

**CARACTERIZAÇÃO TECNOLÓGICA DE METAPIROXENITO DA FORMAÇÃO CÓRREGO DOS BOIADEIROS, NOVA LIMA (MG), BRASIL****B. T. FERREIRA<sup>1</sup>, M. M. SANTOS<sup>1</sup>, R. M. F. LIMA<sup>2</sup>, H. BRITO<sup>3</sup>, O.R.D.R. CARMIGANANO<sup>4</sup>**IFMG- Campus de Congonhas<sup>1</sup>, Departamento de Engenharia de Minas-UFOP<sup>2</sup>, Vale S. A.<sup>4</sup>, Pedras Congonhas Extração e Indústria Ltda<sup>4</sup>ORCID ID: <http://orcid.org/000-0002-0326-1797>  
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**RESUMO**

Rochas e minerais industriais são materiais aplicados na produção de uma grande variedade de produtos, usados pela sociedade moderna. Um mesmo mineral ou rocha industrial pode ter diversas aplicações, dependendo de suas propriedades físicas, mineralógicas e químicas. O presente estudo teve como objetivo efetuar a caracterização tecnológica de uma amostra de metapiroxenito, proveniente da formação Córrego dos Boiadeiros, localizado no Quadrilátero Ferrífero, MG (Brasil), visando verificar possíveis aplicações industriais para o mesmo. Fluorescência de raios X foi utilizada para determinar os teores dos seguintes óxidos: 0,06% TiO<sub>2</sub>, 8,2% Fe<sub>2</sub>O<sub>3</sub>, 24,1% MgO, 2,1% Al<sub>2</sub>O<sub>3</sub>, 48,7% SiO<sub>2</sub> e 1,8% CaO. Na caracterização mineralógica por difração de raios

X, microscopia ótica, MEV/EDS e termogravimetria foram identificados os seguintes minerais: antigorita, clorita, cromita, ilmenita, magnetita, rutilo, talco e tremolita. Para os testes preliminares de concentração, o material usado (-147µm) apresentou 32% de partículas na fração -37µm com d<sub>50</sub> igual a 74µm. Para o campo magnético de 3575 Gauss e fração granulométrica -74µm a recuperação em massa foi de 96,4% e alvura igual a 61,9% para o produto não magnético. Embora os ensaios de separação magnética não tenham gerado concentrados enriquecidos em talco, os produtos não magnéticos apresentaram especificações para as seguintes aplicações: papel (papel de parede e embalagem), inseticida e fertilizante.

**PALAVRAS-CHAVE:** Metapiroxenito, Córrego dos Boiadeiros, talco, caracterização tecnológica, alvura.**TECHNOLOGICAL CHARACTERIZATION OF METAPYROXENITE OF THE CÓRREGO DOS BOIADEIROS FORMATION, NOVA LIMA (MG), BRAZIL****ABSTRACT**

Rocks and industrial minerals are raw materials employed in the production of a wide variety of products, used by modern society. The same mineral or industrial rock can have several applications, depending on their physical, mineralogical and chemical characteristics. The present study had as its objective, the technological characterization of a metapyroxenite sample, belonging to the Córrego dos Boiadeiros body in the Quadrilátero Ferrífero, MG (Brazil) in order to verify its possible industrial applications. For this research study, X-ray fluorescence chemical analyzes were performed, which determined the following oxides: 0.06% TiO<sub>2</sub>, 8.2% Fe<sub>2</sub>O<sub>3</sub>, 24.1% MgO, 2.1% Al<sub>2</sub>O<sub>3</sub>, 48.7% SiO<sub>2</sub> and 1.8% CaO. In the mineralogical characterization by X-ray diffraction,

optical microscopy, SEM / EDS and thermogravimetry, the following minerals were identified: antigorite, chlorite, chromite, ilmenite, magnetite, rutile, talc and tremolite. For the preliminary concentration tests, the material used (-147µm) presented 32% of the particles in the fraction -37µm with d<sub>50</sub> in 74µm. The 3575 Gauss magnetic field and the particle size fraction -74µm generated a mass recovery of 96.4% and a whiteness of 61.9% for the non-magnetic product. Although no talc enriched products were generated by preliminary magnetic separation tests, the non-magnetic products presented specifications for the following applications: paper (wallpaper and packing), insecticide and fertilizers.

**KEYWORDS:** Metapyroxenite, Córrego dos Boiadeiros, talc, technological characterization, whiteness.

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## 1 INTRODUCTION

Rocks and industrial minerals are raw materials utilized in the manufacturing of a wide variety of products, used by modern society. Examples are: ornamental rocks (soapstone, granite, slate, quartzite, marble, etc.), aggregates (gravel and sand), cement manufacturing (limestone, sand, clay and gibbsite), mineral filler (paper, cosmetics, polymers, plastic and others), ceramics, refractory, insulation, abrasives and fluxes. The same mineral or industrial rock can have several applications, depending on their physical, mineralogical and chemical characteristics. In Brazil, the extraction and processing of these mineral goods have been performed by small and medium-sized mining companies (Lins, 2008).

