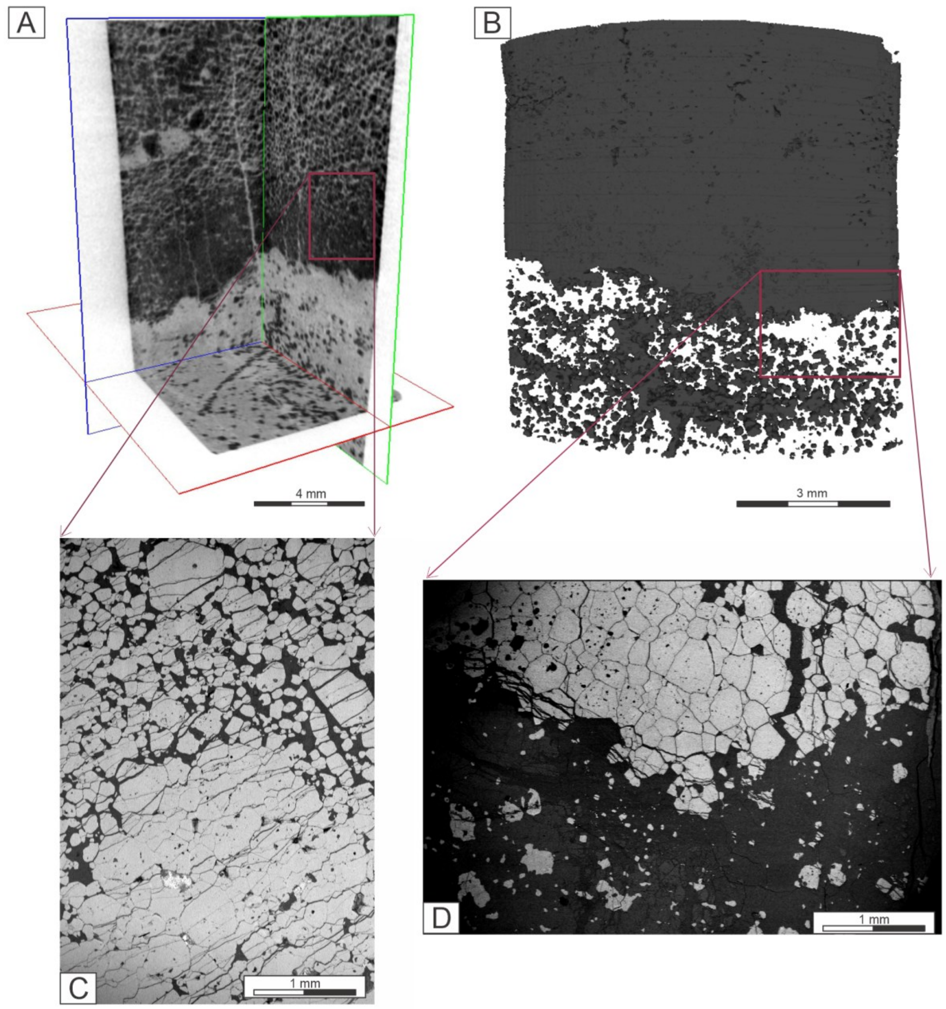

Figure 6 – Sample 310.63 m from borehole I-765-90° of the Ipueira body, highlighting the contact between the semi-massive and massive portions at the base of the Main Chromitite Layer (MCL). A and B. Three-dimensional model obtained by high-resolution X-ray computed microtomography (µCT). C and D. Backscattered electron (BSE) images showing detailed textures in both portions and the transition towards the top of the massive section.
Source: Authors (2023).

5. Discussion and final considerations

The petrogenetic model considered for the Jacurici Complex suggests that the formation of the thick chromite layer occurred through a combination of processes, with in situ crystallization triggered by hydration and crustal contamination (MARQUES and FERREIRA FILHO 2003, MARQUES et al., 2003), followed by remobilization and mechanical transport of crystals along a magmatic conduit (MARQUES et al., 2017, FRIEDRICH et al., 2019).

However, the mechanism responsible for chromite crystallization and the formation of massive layers remains a subject of debate in the literature. Various models have been proposed since the 1960s. In general, these models can be grouped into those that consider formation as an in situ crystallization process and those that attribute chromitite formation to crystal transport. Factors such as variations in oxygen fugacity (ULMER, 1969), pressure changes (e.g., LIPIN 1993, LATYPOV et al., 2018), magma mixing (IRVINE 1977, NALDRETT et al., 2009), and crustal contamination (e.g., IRVINE 1975, MARQUES et al., 2003, LESHER et al., 2019) are all considered potential triggers for in situ crystallization. On the other hand, the challenges in explaining mass balance constraints favor models that propose transport as the primary concentration mechanism, since concentrating chromium from a magma that solubilizes relatively little of this metal is a complex process. Transport could occur through prior accumulation of the mineral in a type of magmatic slurry, which was later introduced into its final position (EALES 2000, VOORDOUW et al., 2009), or through crystal reconcentration by gravitational settling and slumping toward the center of the magma chamber (MAIER et al., 2013, 2018). More recently, an alternative model has been proposed in which crystals form in non-cotectic relations within the magma during ascent, filling the magma chamber before undergoing in situ crystallization, which could explain the formation of large volumes of a single mineral phase, such as chromitites (LATYPOV and CHISTYAKOVA, 2020).

