Technical Report Summary

Serra Norte Complex
Brazil

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1. Executive Summary

1.1. Introduction

The purpose of this Technical Report Summary is to state the mineral resources and mineral reserves for the mines of the Serra Norte Complex to comply with the ownership disclosure requirements of the US Securities and Exchange Commission (SEC). This is required for mining registrants as described in Subpart 229 of Regulation S-K 1300 and disclosed by those involved in mining operations (S-K 1300) and item 601 (b) (96) Technical Report Summary.

VALE is one of the largest mining companies in the world, a large Brazilian exporter, and one of the main private companies in Brazil. With operations on five continents, the company has a global and diversified shareholder base, and its shares are traded on the main stock exchanges in the world. World leader in the production of iron ore, pellets, and nickel, VALE also produces briquettes, copper, gold, silver, cobalt, and metals from the platinum group. These ores are of high quality and produced to meet the needs of the customers in the steelwork industry worldwide competitively. To deliver products quickly, the mining company operates an integrated and efficient logistics chain globally, which includes railways, maritime terminals, and ports, in addition to floating transfer stations and distribution centers.

Serra Norte Complex is part of Vale's Northern System in the southeast of the Pará state in Northern Brazil. Various geological processes in this region also formed large deposits of manganese, gold, copper, palladium, platinum, and nickel. This mineral wealth makes the Carajás region the most geologically important and well-studied area in Northern Brazil.

1.2. Property Description

The Serra Norte Complex is included in mineral tenement 813.682/1969 and is in the mining concession phase. All mineral deposits are within the Carajás National Forest and do not interfere with third-party properties.

The Serra Norte Complex corresponds to deposits called N1, N2, N3, N4, N5 and Gelado tailing dam. The areas in operation are N4E, N4W, N5 and Gelado. There are four processing plants: Plant I (capacity of 85Mt/year), Plant II (capacity of 40Mt/year), Plant III (capacity of 18Mt/year), Plant IV (capacity 3Mt/year) and one plant to recover tailings from Gelado.

Projects N1 and N2 are expected to start up in 2035 and project N3 is expected to start up in 2027. These projects will not require the implementation of new structures for mineral processing, support, temporary or permanent. These needs will be met by structures already in operation at the Carajás Iron Mining Complex. All existing structures are properly licensed.

The Serra Norte complex has four mining easements which are contiguous and form a unique contour that circumscribes all current and future industrial facilities in the Serra Norte complex. Two of the easements are authorized and two are in the approval stage.

1.3. History

The geological surveys in Serra dos Carajás began in 1922, but the first citations on the occurrence of iron formations date back to 1933. In Carta do Brasil ao Milionésimo, published by IBGE in 1960, in the aerial photograph, orebodies C and D of Serra Sul can be seen, which were initially misinterpreted as "limestone plateaus with elevated lakes in the south of Pará". From 1967 onwards, several detailed works began to be carried out on the different targets that compose the areas known as Serra Norte, Serra Sul, and Serra Leste.

In 1977, VALE (at the time Companhia Vale do Rio Doce – CVRD) acquired the shareholding in United States Steel (USS), being solely responsible for conducting the project. In 1979, the construction of the complex, integrating the mine, railroad, and port, of the Carajás Iron Project began. In February 1985, the São Luiz – Carajás railroad was completed. Iron ore production began in 1985, the N4E deposit and the N4W deposit came into operation in 1994. Serra Sul operations started in 2016.

1.4. Geology and Mineralization

The main Carajás iron ore deposits are associated with flat-topped elevated plateaus, in general, elevated areas, between 650-800 meters, defined along two main morphological alignments corresponding to Serra Norte and Serra Sul. These alignments materialize the limbs of the Carajás Syncline.

The Serra Norte Complex corresponds to the inverted limb geological domain of the Carajás Syncline. The high deformation pattern of this domain is reflected in the geometry and the distribution of the iron formations, whose segmentation by faults and folds of different orientations and scales, individualizes plateaus from N1 to N9.

The plateaus of the Serra Norte Complex are limited to the north by the domain of volcanic rocks of the Parauapebas Formation, and to the south, by the domain of terrigenous sediments of the Águas Claras Formation.

At plateaus N4 and N5, where there are mine pits, the geological information was obtained by mapping on a 1:2000 scale, diamond drilling, trenches, and channels. Therefore, at N1, N2, and N3, most of the geological information was obtained from diamond drill cores and surface mapping of alteration materials due to the strong/deep weathering and the absence of cuts and excavations, making the outcrops scarce.

The mineralization at The Serra Norte Complex is mainly formed from supergene alteration of jaspilite, which constitutes the Carajás protolith. The high-grade ore is mainly represented by friable hematite, the structured canga is also considered as a mineralized lithotype.

Deposit N1 is in the extreme west of Serra Norte and corresponds to part of the homonymous plateau. This plateau has an elongated shape in the NW-SE direction. It is predominantly composed of rocks from the Carajás and Igarapé Cigarra formations. In general, the layers show medium to high-angle dips to the northeast, configuring an inverted stratigraphic stack. The thickness of the layer varies between 250-600 m and is strongly controlled by folds and faults.

Deposits N2 and N3 are located on the homonymous plateaus, with an elongated shape in the E-W direction, in the central portion of the Serra Norte. The rocks of the Igarapé Cigarra Formation are predominant in these plateaus. In general, the layers show a medium to high-angle dip to the north, configuring an inverted stratigraphic stacking.

Most of the iron formations of plateaus N2 and N3 were attributed to the Igarapé Cigarra Formation, they do not stand out in the relief due to the low thickness. Structural controls and their relative chronological ordering are like those described for N1, differing by the low continuity of iron formations, which reflects the importance of the faults for the local geological framework.

Plateau N4 is in the central-east portion of Serra Norte, where there are several mine pits, distributed along the homonymous plateau. The dimensions of N4 are big and it is composed of rocks from the Carajás, Parauapebas, and Igarapé Cigarra formations, with a tabular shape and general dip to the west configuring a normal stratigraphic stacking. Before the start of mining, the plateau was already divided into the east and west portions by a drainage that separates the two main bodies of iron formations.

The Carajás Formation occurs continuously in the central portion of the plateaus and corresponds to the domain with the highest thickness of iron formations, which are strongly controlled by strike-slip faults and present thickness between 200-500 meters.

On the N4 plateau, the Carajás Formation assumes a strong N-S trend and defines two occurrence belts called N4W and N4E, with a distinct structural pattern, separated by an eastward verging thrust fault. The N4W region is relatively simpler and behaves like a homocline, the N4E region is more complex, given the rotation of the banding, folding in the southern portion, and drag along the large dextral strike-slip faults.

The N5 plateau is in the extreme east of Serra Norte, where there are five mine pits called N5W, N5N, N5E, N5S, and M1, distributed along the homonymous plateau. This plateau has elongated geometry at the NNW-SSE direction, suffering a strong curvature in the north-central portion as a reflection of interference by folding. The iron formations occupy the central portion of the plateau layers and show a general dip to the west direction, configured at a normal stratigraphic stacking. At N5, the Carajás Formation behaves like a homocline, with a trend varying from NW-SE to N-S and dips to the SE and E. The sinuous character in the northern portion of the plateau is given as a function of a syncline, which, associated with the fault system, verified throughout the plateau, controls the geometry of the iron formation.

1.5. Exploration, drilling, and sampling

1.5.1. Exploration

Exploration work is initially based on highlights of regional mapping on a scale of 1:100 000 produced by the Geological Survey of Brazil (CPRM). Detailed work is developed with mapping at different scales and drilling carried out by Vale´s team.

In and around the mine areas, geophysical anomalies are detailed with mapping and drilling. The geological mapping at a 1:2,000 scale is performed by the short-term geology team, updated monthly. The work is done using GPS precision and the mapped lithologies are classified according to visual classification and compactness.

1.5.2. Drilling

The exploration work carried out in Carajás began in the late 1960s and early 1970s, covering areas of Serra Norte, Serra Sul, Serra Leste, and São Félix do Xingu, all with great potential for geological resources of iron ore.

Long-term drilling campaigns were carried out in spaced grids of 200x200m in all Serra Norte deposits and closures of 100x100m, 100x50m, up to 50x50m, mainly in the mining areas. A summary of drilling per area is presented in Table 1-1.

Table 1-1 – Summary of drilling

Deposit	Total Drilling (m)
N1	82,036
N2	9,851
N3	48,294
N4	502,999
N5	370,976
Gelado	5,168

1.5.3. Hydrology

Groundwater models were prepared using industry-standard water modeling software to support permits for dewatering. Hydrogeological models are tools used to represent the dynamics of groundwater in a simplified way and enable the simulation of different scenarios.

The numerical modeling software FEFLOW and MODFLOW were used in 2020 and 2021 for the simulations of water table drawdown for N1, N2, N3, N4, and N5 open pits. The simulated outflow will be of about 5,530 m³/h, 670 m³/h of which in the N1 pit (FEFLOW, 2020), 164 m³/h for N2 (FEFLOW, 2020), 570 m³/h for N3 (MODFLOW, 2021), 2,636 m³/h for N4 (MODFLOW, 2020) and 1,490 m³/h for N5 (MODFLOW, 2020). To calibrate the models, 78 instruments were used.

The database used was considered satisfactory to achieve the main objective, which consists of building, calibrating, and simulating future mining scenarios in a groundwater numerical model to provide water level data which will be used as input to geotechnical stability analysis and guarantee dry mining operation and depressurized slopes.

1.5.4. Geotechnical

Core logging, surface mapping, and laboratory tests are the main sources of geotechnical information. For core logging and mapping, the collected data follows tables proposed by the International Society for Rock Mechanics and Rock Engineering (1997), Bieniawski (1989) and Martin & Stacey (2018) adjusted by Vale (2019) to fit the iron formation deposits. These characterization parameters are applied to define different rock mass classification systems and to build the geomechanical model.

A combination of historical closer sites and current geotechnical data, with the mining site experience of internal teams supported by national and international consultants, are used to establish internal guidelines and procedures in the slope stability design and operation for pits N1, N2, N3, N4, and N5.

1.5.5. Sampling

The core sampling is performed according to corporate governance procedures and follows mining industry standards. The efficiency of the sampling and the laboratory analysis processes applied in the Serra Norte Complex operations are ensured by periodic reviews and/or audits.

1.5.6. Density determinations

The density database is composed of samples collected by conventional methods, such as volume displacement, volume filling, sand flask, and hydrostatic weighing, as well as geophysical survey data (gamma-gamma). These data are combined to assign the final density values in the geological model.

The tonnage reported in the Serra Norte Complex mines corresponds to the natural base, and therefore, it is very important to determine the average moisture values for each lithology. Such values are obtained by tests, drying an aliquot of the sample, and comparing the dry and wet mass of the sample. Only for Gelado Tailings is the density calculated in dry bases.

1.5.7. Sample preparation and analysis

The physical preparation and chemical assays of the drill hole cores in the Serra Norte deposits were performed following procedures that varied over time. During the different drilling campaigns carried out, the samples were assayed in different analytical flowcharts and later grouped into five flowcharts. The main differences between them are the number of particle size fractions, the number of size fractions with chemical analysis, and the analytes measured, in addition to the type of sieving (dry or wet).

For the geological modeling the samples were grouped in the following particle size ranges: G1: +8 mm; G2: -8+0.15 mm and G3: -0.15 mm, with G1 and G2, subdivided into G1A: +19 mm, G1B: -19+8 mm, G2A: -8+1 mm and G2B: -1+0.15 mm. The long-term geological model database contains analytical results for Fe, SiO_2, P, Al_2O_3, Mn, LOI, CaO, MgO, TiO_2, FeO, K_2O, and Cu. The short-term database contains the analytes Fe, SiO_2, P, Al_2O_3, Mn, LOI, CaO, MgO, and TiO_2.

1.5.8. Quality assurance and quality control

The treatment and the evaluation of historical QA/QC data (prior 2012) related to control samples, twin samples, field duplicates, crushed material duplicates, pulverized material duplicates, external duplicates, and standards did not reveal points of attention (in frequency and/or magnitude) regarding precision and accuracy (of sampling and chemical assays) which compromise the databases used for geological modeling and resource estimation purposes, resources and reserves classification of areas and mines in the Serra Norte and Serra Sul Complexes of the Carajás Mineral Province.

Upon evaluation of the results of QA/QC data for the period from 2012 to 2019, in most cases, the sampling/chemical assay accuracies are good, and analytical biases/flaws are small or insignificant compared to the grade ranges involved. The investigation of the most relevant points of attention has already been requested by the people responsible (geology teams and laboratories involved). QAQC data revealed general indicators of non-compliance, precision, and accuracy considered satisfactory, not compromising the database related thereto.

1.6. Data verification

Vale has data collection procedures in place which included several verification steps designed to ensure the database integrity. Vale staff also conducts regular logging, sampling, laboratory, and database reviews. All technical records related to the borehole, spatial and geophysical trajectory logs, photographs of core boxes, description, density tests, samples, petrography, and physical and chemical results, among others, are kept in the repository(ies) and/or information technology system(s) adequate and accessible for check and/or investigation, whenever necessary.

Mineral resources and mineral reserves are estimated following Global and Vale Ferrous Guidelines and Standards for Mineral Resource and Mineral Reserve Reporting protocols. Consequently, each topic is handled by a qualified person/competent person from the respective department: resources, reserves, mineral processing, geotechnics (pit, project, and dam), hydrogeology, production, strategy, environmental, speleology, finance, mining rights, mining future use, and engineering.

Alongside the mining operation activities, periodic reconciliations are performed at each site. Annual consolidated result reports comparing short-term models, mineral resources, and reserves models, in addition to production grades and tons, are discussed in the annual technical meeting to promote continuous improvement among all involved areas.

1.7. Mineral resource estimate

1.7.1. Estimation methodology

Vale has a set of protocols and guidelines in place to support the estimation process, which the estimators must follow. These include: comprehensive lithological and mineralization domain characterization; selection of all representative samples inside the domain(s); compositing of drill hole information on a consistent support size (length, density, recovery), validation through statistics on lengths and variables before and after compositing; comprehensive understanding of the statistical characters of the variables; in each estimation domain and at the contacts between domains; characterization of the spatial continuity of each variable to be modelled (variograms); understanding of the influence of outliers and variables with highly skewed distributions and selection of an appropriate handling strategy (restricted neighborhood); spatial distribution of drillhole and sample data, mining method and production rates under consideration; selection of an appropriate modelling technique and definition of proper parameters and options to be used (e.g., kriging plan, search strategy, variogram models to be used, post-processing methods); validation of the estimates (visual inspection, checks for global and local bias, confirmation of the kriging plan, and a check on the degree of grade smoothing resulting from the interpolation); and confidence classification.

Estimation was made by Vale personnel. The mineral resource estimate is supported by core drilling. Software used for estimation includes Vulcan, Leapfrog Geo, and Isatis.neo.

Block grades were estimated using Ordinary Kriging (OK) in Vulcan software whilst the variography was performed in Isatis.neo software. Blocks were estimated in a single run with some post-processing corrections. Block estimation was completed on a 25 m x 25 m x 15 m block model, exception was made for the SN3 block model with blocks of 12.5 m x 12.5 m x 15 m. Classification of blocks was assigned according to Risk Index methodology which combines orebody continuity and estimation error. Measured blocks estimated using only one drill hole were downgraded to the indicated blocks. Subsequently, this automated classification was compared with the regular geometric classification method to assess the classification better.

Mineral resources were confined within an optimized conceptual pit shell. The resulting pit extents were considered for reasonableness, such as any potential impact on planned mine infrastructure (processing facilities), and suitability of the current waste projected piles capacities. Pit inter-ramp slope angles vary according to lithology and range from 22-48°.

The commodity pricing forecasts were established using a consensus approach based on long-term analysis and bank forecasts, supplemented with research by Vale’s internal specialists. This approach is considered reasonable to support the mineral resource estimates.

1.7.2. Mineral resource statement

Mineral resources are reported using the mineral resource definitions set out in S–K1300 and are reported exclusive of those mineral resources converted into mineral reserves. A summary of the mineral resource estimates exclusive of reserves is provided in Table 1-2, are stated as metric million tonnage including moisture and dry %Fe grade.

Table 1-2 - Exclusive Mineral Resources of mineral reserves

Target	Classification	Tonnage (Mt)	Fe (%)
N1	Measured	183.4	66.4
	Indicated	138.2	66.4
	Measured + Indicated	321.6	66.4
	Inferred	157.5	66.3
N2	Measured	3.0	65.9
	Indicated	10.2	65.2
	Measured + Indicated	13.2	65.4
	Inferred	22.4	65.3
N3	Measured	15.0	65.8
	Indicated	45.9	65.2
	Measured + Indicated	60.9	65.3
	Inferred	48.8	65.8
N4W	Measured	196.2	66.3
	Indicated	31.1	66.1
	Measured + Indicated	227.2	66.3
	Inferred	5.9	65.9
N4E	Measured	130.9	66.1
	Indicated	17.7	65.9
	Measured + Indicated	148.6	66.0
	Inferred	5.2	65.1
N5	Measured	318.0	66.9
	Indicated	176.3	66.7
	Measured + Indicated	494.3	66.8
	Inferred	56.0	67.3
Gelado	Measured		
	Indicated	85.6	63.8
	Measured + Indicated	85.6	63.8
	Inferred	7.0	63.6
Total	**Measured**	846.4	66.5
	Indicated	505.1	65.9
	Measured + Indicated	1,351.5	66.3
	Inferred	302.7	66.3

Notes to accompany mineral resources tables:

1. *The estimate has an effective date of 31/Dec/2025.*
2. *Ferrous Mineral Resources estimates stated as metric million tonnage inclusive moisture and dry %Fe grade; following moisture contents: 7.77% Serra Norte;. Gelado density is dry bases.*
3. *Serra Norte integrated operation includes N3, N4W, N4E and N5 mines, N1, N2 projects and Gelado tailings dam.*
4. *The mineral resources prospects of economic extraction were determined based on a long-term price of US$92.3/dmt for 62% iron grade.*
5. *Numbers have been rounded.*
6. *Product Recovery: for Gelado Tailings was considered 50%, so the overall processing recovery for Serra Norte Complex is 97.3%.*

Areas of uncertainty that may impact the mineral resource estimates materially include: changes to long-term metal price and exchange rate assumptions; changes in local interpretations of mineralization geometry, structures, and continuity of mineralized zones; changes to geological and grade shape and geological and grade continuity assumptions; changes to the input assumptions used to derive the conceptual optimized open pit shell used to constrain the estimates; changes to the forecast dilution and mining recovery assumptions; variations in geotechnical slope angles, hydrogeological and mining assumptions; and changes to environmental, permit and social license assumptions.

Given the changes since the last Technical Report Summary filed for the fiscal year ended 2021, we're filing an updated Technical Report Summary for the Serra Norte Complex as Exhibit to this annual report.

1.8. **Mineral reserve estimates**

The Serra Norte reserves were based on the measured and indicated resources of the deposits and tailing dam, N1, N2, N3, N4E, N4W, N5 and Gelado, respectively, which were used as input and converted into proved and probable after estimating the reserves. More details about the features can be seen in chapters 12 and 13.

The optimized pit considered environmental, and some structure restrictions, process, and mine costs were also used, which consider additional deepening costs, sales costs, commodity price curve, and geotechnical parameters. Mining recovery and dilution factors were also considered.

Based on these parameters, a family of pits is generated, and the choice is made based on economic criteria. This pit undergoes first geotechnical evaluation, and then, it is optimized again, where corrections of some geotechnical parameters are made. After this second round, the pit goes to operationalization and final geotechnical analysis for final corrections in the operationalized geometry to ensure the safety and stability of the slopes. Gelado tailings dam, reserve is managed based on scheduling and constraints parameters to achieve the optimal results.

Table 1-3 shows the reserve statement results.

Table 1-3 - Proven and Probable Mineral Reserve Statement 2025

Pit/Operation	Classification	Tonnage (Mt)	Fe (%)
N1	Proven		
	Probable	388.1	64.3
	Subtotal Proven + Probable	388.1	64.3
N2	Proven		
	Probable	44.5	63.6
	Subtotal Proven + Probable	44.5	63.6
N3	Proven		
	Probable	114.8	63.7
	Subtotal Proven + Probable	114.8	63.7
N4W	Proven	192.9	64.9
	Probable	117.9	65.1
	Subtotal Proven + Probable	310.8	65.0
N4E	Proven	150.1	65.3
	Probable	8.4	64.8
	Subtotal Proven + Probable	158.5	65.3
N5	Proven	31.1	64.5
	Probable	367.9	65.1
	Subtotal Proven + Probable	399.0	65.0
Gelado	Proven		
	Probable	96.6	63.7
	Subtotal Proven + Probable	96.6	63.7
Total	**Proven**	**374.0**	**65.0**
	Probable	**1138.3**	**64.5**
	Total Proven + Probable	**1512.3**	**64.6**

Notes to accompany the mineral reserves table:

1. The estimate has an effective date of 31/Dec/2025.
2. Iron Ore Reserve estimates stated as metric million tonnes inclusive moisture and dry %Fe grade (Fe2O3); Serra Norte moisture of 7.46%. The point of reference used is in situ tons. Gelado is reported on dry basis.
3. The mineral reserve economic viability was determined based price curve with the long-term price being US$84.3/dmt for 62% iron grade
4. Numbers have been rounded.

The following factors can affect the mineral reserve estimate: commodity prices; US dollar exchange rate; Brazilian inflation rate; geotechnical (including seismicity) and hydrogeological parameters; changes in capital inflows and operating cost estimates; changes in pit designs compared to the currently planned; inventory assumptions; ability of the mining operation to meet the annual production rate; process plant recoveries and the ability to control levels of deleterious elements within the expectations of the LOM plan; assumption plants 1 and 2 will perform as expected; ability to meet and maintain environmental permits and licenses; and ability to maintain social license to operate.

Given the changes since the last Technical Report Summary filed for the fiscal year end 2021, we're filing an updated Technical Report Summary for the Serra Norte Complex as Exhibit to this annual report.

1.9. **Mining methods**

Conventional open-pit mining and dredging methods are used in Serra Norte mines and Gelado dam respectively and based on in-house equipment and labor. All engineering studies are minimum level FEL2.

The production plans aim at an average annual production of around 100 Mt. There may be small variations depending on the company's strategy throughout the life of mine.

Geotechnical parameters are provided for each pit. Periodic inspection procedures are followed to verify the stability of slopes, sterile piles, dams, dikes, and drainages to guarantee the operation safety and continuity.

In the mine operations, mainly big hydraulic and cable excavators are used to produce ore and waste rock. Loaders are also used to ensure greater flexibility in mining, as well as different cleaning and backup jobs for the excavators, when necessary. A fleet of off-road haul trucks is used to transport material to waste dumps and primary crushers. Crawler tractors are planned to maintain production and bench-cleaning areas. Wheel tractors, motor graders, and water trucks complete the rest of the auxiliary equipment fleet. Gelado dam is operated by large electric dredges that pump slurry to treatment plant.

1.10. **Processing and recovery methods**

The Serra Norte complex is of great importance to Vale's production system both in terms of volume and in terms of quality. The installed capacity of this complex is 130 Mty where part of ROM is processed using natural moisture, and part is wet.

The deposits that constitute this complex enable the generation of products with an iron content of around 65% with low variability. In plants that process ROM with natural moisture, there are only crushing and screening steps and only the Sinter Feed product is generated. In the plant that processes wet ROM, in addition to the crushing and screening operations, there is a magnetic concentration step for the fines processing. This plant generates Lump, Sinter Feed, and Pellet Feed products.

In Serra Norte, there is a circuit for processing material from the Gelado dam. The dam material is extracted by dredging and sent to a plant consisting of a protective screening system and a slurry pipeline that carries the material to the same magnetic concentration as the wet plant. The concentrate from this circuit is the Pellet Feed product.

The Pellet Feed product can be destined for the external market or for pelletization in São Luís.

1.11. **Infrastructure**

Most of the infrastructure to support mining operations is in place. There is an urban center close to the Carajás operations that absorb part of the workforce, and another part lives in the city of Parauapebas and the region.

Water may be captured from selected watercourses and drawdown wells under granted licenses. The replacement water for the process comes from the Gelado and Pera dams. Drinking water is also from wells located in the mine. This water is treated in a Water Treatment Plant. Serra Norte Operations monitor water levels, flows, and balances regularly.

Electricity is supplied by the National Interconnected System and is connected to 230 KV voltage.

The internal distribution system is carried out through Vale's electrical networks of 34.5 kV. The consumption in 2024 was around 494,563 MWh, 70.9% of which fed the mineral processing plants, 25.9% was distributed to the N4/N5 mines, and the remaining 3.2% was consumed by the Urban Center and other support structures.

1.12. Environmental, Permitting and Social Considerations

Serra Norte has obtained the necessary operating permits. Environmental monitoring protocols include biological, air quality, soil, climate, iron ore caves, surface and groundwater, dust control, and other protocols needed to meet regulatory compliance.