In the exploitation of ornamental rocks, about 70% of the material at varied-sized fragments is discarded as residues. Aiming to reduce these losses, studies carried out with residues collected in different quarries proved the feasibility incorporation of up to 40% of those materials in red ceramic (Babiski et al. 2012; Aguiar & Gadioli, 2020). Flotation tests performed with soapstone residues from the Santa Rita region in Ouro Preto-MG followed by concentrate leaching with HCl, produced talc for application as filler in the manufacturing of paper (wallpaper and packing) and plastic (Rodrigues & Lima, 2011, 2012; Garcia et al., 2014).

In the Córrego dos Boiadeiros Formation, located in the central region of the Quadrilátero Ferrífero, near Nova Lima - MG, is the presence of meta-ultramafic rocks (serpentinite, steatite, chlorite tremolite shale and tremolite-serpentine granofels) and metamafics rocks (clinozoisite-actinolite granofels) (Fernandes *et al.*, 2016, 2018). In this region, the serpentinite is extracted for application as fundent in the steel industry. For the use of fines generated in the extraction of this rock, studies were conducted, thus proving the possibility of their use in the soybean crops (Carmignano, 2014). Also, this material has shown to be viable for the composite production through the reaction of the serpentine ( $Mg_3Si_2O_5(OH)_4$ ) with LiOH, which has high CO<sub>2</sub> retention capacity (Vieira *et al.*, 2018). Paz *et al.* (2018) synthesized a new catalytic phase Na<sub>2</sub>Mg<sub>2</sub>Si<sub>2</sub>O<sub>7</sub> by the solid reaction of serpentine with NaOH to be used in the production of biodiesel. In addition to the serpentinite, in this region there is occurrence of metapyroxenite, which contains high talc content, reaching in some regions up to 50%. For this reason, in this research, studies of technological characterization of this rock, aiming at the establishment of routes in talc purification for its application in other industrial segments of greater added value have been accomplished.

## 2 MATERIALS AND METHODS

### 2.1 Materials

For this study, metapyroxenite blocks of approximately 20cm X 40cm dimension were collected at several places in the quarry, Pedras Congonhas Extração Arte Indústria Ltda., located in the municipality of Nova Lima - MG, about 20 km from the BR-040 highway. See the location map in Figure 1.



**Figure 2: Flowchart of the preparation steps carried out with the metapyroxenite sample for characterization studies and magnetic separation.**

As can be seen in Figure 2, after breaking the rock blocks by hand hammer to adequate size for feeding the laboratory jaw crusher, some typical fragments (~5 to 7 cm) were sorted in order to make polished thin sections for qualitative mineral identifications and textural studies of the metapyroxenite rock. The remaining broken rock was crushed by a jaw crusher followed by a roll crusher, both in close circuit with a sieve of 2 mm aperture. After the homogenization step, carried out with the crushed sample (-2 mm), it was split to produce a sample of 2.5 kg. Then, this sample was split in sub-samples of ~200 g, which were size classified by sieves (apertures of 1.76, 1.4 and 0.146 mm) for mineralogical and chemical characterizations. Based on size grains of opaque minerals in textural studies of rock, the remained -2 mm sample was ground by rod mill in closed circuit with a sieve of 147  $\mu\text{m}$  aperture. Afterward, the ground material (-147  $\mu\text{m}$ ) was homogenized/quartered to produce another subsample of 2.5 kg for physical and mineralogical characterization. The remaining -147  $\mu\text{m}$  material was size classified by a sieve of 74  $\mu\text{m}$  aperture in order to produce the following fraction sizes: -147+74  $\mu\text{m}$  and -74 $\mu\text{m}$  that were used in magnetic separation tests, aiming to concentrate the talc.

## 2.2 Methods

### 2.2.1 Mineralogical and Chemical Characterization of the Metapyroxenite Sample

#### 2.2.1.1 Optical microscopy and scanning electron microscopy with dispersive X-ray analysis system

For rock textural studies and identification of translucent mineral phases were performed by the analysis of polished thin sections, observed in transmitted light, using the Leica optical microscope, model DMLP. For the identification of the opaque minerals and confirmation of the minerals identified in transmitted light microscopy, the polished thin sections were metallized with a carbon film and analyzed by scanning electron microscope with an X-ray dispersive analysis system (JEOL Model JSM-6010LA, manufactured by the Analytical Scanning Electron Microscope), operating with a working distance of 10 mm and a voltage of 20 kV.

#### 2.2.1.2 X-ray diffraction and thermogravimetric analysis

The identification of the main mineralogical phases was performed by the X-ray diffractometry - XRD (total powder method). The PANalytical model X'Pert<sup>3</sup> Powder diffractometer equipped with copper tube ( $\lambda = 1.5406 \text{ \AA}$ ) was used. The data parameters for the generation of diffractograms using the X-ray Data Collector software were: scanning angle (ranging from 5° to 90°), voltage of 45 kV and filament current of 40 mA. For the interpretation/identification and semi-quantification of the mineral phases present in the generated diffractograms, the High Score Plus software and Rietveld refinement were used based on the PDF-4 database of the International Centre for Diffraction Data (ICDD).

