

The examples documented above were all originally identified by detection of low concentrations of P in the automated chemical typing routine, although phosphate was not identified in most of the P reportings. There are three possibilities for this situation. First, the phosphate is just below the surface of the grain yet still within the volume generating x-rays. Since the entire grain is scanned, we cannot easily determine exactly where the phosphate particle is. The second possibility is that the phosphate phase is too small or too finely disseminated to be easily seen. It is also possible that the 1% phosphate represents spectral noise, although some apatite was located in particles with a 1% phosphate total.

This method has been successfully used to identify iron phosphate and REE (rare earth) phosphates in other samples. Unlike the samples described above in which the phosphate appears dark relative to the iron oxide, these phosphates appear similar to iron oxide in a BEI. Particles examined using the chemical typing routine will indicate iron or REEs, phosphorus, and no calcium as major constituents. Detailed examination of those particles using secondary imaging and quantitative analysis as described above are used to document the phase.

THE INFLUENCE OF MINERAL CHARACTERISTICS AND DISTRIBUTION ON MINERAL PROCESSING OF THE ANITÁPOLIS, BRAZIL, ELUVIAL PHOSPHATE ORE.

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Abstract

The Anitápolis alkaline massif in southern Brazil underlies a sub circular area of 6 km². Bore-hole data show a concentric rock distribution, with mafic rocks in the central part and felsic rocks in the border zone. The rocks are covered by talus and weathered material, 30 m thick on average, and very inhomogeneous in composition. Phosphate mineralization associated mainly with two levels of the weathering mantle and with fresh rocks. A preliminary ore-type classification was based on distribution of apatite, feldspar, vermiculite, biotite-phlogopite, calcite, pyroxene, amphibole and analcime, determined by semiquantitative diffraction method. Technological tests performed on eluvial ore samples from three adits resulted in a subdivision of ore-types based on the difference in behavior due to mineral characteristics during mineral processing.

Introduction

Systematic mineralogical studies carried out during geological exploration and mineral processing development can give very useful guidelines to mine exploitation.

The main rock types of the Anitápolis alkaline massif in Santa Catarina State, southern Brazil, show a concentric distribution and can be grouped into several "series" (Figure 1). Syenite and nepheline-syenite series are found as border varieties, while the ijolite and ultramafic series are centrally located. Sovite veins, although ubiquitous, are concentrated mainly in the central part of the intrusion (1).