Additional environmental and social studies are in due course to support future licensing requirements for the continuity of operations.

Technical studies have been completed for all environmental issues including soil, water, waste, air, noise and closure. Mitigation Programs were developed and implemented in all relevant locations and mine operation.

1.13. Market studies

Iron ore is one of the core products that Vale commercialize globally. Its price and premiums can fluctuate throughout the year according to changes in the balance between its supply and demand and short-term trends due to the market's sentiment.

Vale operates three systems in Brazil for producing and distributing iron ore, which we refer to as the Northern, Southeastern, Southern Systems. Each of the Northern and Southeastern Systems is fully integrated, consisting of mines, railroads, maritime terminals and a port. The Southern System consists of two mining complexes and two maritime terminals.

In 2025, iron ore prices have held steady, traversing within a $96–$110/t range since late 2024, despite geopolitical tensions, tariffs, and trade disputes causing sharp swings in other commodities. China's latest efforts to address overcapacity and target ruinous competition, known as "anti-involution," had gained momentum, and propped up the steel industry, which had been operating in weak margins conditions in 1H25. This has translated to an improved but cautious optimism in the iron ore sector and supported market sentiment. While such measures could limit iron ore usage, they may enhance steel sector profitability, indirectly supporting prices. By the time this report was prepared, the price consensus for iron ore prices at 62% Fe in 2026 of the analysts was USD93/t, with a downward trend going forward until prices reach the long-term level of around USD 84/t and the price consensus for iron ore prices at 65% Fe in 2025 of the analysts was USD 106/t with a downward trend going forward until prices reach the long-term level of around USD 99/t. Additionally, we believe that the expected future production, relative to our iron ore reserves, can be absorbed by the market in the long term given the expected demand by market analysts.

1.14. Capital and operating costs

1.14.1. Capital costs estimate

Economic valuations consider sustaining CAPEX in cash flows, necessary for the maintenance of existing assets/operations, and capital projects which aim to maintain and/or increase the productive capacity. Sustaining CAPEX can be classified into routine and non-routine.

Routine refers to projects aimed at maintaining the operational capacity of the assets, including the acquisition and replacement of equipment and readjustment of operating structures. They are estimated based on a diagnosis made by the Engineering area on the asset base, a maintenance backlog, and the investment, target defined by the company for future years.

Non-routine refers to projects that support the business strategy, ensuring compliance with the production plan, but which do not occur frequently. It is included in this list: expansion of pits, waste and tailings disposal projects, and changes in processes and technologies in the plants, among others. They are estimated based on the expected needs of each operation or production complex over the evaluated horizon. Based on these needs, Vale's multidisciplinary teams estimate the values of the investments considered in the cash flows of the economic evaluations.

The sole purpose of the presented figure is to demonstrate the economic viability of the mineral reserve, therefore it can differ from other information Vale publishes and should not be considered as guidance.

Additionally, economic assessments of reserves consider capital projects that aim to maintain and/or increase productive capacity. The overall capital cost estimate for the LOM or evaluation period is US$ 8,062 million as shown in Table 1-4.

Table 1-4 – LOM Capital Cost Estimate

Capital Cost Type	Unit	Value
Sustaining CAPEX	US$ M	**8,062**
Non-routine	US$ M	**3,156**
Mine and plant	US$ M	1,854
Waste and tailings piles	US$ M	1,302
Routine	US$ M	**4,906**
Capital projects CAPEX	US$ M	**0,0**
TOTAL	US$ M	**8,062**

Note: numbers have been rounded

1.14.2. Operating cost estimates

Operating costs and expenses are grouped as follows:

- Mine and plant Opex: mine and plant costs include mining, processing, storage, and shipping from the ore to the loading points;
- Logistics and distribution costs: logistics and distribution costs include railroad, ports, maritime freight, and distribution centers;
- Sales, R&D, and pre-operational expenses: sales, R&D, and pre-operational expenses are related to team expenses with sales and offices, expenses on research and development of solutions for projects and/or the maintenance of operations, and pre-operational expenses, when there are projects under implementation.

In summary, the mining Opex is forecast considering the costs of the operation or similar operations in previous years and their respective operational indicators as a reference. Thus, future operational indicators are estimated based on long-term mine planning. This way, the estimated costs are projected considering the future changes in the operational indicators of the operations.

Total average unit operating costs and expenses are 44.2 US$/ton of product. LOM average unit operating cost and expenses are composed of:

- Mine and plant: 16.0 US$/ton of product
- Logistics and Distribution: 22.5 US$/ton of product
- Royalties: 5.5 US$/ton of product
- Sales expenses, R&D, others: 0.2 US$/ton of product

The sole purpose of the presented figure is to demonstrate the economic viability of the mineral reserve, therefore it can differ from other information Vale publishes and should not be considered as guidance.

The overall costs and expenses estimate for LOM or evaluation period is US$ 64,709 million as shown in Table 1-5.

Table 1-5 – Operating Costs and Expenses

Type of costs and expenses	Unit	Value

Mine and plant	US$ M	23,482
Logistics and Distribution	US$ M	32,956
Royalties	US$ M	7,994
Sales expenses, R&D, others	US$ M	276
TOTAL costs and expenses	**US$ M**	**64,709**

Note: numbers have been rounded

1.15. Economic analysis

1.15.1. Introduction

The aim of the economic evaluation presented in this chapter is to demonstrate the economic viability of the mineral reserve, therefore the production rates, operating efficiencies, costs and expenditures, taxes, and other information presented can differ from other information we publish and should not be considered as a guidance. Note that our planned production extraction may vary due to continuous mineral exploration and technical studies to add new mineral reserves.

1.15.2. Methodology and assumptions

The economic evaluation methodology used was the Discounted Cash Flow (DCF), the main methodology used to evaluate companies, projects, operations, etc., and widely used by companies, investment banks, and consulting companies.

The forecast cash flow is composed of cash inflows (revenues) minus cash outflows (costs, expenses, taxes, and capital expenses/costs) of an enterprise in a given period. This period may vary according to the Mineral Reserve size associated with the asset (mine, operation, and logistics). When the forecast cash flow brought to present value is positive (greater than or equal to zero), it means that the enterprise is economically viable.

For the valuation of reserves, the cash flows given the mass of product can generate were projected. To estimate the potential annual revenues from the mining of this resource, the annual processed tonnages and grades, the associated process recovery, and the metal prices were taken into account. The operating costs, logistics costs, royalties, taxes, and capital expenditures necessary for its economic use were also estimated. If the forecast cash flow, brought to present value through the discount rate, is positive, it means that the Mineral Resource is economically mineable, and can be classified as a Mineral Reserve. The currency used to document the cash flow is US$ and all costs and prices are in unescalated “real” dollars. The forecast long-term (LT) exchange rate is shown in Table 1-6.

Table 1-6 – Exchange rate

Exchange rate – real terms	2026	2027	2028	2029	2030	LT
R$ / US$	5.60	5.75	5.70	5.60	5.50	5.45

The cash flow period of the economic evaluations is the life of mine (LOM) or until the end of reserves of the operation or project analyzed. The economic valuations of the reserves assume 100% equity, so there are no interest and debt amortization expenses in the cash flows. Revenues from economic evaluations of iron ore reserves are based on projections of international market price indicators, as follows:

- Platts IODEX 62% Fe CFR China
- 65% Fe Index CFR China for the mass that will generate the IOCJ product.
- VIU per additional percentage point of Fe CFR China

It is assumed in the evaluations of operations and projects that produce pellet feed (PF) for supply to our own pellet plants, that the product is sold to third parties at market price, without considering the pelletizing process, that is, without considering the costs of pellet processing and the pellet premiums in revenue.

1.15.3. Economic analysis

The economic valuation model of reserves considered the discounted cash flow method and it took into account annual processed tonnages and grades. The associated process recovery, metal prices, operating costs, logistics costs, royalties, and capital expenditures were also considered. The economic analysis confirmed that Serra Norte is economically viable. The after-tax NPV at a 7.01% discount rate and following a mid-year convention is US$ 19,553 M. The summary of the results of the cash flow analysis is presented in Table 1-7.

Table 1-7 – Economic Evaluation

Net present value of overall cash flow	Unit	Value
Total revenue	**US$ M**	**67,844**
Total costs and expenses	US$ M	-36,198
Mine and plant	US$ M	-12,483
Logistics and Distribution	US$ M	-18,831
Royalties	US$ M	-4,543
Sales expenses, R&D, others	US$ M	-159
Closure costs	US$ M	-182
Income Tax and working capital change	US$ M	-7,078
Operational Cash Flow	**US$ M**	**24,569**
Total CAPEX	US$ M	-5,016
Free Cash Flow	**US$ M**	**19,553**

1.15.4. Sensitivity analysis

The biggest impact in the sensitivity analysis is the price and VIU, followed by opex mine, plant, logistics and distribution, exchange rate, and the total capex.

Upon application of the sensitivity analysis in the main variables, NPV remains positive, confirming the robustness of the mineral reserves.

2. Introduction

2.1. Term of reference and purpose

The Report was prepared to be attached as an exhibit to support mineral property disclosure, including mineral resource and mineral reserve estimates for the Serra Nortel Complex in Vale's Form 20-F for the year ending 31 December , 2025, in compliance with the SEC (US Securities and Exchange Commission) ownership disclosure requirements. This obligation is outlined for mining registrants in Subpart 229 of Regulation S-K 1300 and detailed in item 601 (b) (96) Technical Report Summary.

The effective date of this Technical Report Summary is 31st December 2025.

The assumptions adopted in the preparation of this report involve inherent uncertainties and risks, and the information in this report is not a guarantee of future performance. This report contains estimates, forecasts, and forward-looking statements, which can be identified using words related to future projections, such as "anticipate," "believe," "may," "expect," "should," "plan," "intend," "estimate," "will be," and "potential," among others. These estimates, forecasts, and statements involve several known and unknown risks and uncertainties. Vale and its QPs cannot guarantee that such forward-looking statements will prove to be accurate. The risks and uncertainties related to our estimates and forecasts include, among others, factors related to (a) economic, political, and social issues in the countries where we operate, including factors related to the coronavirus pandemic; (b) the global economy; (c) the financial and capital markets; (d) the mining and metals businesses, which are cyclical, and their reliance on global industrial production, which is also cyclical; I mining, environmental and health and safety regulations, including regulations relating to climate change; (f) operational incidents or accidents, (g) the high degree of global competition in the markets where Vale operates, (h) information available at the time of preparation of the forward-looking statements and (j) data provided by external sources.

Vale and its QPs emphasize that the actual results referring to Vale's mineral resources and reserves may materially differ from the plans, objectives, expectations, estimates, and forecasts expressed herein.

2.2. The Company

VALE is one of the largest mining companies in the world, a large Brazilian exporter, and one of the main private companies in Brazil. With operations on the five continents, the company has a global and diversified shareholder base, and its shares are traded on the main stock exchanges in the world. World leader in the production of iron ore, pellets, and nickel, VALE also produces, copper, gold, silver, nickel, cobalt, and metals from the platinum group. Its ores are of high quality and produced to meet the needs of the customers in the steelwork industry worldwide competitively. To deliver products quickly, the mining company operates an integrated and efficient logistics chain globally, which includes railways, maritime terminals, and ports, in addition to floating transfer stations and distribution centers.

VALE is publicly traded on the New York Stock Exchange (NYSE) and in Brazil on the B3 Stock Exchange. Figure 2-1 shows the location of VALE's business segments in the world.

Figure 2-1 - Location of VALE's business segments.

2.3. Qualified Persons Site visits

Qualified Persons (QPs) involved in the estimation of mineral resources and reserves at Serra Norte are professionals with extensive experience in their areas of operation who pay repeated visits to the respective sites described in this report. Table 2-1 shows the latest visits and future schedule.

Table 2-1 - QPs site visits

QP	Visit period	Visits scheduled
Arnor Barbosa de Couto Junior (Mineral Reserves)	April/2025	First half/2026
Leonardo Hiram Núñez (Mineral Resources)	April, June, October, November and December/2025	First half/2026
Hely Simões Gurgel (Process Development)	-	First half/2026
Luciano Souza Castro (Production Plan)	-	First half/2026
Rodrigo Marinaro (Geotechnical)	-	First half/2026

2.4. **Qualified Persons**

The following Vale employees serve as Qualified Persons (QPs):

Table 2-2 - QPs list

Qualified Persons (QPs)	Role	Sections of responsibility
Alessandro Resende, PQR CBRR	Engineer Specialist	1; 2; 3; 20; 21; 22; 23; 24 and 25
Arnor B. Couto Jr., PQR CBRR	Senior Specialist Engineer	1; 2; 4; 12; 13; 15; 16; 17; 20; 21; 22; 23; 24 and 25
Leonardo Hiram Núñez, MAusIMM	Senior Specialist Geologist	1; 2; 5; 6; 7; 8; 9; 11; 21; 22 and 23
Eduardo F F Cruz, PQR CBRR	Senior Business Specialist	1; 16; 18; 19; 22; 23 and 25
Paulo Rogério Oliveira, PQR CBRR	Manager of assessment of conditions and license renewal	1; 2; 12;15;17; 20; 21; 22; 23; 24 and 25
Hely Simões, PQR CBRR	Process Development Specialist Engineer	1; 2; 10;14; 20; 21; 22; 23; 24 and 25
Teófilo Costa, PQR CBRR	Senior Geotechnical Technical Specialist	1; 2; 7; 13; 20; 21; 22; 23; 24 and 25
Luciano Souza Castro, MAusIMM	Production Plan Specialist Engineer	1; 2; 4; 12; 13; 20; 21; 22; 23; 24; and 25
Rodrigo Marinaro, PQR CBRR	Geotechnical Technical Manager	1; 2; 4; 15.6.4.1; 20; 21; 22; 23; 24; and 25
Wagner José de Castro, PQR CBRR	Senior Specialist Geotechnical Engineer	1; 2; 4; 12; 13; 15.6; 17.5; 20; 21; 22; 23; 24; and 25
Alessandra Teixeira, PQR CBRR	Geotechnical Projects Specialist	1; 2; 4; 12; 13; 20; 21; 22; 23; 24; and 25

2.5. **Previous Technical Reports Summaries**

Vale has filed the following technical report summary on the Serra Norte Operations:

- Alessandro Resende, PQR CBRR, Arnor B. de Couto Jr., PQR CBRR, Hely Simões, PQR CBRR, Teófilo Costa, PQR CBRR. 2021: Technical Report Summary, Serra Norte Complex, Brazil: report current as at 31 December 2021, prepared for Vale S.A., dated April 7, 2022, 202 p.

2.6. **Terms, units and abbreviations**

VALE based all measurements on the metric system and identified exceptions thereto, mainly when listing the English and the metric standards. The currencies are generally based on US Dollars (US$), converted into Brazilian Real per US Dollar. The exchange rate used to convert amounts in Brazilian reais into US dollars is BRL: US$ = 5.60 for 2026, and then a long term mean of 5.45 BRL: US$. Unless indicated otherwise, Dollars are US Dollars and the weights are in metric tons of 1,000 kilograms (2,204.62 pounds). Table 2-3 shows the units used in this report. Table 2-4 shows the abbreviations used in this report, and Table 2-5 shows the chemical symbols used in this report.

Table 2-3 - Units of measure used in this report

Unit	Abbreviation
American Dollar	USD
GigaYears	Ga/Gy
Million Years	Ma
Hectahá	ha
Bond Ball Mill Work Index (metric)	kWh/t
Brazil Real	R$ or BRL
Centigrade	°X
Cubic centimetre	cm^3
Centimetre	cm
Cubic metre	m^3
Cubic metres per second	m^3/s
Day	d
Deadweight ton (imperial ton – long	Dwt
Dry metric tonne	dmt
Gram	g
Gram/liter	g/L
Gram/tonne	g/t
Hour	h
Hours per Year	h/yr
Kilogram	kg
Kilogram per tonne	kg/t
Kilometre	km
Kilopascal	kPa
Kilovolt	kV
Kilovolt amp	kVA
Kilowatt	kW
Kilowatt-hour	kWh
Litre	T
Litre per second	L/s
Megawatt	MW
Meter	m
Meter per hour	m/h
Meter per second	m/s
Metric tonne	t
Metric tonnes per hour	t/h
Metric tonnes per day	t/d
Metric tonnes per Annum	t/a
Minute	min
Micron	Mm
Milligram	mg
Milligram per litre	mg/L
Millimetre	mm
Million	M

Million short ton	MT
Million short ton per annum	MT/a
Parts per billion	ppb
Parts per million	ppm
Percent	%
Second	s
Short ton	T
Square metres	m2
Tonnes per Day	t/d
Troy ounce	Oz.
Wet metric tonne	wmt
Work index	WI
Year	yr

Table 2-4 - List of abbreviations used in this report

Abbreviation	Acronym
ANM	National Mining Agency
BRBF	Brazilian Blend Fines
BSM	Semi-Mobile Crusher
CAPEX	Capital Expenditure
CD	Consolidated Drained Triaxial Shear Test
CDM	Mineral Development Center
CNM	Mineralogical Normative Calculation
CE	Structural canga
CFEM	Financial Compensation for the Exploitation of Mineral Resources
CFR	Cost and Freight
CKS	Carajás Mineral Province
CLI	Interpreted Classification
CLM	Mathematical Classification Key
CLV	Variable of Visual Classification
CPRM	Geological Survey of Brazil
CPT	Technological Research Center
CQ	Chemical canga
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
CS	Social Contribution
CU	Consolidated Undrained Triaxial Shear Test
DCF	Discounted Cash Flow
DCF	Discounted Cash Flow
DNPM	National Department of Mining Production
EBIT	Earnings Before Interest and Taxes
EFC	Carajás Railroad

EL	Environmental License
ELM	Equilibrium Limit Method
WTP	Water Treatment Plant
FAI	Investment Amount
FEGL	Raw Iron Content
FLONACA	National Forest of Carajás
FMN	Manganiferous Iron
FOB	Free on Board
FoS	Sa32aspiactor
GDMS	Geological Database Management System
GM	Mining Group
HC	Compact hematite
HF	Friable hematite
HMN	Manganiferous hematite
HMN	Manganiferous hematite
IBAMA	Brazilian Institute for the Environment and Renewable Natural Resources
IBRAM	Brazilian Mining Institute's Mine Closure Planning Guide
ICM	Intrinsic Correlation Models
ICMBio	Chico Mendes Institute for Biodiversity Conservation
ICMM	International Council on Mining and Metals
IK	Indicator Kriging
IOCJ	Iron Ore Carajás
IR	Risk Index
IR	Income Tax
IRR	Internal Rate of Return
JCS	Joint Compressive Strength
JP	Jaspilite
JRC	Joint Roughness Coefficient
LI	Installation Permit
LO	Operation Permit
LOI	Loss on ignition
LP	Preliminary Permit
LT	Long Term
MD	Decomposed mafic
MS	Fresh mafic
MSD	Semi-decomposed mafic
NN	Nearest Neighbor
NPV	Net Present Value
nRMS	Normalized Root Mean Squared
NYSE	New York Stock Exchange
OK	Ordinary Kriging

OL	Operation License
OL	Operation License
Operation License	Exploratory Data Analysis
OPEX	Operational Expenditure
PAE	Economic Exploitation Plan
PF	Pellet Feed
PI	Inhalable Particles
PT	Suspended Particles
QA/QC	Quality Assurance/Quality Control
QPs	Qualified persons
RAL	An33aspilitert of Mining
RFP	Exploration Technical Report
ROL	Rolled
ROM	Run-of-mine
RPM	Runge Pincock Minarco
RQD	Rock Quality Designation
SEC	Securities and Exchange Commission
SIN	National Interconnected System
SNUC	National System of Conservation Units
TFRM	Mineral Resources Inspection Fee
TMPM	Ponta da Madeira Maritime Terminal
TTG	Tonalite-trondhjemite-granodiorite
UC	Conservation Units
UCS	Unconfined Compressive Strength
USS	United States Steel
VALE	Formerly known as CVRD
VIU	Value-in-use
WSA	World Steel Association
YoY	Year on Year

Table 2-5 - List of chemical symbols used in this report

Element	Symbol
Aluminum	Al
Iron	Fe
Magnesium	Mg
Manganese	Mn
Oxygen	O2
Phosphorus	P
Potassium	K
Calcium	Ca
Silica	Si
Titanium	Ti
Potassium	K

3. Property description and Location

3.1. **Location**

The Serra Norte, Serra Leste, and Serra Sul Mining Complexes are in the State of Pará, north of Brazil. The three mining complexes are referred to as VALE's North System, which is 100% owned by VALE. Serra Norte Mining Complex has the approximate coordinates: 592,230 E and 9,330,150 N using the UTM_SAD 69 datum.

The Serra Norte Complex is in the District of Parauapebas. Access to the site is mainly through the Parauapebas airport and 25 km along state highway PA-275, as shown in Figure 3-1 -.

The actual Serra Norte mine site corresponds to the orebody N1, N2, N3, N4, N5 and Gelado tailings dam. The N4, N5 and Gelado are the current operating mine and dredging areas.

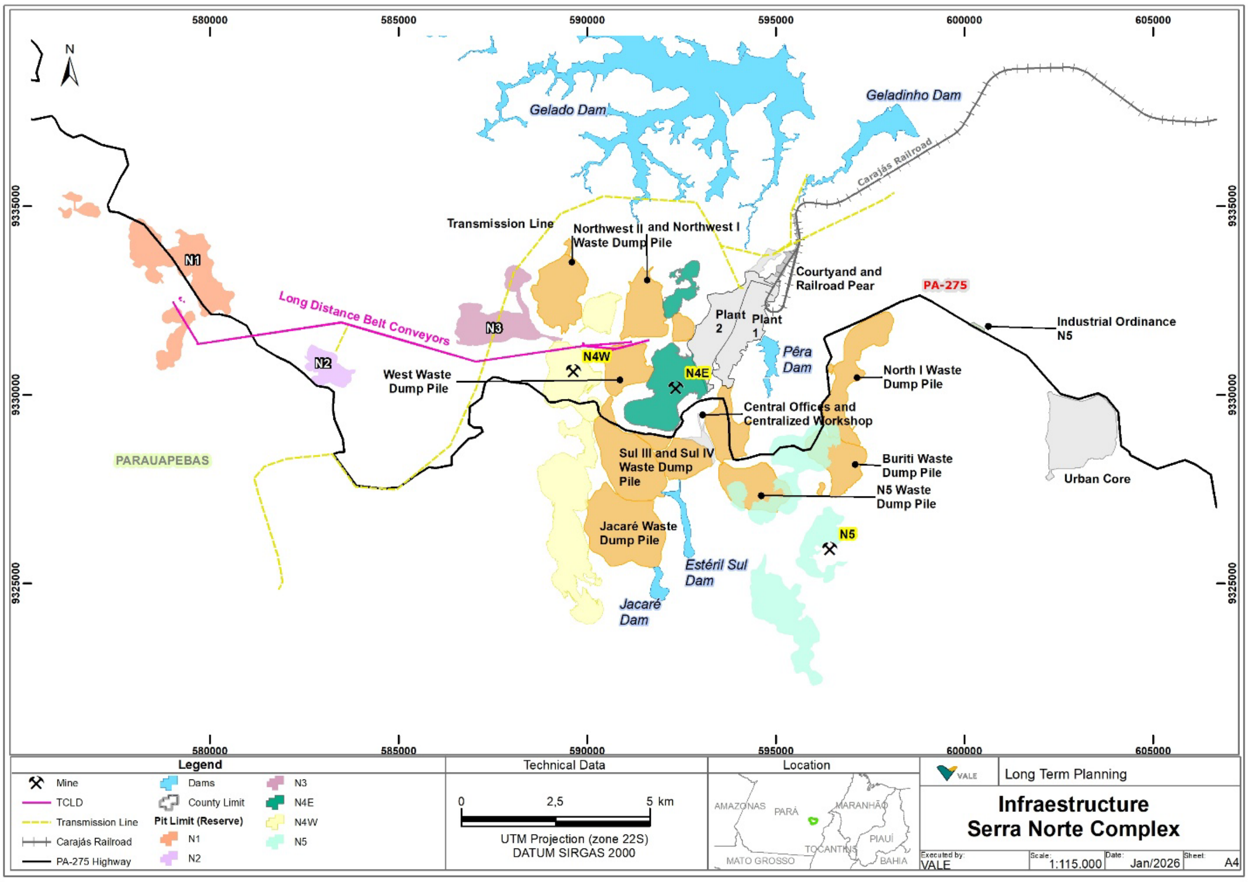


Figure 3-1 - Serra Norte Location Map

The mining activities must start up to six months from the mining concession grant. Annual production reports must be filed. Assuming all other conditions are met, the mining concessions remain valid until the deposit is depleted.

The mining company can conduct mining activities after the appropriate environmental operation license (LO - Licença de Operação) is issued. The mining operations must be in accordance with the Economic Exploitation Plan approved by ANM. If additional minerals are discovered, ANM must be notified of the discovery, and the mining concession must be amended to include the new list of minerals before those minerals can be commercially produced and sold.