The thermograms were made by the thermobalance Model TGA Q50 V20.10 Build 36 - Quantachrome Instruments. The test conditions were: heating ramp = 10°C/minute starting from



room temperature to 1000°C; nitrogen flow = 100 mL/min (90 mL/min for sample purging and 10 mL/min for thermobalance cooling). At the end of each test, the loss on ignition (LOI) of the analyzed sub-sample was also determined.

### 2.2.2 Chemical characterization

The chemical analyzes of the sample fractionation products as well as the preliminary concentration test products were accomplished with the Shimadzu X-ray spectrometer model EDX 720 in the Laboratory of Chemical Analyzes of Pedras Congonhas Extração Arte Indústria Ltda. For this purpose, pressed pellets of the samples were prepared and the calibration curves were used to determine the following contents: Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, MgO, TiO<sub>2</sub>, CaO, SiO<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub>.

### 2.2.3 Physical characterization of the sample used in magnetic separation tests

The size distribution of the sample used in the magnetic separation tests (-147 µm) was determined by combined (wet and dry) sieving (147 to 37 µm). Afterward, an aliquot of the size fraction -37µm was dispersed in 250mL of 0.1% wt/v solution of sodium hexametaphosphate and submitted to ultrasound for 1 minute to be analyzed by laser size analyzer-Cilas model 1064.

### 2.2.4 Determination of whiteness

The whiteness of the feed and magnetic concentration test products were determined by the Color Touch CTP - ISO spectrometer of the Technidyne Corporation, following the International Organization for Standardization (ISO) scale.

The experimental procedure was constituted by confection of the pellet samples (100g) previously ground in an orbital mill (tungsten pan) for 1 minute. The pulverized sample was then homogenized and quartered for removal of a 10 g aliquot which was oven dried for 1 hour at a temperature of 100 °C. Subsequently, this material was introduced into the sample port and pressed at a pressure of approximately 80 psi. Then, the pellet was removed and introduced into the spectrometer and three readings were performed. The final whiteness result was determined by the arithmetic mean of the three readings performed.

### 2.2.5 Preliminary Magnetic Concentration Tests

The magnetic separator Carpco Inc. model WHIMS 3x4L - series 210-97 was used in preliminary concentration trials. Factorial planning design of replicate experiments (2<sup>2</sup>) using Minitab 17 software was used. Based on opaque minerals grain sizes and aiming to access the efficiency of magnetic separation for finer particles (-74 µm), the investigated factors were: sample granulometry (-147 +74µm and -74µm) and magnetic field (3575 Gauss and 5465 Gauss). The variable responses analyzed were: mass recovery and whiteness of the concentrate obtained.

In each of the magnetic separation tests, first, the matrix (basket filled with 6 mm diameter steel balls) was inserted between the magnetic coils of the equipment. Subsequently, the magnetic

field intensity was adjusted to the desired value (3575 Gauss and 5465 Gauss). The pulp with 10% solid was inserted into the apparatus, followed by washing water opening to remove the non-magnetic particles, which were collected in a non-magnetic product bucket. Removal of the magnetic product (particles retained in the matrix) was enacted in another pail after the equipment was shut down. Finally, the non-magnetic ("purified talc") and magnetic products were filtered, dried, weighed, homogenized and quartered to take aliquots for the determination of whiteness and chemical analyzes.

### 3 RESULTS AND DISCUSSION

#### 3.1 Mineralogical characterization

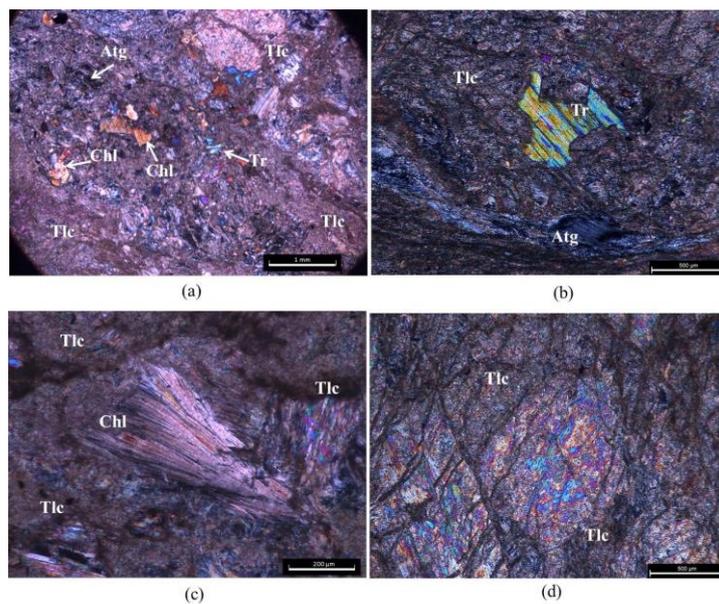
In Figures 3 and 4, optical microscope photomicrographs are presented, evidencing characteristic features and translucent minerals identified in the metapyroxenite sample studied.