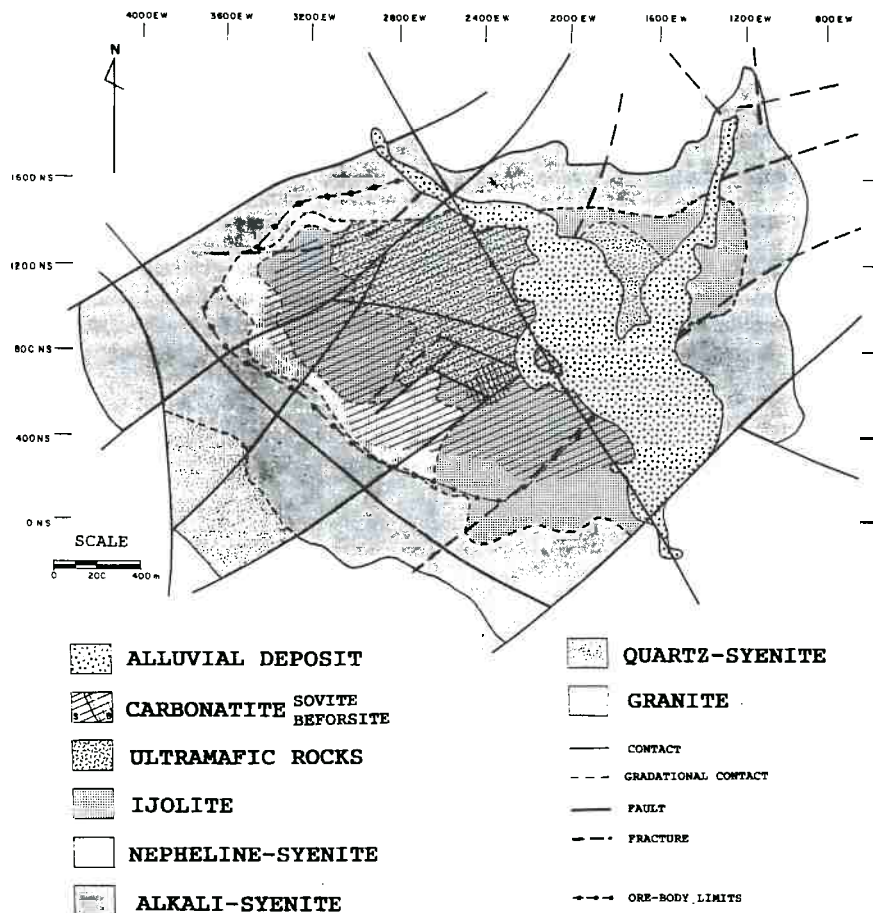


Figure 1 - Geological Map of the Anitápolis Alkaline Massif

Three levels in a semi-mature soil profile, with an average thickness of 30 m, were identified. they are constituted by one talus deposit and two subjacent saprolitic levels.

A talus deposit, up to 20 m thick, which is constituted predominantly of blocks of alkaline and granitic host rocks in a silty-argillaceous matrix, forms the uppermost layer. The main minerals in this layer are feldspars, goethite, vermiculite and/or smectite and kaolinite, some quartz derived from host rocks, supergenic phosphates and magnetite. Apatite associated with amphiboles and pyroxenes occurs only in a basal talus level, called the "A" horizon.

The next level is the "B" horizon, composed of weathered alkaline rocks, with an average thickness of 10m. The main minerals are feldspars, vermiculite, iron oxides and hydroxides, several clay minerals, apatite and pyroxenes, with subordinate amphiboles and magnetite.

The lowermost "C" horizon is poorly developed and lies directly on the fresh rocks; it shows only incipient weathering. The mineralogy is very similar to that of the underlying rock. Calcite, if present, has not been leached out completely and biotite-phlogopite is partially transformed into vermiculite.

The phosphate mineralization is associated with the eluvial overburden, which has an average P_2O_5 grade of 8.2%, and also with fresh rock, which have been investigated at a depth of 100 m, with an average P_2O_5 grade of 5.9%.

Apatite from low grade igneous ores is normally concentrated by anionic flotation, a process highly influenced by the liberation of apatite and superficial coatings by iron oxides-hydroxides, behavior of the apatite in the comminution and desliming operations, and the nature of the gangue minerals (2). The presence of minerals containing iron and alkaline-earths, such as carbonates, barite, phlogopite, vermiculite, amphiboles, etc., can, in fact, interfere in the process, as these minerals reduce the flotation selectivity of the apatite and/or may be incorporated in the concentrate as minor constituents.

Consequently, all the mineralogical studies performed were directed to the afore mentioned parameters, with emphasis on the characteristics of apatite grains and mineralogical composition and distribution of gangue minerals.

Methodology

Semiquantitative X-ray Diffraction Analysis

To recognize the mineralogical variations in the ore-body, a program of semiquantitative X-ray diffraction analysis was developed specifically for the project. The content of each mineral was correlated with its selected diffraction peak intensity according equation 1, using gibbsite as an internal standard (3). In this equation, W_i = percentage of mineral i in weight, I_i = diffraction peak intensity of mineral i , I_s = standard diffraction peak intensity, a = linear coefficient and c = a constant.

$$W_i = a * (I_i / I_s) + c \quad (1)$$

To establish calibration curves, the mineralogical composition in standard samples was determined by modal analysis, supported and checked by mineral separation techniques and chemical analysis. The addition of pure mineral concentrates, prepared from samples of the same ore-body, was also used to extend the mineral range.

Diffraction peak intensities on the grain size and the adopted comminution process were reported (4, 5). Pulverization tests in a Herzog HSM 100H vibrating mill were made to determine the best conditions to obtain a good resolution, avoiding preferential orientation. The final grain size was minus 0.074 mm with 50% in weight under 0.01 mm.

The complex mineralogical assemblage, as well as some interferences between diffraction patterns and compositional variability in some groups of minerals, like feldspars, amphiboles, and pyroxenes, led to the selection of low to medium intensity diffraction peaks for some minerals instead of major peaks, with some loss of resolution. Deconvolution analysis of overlap peaks was not made. Table I shows the selected peaks and the mean deviation for calibration curves of each mineral.