3.2. **Mineral, Surface Rights and Easements**

At Serra Norte, the mining right was grouped in a permit referred to as "Mining Group" (*Grupamento Mineiro or* GM) which is concession grouping, allowing processing and approval of mining rights for a group of concessions in a single process. Figure 3-2 presents the mining right of Serra Norte (813.684/1969), which is part of a Mining Group (852.145/1976) among other operations, including Serra Sul and Serra Leste. Table 3-1 shows further information on Serra Norte mining concession.

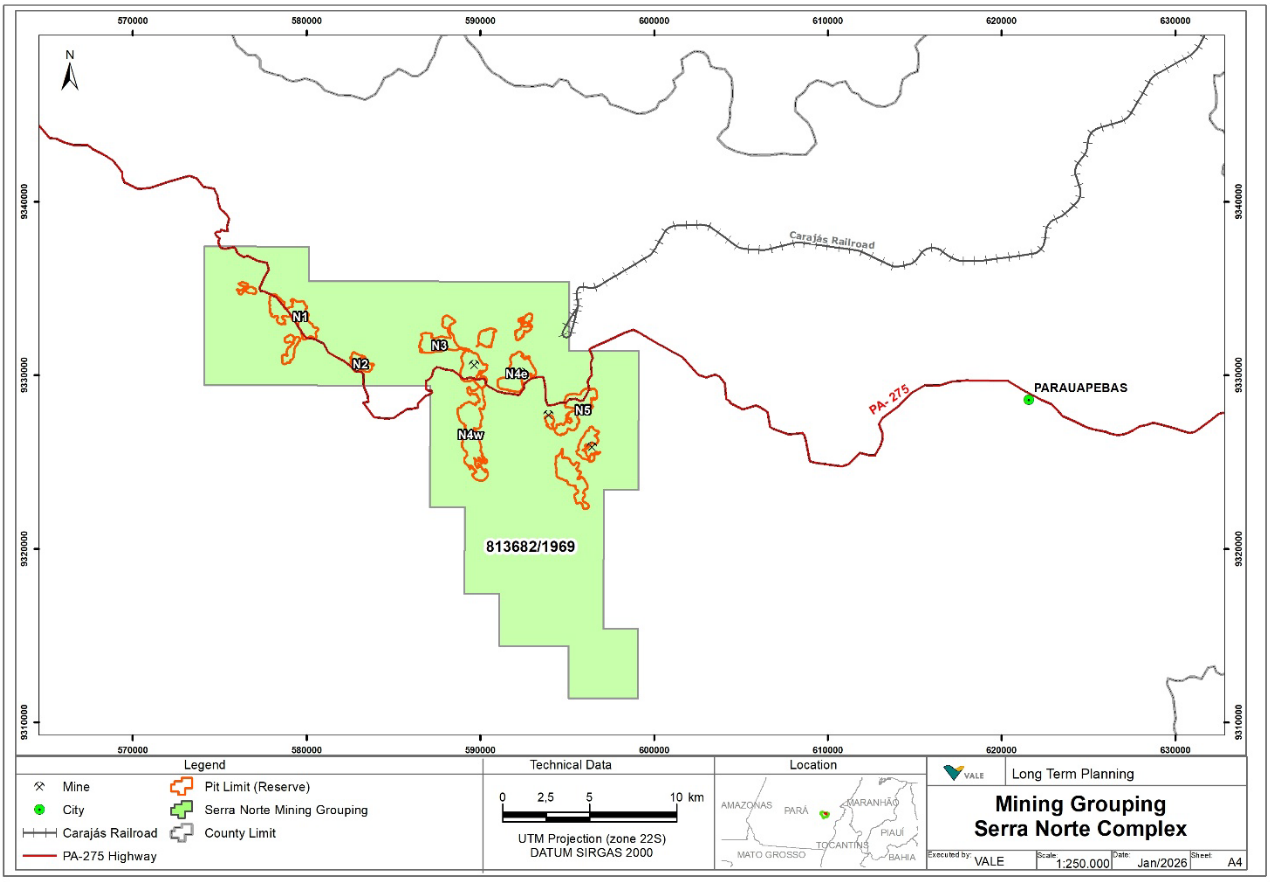


Figure 3-2 - Serra Norte Mining Concession

Table 3-1 - Serra Norte Mining Rights forming the Concession Grouping

ANM Process	City	Area (ha)	Title	Number	Issue date	Element	Mine
813.682/1969	Parauapebas	30,000	Mining Concession	74.508	06/09/1974	Iron	Serra Norte

Currently, the Serra Norte complex possesses four mining easements as follows.

- Easement 1, with an area of 4,052.46 ha, whose technical report was approved on 13/07/88;
- Easement 2, with an area of 8,527.54 ha, whose technical report was approved on 01/12/88;
- Easement 3, with an area of 15,565.33 ha, whose technical report approval was requested at the same time PAE was registered on 30/01/2009 and reiterated in 03/07/2013;
- Easement 4, with an area of 10,031.52 ha, was requested on 17/02/2017, which the PAE was approved on 19/04/2021.

These 4 easements are contiguous and make a unique shape that encompasses all current and future industrial installations necessary for the Serra Norte life of mine.

Vale is required to pay a monthly federal fee known as Financial Compensation for the Exploitation of Mineral Resources (“CFEM”) over the sales of iron ore, at the current rate of 3.5%. The state of Pará also imposes a tax on mineral production (“Taxa de Fiscalização de Recursos Minerais – “TFRM”), which is currently assessed at a rate of R$ 14.4039 per metric ton of minerals produced in or transferred from the state.

An annual mining report (RAL - Brazilian acronym) is required to be lodged with ANM, detailing the production for the year. This reporting obligation has been met for each year since concession grant.

3.3. **Surface rights and Easement**

According to the General Mining Law and related legislation, surface rights are independent of mineral rights. The law requires that the holder of a mineral concession either reach an agreement with the landowner before starting relevant mining activities (i.e., exploration, exploitation, etc.) or complete the administrative easement procedure, following the applicable regulation. Surface property is acquired through:

- The transfer of ownership by agreement of the parties (derivative title);
- Acquisitive prescription of the domain (original title);
- Temporary rights to use and/or enjoy derived powers from a surface property right may be obtained through usufruct (a right to temporarily use and derive revenue) and easements.

As indicated by Vale, the Serra Norte is located within the National Forest of Carajás (FLONACA), which belongs to the Federal Government and there are no interferences of the operations with third-party properties, as shown in Figure 3-3.

The Gelado Dam is mostly part of third-party mining processes, located in the Sustainable Use Conservation Unit - APA do Gelado and has an easement report issued by ANM for the entire area of the mentioned dam.

The Mining Easement is the instrument that aims to make the mining enterprise viable. It is an area located inside or outside the title polygon for installing the structures necessary for the development of mining work.

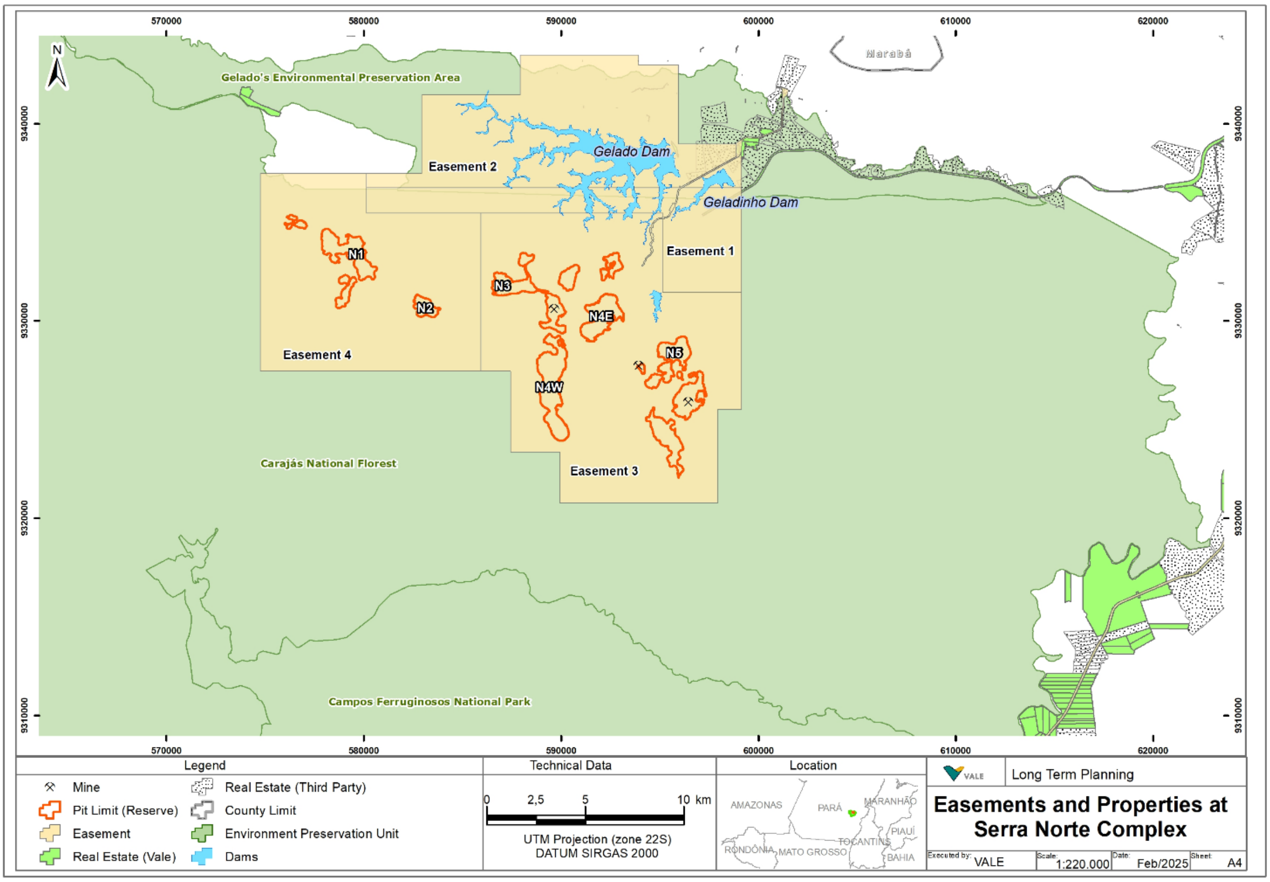


Figure 3-3 - Easements and properties at Serra Norte.

3.4. **Royalties**

In compliance with the Brazilian Mining Law, VALE is required to pay a monthly royalty of 3.5% on iron ore net sales, called "Financial Compensation for Mineral Resources Exploitation" (CFEM). The State of Pará also imposes a tax on mineral production called TFRM, which is currently calculated as BRL 14.4039 per metric ton of ore produced in or shipped out of the state.

This section details the licenses required to operate in compliance with Brazilian laws and which entitle VALE to mine, process ore, access water, treat effluents, use explosives, and draw from the power supply. The main licenses are listed in Tables 17-1 and 17-2.

4. Accessibility, climate, local resources, infrastructure and physiography

4.1. Physiography

The mine site is in the Amazon region at an average elevation of 800 meters.

There is a rich mosaic of plant life directly associated with the rocky substrate on the plateaus covered by ferruginous outcrops in the project areas.

The original forest near Serra Norte has been modified by large-scale agricultural and livestock activities, resulting in a mix of pasture and remnants of forest.

The national protected areas in Serra Norte vicinity are:

- Tapirapé-Aquiri National Forest;
- Itacaiúnas National Forest;
- Carajás National Forest;
- Campos Ferruginosos National Park;
- Tapirapé Biological Reserve;
- Xikrin do Cateté Indigenous Land;
- Igarapé Gelado Environmental Protection Area.

These areas add up to 1.2 million hectares which are relatively well preserved, in contrast to the anthropized areas in the surroundings.

4.2. Accessibility

Serra Norte is connected by paved highways (PA-275, PA-150 and PA-70) with nearby cities, including the City of Parauapebas and Canaã dos Carajás, which is 40 km from the mine site. The regional airport (Carajás airport) is serviced by daily flights connecting to local and interstate cities (e.g: Belo Horizonte).

The ore is shipped via the Carajás railway, connecting the mine to Ponta da Madeira port located in the city of São Luis, in the State of Maranhão.

4.3. Climate

The project area is in a humid tropical monsoon region with dry springs, hot weather, and high average temperatures. The coldest months are between January and March (18-21°C average), which coincides with part of the rainy season. The highest temperatures are recorded from June to August (35°C average).

The rainy season lasts from November to April, with average monthly precipitation of 400 mm, and the dry season is from May to October, with 24 mm monthly average precipitation. Annual precipitation ranges from 1,500 to 1,900 mm. The average temperature is 24.5°C, with the maximum average reaching 32.5 °C and the minimum is never lower than 18°C.

Humidity in the region is between 70 and 85% on average. In the driest months, June to August, it reaches a minimum of around 50%. During the rainy months, October to May, it can exceed 95%.

4.4. Local resources

The Serra Norte Operations is in the Carajás province in the State of Pará, Brazil. The nearest city is Parauapebas (population 305.771, census 2025), approximately 50 km east of the mine.

A greater range of general services, including hospital, accommodations, food, etc. is available in the city of Parauapebas, Canaã dos Carajás and even in state capital, Belém.

4.5. **Infrastructure**

The Serra Norte operation has the following main infrastructure:

- Water catchment points, pipelines, and a treatment station;
- Power line and substations;
- Maintenance workshops;
- Administrative buildings;
- Medical center;
- Offices and warehouses;
- Processing Plants I, II, and III.
- Semi-mobile crushers;
- Railway terminal;
- Ore stockpiles;
- Fuel stations;

Most of the workforce resides in Parauapebas and Canaã dos Carajás cities. A third party is responsible for the personnel transportation to the mine site.

Additional information on infrastructure is provided in Sections 15 and 18.

5. History

5.1. **Exploration and development history**

The first geological survey in Serra dos Carajás was carried out in 1922 by Avelino Ignácio de Oliveira, who revealed the occurrences of galena in São Félix do Xingu and carbonaceous material in the Fresco River. The first citations involving iron formations were made in 1933 when the engineer Luiz Flores de Moraes Rego referred to “flat-top hills where general fields are found” in the high region of the Itacaiúnas River. In 1951/1952, geographer Luiz Castro Soares conducted an aerial survey of the phyto-physiognomy of the region, where he observed the existence of non-forest formations with large clearings and lakes.

The first publication of Carajás can be seen in the aerial photograph of bodies C and D of Serra Sul in Carta do Brasil ao Milionésimo, published by IBGE in 1960, seven years before the discovery of the deposits (Magalhães, 1960). In this publication, the areas of elevated fields were wrongly classified by the author as “limestone plateaus with elevated lakes in the south of Pará”. As seen later, they correspond to iron plateaus and the lagoons fill sinkholes over cangas.

In 1967, the pioneering mapping “Stratigraphic, Structural and Economic Geology of the Araguaia Project Area” – DNPM/PROSPEC (1954 to 1966) was released. In this work, a complete aerial photogrammetric survey was carried out, but the occurrences of iron ore were not identified due to lack of fieldwork. Due to the presence of lakes, the land clearings were interpreted as karst relief. In the same year, the United States Steel (USS) created the Brazilian Exploration Program – BEP, to explore manganese, since it is strategic for the steel industry and for the American economy during the cold war. At the end of May 1967, reconnaissance flights were made between the Tocantins and Tapajós rivers.

In July 1967, the Brazilian Exploration Program team received the aerial photos of the Araguaia Project and verified the existence of several large land clearings in the forest, like those seen in the reconnaissance flights carried out in May 1967.

On July 31, 1967, the first helicopter landed in the Serra Arqueada hematite canga glade. In August, an overflight was made, at low altitude with a single engine plane, in the clearings of Serra Norte verifying the great similarity with the canga cover of Serra Arqueada and an aeromagnetic survey was carried out in Sereno, Serra Leste, Serra Norte, and Serra Sul. Preliminary field surveys of Serra Norte (N1, N2, N3, N4, N5) and Serra Sul were also conducted. In September 1967, potential of 2 to 35 billion tons of iron ore was communicated to the United States Steel in Pittsburgh (USA) .

Between September and October 1967, exploration requests were prepared and filed at Departamento Nacional de Produção Mineral (DNPM), covering a total of 160,000 hectares of Serra Norte, Serra Sul, Serra Leste and São Félix.

In April 1970, Amazônia Mineração S.A. was created, constituted 51% by VALE (at the time Companhia Vale do Rio Doce – CVRD) and 49% by United States Steel. The evaluation of the Carajás iron deposits began in 1970, carried out with air support, due to the lack of access by road. Between 1970 and 1972, intensive exploration work was carried out on the identified occurrences. CVRD geologists, led by engineer Aluízio Licínio de Barbosa, together with the United States Steel team, were responsible for estimating iron ore potentials in Serra dos Carajás. Total resources of about 18 billion tons of iron ore, with 66% Fe content, concentrated in four main deposits were determined: N4, N5, N1 (Serra Norte), and S11 (Serra Sul).

In 1977, VALE (CVRD) acquired the shareholding in United States Steel, being solely responsible for conducting the project. In 1979, the construction of the complex of the Carajás Iron Project started, integrating the mine, railroad, and port. In February 1985, the São Luiz – Carajás railroad was completed. Iron ore production began in 1985 in the N4E deposit, and the N4W deposit came into operation in 1994. Serra Sul operations started in 2016.

5.2. **Historical Productions**

Serra Norte historical production is summarized in Table 5-1.

Table 5-1 - Past production of Serra Norte mines.

Years	Ore (t)	Waste (t)	Total (t)	Product (t)
2016	159,919,775	62,535,175	222,454,950	143,560,547
2017	141,690,807	63,523,090	205,213,897	142,683,237
2018	134,443,397	73,349,550	207,792,947	131,536,360
2019	117,010,321	101,548,705	218,559,026	115,277,540
2020	110,185,273	100,758,725	210,943,999	109,123,167
2021	111,857,464	109,042,539	220,900,002	109,268,321
2022	98,395,822	98,779,988	197,175,810	96,257,770
2023	92,773,414	125,051,962	217,825,376	91,268,244
2024	89,358,640	115,295,328	204,653,968	87,587,239
2025	79,267,836	130,212,491	209,480,328	78,133,407

6. Geological setting, mineralization, and deposit

6.1. Regional geology

The Carajás Mineral Province (CKS) comprises an area of approximately 30,000 km^2 located in the southeast of Pará state and stands out as the main operating polymetallic province in the country, hosting world-class deposits and important mines of Fe, Cu, Au, Mn, and Ni.

The province occupies the eastern portion of the Amazonian Craton (Figure 6-1) and corresponds to the oldest core, of Archean age, limited by the Geochronological Province of the Central Amazon (1.9-1.7 Ga) to the west and by the Paraguay-Araguaia mobile belt (700-450 Ma) to the east (Santos, 2000 and Santos, 2003). Although the classifications of the Amazon Craton are a matter of debate in the scientific literature, the subdivision of its southeast portion is well accepted and justified, both from the geochronological point of view and from the orientation of its main structures. In this sense, the domains Rio Maria, of Mesoarchean age, with preferential N-S orientation, Carajás (Neoarquean), with WNW-ESE orientation, and Bacajá (Paleoproterozoic), with NW-SE orientation, are recognized. The tectonic evolution of this portion of the craton is not clear, and the boundaries between these domains are fuzzy and usually transitional.

The geological framework of the southeastern portion of the Amazon Craton is widely discussed in scientific literature, with different proposals for evolution, subdivision, and nomenclature. According to the definition by Tassinari and Macambira (2004), adopted here, the Carajás Mineral Province would fit into the Maroni-Itacaiúnas Geochronological Province, limited by the Central Amazon Province to the west, the Bacajá domain to the north, and the Araguaia Belt to the east. This geochronological province would be subdivided into the Rio Maria Granite-Greenstone Terrane Meso-Archaean domain Dall'Agnol et al., 1987;'Dall'Agnol et al., 1997, 2006; Althoff et al., 2000) and the Carajás Neo-Archaean domain (Araújo and Maia, 1991; Vasquez et al., 2008).

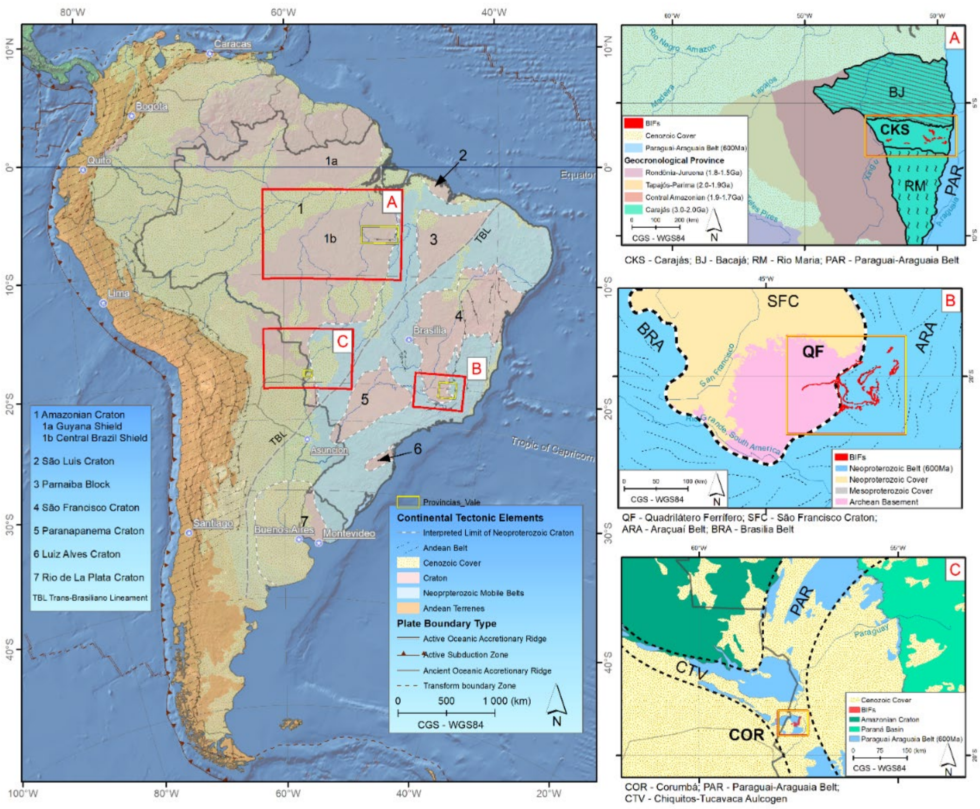


Figure 6-1 - Tectonic map of South America (Cordani et al. 2016; Gómez et al. 2019), with localization of the Brazilian mining provinces operated by Vale.

6.1.1. Stratigraphy

In general, the Carajás Mineral Province is composed of three main litho-structural domains intercalated according to elongated ranges in the WNW-ESE direction. The main mineralized domain encloses the succession of metavolcanic sedimentary rocks of the Itacaiúnas Supergroup (DOCEGEO, 1988), cut by anorogenic granites, several generations of intrusive rocks, and covered by sediments of varying age. This unit is limited by a granite-gneissic basement to the north and south and a Mesoarchean granite-greenstone belt sequence to the east, correlated to the Andorinhas Supergroup (Figure 6-2 and Figure 6-3).