Figure 3 (a) the antigorite (Atg), tremolite (Tr) and chlorite (Chl) minerals are observed, which give a porphyroblast unequigranular texture, with a fine-grained talc matrix. Figure 3 (b) shows anhedral antigorite grains (Atg) with elongated shape, basal cleavage and lamellar habit, subhedral tremolite grains (Tr) in blade forms with perfect basal cleavage in one direction and moderate relief, both inserted in a talc matrix (Tlc). Figure 3 (c) shows the chlorite mineral (Chl) with an elongated form in talc (Tlc) matrix. In Figure 3 (d), the eye bird microtexture of the talc (Tlc) is observed.

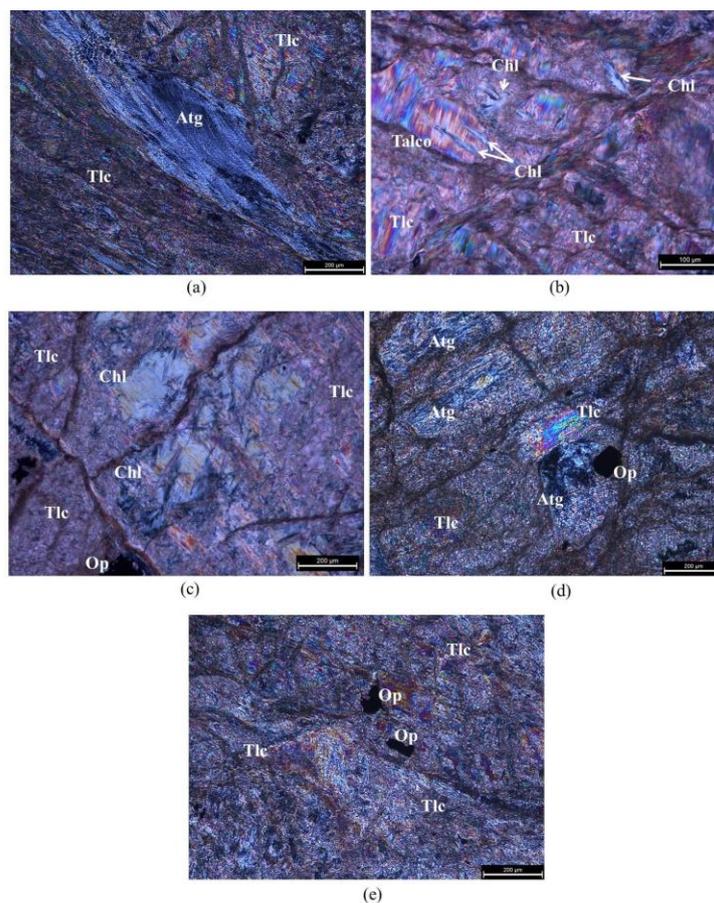
Figure 4 (a) shows the antigorite mineral (Atg) with an elongated shape and lamellar habit in talc (Tlc) matrix. In Figs. 4 (b) and 4 (c), chlorite grains are found in the talc matrix, showing medium to high relief, perfect basal cleavage and lamellar habit. Chlorite grains (Chl) are grouped in an oriented way, giving the lepidoblast rock texture. In Figures 4 (d) and 4 (e), the presence of opaque grains in talc and antigorite matrix (Atg) with small size is noticed. As can be seeing, opaque minerals (probably metal oxides) have dimensions that are less than 0.100 mm. However, in order to release these minerals, the rock must be ground at -147  $\mu\text{m}$  for further talc concentration step.

Confirmation of translucent minerals identified in optical microscopy, presented in Figure 3 and the identification of opaque minerals (Figure 4), are presented in Figure 5. In Figures 5 (a, b and c), backscattered electron images are shown, containing the points marked for chemical analysis by EDS, the results of which are presented in the respective tables, located at the bottom of the figures. Based on these results, the following minerals were identified: tremolite, antigorite, talc, chromite, magnetite and ilmenite. It should be noted that the talc present in metapyroxenite has an approximate content of 3.8% FeO. Intergrowths of magnetite with chromite and ilmenite are also observed (Figure 5 (a) and (b)).