Table I - Selected Peaks and Mean Deviation for Calibration Curves

| Mineral | Grade range (%) | Mean deviation (%) | Intensity (I/I_{100}) | Peak measur. | d (Angs.) |
|--------------|-----------------|--------------------|---------------------------|--------------|-------------|
| apatite | 2 - 60 | 8.3 | 70; 100 | area | 2.77 + 2.80 |
| calcite | 2 - 30 | 12.1 | 100 | high | 3.03 |
| biot.-phlog. | 2 - 60 | 12.1 | 100 | area | 10.0 |
| magnetite | 3 - 60 | 12.4 | 40 | area | 1.48 |
| feldspars | 5 - 60 | 21.8 | 80 | area | 3.78 |
| | 10 - 60 | 17.2 | 70 | area | 4.22 |
| quartz | 5 - 55 | 8.7 | 17 | area | 1.82 |
| pyroxenes | 5 - 80 | 14.3 | 100 | high | 2.98 |
| amphiboles | 3 - 30 | 18.6 | 100 | area | 8.4 |
| analcime | 3 - 30 | 16.1 | 100 | area | 5.6 |

The mean deviation of about 15% for standard calibration curves was considered adequate to detect the major mineralogical variations in the ore-body that can interfere in the flotation process. Vermiculite, the most important clay mineral (> 90%), shows a drastic decrease of the diffraction peak intensity during the grinding process and can not be quantified by this method with the adopted pulverization conditions. Its content was estimated by difference from 100%. The vermiculite proportions obtained by difference show a good correlation with other mineralogical analysis performed later (1).

Applied Mineralogy Studies

Mineralogical studies were made on ore samples and pilot plant products to determine mineral compositions, liberation degree of apatite, surface coatings on apatite grains, slimes content and other parameters of particular interest to the mineral processing.

The ore samples were processed experimentally to obtain data to be correlated with industrial or pilot plant results. The preparation included crushing and milling, followed by desliming in a wet sieve screen (0.037 mm). The screen oversize and pilot plant products were submitted to mineral separation techniques with heavy liquids and a Frantz isodynamic separator, followed by microscopic, X-ray diffraction, and chemical analysis.

Mineralogical Distribution

Apatite shows a wide distribution (Figure 2). Enrichment is observed in the north-western portion of the deposit, associated with a greater thickness of the weathered mantle (40 m to 50 m) and with the presence of supergenic phosphates (goyazite and/or gorceixite and/or amorphous phosphates). Lower grades are found at border regions and in a south-eastern portion of the deposit, where a small brecciated beforite plug occurs.

The feldspar (orthoclase, microcline and albite) distribution in the eluvial ore (Figure 3) is closely related to the composition of underlying rocks. The same occurs with the pyroxenes and vermiculite (biotite-phlogopite). Additional feldspar enrichment also occurs in the talus fans of the south-western portion of the deposit.

Vermiculite, usually interlayered with hydrobiotite, is the most abundant clay mineral, with concentrations up to 50% or more (Figure 4). Kaolinite, chlorite and illite occur locally and are included with the vermiculite. Amphiboles, usually less than 10%, occur mainly in an E-W elongated portion in the northern area of the deposit. Two varieties are found, namely a sodic amphibole, eckermannite-arfvedsonite, and a calcic amphibole, tremolite-actinolite.

Pyroxenes, represented by intermediate varieties between diopside-augite and aegirine, show a wide distribution (Figure 5), up to more than 30%. Pyroxenes are absent only in a small south-eastern area, where phoscorite veins and the brecciated beforite plug occur. Calcite, the main carbonate mineral, usually represents less than 20% of the mineral content, while dolomite grades are still lower, about one tenth that of calcite.

Magnetite is a common accessory mineral in the residual ore-body, representing less than 10% by mass. Analcime and nepheline show restricted distributions.

Preliminary Ore Types

A preliminary ore typology (Table II) was based only on the mineralogical distributions of the main iron-magnesium silicates, because the different mineralogical compositions are related to a distinct behaviour in the flotation process. The different layers of the eluvial ore-body were not considered at this stage.

This preliminary typology, with six different classes of ores, avoids the possible interferences of vermiculite and pyroxenes in the flotation process, while the other factors related to the local presence of amphiboles and carbonates in the ore-body, could be controlled theoretically by ore blending.