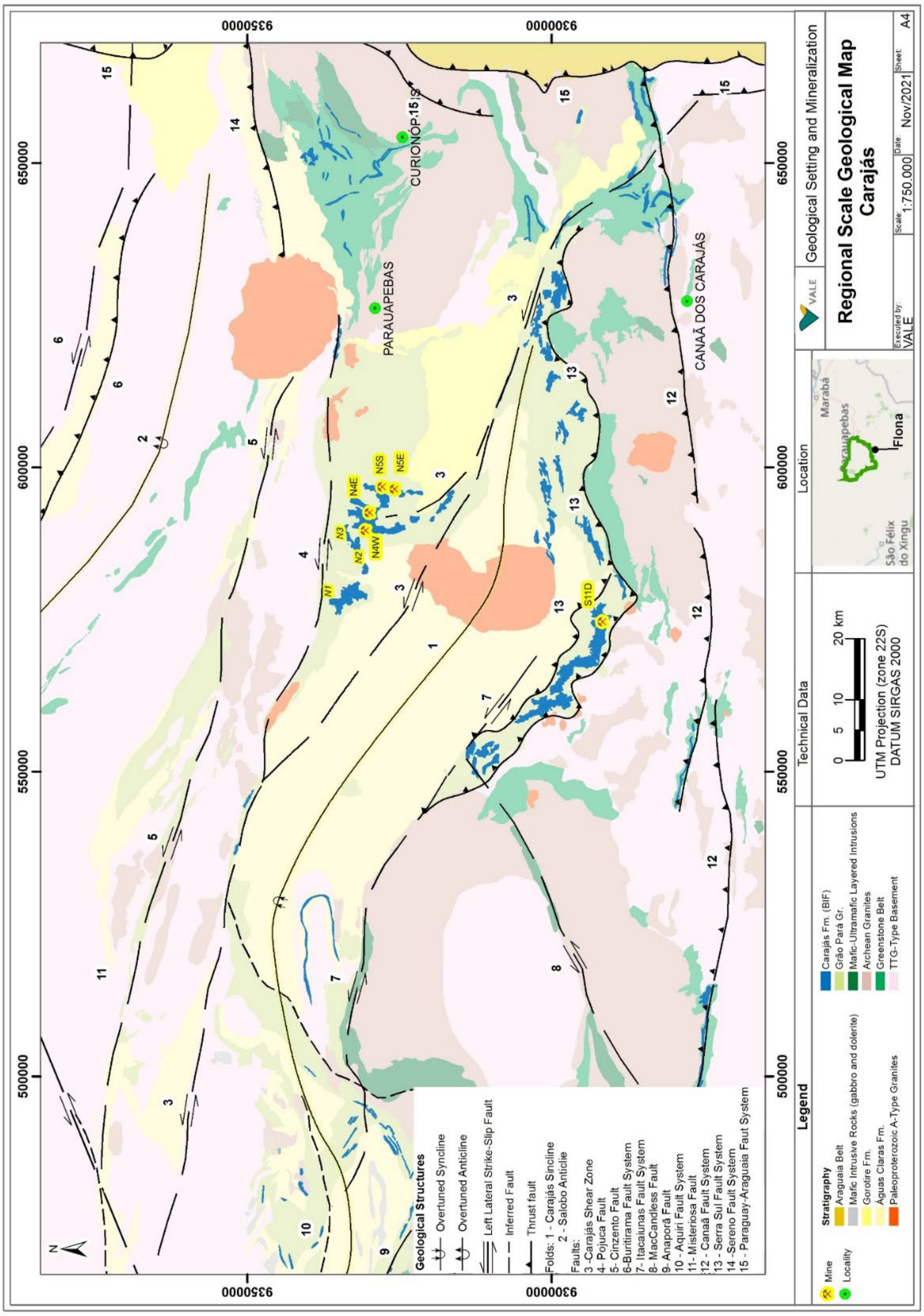


Figure 6-2 - Geological Map the Carajás Mineral Province (Costa et al., 2017).

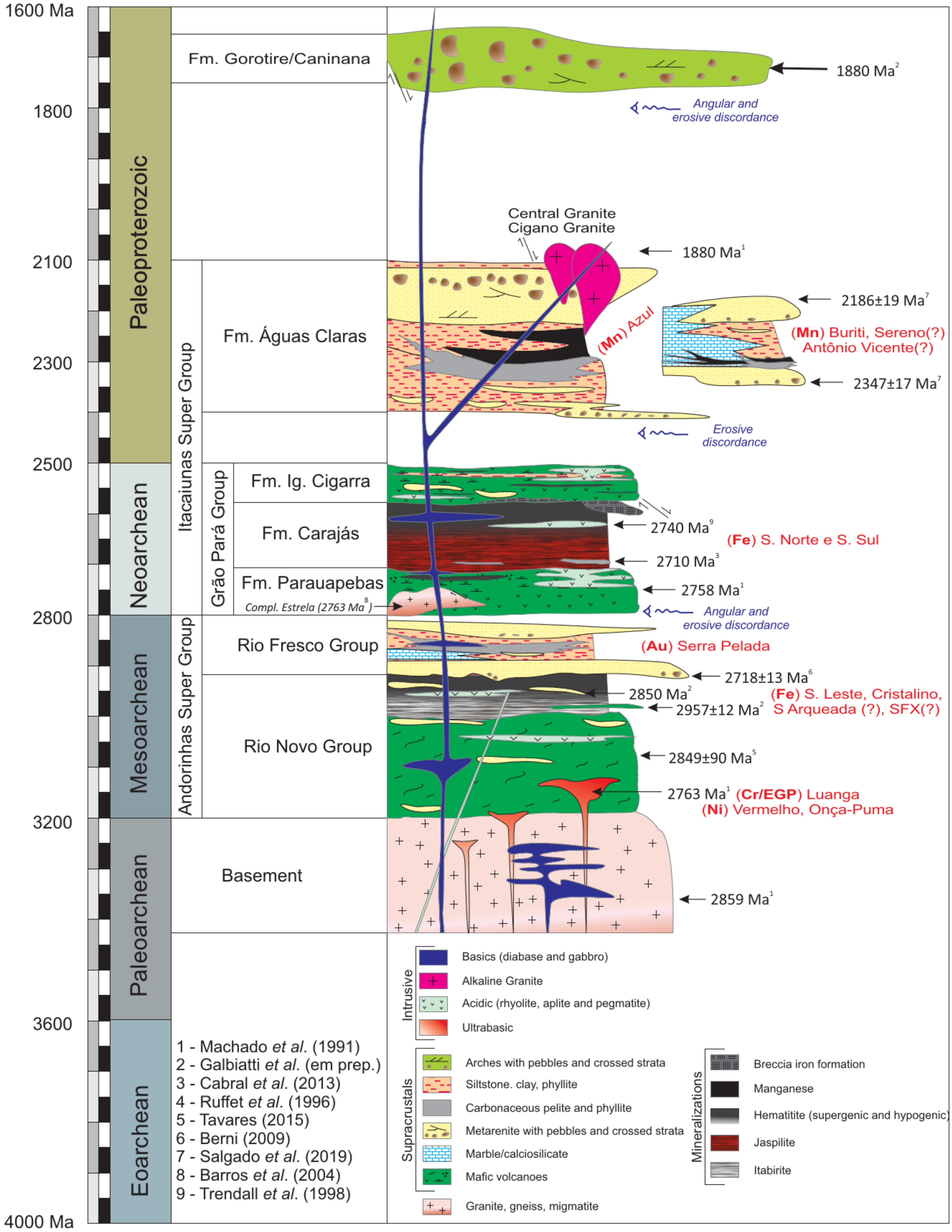


Figure 6-3 - Stratigraphic Column of the Carajás Mineral Province.

6.1.2. Granite-gneiss terrains

The granite-gneiss terrains comprise a set of Tonalite-trondhjemite-granodiorite (TTG) granites and gneisses, amphibolites, and migmatites predominant in the northern and southern limits of the Carajás Mineral Province, originally attributed to the Xingu Complex (Silva et al., 1974; Hirata et al., 1982; DOCEGEO, 1988) which, with the increase in the geological knowledge, has been reviewed and subdivided, mainly in the southern portion of the Carajás Mineral Province.

Estrela Complex: defined by Barros (1997) as a set of granites, monzonite, syenite and diorite dating from 2,760 Ma (Barros et al., 2001), which intrude the base of the Andorinhas and Itacaiúnas supergroups in the Carajás Block.

Plaquê Suite: comprises bodies with syn-collisional granitic to granodioritic composition, with calcium-alkaline to alkaline character, dated 2,736 Ma (Avelar et al., 1999) and correlated to the Planalto and Serra do Rabo granites (Santos, 2003).

6.1.3. Andorinhas Supergroup

With wide representation in the Rio Maria Domain, the Andorinhas supergroup encompasses a Meso-Archaean succession (3.0 to 2.86 Ga) of the granite-greenstone belt type. It constitutes a metamorphic succession under greenschist to amphibolite facies conditions, composed of granitoids, mafic/ultramafic intrusive, and volcanic rocks, which occur intercalated with clastic and chemical sediments (Macambira and Lafon, 1995; Althoff et al., 2000; Souza; et al., 2001;'Dall'Agnol et al., 2006; Oliveira et al., 2009, 2011; Almeida et al., 2011, 2013). These lithologies were grouped by Santos et al. (2000) in the groups: Babaçu, Sapucaia, Lagoa Seca, Gradaús, Tucumã and São Félix do Xingu, in addition to the TTG granitoids (Arco Verde, Caracol, Mahogany and Cumaru) and calc-alkaline granitoids (Guarantã, Rio Maria, Mata Surrão and Xinguara). In the east and south portions of the Carajás domain, there is a set of metavolcanosedimentary rocks correlated to the Andorinhas Supergroup (DOCEGEO, 1988), here subdivided into the Rio Novo and Rio Fresco groups.

Rio Novo Group: originally defined in the Serra Leste region as a greenstone belt-type sequence, metamorphosed into greenschist facies, with mafic, ultramafic, and felsic rocks and sediments (Hirata et al., 1982; Meireles et al., 1982). The base of the package is composed of shales with varying proportions of chlorite and amphibole, which are interbedded with lenses of metasediments, including amphibolite itabirite, that grades to siliceous itabirite at the top.

Rio Fresco Group: originally defined as the entire Carajás cover (Hirata et al., 1982; Meireles et al., 1982; DOCEGEO, 1988), it is now restricted to metasediments that cover the rocks of the Rio Novo Group in the Serra Leste and Serra Pelada region. This unit is composed of a succession of meta-sandstones and metapelites (locally carbonaceous), with discontinuous levels of dolomitic marble (2 and Figure 6-23).

6.1.4. Mafic-ultramafic complexes

They are complexes such as Luanga (Medeiros Filho and Meireles, 1985; Suita et al., 1988; Ferreira Filho et al., 2007) and related ones (Onça-Puma, Vermelho and Madeira), dated 2,763 Ma (Machado et al., 1991) that occur as intrusions in the basement and the basal portion of rocks attributed to the Rio Novo Group (Figure 6-2 and Figure 6-3). They host Ni and Cr deposits and present the same deformation pattern as the Rio Novo Group shales, indicating contemporaneity. The strong deformation and evidence of metamorphism of the Gabro Santa Inês (DOCEGEO, 1988), which occurs as an intrusive anorthositic leucogabbro body in the basement and base of the Rio Novo Group, suggest chrono-correlated placement to the ultramafic rocks.

6.1.5. Itacaiúnas Supergroup

The Itacaiúnas Supergroup (DOCEGEO, 1988; Figure 6-2 and Figure 6-3) is a Neo-Archaean succession that encompasses the Grão Pará Group (CVRD/AMZA, 1972; Beisegel et al., 1973) and its correlated units (Igarapé Salobo, Igarapé groups Pojuca and Igarapé Bahia; DOCEGEO, 1988).

Grão Pará Group: was defined by CVRD/AMZA team (1972) and named in honor of the original name of the captaincy that currently corresponds to the state of Pará. It comprises a volcano-sedimentary sequence of neo-Archaean age, where the mineralized layer occurs interspersed with two layers of mafic volcanic rocks, named, from bottom to top, as Parauapebas Formation, Carajás Formation, and Igarapé Cigarra Formation.

The Parauapebas Formation was originally defined by CVRD/AMZA team (1972) as the Lower Paleovolcanic Sequence and later renamed due to the occurrence of felsic volcanics (Machado et al., 1991). The age of this unit is well defined by U/Pb dating, with results around 2,750 Ma (Wirth et al., 1986; Lindenmayer et al., 1998; Tavares, 2015). The succession occurs according to a stratiform body of indeterminate thickness (>200 m), which represents the stacking of several flows in conformable transitional contact (<1 m) with the overlying sediments.

The Carajás Formation was named by CVRD/AMZA team (1972) for forming the main crests of the Serra dos Carajás. This unit consists of iron formations deposited during the Neo-Archaean (2,740 Ma., Trendall et al., 1998) and is host to the world-class iron ore deposits of the Carajás Mineral Province. In general, it occurs as large discontinuous bodies, which define the relief in canga plateaus, which inhibit the growth of the tropical forest, typical of the surrounding region (Figure 6-4).

Figure 6-4 - Plateaus of S11D (left) and N1 (right) of Carajás Mineral Province.

The thickness of the iron formations varies between the different plateaus and is normally proportional to their area in plan, typically varying between 100-200 m, and may exceed 500 m in the main deposits (Figure 6-4). Hematites are distributed throughout the province and constitute high-grade ores (> 60% Fe). They are classified according to their compactness and contaminants (when present) and are associated with supergenic and hypogenic processes developed on jaspilite (Lobato et al., 2005; Silva et al., 2008). Friable supergenic ore is the predominant type, occurring from the surface to average depth of 150 m, exceeding 300 m in the main deposits (Figure 6-5).

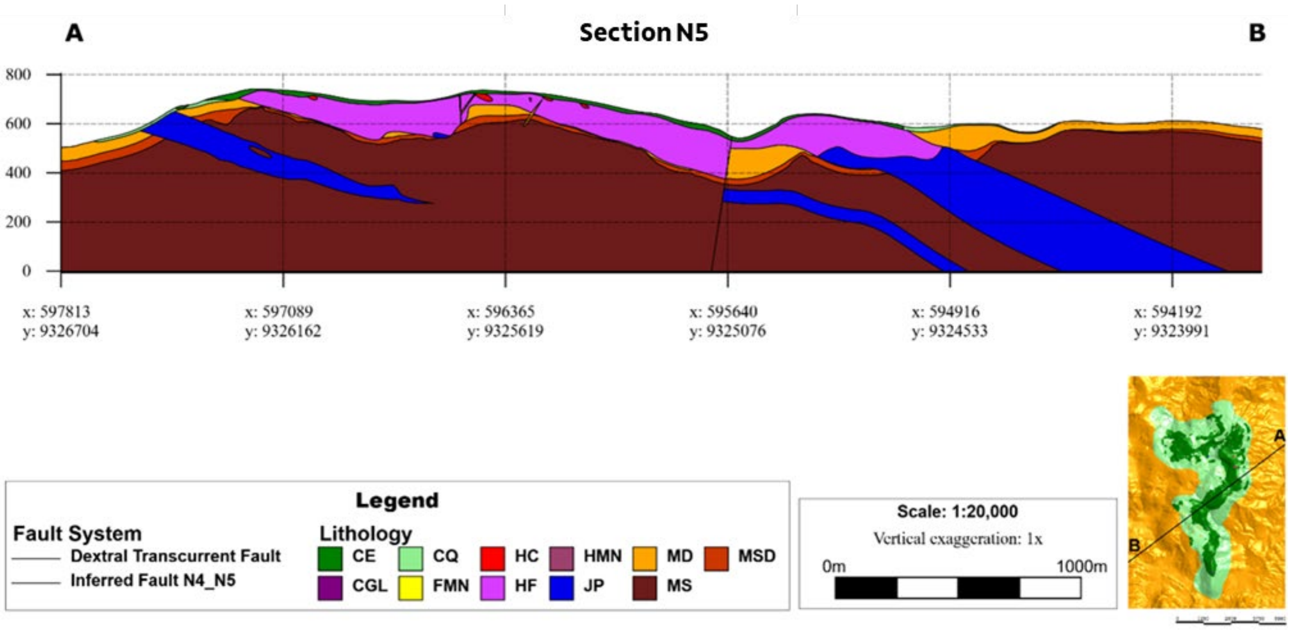


Figure 6-5 - Geological cross-section of the N5 mine, Carajás Mineral Province

The Igarapé Cigarra Formation was originally defined by CVRD/AMZA team (1972) as the Upper Paleovolcanic Sequence and later renamed due to the identification of sedimentary levels (Macambira, 2003). It occurs according to a stratiform body, in conformity with the banding of iron formations, with thickness of about 300-400 m (CVRD/AMZA, 1972). It is predominantly composed of basalts with intercalations of tufts and clastic sediments and iron formation lenses (Macambira, 2003). In Serra Sul, the contact between the Carajás Formation and the Igarapé Cigarra Formation is locally marked by a breccia horizon in the iron formation.

6.1.6. Proterozoic covers and intrusions

The Águas Claras Formation is the main sedimentary cover overlaying the Grão Pará Group in the Carajás Mineral Province. It was originally defined by CVRD/AMZA team (1972) as the Gorotire Formation, later renamed the Rio Fresco Formation (Hirata et al., 1982; DOCEGEO, 1988), receiving its current name from the works of Nogueira (1995), who characterized the sedimentation environment of this unit. It constitutes a package of pelites and sandstones about 1,500 m thick, respectively subdivided into the Lower and Upper members, which occur superimposed to the rocks of the Grão Pará Group by erosive unconformity (Figure 6-3). The age of this unit is not well defined yet, but recent studies indicate that its deposition would be younger than 2.45 Ga (Cabral et al., 2017), compatible with the age range defined for quartzites from the Buritirama Formation (2,186-2,347 Ma, Salgado, et al., 2019). The manganese ore from the Azul mine is associated with the pelites of the Lower Member of this unit, which is correlated, in terms of age and environment, with the Buritirama manganese mine and the Sereno and Antônio Vicente deposits.

Serra dos Carajás Suite comprises a set of anorogenic alkaline to calcium-alkaline granites and post-tectonic acid dikes that cut the rocks of the Xingu Complex, the Andorinhas Supergroup, the Itacaiúnas Supergroup, and the Águas Claras Formation (DOCEGEO, 1988). The Central, Cigano, Pojuca, and Musa granites are dated between 1,800-1,900 Ma (Gibbs et al., 1986; Machado et al., 1991); therefore, chronocorrelates to Uatumã Magmatism.

The Gorotire Formation also known as the Caninana Unit (Pereira, 2009; Pereira et al., 2009), constitutes a siliciclastic cover composed of conglomerates and arcosean sandstones about 300 m thick (Barbosa et al., 1966), formed in an anastomosing river environment (Oliveira and Nascimento, 2013; Nascimento and Oliveira, 2015) in a restricted basin developed during the reactivation of the Carajás Fault (Lima and Pinheiro, 2001).

Mafic Intrusives: the Rio da Onça Gabro (Tavares, 2015) and the Rio Pajeú Diabásio (Macambira et al., 2014) occur as undeformed dykes with direction close to N-S, cutting through all aforementioned units. These dikes continue for hundreds of kilometers and have a strong magnetic signature, being easily observed in aerial survey products.

6.1.7. Cenozoic units and recent coverage

Cangas: commonly formed from the weathering of iron formations or the residual concentration of iron and aluminum oxides from the host rocks. They are divided, depending on their structure, composition, and iron content, into structured (rich or ore), detrital, and chemical (or laterite) types. They usually have high concentrations of aluminum, phosphorus, and manganese, which do not favor their use as ore. However, they can make up a fraction of ROM in a diluted form, being, therefore, subject to economic use. Big part of the caves recorded in Carajás is associated with cangas domains, mainly on the edge of the plateaus.

Eluvium-colluvial deposits: form small discontinuous deposits of little economic interest at the base and the slopes of the plateaus.

Alluviums: do not form significant iron ore deposits.

6.1.8. Metamorphism and deformation

The Carajás Mineral Province registers a polyphase tectonic evolution, attested by its wide range of age distribution and by the high complexity of its structural arrangement (Figure 6-2 and Figure 6-3).

The compilation of structures and geochronological data supports the interpretation of three main moments of deformation (or tectonic cycles), responsible for the architecture of the Carajás Mineral Province:

The Archean Cycle comprises the main period of crustal growth in the Carajás Mineral Province, responsible for the formation and deformation of the TTG basement (Xingu Complex and related), deposition and deformation, with low-grade metamorphism, of the rocks of the Andorinhas Supergroup, ending with the sedimentation of the Grão Pará Group. Recent studies (Ganad et al., in prep.) propose its subdivision into events: G1 (3,015-2,920 Ma), G2 (2,880-2,835 Ma), G3 (2,780-2,720 Ma) and G4 (2,590-2,530 Ma). The first two events are associated with dome-and-keel tectonics. The latest events related to the opening of the Carajás Basin and the development of the first IOCG system.

The main structures attributed to this cycle are folds with the axis around E-W, present in the basement and greenstone belt sequences of the Andorinhas Supergroup (such as the Serra Pelada synclines, Rio Maria; DOCEGEO, 1988), and the implementation of a fault system (Carajás and Gray faults), at first with sinistral trans-tensional character (Araújo and Maia, 1991; Pinheiro, 1997; Pinheiro and Holdsworth, 2000).

The Paleoproterozoic Cycle is the event responsible for the current geometry of the province. It occurred with no record of significant metamorphism and is recorded in SSW-verging regional-scale folds, such as the Carajás Syncline (CVRD/AMZA, 1972; Beisegel et al., 1973). This event is also responsible for the reactivation of faults in the dextral transcurrent regime (Araújo and Maia, 1991; Pinheiro, 1997; Pinheiro and Holdsworth, 2000) and for the placement of the first IOCG system (Ganad et al., in prep.).

Faults and folds correlated to this cycle are important from a prospective point of view, as they interfere in the thickness and the geometry of iron formations and may have been responsible for the hypogenic formation of high-grade bodies.

The Neoproterozoic/Paleozoic Cycle is equivalent to the Brasiliano orogeny (700-450 Ma), which defines the current cratonic limits of the interior of the South American Platform (Almeida et al., 1973; Almeida et al., 1981; Cordani et al., 2016; Gómez et al., 2019). This event expresses the development of a moving belt that verges westward and is characterized by a sequence of N-S direction folds and faults. It is mainly marked by the development of brittle-ductile structures, such as kink-style folds, usually with an axis around N-S that occur at various scales, in addition to the intrusion of mafic dykes with orientations similar to these fold axes.

The structures of this cycle interfere in the deposits, with variation in the thickness and the geometry of the iron formations (either by duplication of layers due to folding and faulting or omission of these layers, due to faulting), in addition to the hypogenic formation of high-grade bodies in fault zones.

6.2. **Local geology**

6.2.1. Physiography

The plateaus of the Serra Norte Complex generally constitute elevated areas, with elevations between 650-800 m, limited by the domain of volcanic rocks of the Parauapebas Formation to the north, which configure an extensive plain, with elevations between 200-400 m, and by the domain of terrigenous sediments of the Águas Claras Formation to the south, which present morphology of intercalated crests and valleys, aligned according to the NW-SE direction, with elevations ranging from 500-700 m (Figure 6-6).

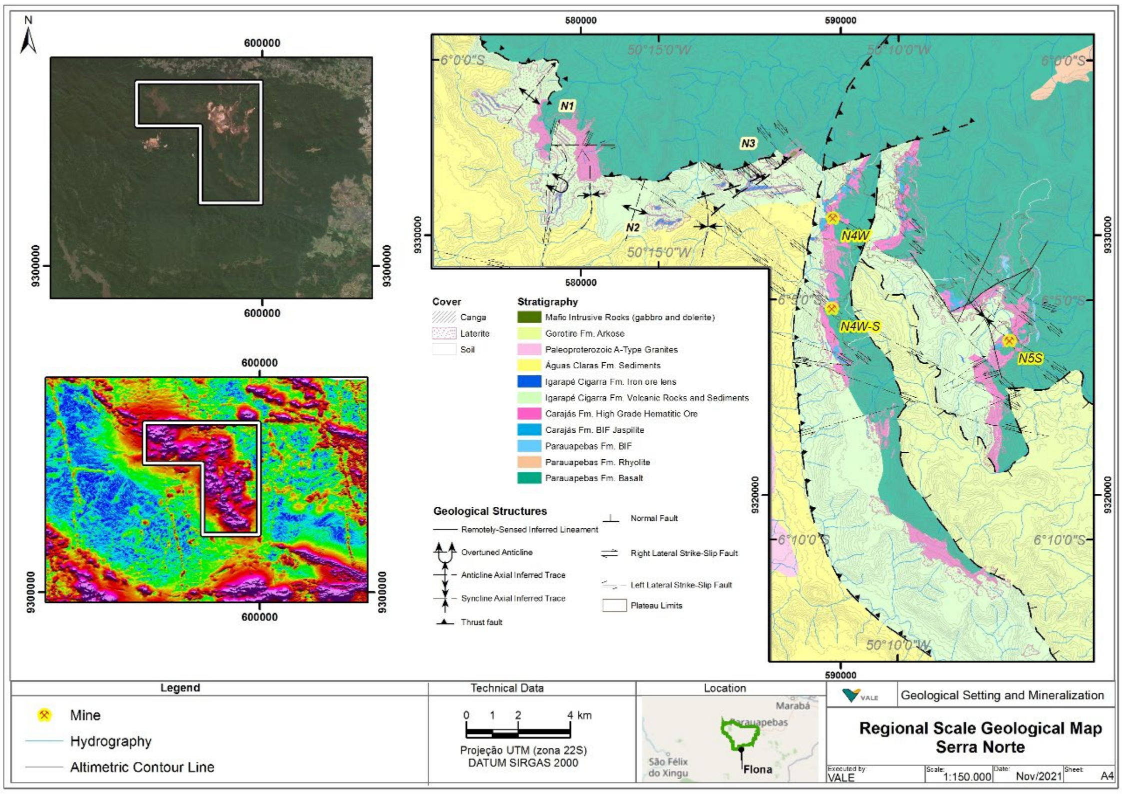


Figure 6-6 - Geology of the Serra Norte Complex (right) and satellite and aero-geophysical (MAG) images

6.2.2. Stratigraphy

The Serra Norte stratigraphic succession encompasses the entire Grão Pará Supergroup and Águas Claras Formation, in addition to the Cenozoic and recent sedimentary covers.