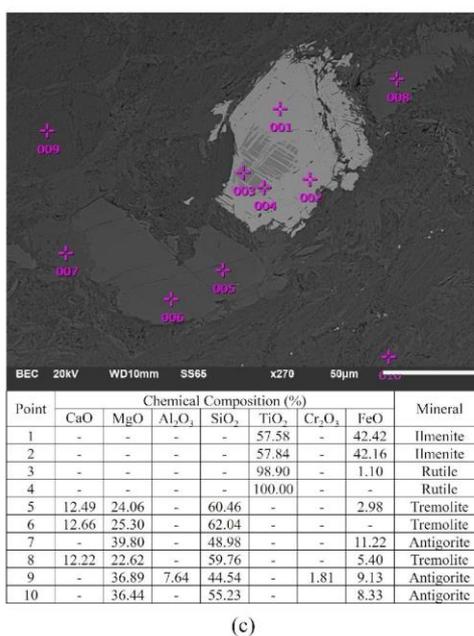
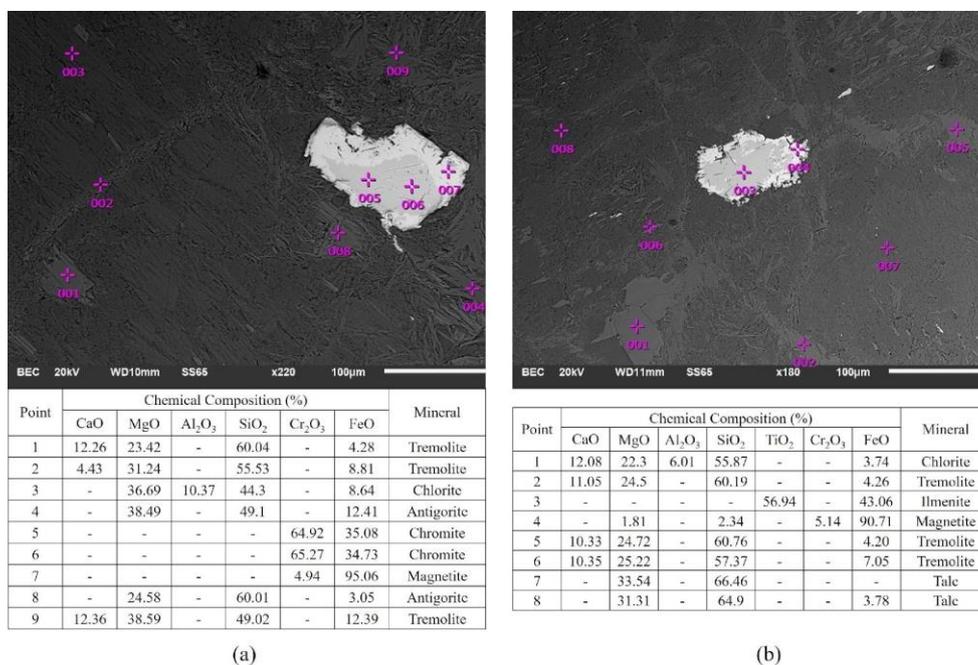
The main minerals identified by X-ray diffraction of the studied metapyroxenite sample were (Figure 6): talc, tremolite, chlorite, and antigorite. The non-identification of the opaque minerals observed in the optical microscopy and identified by SEM/EDS (magnetite, ilmenite, rutile and chromite) may be related to their small proportion in the sample, which may be below the detection limit of the X-ray diffraction technique.



**Figure 3: Characteristic photomicrographs of metapyroxenite rock (in transmitted light), showing talc matrix (Tlc), containing antigorite (Atg), tremolite (Tr) and chlorite (Chl) grains observed with crossed polarizers. (a) 2.5x objective lens, (b) and (d) 5x objective lens, (c) 10x objective lens.**



**Figure 4: Typical photomicrographs metaproxenite rock (in transmitted light), showing talc matrix (Tlc), containing antigorite grains (Atg), tremolite (Tr), chlorite (Chl) and opaque minerals (Op) observed with crossed polarizers. 10x objective lens (a, c, d and e) and 20X objective lens (b).**

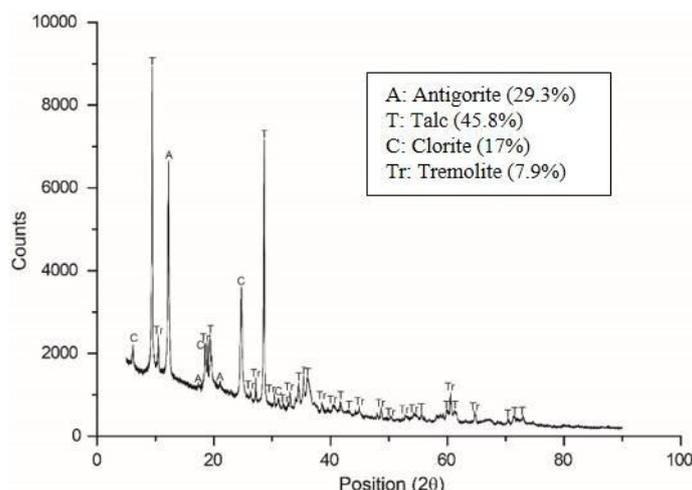


**Figure 5: Photomicrography of backscattered electrons and chemical analysis by EDS showing intergrowths of magnetite with chromite in antigorite and tremolite matrix (a) and magnetite with ilmenite in talc and tremolite matrix (b). In (c) a grain of ilmenite and rutile intergrowing is identified.**

In Table 1, the mineralogical semi-quantification by size fraction and of the global metaproxenite sample have been presented. As can be seeing the coarse fraction (-1.76+1.4 mm)

is enriched with talc and poorer in tremolite. The global sample is constituted by 45.8% talc that is predominating in all size fractions of the sample (Table 1). Like talc, the antigorite predominates and corresponds to 29.3% of the mineralogical assembly of metapyroxenite. Moreover, chlorite and tremolite constitute it with 17.0% and 7.9%, respectively.