The Main Chromitite Layer (MCL) in the studied core consists of a basal sublayer of semi-massive chromitite with a network texture, approximately 0.6 meters thick, followed by massive chromite ore, also referred to as "lumpy" in Vale do Jacurici Mining operations, with an approximate thickness of 5 meters. The semi-massive layer contains 60% to 85% chromite by volume, while the massive portion can exceed 90% chromite by volume. Considering the mass balance calculations by Naldrett et al., (2012) for chromitite formation in the Bushveld Complex—where a magma with approximately 0.25 wt% Cr_2O_3 solubility and cotectic relationships between crystallizing minerals were assumed—the volume of magma required to generate a 6-meter-thick layer with approximately 80% chromite, as estimated for the preserved volume of chromite in the MCL of the Jacurici Complex, would be around 8 km of magma column. However, the preserved cumulate rocks above the MCL are only a few meters thick. This supports the conduit model proposed by Marques and Ferreira Filho (2003), even when considering exceptional solubility conditions (under high oxygen fugacity). The conduit model explains the lack of preservation of the estimated magma volume, but the concentration mechanism remains unresolved.

Detailed petrographic studies presented in this contribution show that the sections of the semi-massive chromitites, both from the lower portion (Lower Ultramafic Unit - LUU) and upper portion (Upper Ultramafic Unit - UUU), as well as from the base of the Main Chromitite Layer (MCL), have similar characteristics. Chromite comprises about 30 to 40% by volume in the chromitites of the LUU and UUU, and up to approximately 60% in the semi-massive portion at the base of the MCL. All exhibit a network texture, subhedral to euhedral crystals, and few inclusions, although the base of the MCL has a slightly higher volume of inclusions compared to the others. The 3D model obtained by high-resolution X-ray computed microtomography (μCT) suggests that the semi-massive chromitite has a "chicken-wire" texture and that the transition to the massive portion is abrupt.

The massive chromitites of the MCL have varied textures, sometimes marked by massive bands of chromite formed by many densely compacted and not well-classified crystals, and sometimes by portions with more dispersed crystals with a subhedral to euhedral tendency associated with olivine/orthopyroxene, mostly serpentinized. From the beginning of the massive part to the middle of the layer, there is an increase in the number of chromite crystals with inclusions and the number of inclusions in each crystal, with some levels having almost all crystals containing multiple inclusions, as is the case with sample 305.67 m. These inclusions vary greatly in distribution and size, ranging from tiny, prismatic, and oriented along crystallographic axes to randomly distributed. Sometimes they are concentrated in the core of the chromite crystals and sometimes at the edges. Oval-shaped inclusions are also common. A more detailed compositional analysis showed a higher frequency of minerals such as orthopyroxene and amphibole (hornblende), with smaller proportions of clinopyroxene and dolomite also identified. Towards the top of the layer, there is a decrease in the number of inclusions in chromite, being very few in sample 307.02 m, which marks the end of the layer.

The presence of hydrated minerals and dolomite in the Monte Alegre Sul segment, further north, justified the interpretation that the assimilation of carbonate rocks could have contributed to the introduction of CO_2 and released water into the magmatic system, causing an increase in oxygen fugacity, which would favor the crystallization of chromite (Friedrich et al., 2019). The findings of hydrated minerals and dolomite also as inclusions in chromite from the MCL of the Ipueira body corroborate this hypothesis.

Friedrich et al., (2019), based on previous studies by Prichard et al., (2015), suggest that chromium supersaturation could explain the presence of abundant inclusions in chromite, as it would favor rapid skeletal crystallization of the crystal, incorporating inclusions in spaces that would later be closed during crystallization. The low presence of inclusions in the semi-massive chromitite layers and at the top of the MCL, contrasting with the abundant volume of inclusions in the middle of the MCL, seems to suggest that, indeed, the peak of crystallization and accumulation occurred during the formation of the more massive portion, possibly reflecting this stage of supersaturation.

The abrupt contact between the semi-massive and massive portions of the MCL, illustrated in Figure 6, and the beginning of the layer marked by compaction texture, suggest a change in the accumulation process. The process seems to have started in situ, with the presence of network texture and possible "chicken-wire" texture, a texture observed in other complexes and used to suggest in situ crystallization (see Latypov et al., 2022), and later was replaced by a more complex accumulation process to generate the massive layer. The presence of clusters of chromite rich in inclusions and others with few inclusions in the same section suggests a mixture of crystals formed under different conditions. Similarly, the abundant volume of inclusions in the middle of the MCL supports the interpretation of a turbulent event with a large presence of volatiles during the formation of this interval. The data obtained here seem to reinforce Friedrich et al., (2019) suggestion that the abundance of volatiles could have favored the slumping of crystals and concentration to form the massive intervals.

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