The main iron ore deposits are mostly hosted at Fm. Carajás, which is part of the Neo-Archaean metavulcanosedimentary sequence of Grão Pará Group (Itacaiunas Supergroup), which superimposes the crystalline basement and the Mesoarchean greenstone belt sequence of the Andorinhas Supergroup and are covered by the terrigenous sediments of the Águas Claras and Gorotire formations and was cut by acidic and basic intrusive rocks.

Mafic rocks are the host rocks of the iron formation, occurring both at the base and at the top of it. They are represented by the mafic rocks of the Parauapebas (bottom) and Igarapé Cigarra (top) formations, according to Macambira (2003). Mafic rocks mainly correspond to basalts. For geological modeling purposes, they were not classified in the mentioned stratigraphic units, and are considered only as mafic rocks, discriminated into decomposed mafic (MD), semi-decomposed mafic (MSD), and fresh mafic (MS). In addition to their occurrence as host rock (top and base of the iron formation), they also occur as sills and mafic dykes in iron formations (Figure 6-67).

Decomposed mafic (MD) – It presents a high degree of alteration, poorly structured, with color ranging from reddish to yellowish, clayey, with predominantly soft consistency.

Semi-decomposed mafic (MSD) – It is an intermediate-term between MS and MD, sometimes still showing relicts from the original texture of the rock, but already with deep mineralogical transformation, and consequently, in its color.

Fresh mafic (MS) – rock not affected by weathering, systematically chloritized, and corresponding to the product of the hydration of basalts and diabases. Its color is dark green, sometimes with typical volcanic structures, such as quartz amygdales. Compositional variations and even non-ferrous clastic and chemical sediments were grouped under this name to simplify the geological interpretations.

Conglomerate (CGL) – Occurs strictly in the Morro1 region, in the form of a lenticular body with high-energy clastic material at the base of the iron formation. It presents a siliceous matrix with sub-rounded centimeter-sized clasts of MS and, in a lesser proportion, angular centimeter-sized clasts of JP, thus exhibiting low maturity. It is mainly composed of silica, followed by iron and alumina, with an average thickness of 40m and can reach up to 75m.

Quartzite (QRT) – Corresponds to a tectonic breccia observed in N2 drill core samples, indicating intense tectonic activity in the southern region of the area. In the N2 region, the sandstones of the Águas Claras Formation are stratigraphically below the Grão-Pará Group, suggesting a thrust fault. This fault was responsible for the deformation and transformation of sandstones into quartzites. These breccias consist of a sequence of medium to coarse-grained quartzites, sometimes highly fractured and brecciated, composed of angular fragments of quartzite and ferruginous quartzite supported by chloritic-quartzose matrix. Mineralogically, they are composed of quartz and feldspar, with localized occurrences of sericite.

Figure 6-7 – Main Waste Lithotypes of Serra Norte

6.2.3. Mineralization

The Carajás Mineral Province hosts world-class deposits of Fe, Cu, Au, Mn, and Ni, resulting from polyphase tectonic evolution, accompanied by hypogenic and supergenic enrichment processes, developed on sedimentary and magmatic rocks of the Archean core of the Amazonian Craton.

Mineralization occurs mainly as a product of supergenic enrichment, developed on jaspilites (algoma-like BIFs interlayered with basalts) in high, flat-topped regions that make up the plateaus observable by remote sensors. The irregularity and discontinuity of the deposits along this mineral province demonstrates the existence of structures inherited from deformational events that favored the thickening of the jaspilite and the efficiency of supergenic processes through the tilting and fracturing of these rocks.

The different types of iron formation and host rocks of the Serra Norte district are described below (Figure 6-68). The mean grades mentioned refer to the average grades of the samples (weighted by length) of each lithotype modeled in this review, considering the interpreted classification (CLI).

The cangas represent a product of weathering on the rock sequences typical of the region. For modeling, they are divided into two different types: structural canga (CE) with iron grades greater than or equal to 55%, products of the weathering of iron formation, and chemical canga (CQ), which is covering the mafic rocks.

Chemical canga (CQ) – represents the iron-aluminous crusts that usually cover the decomposed mafic rocks. It has a colloform texture and high porosity. It often has a high content of Al_2O_3, evidenced by the light coloring of gibbsite and clay minerals. Hematite fragments are scarce or absent. In general, the iron grade is under 55%, with high phosphorus and Al_2O_3.

Structural canga (CE) – term commonly used by Vale to designate ferruginous lateritic crusts. It is usually located over iron ore outcrops *in situ*. It also occurs as transported canga, but at short distance from the source area, being a good indicator of the location of ore bodies. The thickness is variable, reaching more than 20 meters. It has iron grade above 55% and relatively low Al_2O_3 and phosphorus grades, thus allowing its potential use as iron ore.

Jaspilite (JP) – banded iron formation, usually of the oxide facies, composed of alternating bands of opaque minerals, such as hematite (predominantly), magnetite or martite, and reddish or white bands composed of jasper and/or chert. Hematite crystals occur mainly in the form of microcrystalline and lamellar hematite, in addition to martite and magnetite, magnetite being uncommon and generally martitized, with kenomagnetite relicts (Lobato et al. 2005). The jaspilite is reddish-gray and represents the ore protolith of the Carajás iron deposits. It occurs predominantly at the base of the iron formations, in contact with mafic rocks or as lenses, immersed in a large mass of friable hematite. The thickness of the lenses is usually small (a few meters), ranging from centimeters to about 20 m. The jaspilite that occurs in the basal portion can reach up to 350 m in thickness, the continuity in-depth in some regions of the mine is unknown. In the large mass of jaspilite, which constitutes the base of the iron formation, hematite lenses, more commonly friable hematite, are observed in regions close to the jaspilite/hematite top contact.

Friable hematite (HF) – is the predominant type of ore, occurring throughout all Serra Norte mines. It is commonly banded, locally showing primary lamination planes. It consists of a gray friable hematite material with metallic luster with high porosity. It can be powdery or disaggregate into small fragments (placoid or not).

Hematite crystals occur mainly in the form of microcrystalline, lamellar, anhedral-subhedral, and euhedral-subhedral hematite, in addition to martite, as magnetite pseudomorphs (Lobato et al. 2005). It is predominantly formed by the supergenic enrichment of the ore protolith (jaspilites). It has variable thickness in the enrichment profile, reaching up to 350 m and great continuity throughout the dip.

Compact hematite (HC) – a material rich in iron and, like HFs, generated from the weathering alteration of jaspilite. Its color varies from black to reddish-brown, the latter being typical of a goethite/limonite cementation, which is deemed be responsible for the high compactness of this lithotype. HC occurs subordinately throughout the entire deposit, like lenses inside the large friable hematite mass, usually with thicknesses around 5 to 10 m, without considerable lateral continuity (few tens of meters). Locally, it can reach thicknesses of up to 50 m. The color of HC is bluish-gray color with metallic luster. It is dense, with low porosity, and it can be banded, characterized by the original banding of the preserved jaspilite, defined by compact layers alternating with porous or brecciated layers. This lithotype can also be massive, with the original texture destroyed, composed of aggregates of hematite crystals. Fe grades are between 59 and 69%. Al_2O_3 represents an important contaminant in this lithology.

Manganiferous hematite (HMN) – The color of manganese hematite is dull dark gray, it occurs in lenses with thicknesses ranging from 5 to 10 m, and locally, it may reach thicknesses of 60 m, without much lateral continuity, dispersed within the mass of friable hematite. HMN is a material rich in Fe and with Mn grades greater than 2% (global). It is usually positioned at the base of the hematite bodies, a probable zone of accumulation of Mn leached from the weathered horizons.

Manganiferous Iron (FMN) – It is a material which apparently represents an intermediate product of the weathering alteration of jaspilite, enriched with Mn. It occurs as small lenses (usually a few meters thick, reaching up to 30 m), with little lateral continuity, within the mass of friable hematite.

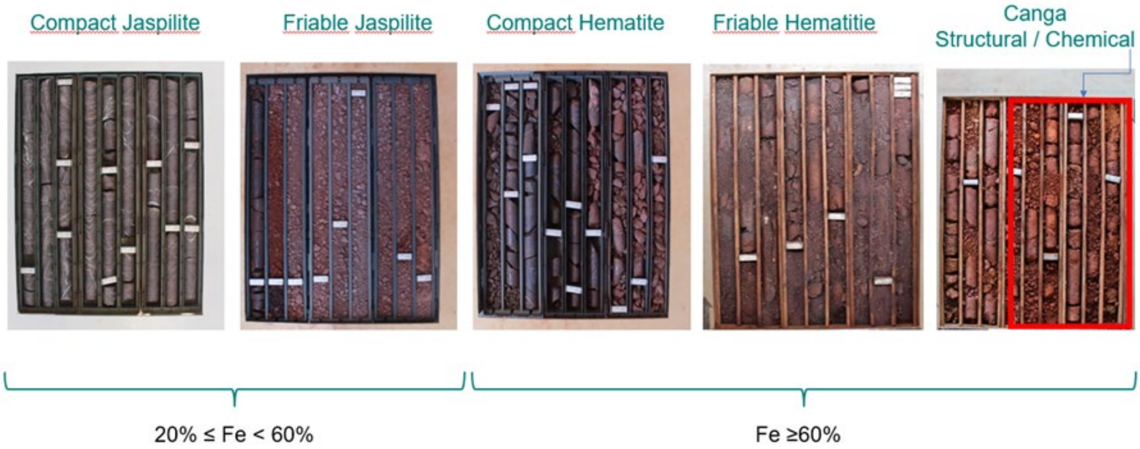


Figure 6-8 – The types of Iron formation in Serra Norte district.

6.2.4. Structural

In general terms, the main Carajás iron ore deposits are associated with flat-topped elevated plateaus, defined along two main morphological alignments corresponding to Serra Norte and Serra Sul. These alignments materialize the limb of the structure defined as Carajás Syncline (Figure 6-2) which reaches length of about 150 km and width of 100 km (CVRD/AMZA, 1972; Beisegel et al., 1973). The Serra da Bocaina region, also known as Água Boa plateau, corresponds to the closure zone of this syncline and has a large concentration of jaspilite type ore protolith. This region must not have experienced the ideal conditions for the formation of significant iron ore deposits or even for the preservation of possible previously formed deposit.

The Serra Norte Complex corresponds to the inverted limb geological domain of the Carajás Syncline. The high deformation pattern of this domain is reflected in the geometry and distribution of the iron formations, whose segmentation by faults, such as the Carajás Fault (Pinheiro and Holdsworth, 1997), and by folds of different orientations and scales, individualize the plateaus from N1 to SN9 (Figure 6-66).

6.3. **Property geology**

6.3.1. N1 Plateau

The N1 deposit is in the extreme west of Serra Norte and corresponds to part of the homonymous plateau (Figure 6-6).

6.3.1.1. Deposit dimensions

This plateau has an elongated shape in the NW-SE direction, with dimensions of about 6 km x 3 km and elevations between 650-800 m. It is predominantly composed of rocks from the Carajás and Igarapé Cigarra formations of the Grão Pará Group, which make contact with rocks of the Parauapebas Formation on the northeast edge of the plateau, and the Águas Claras Formation to the southwest. In general, the layers show medium to high angle dips to the northeast, configuring inverted stratigraphic setting. (Figure 6-99).

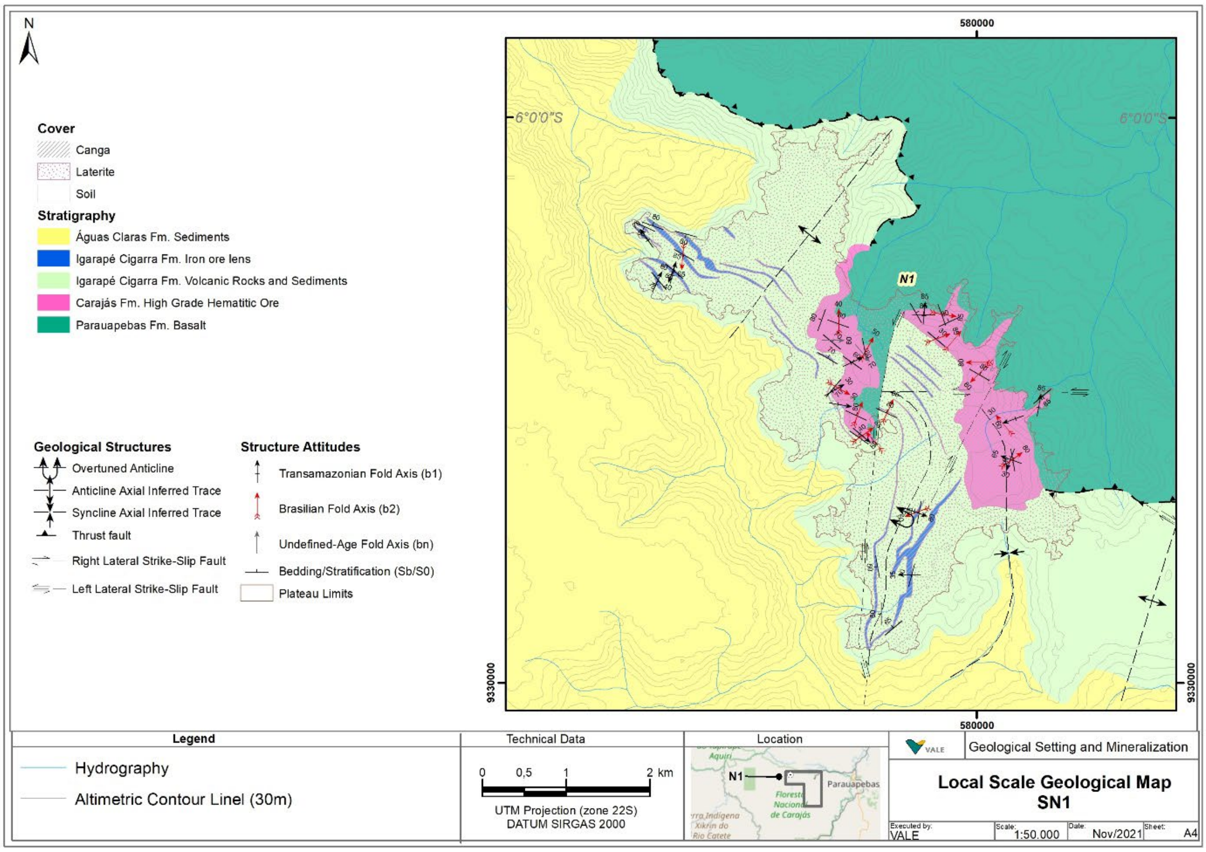


Figure 6-9 - N1 Geological map

6.3.1.2. Lithologies

The Parauapebas Formation occurs outside the plateau and marks the base of the Grão Pará Group. It is formed by a thick outflow of basalts and basaltic andesites, locally amygdaloid and vesicular, commonly hydro-thermalized, which occur underlying the rocks of the Carajás Formation, by a conformable transitional contact. In the N1 region, they are often represented by chloritites cut by carbonate and hematite veins.

The Carajás Formation comprises about 20% of the plateau area and corresponds to the thickest domain of the iron formations. It coincides with the highest elevations and occurs continuously along the northeast edge of the plateau, from the proximity of the contact with the rocks of the Parauapébas

Formation to its central portion, where it makes transitional contact with the rocks of the Igarapé Cigarra Formation Figure 6-910).

The iron formations of the Carajás Formation domain occur according to a sub-verticalized tabular layer with a variable dip either to the northeast or southwest. Thus, its thickness in plan tends to reflect the thickness of the layer, which varies between 250-600 m and is strongly controlled by folds and faults (Figure 6-109).

The Igarapé Cigarra Formation is made up of large volumes of volcanic rocks, mainly flows and tuffs, of bimodal nature, which occur interlayered with lenses of chemical sediments and, subordinately, terrigenous. The iron formations of this unit occur beside long vertical bodies with thickness varying between 30-200 m, 50 m average, generally in pairs of parallel layers, which reflect the folding process.

It is also observed, both in drill cores and in outcrops, that the N1 iron formations, mainly in the domain of the Carajás Formation, occur intercalated with several bodies of mafic rocks, with variable orientation, generally of not of great thickness. These bodies have a basic/intermediate composition and make contacts that are conformable or non-conformable with the compositional banding of the iron formations, configuring sills and dykes (Figure 6-1010).

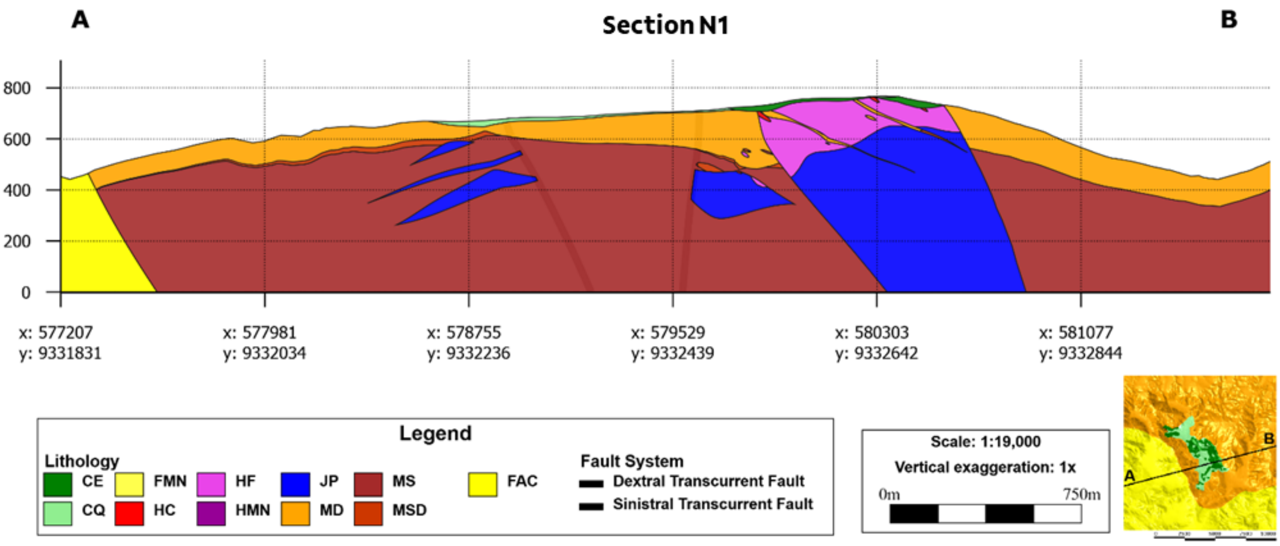


Figure 6-10 - N1 Geological section

6.3.1.3. Structures

In N1, the layers are arranged in NW-SE direction, and the outline in plan and vertical section of the N1 iron formations shows its strong structural control, in which faults and folds condition its thickness and continuity (Figure 6-9 and Figure 6-10). The main structures controlling mineralization have been recognized since the works from the 1970s (CVRD/AMZA, 1972; Beisegel et al., 1973) and will be presented below in chronological order, from the oldest to the youngest structure and related to the probable tectonic events responsible for its generation:

Structures correlated to Transamazonian tectonism:

• Thrust fault to SW, located to the north and east of the plateau, in the contact between the lithotypes of the Parauapebas Formation and the Igarapé Cigarra Formation (Figure 6-96). This fault marks the complete or partial omission of the rocks of the Carajás Formation, mainly outside the plateau domain;

• Closed fold axes to recumbent isoclines, with NW-SE direction and flanks dipping to NE, traceable for 1.5 km average, in rare cases longer than 3 km (Figure 6-96). These structures can occur rotated, due to the superposition of younger tectonic events, and are mainly observed in the iron formations of the Igarapé Cigarra Formation domain and more difficult to notice in the Carajás Formation domain, where they predominate in close contact with the rocks the Parauapebas Formation;

• Sinistral transcurrent fault of N-S direction, in the central portion of the plateau. This structure is characterized by the formation of breccias, rotation of structural elements (such as bedding and fold axes), and by the discontinuity of the main body of iron formation, which occurs in the west block with reduced thickness (Figure 6-106); and

• System of small sinistral transcurrent faults, NE-SW orientation, located in the central portion of the plateau and responsible for the extension of sections of the iron formation in the NE direction (Figure 6-10).

- Structures correlated to Brasiliano tectonism:

• Axes of open folds, with directions varying from NE-SW to NS, tracked over long distances, mainly observed in iron formations in the domain of the Igarapé Cigarra Formation, and in general, reflected as kink-style folds in iron formations of the Carajás Formation domain; and

• E-W direction sinistral transcurrent fault, positioned in the central portion of the plateau and responsible for the narrowing of the north portion of the main iron formation body. This fault occurs in association with a strong magnetometric anomaly and to a fractured zone approximately 500 m thick, locally brecciated. It is common to observe part of these fractures filled by-veins of compact magnetite up to two meters thick that transpose the banding, suggesting hydrothermal alteration. To the west of the large N-S transcurrent fault, the E-W direction fault takes dextral shear direction (Figure 6-96).

6.3.1.4. Mineralization

Mineralization at N1 is mainly formed from the supergenic alteration of jaspilite, which constitutes the Carajás ore protolith. The high-grade ore consists of friable hematite, compact hematite, and manganese hematite, which occur in a sub-horizontal tabular layer, which tends to follow the topographical surface, commonly covered by canga carapace, also considered as a mineralized lithotype.

The friable hematite (HF) corresponds to 80% of the mineralization, and in the area where the iron formation thickness is the greatest, the maximum thickness is 400 m, with average global iron grade of 66.388% Fe and average density of 3.03 g/cm^3. It has high porosity, dark gray color, and laminated to banded texture, locally foliated or brecciated. It can be powdery or disaggregated into small plaques and fragments. It is essentially constituted by iron oxides, mainly hematite and martite, with subordinate magnetite, in addition to goethite and limonite in the shallow depth horizons. Hematite crystals are mainly microcrystalline in lamellar, granular, or pseudomorphic forms in small euhedral-subhedral magnetite crystals. Near the contacts with mafic rocks, it is common to present contamination by manganese, aluminum and phosphorus, while silica appears as a contaminant in the vicinity of the contact with the jaspilites. HF also may contain small lenses/bands/passages of compact hematite.

Compact hematite (HC) corresponds to 7% of the mineralization and usually occurs along veins, filling fractures or associated with mafic rocks, suggestive of hypogenic origin. In general, it presents decimetric to metric thickness, maximum 87 m, average global iron grade of 66.41% Fe and average density of 3.69 g/cm^3. It is a bluish-gray rock, metallic luster and massive texture, rarely foliated, which can preserve banding relicts, marked by differences in texture and size of the crystals. It has low porosity and is essentially composed of iron oxides, mainly hematite, sometimes specular, and martite.

Manganese hematite (HMN) is very subordinate, corresponding to 1% of the mineralization. It usually occurs close to contact with mafic rocks, as discontinuous lenses up to 30 m thick, with average density of 3.81 g/cm^3 and about 61.72% Fe and 3.3% Mn. Its color is dark greenish gray, matte luster, with high porosity, and it is constituted by association of hematite, pyrolusite, bixbyite, ramsdellite, cryptomelane, chalcophanite, and hollandite.

The structured canga (CE) comprises 15% of the mineralization and constitutes superficial crust up to 47 m thick, formed by weathering processes directly on the mineralized types described above. It has average grade of 63.7% Fe, average density of 3.3 g/cm^3, evident banding, dark gray reddish color, and is composed of variable proportions of goethite, limonite, hematite, magnetite, and martite.

Although jaspilite (JP) is not a type mineralized in Carajás, it will be described here, as it is genetically related to mineralization, with which it makes transitional and gradational contacts, due to the locally sharp increase in iron grade, given by structural discontinuities. It occurs preferentially below the mineralized zone, in some cases inside it, close to the surface, raised by folds and faults, or resulting from incomplete alteration processes. It is characterized by high hardness and low porosity, with primary compositional banding and lamination of thickness ranging from 0.1-3 cm, average grade between 30-45% Fe and average density of 3.35 g/cm³. The banding is defined by the alternation of dark gray layers with metallic luster, composed of hematite, with subordinate magnetite and martite, which are intercalated with white to red and brownish siliceous layers, formed by cryptocrystalline quartz varieties. At depth, carbonate and hematite veins are commonly observed, probably associated with hypogenic processes.

6.3.2. N2 and N3 Plateaus

6.3.2.1. Deposit dimensions

The deposits of N2 and N3 are located on the homonymous plateaus, with an elongated shape in the E-W direction, in the central portion of the Serra Norte (Figure 6-6). The N2 plateau has dimensions of about 1 km x 1 km, while N3 reaches 3 km x 1.5 km, both with elevations between 650-700 m. The rocks of the Igarapé Cigarra Formation of the Grão Pará Group are predominant in these plateaus and make contacts to the north with rocks of the Parauapebas Formation and to the south with those of the Águas Claras Formation. In general, the layers show medium to high angle dip to the north, configuring inverted stratigraphic pattern (Figure 6-1111).