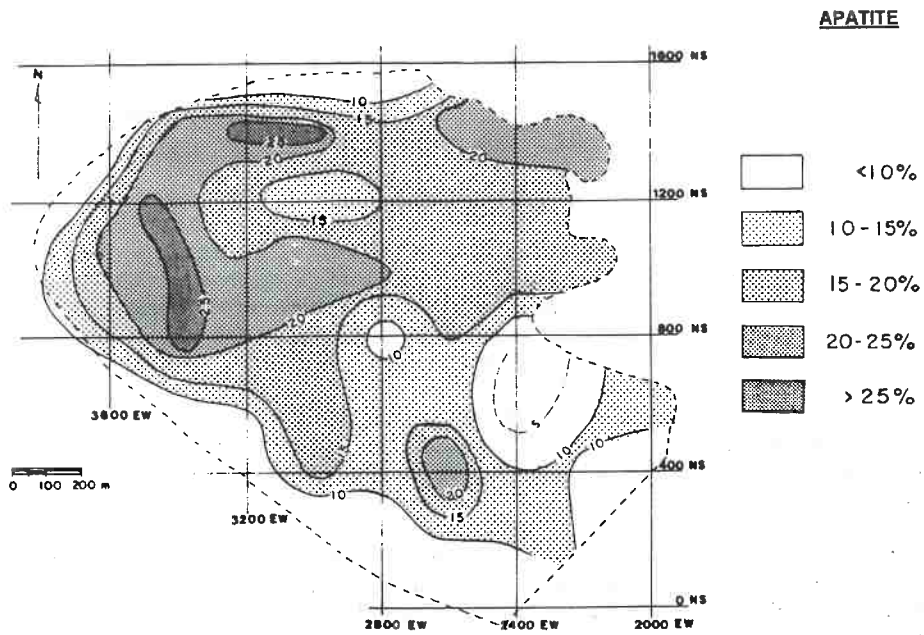


Figure 2 - Apatite Distribution

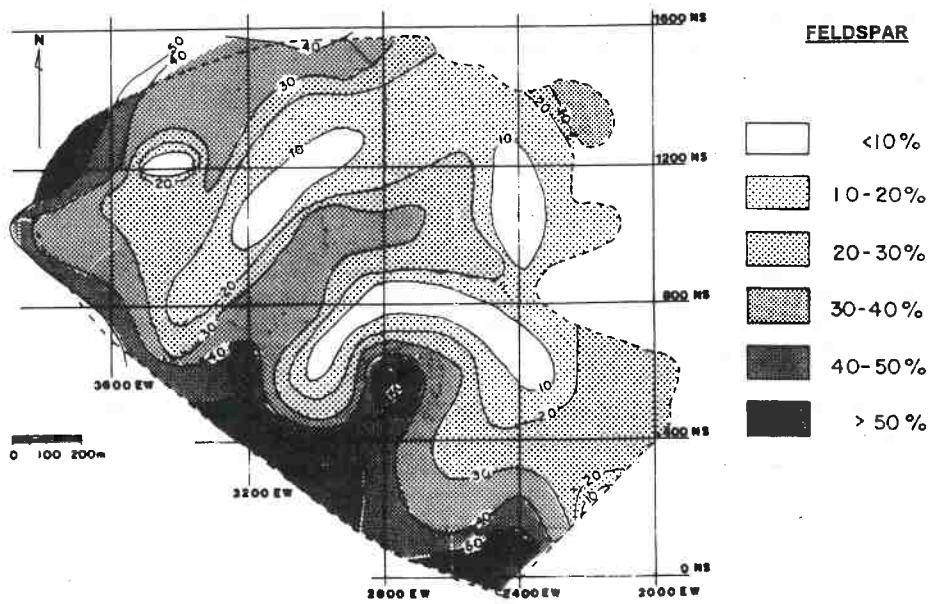


Figure 3 - Feldspar Distribution
322

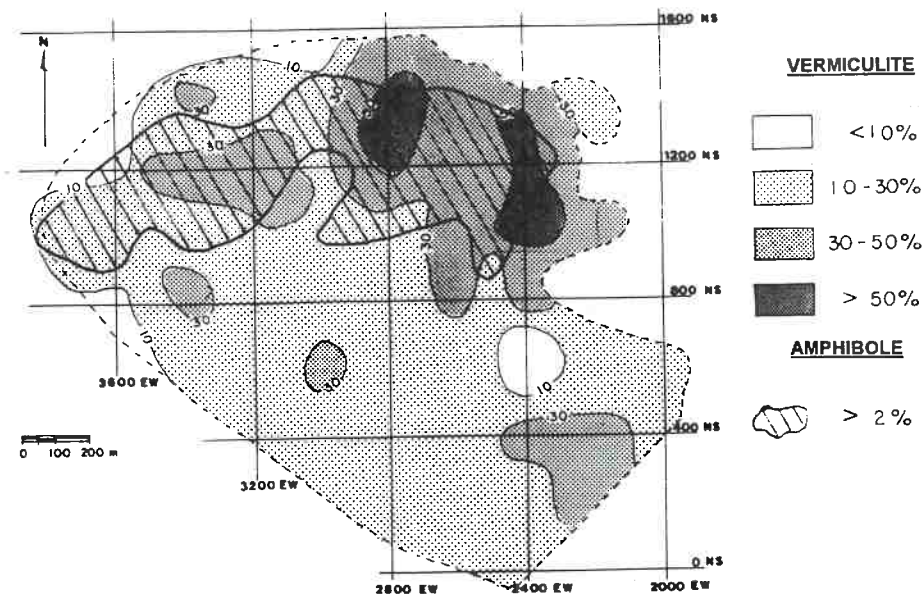


Figure 4 - Vermiculite and Amphibole Distribution

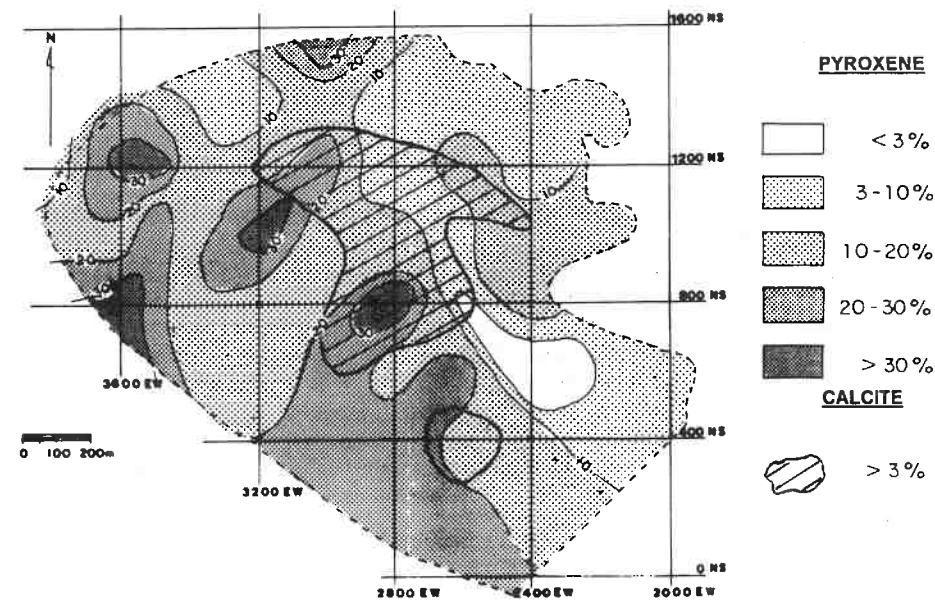


Figure 5 - Pyroxene and Calcite Distribution
323

Table II - Preliminary Typology

| Ore Type or Class | Minerals (%) | | Percentage of ore type in the ore body |
|----------------------|--------------|-------------|---|
| | pyroxene | vermiculite | |
| 1 | < 30 | < 30 | 64 |
| 2 | > 30 | < 30 | 3 |
| 3 | < 30 | 30 to 50 | 27 |
| 4 | > 30 | 30 to 50 | traces |
| 5 | < 30 | > 50 | 5 |
| 6 | > 30 | > 50 | nil |

Although localized compositional variations were detected, the eluvial ore-body is basically composed of two types of material, the most abundant, class "1", being mainly feldspathic with a few iron-magnesium silicates, and the other one, class "3" with higher amounts of vermiculite, class "3". Types with higher contents of pyroxenes, classes "2" and "4", are poorly represented in the ore-body.