**Figure 6: Diffractogram sample used in the identifying the phases: Talc (T), (C) and Tremolite (T).**



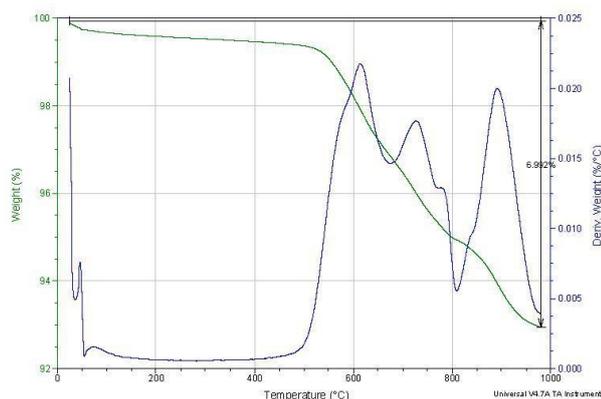
**of the metapyroxenite magnetic separation, following mineral Antigorite (A), Chlorite**

**Table 1: Mineralogical the metapyroxenite identified by X-ray**

**semi-quantification of sample (main minerals diffraction – Rietveld)**

		Mineral (%)			
Size fraction (mm)	Wt (%)	Talc	Antigorite	Chlorite	Tremolite
		$Mg_3Si_4O_{10}(OH)_2$	$(Mg,Fe^{2+})_3Si_2O_5(OH)_4$	$(Mg,Al,Fe)_{12}[(Si,Al)_8O_{20}](OH)_{16}$	$Ca_2Mg_5Si_8O_{22}(OH)_2$
-1.76+1.4	37.0	51.0	25.4	21.3	2.3
-1.4 +0.417	34.6	43.4	32.2	14.0	10.4
-0.417	28.4	41.9	30.9	15.1	12.0
Global	100.0	45.8	29.3	17.0	7.9

In Figure 7, the thermogram of the global metapyroxenite sample is shown. In the first region of the thermogram, peaks between 45°C and 100°C were observed, corresponding to the elimination of the water absorbed physically by the samples at room temperature. The two distinct decomposition regions identified in the thermogram shown in Figure 7 (550°C to 650°C and 550°C to 810 °C) are related to the decomposition of chlorites with brucite and mica type layers (Piga *et al.*,1992), respectively. Between 540 °C and 810 °C, the chlorite may undergo changes to the enstatite, spinel and forsterite phases. It is possible that decomposition of serpentine (antigorite) to olivine, occurring at temperatures close to 600°C (Deer *et al.*, 1992; Piga *et al.*, 1992). In the third region, the interval between 810°C and 1000°C indicates the decomposition of talc in enstatite and cristobalite, as well as the formation of diopside and talc through the tremolite, according to studies by Deer *et al.*, (1992) and Piga *et al.*, (1992). As can be seeing, the thermal decomposition of sample corroborate with the results of XRD, previously presented.



**Figure 7: Thermogram of the metapyroxenite sample used in magnetic separation tests.**

### 3.2 Chemical characterization

In Table 2, the size by size chemical composition and loss on ignition of the metapyroxenite studied sample are presented. As it has been observed, the three size fractions analyzed had an approximate average content of 26% of MgO, 9% of Fe<sub>2</sub>O<sub>3</sub>, 2% of Al<sub>2</sub>O<sub>3</sub>, 2% of CaO and 53% of SiO<sub>2</sub>. The high SiO<sub>2</sub> value corroborates with the results of X-ray diffraction and indicates the predominance of silicate minerals (talc, tremolite, antigorite and chlorite) in the rock. The CaO is related to the presence of the tremolite in the rock. The low percentage of TiO<sub>2</sub> (0.05%) and Cr<sub>2</sub>O<sub>3</sub> (0.6%) is consistent with the presence of trace minerals that have such oxides in their chemical formulas (chromite, ilmenite, aluminochromite and rutile) that were identified by MEV/EDS.