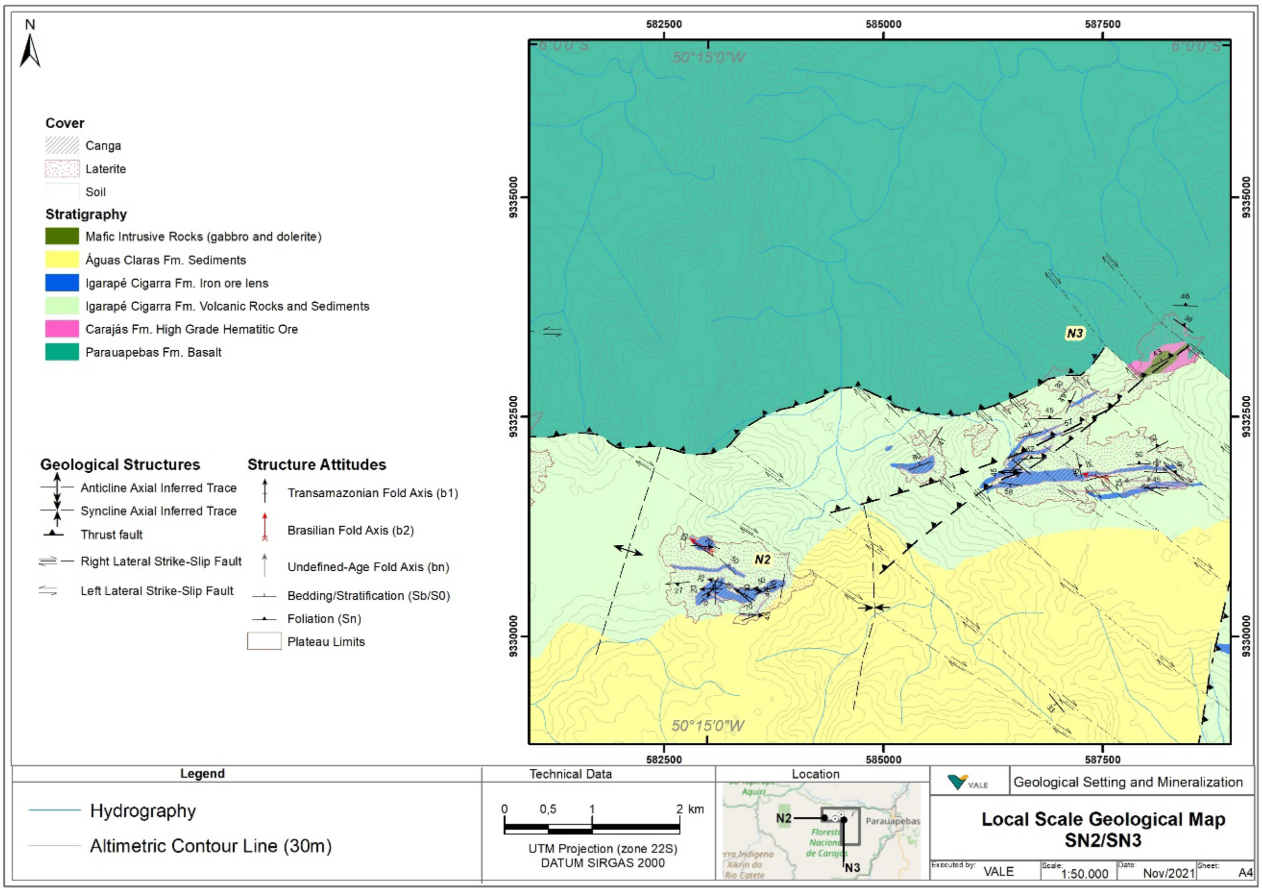


Figure 6-11 - N2 and N3 Geological map.

6.3.2.2. Lithologies

The Parauapebas Formation occurs in the low region after the northern edge of the plateau, where schist outcrops and probably represent the product of the deformation by faults on the chloritites found in the less deformed zones of the larger plateaus.

Most of the iron formations of the N2 and N3 plateaus were attributed to the Igarapé Cigarra Formation, except the extreme northeast portion of N3, which is correlated to the Carajás Formation. In general, they comprise about 20% of the area of the respective plateaus and do not stand out in the relief due to the low thickness.

The Igarapé Cigarra Formation is predominantly constituted of volcanic rocks interlayered with lenses of chemical and subordinate terrigenous sediments, identified in N2 drill cores. In this plateau, the iron formations occur according to sub-verticalized bodies, with thickness varying between 10-200 m, 100 m average, while in N3, they vary between 30-250 m, 150 m average (Figure 6-122).

The stratigraphic stacking on these plateaus is similar to that of the Igarapé Cigarra Formation on N1, as well as the main characteristics of its iron formations. These outcrops are parallel and continuous lenticular bodies, modeled as isolated layers in the stratigraphic stacking, in order not to overestimate the volume of iron formations in depth (Figure 6-1112). Unlike N1, these layers occur in N2 and N3 in a segmented way, broken by several strike-slip and thrust faults, usually oblique to the main direction of the layers.

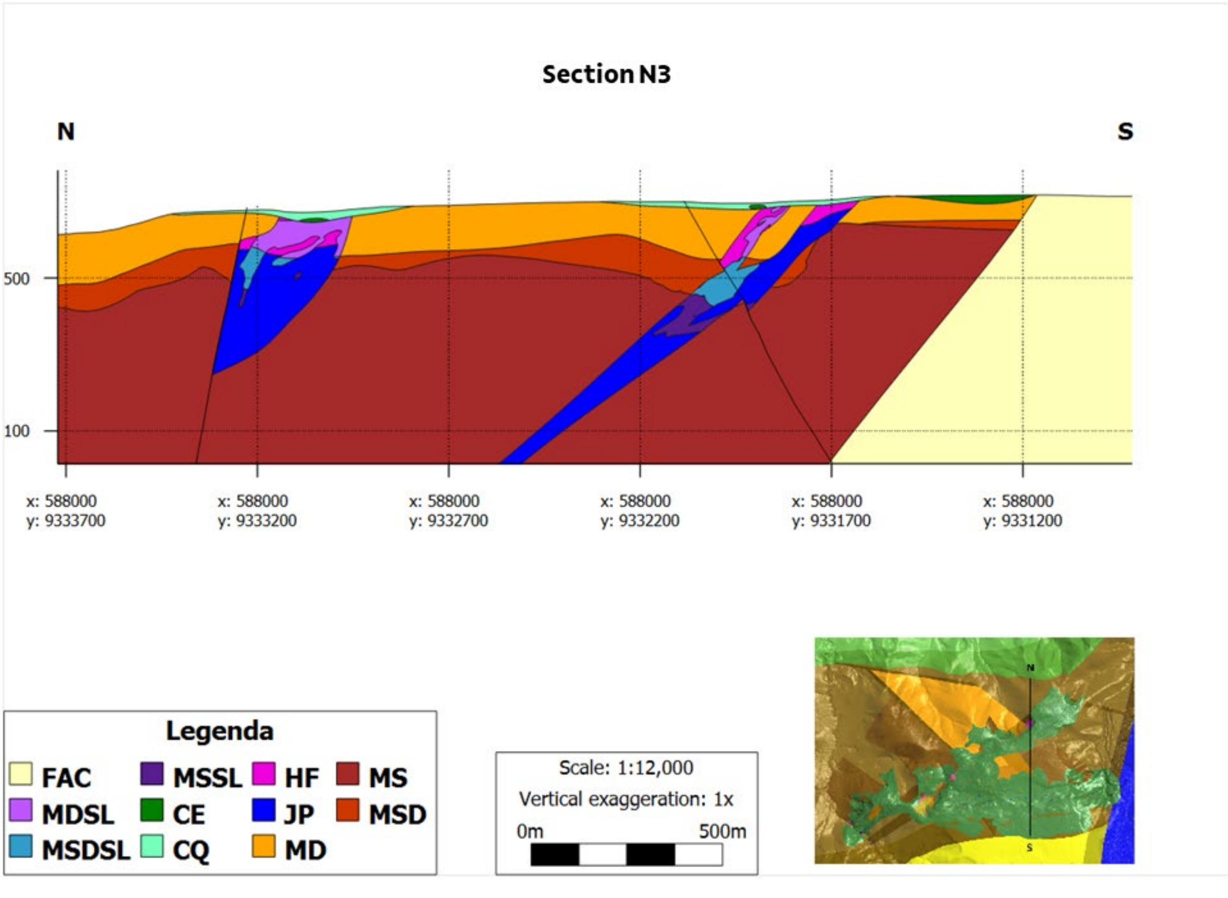


Figure 6-12 - N3 Geological section

6.3.2.3. Structures

The geological map of the N2 and N3 regions shows strong alignment of rock layers in the E-W direction (Figure 6-1111). Structural controls and their relative chronological ordering are similar to those described for N1, differing by the low continuity of iron formations, which reflects the importance of faults for the local geological framework.

Structures correlated to Transamazonian tectonism:

• E-W thrust fault with vergence to the south, located in the north of the plateaus, in the contact between the rocks of the Parauapebas Formation and the Igarapé Cigarra Formation (Figure 6-11). This fault marks the omission of the rocks of the Carajás Formation, except the extreme northeast portion of N3. Thrust faults with NE-SW direction, verging to SE, derive from the large E-W fault, locally constituting a fault system;

• Although the repetition of layers has been interpreted as a result of stratigraphic stacking, this could also be explained by folding. The rheology of rocks from the domain of the Igarapé Cigarra Formation is very favorable to this process, and in this case, it would originate closed folds to recumbent isoclines with an axis in the NE-SW direction, verging towards SE, compatible with the Transamazonian tectonism; and

• System of long dextral strike-slip faults with NW-SE orientation, located mainly in the N3 plateau, responsible for the segmentation of the iron formations, which is articulated with the small sinistral strike-slip fault system, with NE-SW orientation, in the central portion of N2, compatible with the Transamazonian tectonism (Figure 6-1111).

Structures related to Brazilian tectonism:

• Axes of open folds, with direction varying from NE-SW to N-S, mainly observed outside the plateau domain and reflected as kink-style folds in the iron formations.

The iron formations of the Carajás Formation domain occur restricted to the northeast sector of N3, according to a sub-verticalized tabular layer, with northwest dip cut by a significant passage of mafic rock, associated with a thrust fault (Figure 6-1111).

Basic to intermediate composition mafic sills and dykes with small thickness and variable orientation are mainly observed in drill cores intercalated with N2 and N3 iron formations.

6.3.2.4. Mineralization

The mineralization of N2 and N3 is formed through the alteration of jaspilite and has characteristics very similar to those described above for N1. For this reason, it will be addressed briefly here, emphasizing mainly its exclusive aspects in the area of plateaus under consideration (Table 6-1 and Table 6-2).

Table 6-1 - Characteristics of the mineralization in N2

Lithotype	Deposit partition (%)	Maximum section thickness (m)	Average iron grade (%Fe)
Friable Hematite (HF)	84	200	66,24
Canga (CG)	12	55	63,67
Compact Hematite (HC)	4	45	66,01
Manganiferous Hematite (HMN)	< 1	25	61,56

Table 6-2 - Characteristics of the mineralization in N3

Lithotype	Deposit partition (%)	Maximum section thickness (m)	Average iron grade (%Fe)
Friable Hematite (HF)	66	160	65,07
Canga (CG)	24	45	62,51
Compact Hematite (HC)	10	50	65,43
Manganiferous Hematite (HMN)	< 1	1	58,44

6.3.3. N4 Plateau

6.3.3.1.1. Deposit dimensions

The N4 Mine is subdivided into several pits, called N4WN, N4W, N4WC, N4WS, N4EN, and N4E, distributed along the homonymous plateau, in the central-east portion of Serra Norte (Figure 6-13). The N4 Plateau has big dimensions and is composed of rocks from the Carajás, Parauapebas, and Igarapé Cigarra formations, with a tabular shape and general dip to the west configuring a normal stratigraphic stacking. Prior to the start of mining, the plateau was already divided into the east and west portions by a drainage that separates the two main bodies of iron formations. The eastern portion has an elongated shape in the N-S direction and dimensions of about 8.5 km x 1 km, while the west is more regular, with average dimensions of 4 km x 2 km, both with elevations between 650-750 m (Figure 6-13).

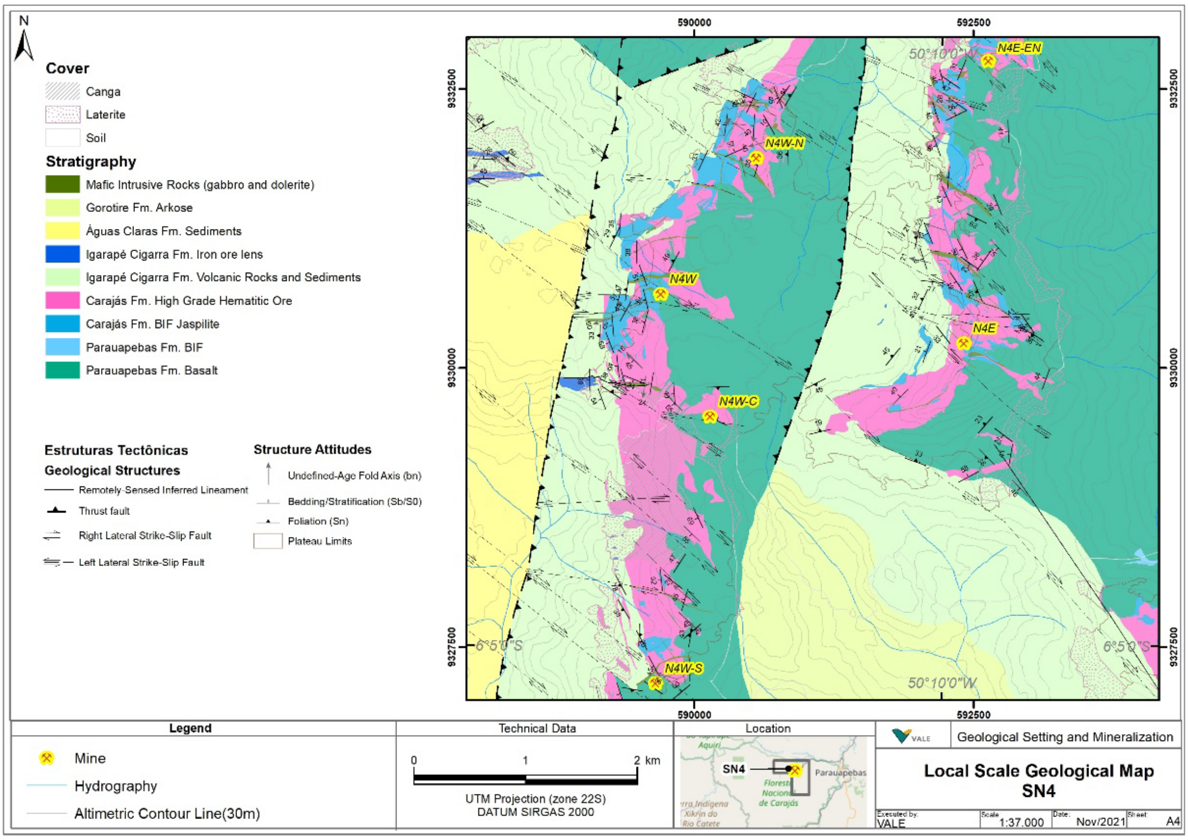


Figure 6-13 – N4 Geological map

6.3.3.2. Lithologies

The rocks of the Parauapebas Formation predominate in the eastern portion of the plateau, underlaying the rocks of the Carajás Formation by a conformable transitional contact, but they also occur in the central portion, in contact by fault with the rocks of the Igarapé Cigarra Formation (Figure 6-13).

The Carajás Formation occurs continuously in the central portion of the plateau and comprises about 40% of its area. This unit coincides with the highest elevations and corresponds to the domain with the highest thickness of iron formations, which are strongly controlled by strike-slip faults and present thickness between 200-500 meters, in plan Figure 6-13).

The Igarapé Cigarra Formation overlaps the Carajás Formation by a conformable transitional contact, outcropping to the west thereof. It consists of large volumes of bimodal volcanic rocks, interlayered with small lenses of iron formations, with thickness varying between 5-100 m (Figure 6-13).

The terrigenous sediments of the Águas Claras Formation overlap the domain of the Igarapé Cigarra Formation to the east of the plateau boundary.

Intrusive rocks define bodies of metric thickness and variable orientation that tend to follow the fault planes and cut through the entire Grão Pará Group sequence. These rocks have basic/intermediate composition, predominantly fine texture, and conformable to non-conformable contacts with the bedding and the banding, configuring families of sills and dikes (Figure 6-14).

The Gorotire Formation arkoses are considerably younger and occur limited by large normal faults, which define a graben, located in the southern portion of the plateau (Figure 6-14).

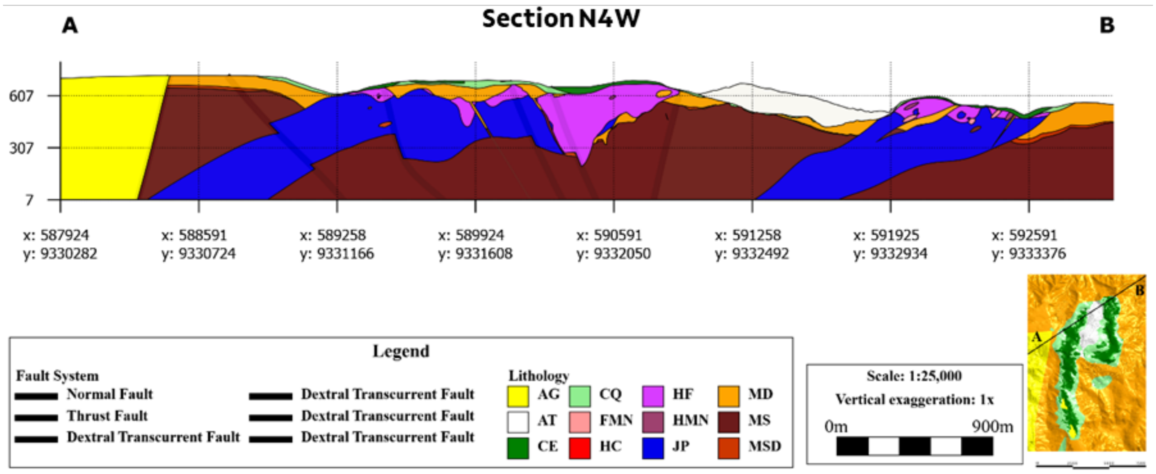


Figure 6-14 – N4W Geological section

6.3.3.3. Structures

On the N4 plateau, the Carajás Formation assumes a strong N-S trend and defines two occurrence belts called N4W and N4E, with a distinct structural pattern, separated by an eastward verging thrust fault (Figure 6-13).

The N4W region is relatively simpler and behaves like a homocline, with layers generally aligned in the N-S direction, segmented by several transcurrent faults in the NW-SE direction (Figure 6-13).

The N4E region is more complex, given the rotation of the banding, which dips to the north in the southern portion of the deposit, defining a fold that, in plant view, takes the shape of the letter "J," caused by the drag of the mineralized layer along the large dextral strike-slip faults (Figure 6-13).

Structures correlated to Transamazonian tectonism:

• ENE-WSW thrust fault, with a southern vergence, located north of the plateau, in the contact between the rocks of the Parauapebas Formation with those of the Carajás and Igarapé Cigarra Formations (Figure 6-13). This fault is compatible with the tectonic vector and necessary to justify the direct contact between the rocks of the Parauapebas and Igarapé Cigarra formations;

• System of long dextral strike-slip faults, with NW-SE orientation, which is articulated with small dextral transcurrent faults, of E-W orientation, responsible for the segmentation of the iron formations (Figure 6-13); and

• Open folds with a sub-horizontal axis in the E-W direction mainly observed in the northern portion of the plateau.

Structures correlated to Brasilian tectonism:

• Thrust faults with N-S direction, verging both east and west, which seem to be the product of the reactivation, during Brasiliano, of splays from the Carajás Fault formed in Transamazônico;

• Reactivation of faults with NW-SE orientation, giving sinistral kinematics to these, mainly in N4E (Figure 6-13); and

• Kink-style folds that form with varying scales of occurrence and axis orientations, mainly present in the iron formations.

6.3.3.4. Mineralization

As already described for the previous deposits, N4 mineralization is formed after the alteration of jaspilite and will be addressed briefly here, with emphasis mainly on the unique aspects of the area under consideration (Table 6-3).

Table 6-3 - Characteristics of the mineralization in N4

Lithotype	Deposit partition (%)	Maximum section thickness (m)	Average iron grade (%Fe)
Friable Hematite (HF)	94	470	66,58
Canga (CG)	4	77	63,54
Compact Hematite (HC)	1	116	65,97
Manganiferous Hematite (HMN)	1	92	61,76

6.3.4. N5 Plateau

6.3.4.1. Deposit dimensions

The N5 Mine is subdivided into five pits called N5W, N5N, N5E, N5S, and M1, distributed along the homonymous plateau, located in the extreme east of Serra Norte (Figure 6-15). This plateau has dimensions of 7 km x 1.5 km, altitudes between 650 m and 800 m, and elongated geometry in the NNW-SSE direction. The geometry of the plateau suffers a strong curvature in the north-central portion as a reflection of interference by folding. It comprises rocks from the Parauapebas, Carajás and Igarapé Cigarra formations, of the Grão Pará Group. The iron formations occupy the central portion of the plateau and contact with the rocks of the Parauapebas Formation to the east and north, and those of the Igarapé Cigarra Formation to the west. In general, the layers show general dip to the west direction, configuring a localized normal stratigraphic stacking.

6.3.4.2. Lithologies

The Parauapebas Formation was mapped on the east and north edges of the plateau, in contact with the Carajás Formation. This corresponds to the thickest domain of the iron formations, which outcrop continuously, with thickness between 100-700 m in plan, in the central portion of the plateau, and comprises about 40% of its area, coinciding with the highest elevations and controlled by faults and folds (Figure 6-15). The Igarapé Cigarra Formation overlaps the Carajás Formation by a conformable transitional contact, outcropping to the west. It consists of large volumes of bimodal volcanic rocks, interlayered with small lenses of iron formations, with thickness varying between 10-60 m (Figure 6-16).

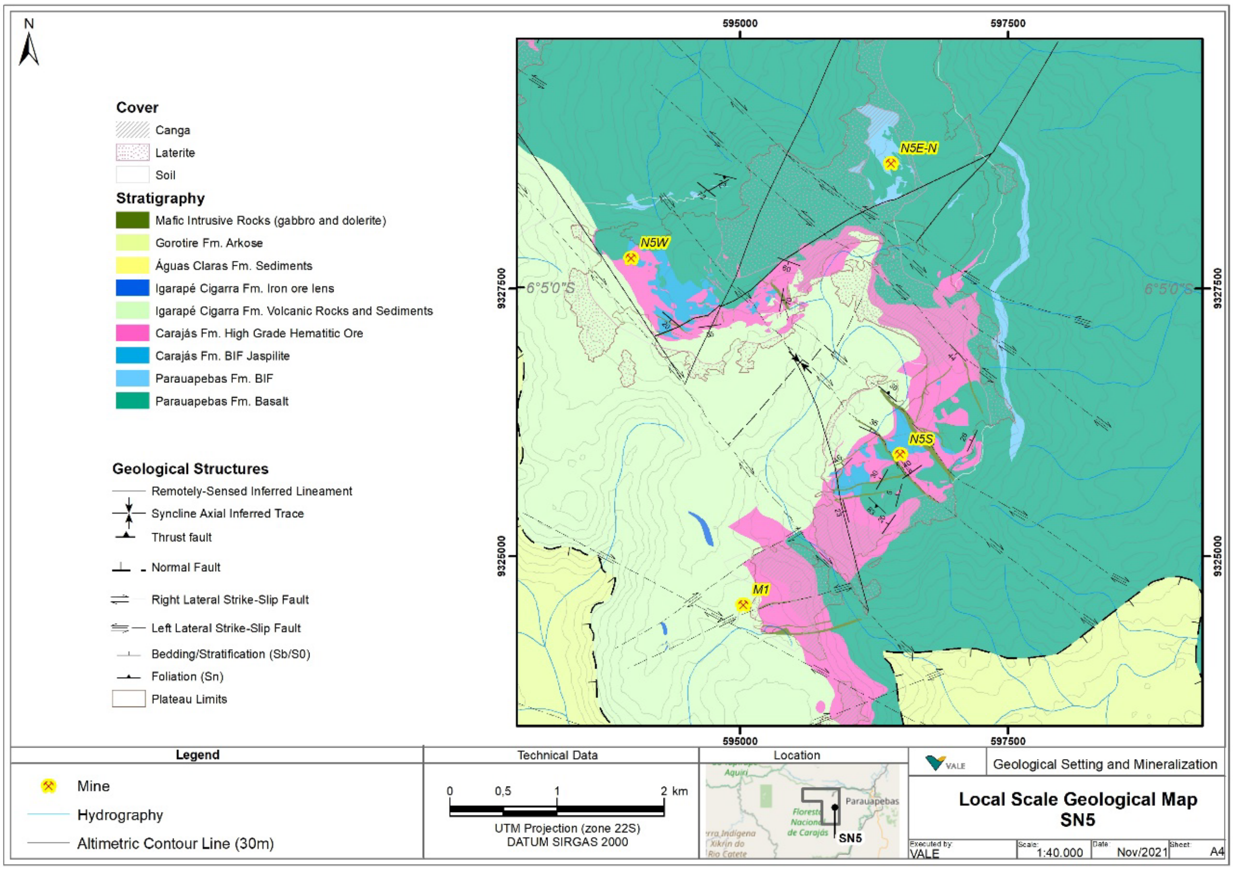


Figure 6-15 - N5 Geological map

Intrusive rocks define bodies of metric thickness and variable orientation that tend to follow the fault planes and cut through the entire Grão Pará Group sequence. These rocks have basic/intermediate composition, predominantly fine texture, and make conformable to non-conformable contacts with the bedding and the banding, configuring sill and dike families (Figure 6-15). To the west and south of the plateau, arkoses of the Gorotire Formation predominate, which constitutes a considerably younger unit occurring along a graben (Figure 6-15).