Technological Studies

Based on borehole descriptions and preliminary typology four galleries were located and sampled for applied mineralogical studies:

- gallery GJH: eluvial ore with a high vermiculite content (54%) and a low amphiboles content (9%);
- gallery GWM: eluvial ore with a high pyroxene content (24%) and medium proportions of vermiculite and amphiboles;
- gallery GGM: eluvial ore with a high feldspar content (40%) and low proportions of vermiculite (24%) and pyroxenes (5%);
- gallery GVV: low depth eluvial material basically composed of talus with a high content of supergenic minerals.

Pilot plant tests were made with samples from three of them - GJH, GWM and GGM.

Mineralogical Studies

Sixteen samples of the main preliminary ore types were obtained for detailed mineralogical studies. The main characteristics of these samples are summarized in Table III.

Table III - Main Characteristics of Ore Samples

| | range (%) | average (%) |
|---|-------------|-------------|
| apatite | 6 to 49 | 21 |
| feldspar | < 0.5 to 70 | 16 |
| vermiculite | 10 to 75 | 40 |
| pyroxene | 2 to 40 | 12 |
| amphiboles | < 0.5 to 9 | 3 |
| magnetite | < 0.5 to 5 | 2 |
| others (a) | < 0.5 to 24 | 4 |
| liberation degree of apatite (b) | 77 to 97 | 89 |
| surface coating of apatite | < 10 to 40 | < 15 |
| slimes (-0.037 mm) | 17 to 30 | 24 |
| loss of P ₂ O ₅ in the slimes | 8 to 19 | 12 |

- (a) other clay minerals and supergenic phosphates
(b) ore grinded to minus 0.3 mm

Behaviour of the Eluvial Ore in Pilot Plant Tests

The results of the pilot plant tests are summarized in Table IV. The total recovery of P₂O₅ ranges between 72% and 79%. Slimes represent 20% to 30% in weight and contain 15% to 20% of the overall total phosphorus.

Table IV - Concentrate Grades and P₂O₅ Recovery in Pilot Tests

| Sample (gallery) | Concentrate Grades (%) | | | | SiO ₂ | % P ₂ O ₅ Recovery |
|---------------------|-------------------------------|--------------------------------|--------------------------------|------|------------------|---|
| | P ₂ O ₅ | Fe ₂ O ₃ | Al ₂ O ₃ | MgO | | |
| GGM | 41.0 | 0.40 | 0.32 | 0.15 | 3.61 | 78.5 |
| GJH | 36.9 | 1.46 | 0.13 | 1.22 | NA | 78.8 |
| GWM | 37.8 | 1.19 | 0.75 | 1.07 | 6.24 | 71.5 |

NA - not available

Carbonates, magnesium-rich vermiculite and iron hydroxides tend to follow apatite in froth flotation, particularly below 0.074 mm. Calcic amphibole tends to float with apatite in all granulometric sizes, leading 20% to 60% of them to the concentrates. Small amounts of carbonates, below 2% to 3%, do not interfere noticeably in flotation of apatite.

The excellent behaviour of the GGM gallery ore in the flotation tests, with a recovery of phosphate around 95% and high grades of concentrate, is explained by the absence or minor presence of deleterious minerals - no carbonates, traces of amphiboles and highly altered vermiculite poor in magnesium.

Technological Ore Types

Systematic mineralogical studies carried out during geological exploration and the development of mineral processes led to the identification of the ore parameters which interfere in the process. These interferences in the Anitapolis eluvial ore are related to the presence of vermiculite, amphiboles and carbonates, which can be minimized and/or controlled by ore blending.

Vermiculite shows a wide distribution; enrichments are observed in the north-eastern portion of the deposit, while magnesium-rich varieties are related to the depth of the weathering in the mantle material. Amphiboles and carbonates occur in small amounts and show restricted distributions. Carbonates are related to "C" horizon of the weathered mantle. The presence of amphiboles was not considered in order to establish the final typology, because their interference is not only related to their proportion in the ore but also to their composition.

The final adopted ore typology, according to the results of pilot tests, was:

- type "A": basal, apatite enriched, portion of talus, usually poor in vermiculite;
- type "B1": eluvial ore with less than 30% of vermiculite;
- type "B2": eluvial ore with more than 30% of vermiculite;
- type "C": semidecomposed rock; presence or absence of carbonates defines sub-types "C1" and "C2"

The planned open pit for the eluvial ore shows a waste to ore relation of 0.2 and the following distribution of the ore classes:

- type "A" 20%;
- type "B 1 " 47%;
- type "B2" 22%;
- type "C" 4% .

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