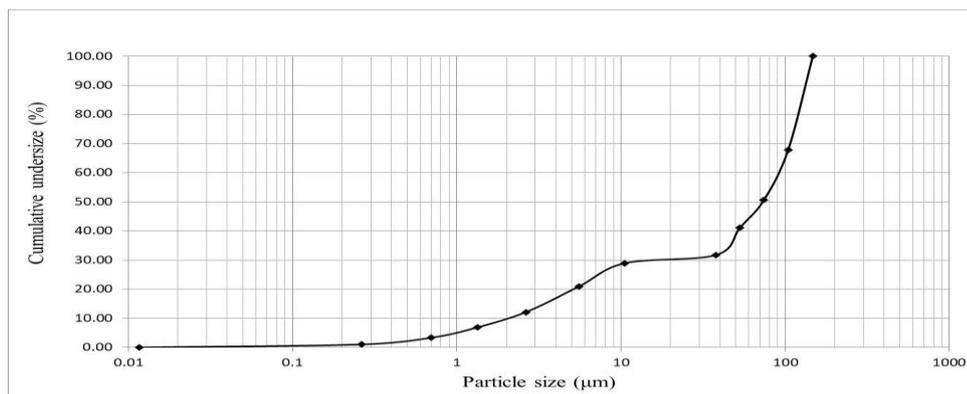
**Table 2: Size by size chemical composition and loss on ignition of the metapyroxenite of the Córrego dos Boiadeiros**

Fraction size (mm)	Weight (%)	Grade (%)							
		TiO <sub>2</sub>	Cr <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	CaO	LOI
-1.76+1.4	37.0	0.051	0.580	8.913	25.892	2.266	53.102	2.029	6.940
-1.4+0.417	34.6	0.055	0.0585	8.850	26.286	2.261	52.857	1.891	6.990
-0.417	28.4	0.072	0.591	9.014	26.227	2.385	52.522	1.986	6.970
<b>Total</b>	<b>100.0</b>	<b>0.059</b>	<b>0.585</b>	<b>8.920</b>	<b>26.123</b>	<b>2.298</b>	<b>52.853</b>	<b>1.969</b>	<b>6.966</b>

The grade of CaO in fraction size -1.76+1.4 mm is not coherent with the content of chlorite determined by XRD-Rietveld refinement. Probably, both chlorite [(Mg,Al,Fe)<sub>12</sub>[(Si,Al)<sub>8</sub>O<sub>20</sub>](OH)<sub>16</sub>] and antigorite [(Mg,Fe<sup>2+</sup>)<sub>3</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>] could be overestimated, since the λ<sub>CuKα</sub> = 1.5406 Å causes Fe fluorescence, which is present in their crystalline structures. The others mineral also could be a little underestimated (Martins et al., 2019).

### 3.3 Size distribution of metapyroxenite used in magnetic separation

In Figure 8, the size distribution of the sample used in the magnetic concentration test is presented. It is observed that approximately 32% of the particles are -37 μm and 50% -74 μm.



**Figure 8: Particle size distribution of the sample metaproxenite (-147 μm) used in the magnetic separation tests.**

### 3.4 Preliminary talc concentration tests

In Table 3, the results of the magnetic separation tests, performed with the metaproxenite sample, are presented.

**Table 3: Raw results of the non-magnetic product of metaproxenite sample – talc concentration**

Test	Factors		Variables responses		Chemical Composition (%)				
	A	B	Mass recovery (%)	Whitness (ISO)	SiO <sub>2</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	Cr <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>
1	-74	5465	93.1	62.7	56.111	27.869	9.904	0.769	0.061
2	+74	3575	92.6	63.1	55.646	27.955	9.936	0.775	0.057
3	-74	3575	94.9	62.1	56.300	27.661	9.907	0.768	0.060
4	+74	5465	92.3	61.1	54.960	27.373	9.929	0.776	0.057
5	-74	3575	96.4	61.9	55.726	27.499	9.867	0.755	0.068
6	-74	5465	93.8	62.0	56.267	27.878	9.910	0.770	0.059
7	+74	3575	93.4	61.7	55.111	27.887	9.930	0.776	0.059
8	+74	5465	92.0	62.7	55.147	27.896	9.933	0.777	0.055

*R<sup>2</sup> = Model fit = 88.51%*

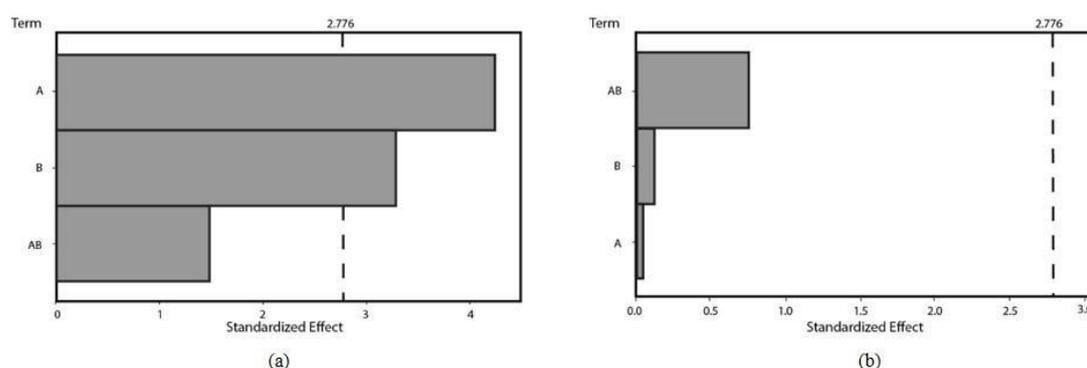
A: Size fraction (μm); B: Magnetic field intensity (Gauss)