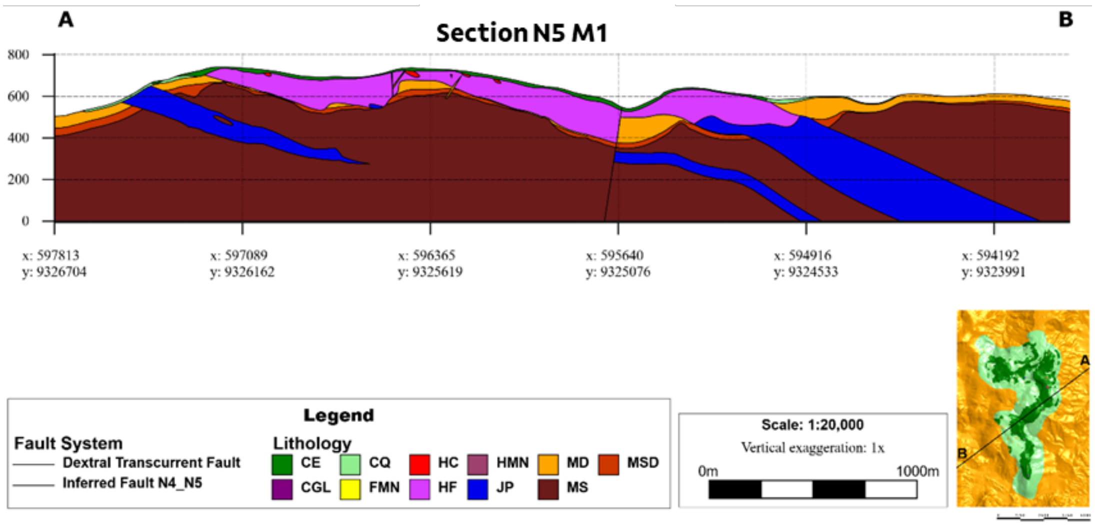


Figure 6-16 - N5 M1 Geological section

6.3.4.3. Structures

At N5, the Carajás Formation behaves like a homocline, with a trend varying from NW-SE to N-S and dips to SE and E. The sinuous character in the northern portion of the plateau is given as a function of a syncline, which, associated with the fault system, verified throughout the plateau, controls the geometry of the iron formation (Figure 6-15).

Structures correlated to Transamazonian tectonism:

• Dextral transcurrent fault system, with NW-SE orientation, which is articulated with small dextral transcurrent faults, with E-W orientation, responsible for the segmentation of iron formations (Figure 6-15).

Structures correlated to Brazilian tectonism:

• Reactivation of part of the faults with NW-SE orientation, giving sinistral kinematics to them (Figure 6-15);

• Kink-style folds that form with different scales of occurrence and axis orientations, mainly present in the iron formations; and

• The Buriti Syncline, with the axis falling to SW, is not compatible with the tectonic vector of either event. However, this structure is here experimentally correlated to Brasiliano, considering that the presence of the reactivated fault system may have acted as a modifier of the general field of stress on a local scale.

6.3.4.4. Mineralization

As already described for the previous deposits, N5 mineralization is formed after the alteration of jaspilite and will be addressed briefly here, with emphasis mainly on the unique aspects of the area under consideration (Table 6-4).

In the N5 mine, the lithology known as iron-manganese (FMN) occurs as small lenses, with a thickness of up to 35 m and low lateral continuity, normally located close to the contact with sills and dikes, which suggest a hydrothermal origin. It is characterized as a hematitic material, weakly magnetic, with greenish-gray color, metallic luster, and high porosity, ranging from friable to powdery. It has low average overall iron grade (43.30%), high Mn grade (7.74%), and contaminants, such as Al_2O_3 (2.11%), in addition to loss on ignition (LOI) of 1%.

Table 6-4 - Characteristics of the mineralization in N5

Lithotype	Deposit partition (%)	Maximum section thickness (m)	Average iron grade (%Fe)
Friable Hematite (HF)	83	250	66,87
Canga (CG)	11	55	63,52
Compact Hematite (HC)	4	110	66,32
Manganiferous Hematite (HMN)	2	90	61,51

6.3.5. Gelado Dam

6.3.5.1. Deposit dimensions

The Gelado dam receives material from Plant 5 and is subdivided into 4 branches. It has depths ranging from 1m to 25m, which can vary depending on the original topography of the land. On average, the deposit is 15m thick. The deposit is distributed in two portions: the emerged part and the submerged part (Figure 6-17).

6.3.5.2. Lithologies

The lithology model comprises two major components, Waste material representing the natural surface, and Ore representing mineralized tailings material.

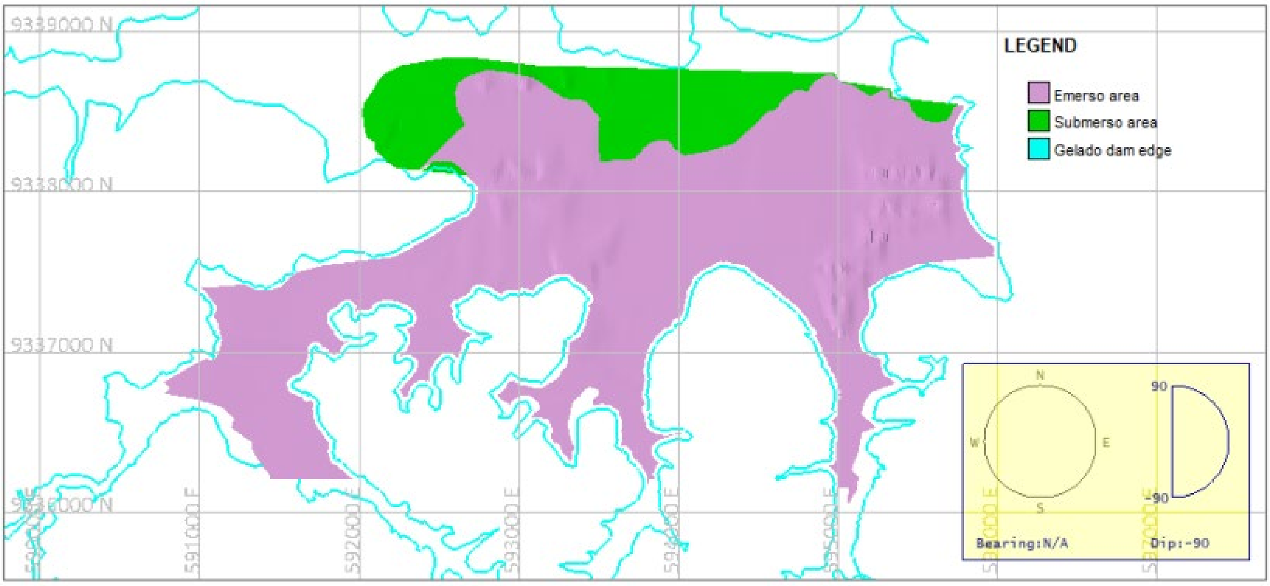


Figure 6-17 – Gelado Dam map

The deposit is comprised of two regions, emerged and submerged, depending on the water level.The Figure 6-18 below shows the interpretation of ore and waste zones, basically the end of the borehole marks the contact.

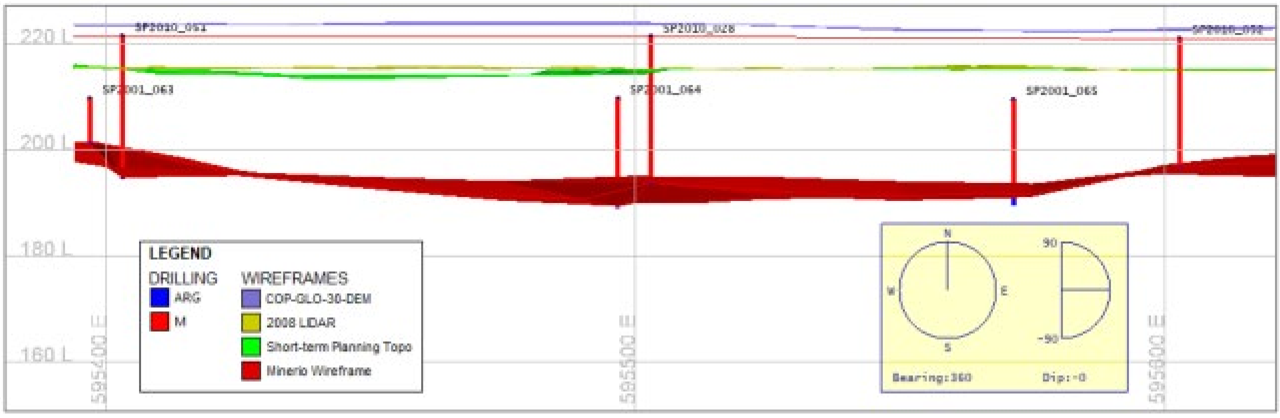


Figure 6-18 – Gelado Dam section

6.3.5.3. Mineralization

Geological structures are not described in the boreholes; however, the existing structures are from the sedimentary deposition, originated by the discharge flow from the plant. An increase in grain size is observed near the discharge area and a reduction in more distal portions.

7. Exploration

7.1. Exploration

7.1.1. Introduction

Mineral exploration started in the ‘70s and is still in progress. Currently, most of the areas comprise a drilling grid of 100x100m, 100x50m or 50x50m within the mining areas, focused on detailing the ore bodies and investigation of new potential areas for reclassification of resources to measured and indicated. In the surrounding regions, the grid is generally spaced by 200x200m.

7.1.2. Topography

The topographic surveys used for modeling, resources and reserves estimation were generated by composing of detailed topographic surveys carried out by the short-term teams and LiDAR aerial surveys acquired under the supervision of Vale since 2006. The mine team prioritize the use of information to cover all operational areas, with airborne lasers being used to complement the polygonal area of interest. The topography is available about Horizontal Datum SAD69 and Vertical Datum PD04, projected at UTM-22S.

7.1.3. Geophysics

The most used geophysical tools in ferrous mineral exploration are aeromagnetic surveys, aerial FTG gravimetry, geophysical profiling of drillholes by gamma-gamma and two-dimensional electrical imaging surveys.

Geophysical drillholes surveys have been applied systematically since 2012 in Vale's projects. Several geophysical logging tools have been used based on acoustic, electrical, nuclear and optical techniques, depending on the purpose, although the most common is the use of natural gamma radiation and gamma-gamma radiation tools. The survey is carried out by an outsourced company, supervised by Vale's team of geophysicists, who are also responsible for QA/QC of the data and the interpretation of the results.

The main geophysical anomalies detected in mine areas are handled and selected as targets of geological mapping and drilling. In addition, part of the most recent holes have been profiled by the gamma-gamma method.

7.1.4. Qualified person’s interpretation of the exploration information

The Serra Norte Complex has been extensively explored since the ‘70s and a big database has been developed because of both exploration and mining activities. The primary exploration method is core drilling and assay collection. However, progress in geophysics has improved the amount and the quality of data that can be used for geological interpretations and geological modeling.

7.1.5. Exploration potential

Further work is required to determine the exploration potential below the current open-pit operations and new targets identified from mapping or geophysical anomalies, mainly associated with friable and compact hematites. However, the data available so far confirms the great continuity of the iron formation bodies both on the surface and in-depth, which shows positive expectations regarding the exploration potential of this area.

7.2. Drilling

7.2.1. Overview

The exploration of Serra Norte started in the late 60’s and continued to the early 70’s. At this time, a large exploration campaign was carried out, covering the entire Mineral Province of Carajás. The project included the areas of Serra Norte, Serra Sul, Serra Leste, and São Félix do Xingu, all with great potential for geological resources of iron ore. Currently, this work is coordinated by Ferrous Geology and Drilling Management.

7.2.2. Drilling on property

Long-term drilling campaigns in Serra Norte were carried out in various periods, with the first records from the 1960s. In general, the drilling grids have spacings of 200x200 in horizontal projection in all Serra Norte deposits and closures of 100x100m, 100x50m, or 50x50m in irregular grids, mainly in the mining areas of N4 and N5. Table 7-1 shows a summary of the drilling campaigns carried out in the Serra Norte deposits and Figure 7-1 to Figure 7-44 presents the spatial distribution of these drilling campaigns in each deposit.

Table 7-1 - Distribution of drilling campaigns over the years in all Serra Norte deposits.

Target	Year of Campaign	Meters
N1	1968-1971	3,760
	2001-2007	46,739
	2012-2013	6,735
	2017-2021	24,802
	Total	**82,036**
N2	1970	516
	2002	1,893
	2012 - 2013	6,992
	2015 -2022	450
	Total	**9,851**
N3	1970	483
	2002	1,186
	2009-2011	15,896
	2018-2020	28,161
	2023	2,567
	Total	**48,294**
N4	1970-1979	21,271
	1991-1999	45,171
	2000-2006	71,161
	2007-2011	159,666
	2012-2022	139,365
	2022-2024	66,363
	Total	**502,999**
N5	1970 - 1971	5,138
	1993-1999	20,683
	2000-2006	110,972
	2007-2011	62,370
	2012-2021	120,811
	2021-2023	51,002
	Total	**370,976**
Gelado	2001	2,503
	2010	2,665
	Total	**5,168**
TOTAL		**1,019,324**

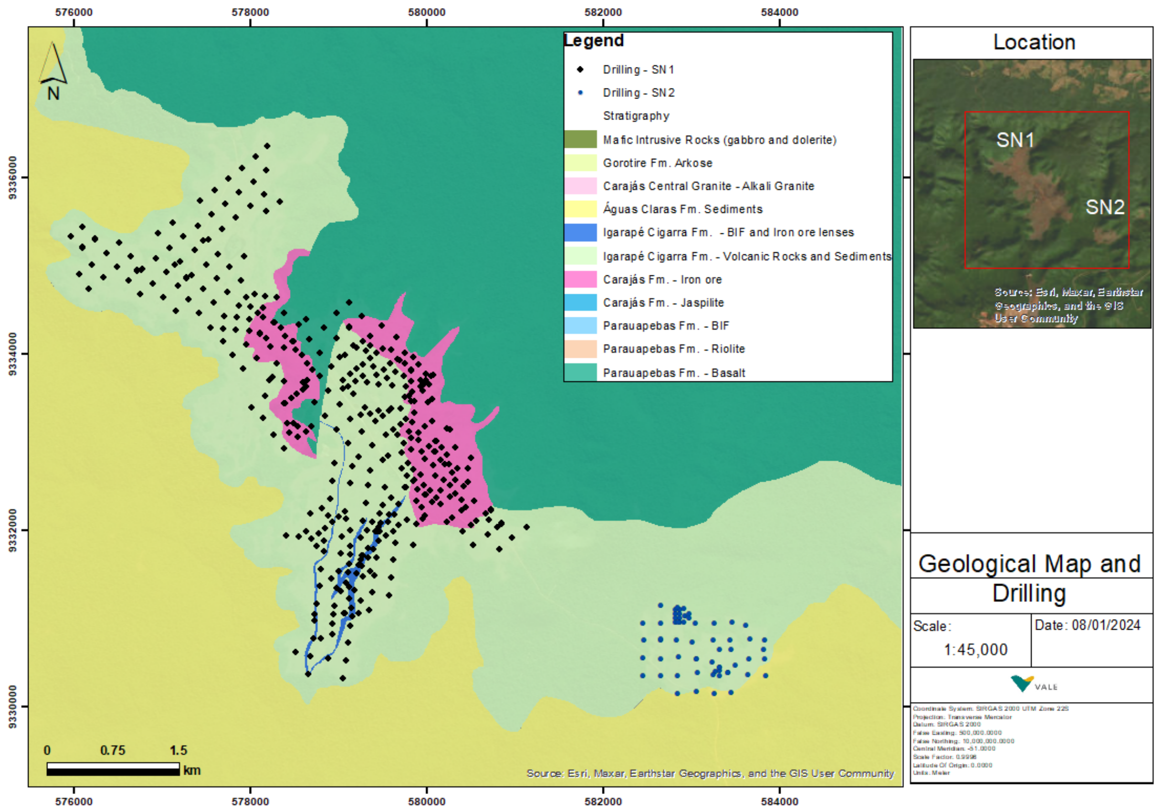


Figure 7-1 - Spatial distribution of the long-term geological drilling in the N1 and N2 deposits.

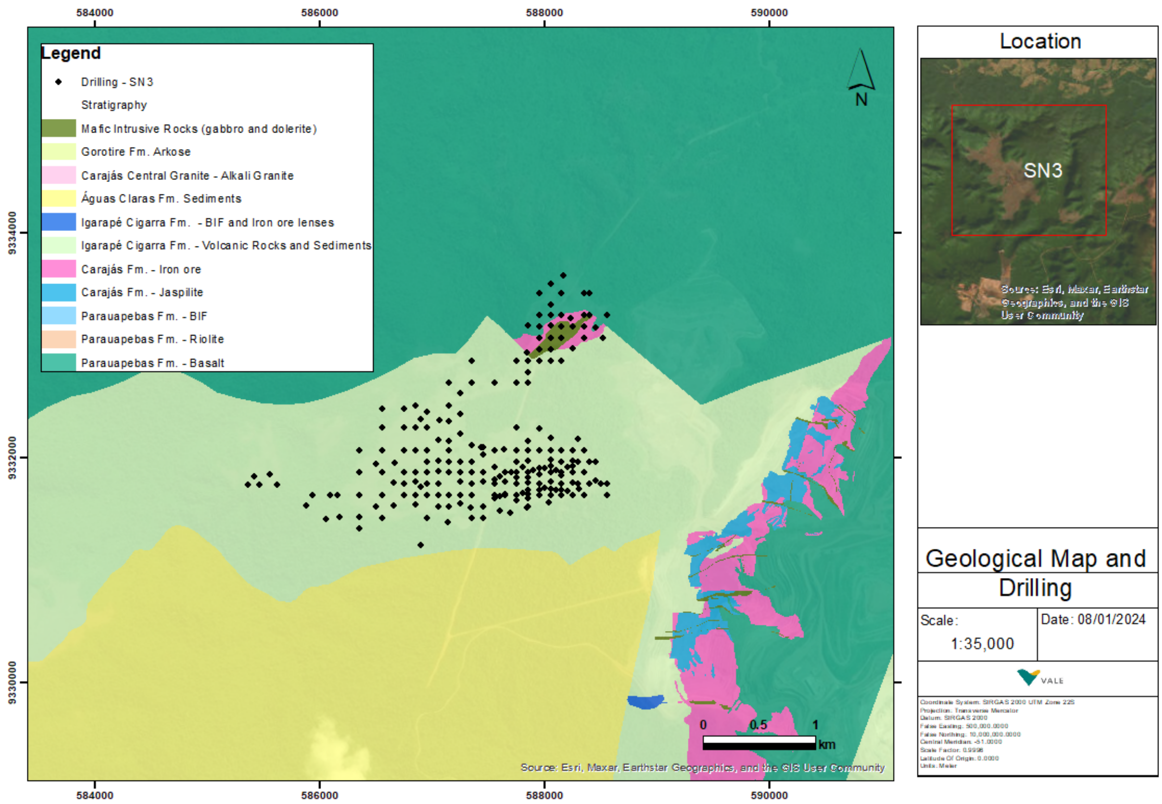


Figure 7-2 - Spatial distribution of the long-term geological drilling in the N3 deposits.

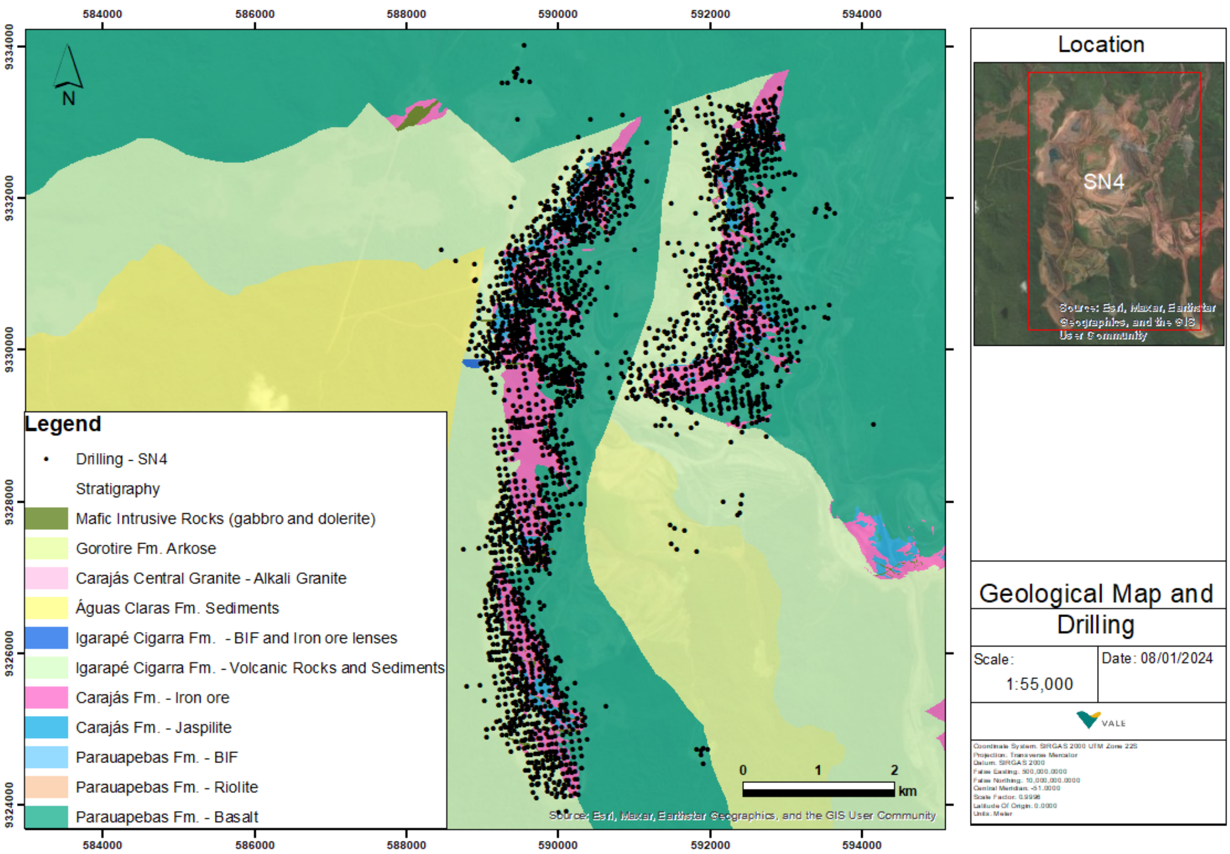


Figure 7-3 - Spatial distribution of the long-term geological drilling in the N4 deposits.