It is observed in Table 3, that the mass recovery of the magnetic concentration tests ranged from 92 to 96.4% and the whitness values of the non-magnetic product ranged from 61.1 to 63.1%. This means an increase of 1.1 to 3.1% compared to the whitness (60%) of the feed sample. These results are coherent with the constancy of the Fe<sub>2</sub>O<sub>3</sub> contents of the non-magnetic products



analyzed in regards to feed samples  $-147\mu\text{m} + 74\mu\text{m}$  (9.932% of  $\text{Fe}_2\text{O}_3$ ) and  $-74\mu\text{m}$  (9.918% of  $\text{Fe}_2\text{O}_3$ ). As the grain sizes of oxide minerals identified (magnetite, chromite, ilmenite and rutile) are  $< 0.100$  mm, the low efficiency of the preliminary magnetic concentration tests, it is probably related to the Fe in chemical composition of silicate minerals: talc, antigorite, chlorite and tremolite, as can be observed in SEM/EDS analyzes.

In Figure 9, the Pareto graphs for the granulometry (A) and magnetic field (B) factors are presented on the mass recovery (Figure 9(a)) and whiteness (Figure 9(b)) of the obtained concentrates. It is observed that there is an individual effect of granulometry and magnetic field only for mass recovery. None of the factors at the levels investigated were significant for the whiteness of the non-magnetic material. This may have occurred due to the presence of the antigorite and chlorite as soon as talc minerals, which contain Fe in their chemical formulas in the analyzed samples. The use of a higher magnetic field, above 5465 Gauss, associated with a coarser granulometry ( $+74\mu\text{m}$ ) could be tested. However, exploratory mineralogical studies of both magnetic and non-magnetic products have to be done in order to evaluate the selectivity separation of talc from the gangue minerals.



**Figure 9: Pareto graphs showing the effects of the coded factors granulometry (A) and magnetic field (B) on the mass recovery (a) and whiteness (b) of non-magnetic products.**

From the surface graph of the mass recovery as a function of the granulometry and magnetic field (Figure 10), it becomes evident that finer granulometries and lower magnetic field increased the mass recovery. The parameters that provided the greatest mass recovery were: particle size  $-74\mu\text{m}$  and magnetic field equivalent to 3575 Gauss, which provided a mass recovery equivalent to 96.4%.

The industrial sectors of insecticides and fertilizers do not require minimum values of whiteness and other specifications for the talc, so it can be concluded that the non-magnetic products of magnetic separation can be used in these two sectors, provided they present 99% of the particles smaller than  $44\mu\text{m}$  for the first and without granulometric restriction for the second. In addition, it can be used as filler for wallpaper and packing (Rodrigues & Lima, 2011, 2012).

## 4 CONCLUSIONS

The studies performed with the metapyroxenite of the *Córrego dos Boiadeiros* Formation indicated global contents equivalent to 0.06% of  $\text{TiO}_2$ , 8.2% of  $\text{Fe}_2\text{O}_3$ , 24.1% of  $\text{MgO}$ , 2.1% of  $\text{Al}_2\text{O}_3$ ,

48.7% of SiO<sub>2</sub>, 1.8% of CaO, as well as a loss on ignition (LOI) of approximately 7%. The mineralogical characterization of the material provided the identification and proportion of the following mineral phases: talc (45.8%), antigorite (29.3%), chlorite (17%), tremolite (7.9%) and approximately 0.1% of metallic oxides (ilmenite, chromite, aluminochromite, magnetite and rutile). In the magnetic separation, the granulometry and magnetic field factors were only significant for the mass recovery response variable. The 3575 Gauss magnetic field and the particle size fraction -74µm generated a mass recovery of 96.4% and a whiteness of 61.9% for the non-magnetic product, corresponding to an increase of up to 3.1% when compared to the whiteness of the feed. Although the products of the preliminary tests of magnetic concentration were not enriched with talc, the generated products can be applied in the industries of paper (filler), insecticide and fertilizer.

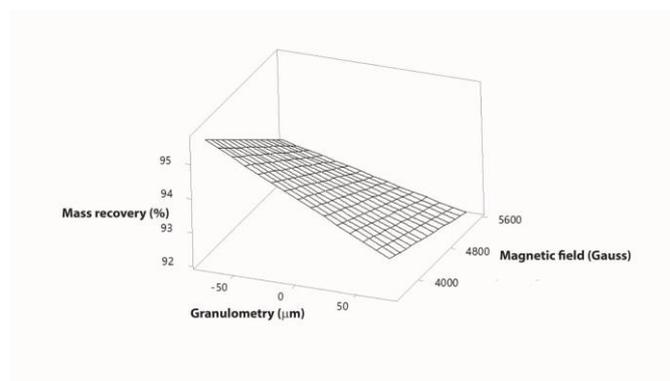


Figure 10: Surface chart of mass recovery versus magnetic field, granulometry of magnetic separation.

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