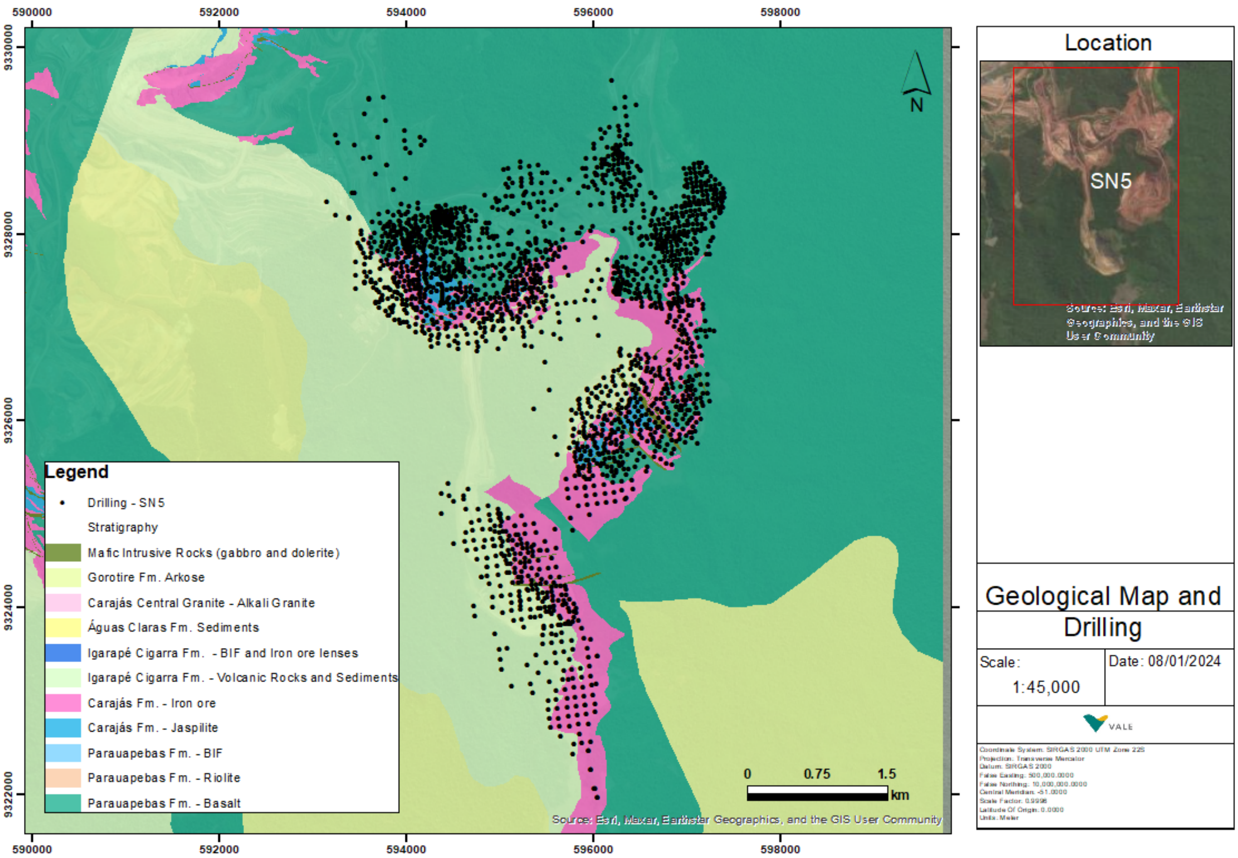


Figure 7-4 - Spatial distribution of the long-term geological drilling in the N5 deposit.

7.2.3. Drilling excluded for estimation purposes

Boreholes that showed inconsistencies during the database validation process were either fixed in the database or excluded from the resource estimate. Further discussions on this item are presented in the sample regularization process for grade estimates and resource classification in Chapter 11 (Mineral Resource Estimates).

7.2.4. Drill methods

The drilling type is conventional rotary diamond drill, and most drill holes are vertical to sub-vertical. The drilling diameters are variable over time between HW (76.2mm), HQ (63.5mm), or even NW (54.7mm), NQ (47.3mm), BW (42mm), and BQ (36.4mm). The last two diameters are adopted only in some situations due to operational issues.

7.2.5. Logging

In the Serra Norte deposits, the geological logging of the holes drilled between 1968 and 1972 were recorded in the research report prepared at the end of the campaign. Since 1991, the core logging was made in field notebooks and from 2003 onwards, carried out directly in digital media. In addition to the geological logging, geotechnical descriptions were also performed in several holes, using a standard spreadsheet, in which macroscopic characteristics were described, such as degree of alteration, compressive strength, type of discontinuity, roughness, type of filling and RQD (Rock Quality Designation), among others. For all these items, there were standardized codes for filling in the worksheet. There was also a descriptive field for relevant observations.

Since 2012, the description standards defined by Ferrous Geology and Drilling Management are used. The procedure for all Serra Norte areas stipulates standard sampling of 15m for brown field projects and mines in Carajás, and 10m for exploration areas. This sample support can vary 50% for the minimum length and 10% for the maximum length. In this case, the minimum length can be 7.5m and the maximum 16.5m for mining areas. The collection is made on the left side of the box, along its length, keeping the remaining 50% in the core boxes. The friable materials are collected with the help of a metal shovel with standardized dimensions, according to the drill hole diameter and compact materials, such as compact hematite (HC), jaspilite (JP), and unaltered mafic rocks (MS), are cut lengthwise using a diamond saw.

Currently, most drillholes are stored in the Serra Norte Core Shed located at the N5 mine.

7.2.6. Recovery

Core recovery is good for all deposits of Serra Norte Complex. The average recovery of the drillholes core is about 90%. Areas of poor recovery are typically limited to fault and shear zones. Drillholes below 50% recovery are excluded from the database.

7.2.7. Collar surveys

The drillhole coordinates data is obtained through topographic surveys and stored in Geological Database Management System. Currently, this data is collected about Horizontal Datum SIRGAS2000 and Vertical Datum IMBITUBA, projected at UTM-22S.

7.2.8. Down hole surveys

Different surveying equipment was used, such as the Maxibor I, Maxibor II, Stockholm, Deviflex and Reflex gyroscopes. The survey was also conducted using Tropari equipment; however, the data was not incorporated into the geological model due to magnetic interference from the iron formation. Instead of the Tropari measurements, the dip direction from the collar was used. Only a small portion of the dataset was affected.

Comments on material results and interpretation

Drilling and surveying were conducted in accordance with industry-standard practices at the time the drilling was performed and provided adequate coverage of the zones of iron ore mineralization. Generally, the collar and down hole survey methods used provide reliable sample locations. The drilling methods provide good core recovery. The logging procedures provide consistency in the descriptions.

This data was suitable for mineral resource and mineral reserve estimation. There are no drilling or core recovery factors in the drilling to support the estimates known to QP that could materially impact the accuracy and the reliability of the results.

7.3. Hydrogeology

7.3.1. Groundwater model

Hydrogeological models have been developed for all mining sites within the Serra Norte region, based on datasets compiled in 2023. The construction and updating of these models are carried out by a third-party consultant, while VALE's technical team oversees the analysis and validation of hydrogeological data.

Raw-water demand in Serra Norte is met through both surface-water and groundwater sources. Surface water is extracted from the Igarapé Gelado dam and used in the wet processing plants for iron ore. Groundwater is obtained from deep tubular wells in the N4 and N5 Mines and is used for various purposes, including supplying the Water Treatment Plant (WTP), road spraying, maintaining flows in the Jacaré and Buriti streams, and serving other industrial requirements. Any excess water is discharged into the Pêra and Gelado dams.

Hydrogeological models play a critical role in characterizing groundwater dynamics by enabling the simulation of outflow rates, water availability, slope depressurization behavior, and groundwater-level distribution. These modeled parameters constitute essential inputs for geotechnical stability assessments.

The key parameters of the Serra Norte hydrogeological model are presented in Table 7-2.

Table 7-2 - Summary of the general conditions used and the results of the numerical simulations

Pit	Calibrated model year	Software	nRMS (%)	Drainage flow rate (m^3/h)	Number of instruments considered in the calibration
N1	2020	FEFLOW	2.32	662	16
N2	2020	FEFLOW	2.32	164	16
N3	2023	Visual MODFLOW	3.60	294	63
N4	2023	Visual MODFLOW	6.55	2.900	63
N5	2023	Visual MODFLOW	8.42	726	35

Dewatering operations at Serra Norte are carried out through the use of pumping wells and drainage tunnel strategically installed within the iron-formation units. In addition, slope depressurization is achieved through the application of horizontal drain holes and supplemental pumping wells.

7.3.2. Comment on results

The available hydrogeological data are considered sufficient to support the primary objective of constructing, calibrating, and simulating future mining scenarios within a numerical groundwater-flow model. As the groundwater-monitoring network continues to expand, ongoing improvements to operational procedures and monitoring protocols were implemented.

7.4. Geotechnical

7.4.1. Sampling Methods and Laboratory Determinations

VALE's geotechnical procedures follow a comprehensive approach that includes geotechnical mapping, core logging, and laboratory testing. The delineation of geotechnical domains is based on both regional and local surface geological mapping, complemented by information obtained from drill-hole investigations.

A wide range of drillhole survey geotechnical parameters is routinely recorded, including uniaxial compressive strength, weathering grade, degree of fracturing, Rock Quality Designation (RQD), discontinuity types, alpha angle of the principal discontinuity, and detailed characteristics of the main discontinuities, such as aperture, roughness, spacing, wall alteration, wall-filling material, type, and thickness. These parameters support the development of geomechanical classification systems consistently applied across all VALE mining operations.

In the Serra Norte context, rocks with compressive strengths below 5 MPa are categorized using the Weak Rock Classification, whereas materials with compressive strengths equal to or exceeding 5 MPa are classified according to the Rock Mass Rating (RMR) system. The Geological Strength Index (GSI) is also employed, derived through an empirical correlation with the RMR value using the expression $GSI = RMR - 5$.

As of December 31, 2025, a total of 653,101 meters of geotechnical drilling and 12,363 geotechnical surface-mapping points had been incorporated into the development of the Serra Norte geomechanical model.

7.4.2. Quality assurance and quality control

A complete Vale QA/QC program for geotechnical core logging description is under development. Currently, the cross-validation techniques used were based mainly on three empirical correlations. The first one correlates Vale´s crushing testwork results with the estimates of rock compressive strength. The second correlates the estimated compressive strength with the material weathering degree. The third correlates with the degree of fracturing, RQD, and joint spacing.

The strength and elastic laboratory test results were validated by either and internal geotechnical team or an independent company. Specimens with inconsistent and/or unconclusive results were discarded.

8. Sample preparation, analyses, and security

8.1. Overview

The Vale corporate governance process supports the acquisition of reliable data for Mineral Resource and Mineral Reserve estimation. Each operation has documented protocols and internal controls for drilling, sampling, sample preparation, and assaying procedures approved by Vale's Resource Management Group. Documentation of the protocols is kept as current, and the personnel receive adequate training to apply them. All data is properly identified by unique reference numbers so that drill hole information can be reliably restored from the independent collar, survey, geology, physical properties, and assay tables. All data is verified and checked before entry in the database. The sampling practices and assaying methodologies are clearly described and supported. The proficiency and the technical capabilities of the sample preparation and assaying facilities are confirmed by periodic reviews–and - or audits. The database contains all relevant information for Mineral Resource and Mineral Reserve estimation. The database used in estimation contains unbiased and representative data, and any major issues identified by QA/QC programs have appropriate corrective actions applied and disclosed.

8.2. Sampling methods

The drill core samples are taken in Vale core sheds, with the sampling plans prepared by geologists shortly after the description and the collection carried out by the technical assistants, usually from contracted companies. Between 1960 and 1979, physical preparation and chemical assays were carried out internally in laboratories located in Serra Norte (N1 area) and Belo Horizonte, Minas Gerais. In 1989, VALE´S laboratory was inaugurated at the N4E mine, currently belonging to the Ferrous North Management of Process Development and Laboratories. The laboratory performs physical preparation activities and chemical analysis of exploration and production samples of iron and manganese ores. Between August 2008 and mid-August 2009, the samples from geological exploration were prepared in an outsourced laboratory of the company SGS Geosol Laboratório Ltda. located in the city of Parauapebas, in state of Pará. Between mid-August 2009 and April 2013, the samples were prepared by the company Intertek do Brasil Inspeções Ltda. in the physical preparation laboratory of GAMIK/VALE, located in the N5 mine, later using the laboratory in the city of Parauapebas. The physical preparation work outsourced to SGS Geosol and Intertek was carried out under supervision by VALE (Laboratories Management). Since April 2013, samples began to be prepared in VALE's laboratory, located at the N4 mine (Ferrous North Management of Process Development and Laboratories), where chemical assays are also carried out.

During the different drilling campaigns carried out in the Serra Norte deposits, the samples were assayed in different analytical flowcharts. The main differences between the analytical flows are the number of particle size fractions, the number of size fractions with chemical analysis, and the measured analytes, in addition to the type of sieving (dry or wet). Since mid-November 2008, a general review was carried out on the physical preparation flows of geology samples and a new standard flowchart was defined, which is in use until now. In this flow, several sieves are used (relief of the load in the sieving process), but only five granulometric fractions are generated, resulting from the mass composition of the various sieves. For the five fractions generated (+19 mm, -19+8 mm, -8+1 mm, -1+0.15 mm, and -0.15 mm), aliquots are taken for chemical assays. The sieving is done in dry process.

For the modeling work, a single file was generated with the samples grouped in particle size ranges: G1: +8 mm; G2: -8+0.15 mm and G3: -0.15 mm, with G1 and G2 being subdivided into G1A: +19 mm, G1B: -19+8 mm, G2A: -8+1 mm and G2B: -1+0.15 mm. The G2A and G2B ranges have mass results but no chemical assays. The long-term geological model database contains the results for the following analytes: Fe, SiO_2, P, Al_2O_3, Mn, LOI, CaO, MgO, TiO_2, FeO, K_2O, and Cu. The short-term database contains the analytes Fe, SiO_2, P, Al_2O_3, Mn, LOI, CaO, MgO, and TiO_2.

8.3. **Sample security methods**

8.3.1. Quality assurance and quality control

The historical QA/QC data, prior to 2012, related to control samples, twin samples, field duplicates, crushed material duplicates, pulverized material duplicates, external duplicates and standards did not reveal points of attention (in frequency and/or magnitude) regarding precision and accuracy (of sampling and chemical assays) that compromise the databases used for geological modeling and resource estimation purposes, resources and reserves classification of areas and mines in the Serra Norte and Serra Sul Complexes of the Carajás Mineral Province.

The current QA/QC data, since 2012 stored in the Geological Database Management System (GDMS), shows that in the period from 2012 to July 2019, the Carajás Lab processed samples from geological exploration, short-term and long-term geology according to the analytical flows of global chemistry and chemistry by particle size fractions from Serra Sul and Serra Norte areas.

Assays for Al_2O_3, Fe, Mn, P, LOI, and SiO_2 follow Vale standard PTP-000915 Version 02 of 08/08/2019 and relate to the following quantities: 1,640 crushed material duplicates, 3,380 pulp duplicates, and 1,938 samples of 7 types of standards.

Checks between different Vale laboratories (Carajás, Alegria and Timbopeba) and external laboratories (Intertek and SGS Geosol) were also carried out. The results of 470 external duplicates related to the following interlaboratories were evaluated: Carajás x Alegria (179 duplicates), Carajás x Intertek (54 duplicates), Carajás x SGS Geosol (105 duplicates) and Carajás x Timbopeba (132 duplicates).

The last laboratory QA/QC assessment was done in April 2021 by Vale personnel. In general, the laboratory performance is classified as satisfactory (conforming results ≥ 90% or very close to 90%) and/or admissible (conforming + acceptable results ≥ 90% or very close to 90%). In most cases, sampling/chemical assays accuracies are good and analytical biases/flaws are small or insignificant compared to the grade ranges involved.

For the Fe, the technical performance of the laboratory is satisfactory and considered acceptable. For contaminants, the technical performance varied from satisfactory to unsatisfactory (there are some points of attention at lower grades). Crushed material duplicates and pulp duplicates DP show higher percentages of non-conforming results and higher mean relative inaccuracies (although still acceptable), most likely influenced by the higher frequency of lower grades for Al_2O_3, Mn, P, LOI and SiO_2 analytes.

External duplicates assayed in the Intertek laboratory indicate a slight trend of overestimation at lower grades (still acceptable and conservative bias) for analyte P. External duplicates assayed in the SGS Geosol laboratory indicate a slight trend of overestimation and underestimation at lower levels (bias still acceptable) for P (conservative bias) and LOI (non-conservative bias), respectively.

The standard control samples indicate a trend of small overestimation at very low grades for Al_2O_3, Mn and P. The most relevant points of attention are under investigation by geology and laboratories teams.

Routine laboratory inspections are made to check organization and storage, equipment (scales, ovens, sieves, crushers, mills/pulverizers, splitters), operating procedures, and records related to the internal QA/QC program. QAQC data revealed general indicators of non-conformity, precision and accuracy considered satisfactory, not compromising the database related thereto.

8.3.2. Database management system

The main information of the database of short- and long-term drillholes, as well as geotechnical holes, is organized in three tables: Header, Survey, and Assay.

The basic data comprised in the Header table are hole identification, east and north coordinates, elevation, depth, recovery in percentage, hole completion date, DATUM and whether the hole has been profiled or not.

For the Survey table, in addition to the hole identification, there is information about the azimuth, dip and depth of the hole.

The Assay table is composed of the following data: hole identification, sample code, intervals from/to, sample length, sample lithology, global chemistry of the different analytes, particle size in the ranges corresponding to the flowchart, chemistry by range of the different analytes, granulometric closure, chemical closure, recovery of samples in percentage, identification of the analytical flowchart used, date on which the results were made available by the laboratory and the type of sample.

8.3.3. Header table validations

The items below describe the validations made in the Header table in long, short-term and geotechnical drillholes of Serra Norte database.

Validation of Holes with Topography

Validation of the position of the holes, verifying the existence of conflicts of positioning in relation to the original and current topographies. All holes that showed differences greater than 10m were checked. Some holes were identified with elevation above the original topography or below the current topography, but these differences do not correspond to errors, as these holes are located in dump areas.

Validation of New Holes in the Database

This verification is done by comparing the database of the previous model with the current one. Thus, it is possible to check the difference in the total depth of the two databases and identify the new holes.

Drillhole Recovery Validation

For this check, the recovery column was considered, making a formula to indicate the holes with recovery below 50%. Holes with low recovery were discarded.

Validation of Duplicate Coordinates

This validation aims to identify holes with the same East and/or North coordinates. Holes with identical coordinates were discarded or there was partial use of the data. This can occur in cases of holes interrupted by operational problems that had to be re-drilled later.

DATUM Validation

This validation intended to assure that all hole position data is in the same Coordinate System and Datum. Vale defined Horizontal Datum SIRGAS2000 and Vertical Datum IMBITUBA projected at UTM-22S for Serra Norte.

Coordinate Validation

In this validation, the coordinates of the original files from the Survey Monitoring spreadsheet are compared to the coordinates taken from the Geological Database Management System. No errors were found.

8.3.4. Survey table validations

The acquisition of the Survey table was made by extracting the GDMS data, original logging files and validated Header table data taken from GDMS. The items below describe the validations carried out on the Survey table in the database of Serra Norte model.

General Profile Validation

The general check of the profiling is done after the preparation of the Survey spreadsheet with all necessary data, namely: Hole, Depth (Prof.), Azimuth (Azim) and Inclination (Dip). Typically, the trajectory deviation data is required to cover at least 85% of the hole total length. The checks involve Azimuth differences, Dip differences, whether the hole has been profiled or not, the type of range and overall check of the difference between subsequent readings. The latter is the verification of the intervals whose dip or azimuth difference is greater than or equal to 1.4°/m.

Header x Survey Depth Validation

In this validation, the final depth of the Header table versus the final depth of the Survey table is checked.

Validation of Dip and Azimuth x Drilling Follow-up Worksheet

This validation refers to the comparison of the Dip and Azimuth values used in the modelling versus the original values in the Survey Monitoring spreadsheets (data considered official).

Dip and Azimuth Consistency Validation

The purpose of this validation is to check whether the holes with Azimuth equal to 0 are vertical and vice versa. There shall be azimuth for holes which are not vertical. We can also check the minimum and maximum values of dip and azimuth. It is important the dip always to be negative.

8.3.5. Assay table validations

The items below describe the validations performed in the Assay table of Serra Norte database.

Duplicate Sample Validation

This validation serves to identify the presence of duplicate samples in the database. No errors of this type were found.

Gap and Overlap Validation

This is one of the main checks in the database. It serves to identify the correct arrangement of the intervals, considering the “From” and “To” interval. This validation aims to highlight Gap errors (intervals with missing length) or Overlap (intervals with overlapping length). The check is done directly by crossing “From” and “To” information. No errors were found.

Validation of Calculated Global Grade

This validation aims to check the global chemical values of all analytes calculated in the samples with particle size and range analysis. This calculation is made through a weighted average of the grade by mass in the granulometric ranges using the formula:

GL = (Fe1A*G1A+Fe1B*G1B+Fe2A*G2A+Fe2B*G2B+Fe3*G3)/(G1A+G1B+G2A+G2B+G3)

No errors were found in the global grade calculations.

Validation of Anomalous Values

The check of anomalous values consists in verification of whether the maximum and minimum values are coherent with each analyzed element. It is possible, for example, to highlight column changes (P and Al_2O_3, for example). In the database, there cannot be chemistry values equal to 0, the minimum must always be the limit of detection. It is also possible to detect negative values. No inconsistent values were found in this check.

Granulometry Versus Chemical Validation by Range

This check is just to assure that necessarily; there is chemistry per range for any ranges with granulometry.

Validation of Equal Analytical Results in Different Samples

This is a simple but important check that considers the existence of equal results for some analytes. The check is done in the Assay, element by element, sorting and checking the difference or existence of equal results. This check must be done for all analytes and its considered an error when there are the same results for two different samples. No equal global results were found between two samples on all elements.

Sample Recovery Validation

The check must be done with a filter considering minimum recovery of 60% according to the "Manual of Good Practices of the Resource Estimation Management". There may also be intervals with recovery lower than 60%, but they are intervals with NR-NS identification (not recovered - not sampled).

Particle Size Closing Validation

To check the Particle Size Closing, the sum of the granulometry values must be considered. Subsequently, compare it with the value taken from the Assay Table. The acceptable limit for particle size closing is from 99% to 101%.

Chemical Closing Validation

It verifies the stoichiometry of the chemical results and the sum of the granulometric fractions. In this validation step, it is checked whether the closure has been calculated correctly and whether the closure limits are acceptable. For this calculation, the following equation was used:

$$(Fe*1.4297)+SiO_2+(P*2.2913)+Al_2O_3+(Mn*1.2912)+CaO+MgO+TiO_2+K_2O+(Cu*1.2518)+LOI$$

Although this check shows chemical closures below or above an accepted range, this is not a reason to invalidate the samples. Therefore, all these samples remain in the database, they were used in geological modeling, and it will be geostatistically assessed whether they will be used in the estimates.

Depth Validation between Assay, Header and Survey Tables

This is one of the main database checks. Basically, it consists of comparing the depth of drillholes in the three tables. The total depth of each hole must be the same in all tables.

8.4. Density Determinations

Density is an attribute with direct impact on quantifying of the mass of any mineral deposit, and exactly because of that, it is handled as a highly relevant item in 'VALE's iron ore geological models. Several works have been developed by professionals from the company over the years applying different methodologies to determine the density values, among which the following stand out: traditional methods (Santos, 2006), geophysical logging (Almeida, 2011), and normative mineralogical calculation (Ribeiro et al., 2014; Motta et al., 2016). Currently, the density values attributed to the blocks are made combining the three methods and the results can be seen in Chapter 11.

The validation of each method adopted, as well as the final value, was done through the analysis of descriptive statistics, visual inspection of vertical sections and review of the chemical analysis of each material. The validation aims to observe the consistency between the average; minimum and maximum values compared to those used in previous models and results from conventional methods.

8.4.1. Direct acquisition methods

The most used methods were Volume Fill and Sand Flask for friable materials or Volume displacement and Hydrostatic weighing method for compact materials. Below, a brief description of each methodology:

- Volume Fill Method: Consists of digging a hole with regular walls, removing the material and weighing it, coating the hole with thin plastic, and filling it with a known volume of water.
- Sand Flask Method: Consists of digging an opening in the floor with regular walls, removing and weighing the extracted material. This hole is then filled with selected sand of known density, and from the selected sand volume and mass data, the material density is determined.
- Volume Displacement Method: Density is calculated from the relationship between sample weight and water displacement caused by immersing the sample in a graduated container.
- Hydrostatic Weighing Method: Density is derived from the ratio between the weight of the sample divided by the loss of weight when the same sample is immersed in water, using the Jolly scale.

Moisture is obtained by drying an aliquot of the sample, comparing the dry (M) and the wet mass of the sample ($M+MH_2O$). This is very important because in Vale iron ore mine evaluations, the tonnage calculations are carried out with the density in the natural base (ρu), considering the mass of free water (MH_2O) obtained from the moisture measurements (u). In all conventional density determination methodologies, natural density and moisture values are determined, and dry density is calculated.

8.4.2. Indirect acquisition methods

Gamma-gamma or gamma backscattered geophysical logging is based on the interaction of radiation with the surrounding matter. The gamma-gamma probe has a radioactive source and a scintillation meter. This probe emits gamma radiation, and depending on the electron density present, it is deflected. The scintillation meter measures the amount of radiation scattered through the medium, so the denser the rock, the smaller the scattered amount. The technique continuously records variations in the specific masses of rocks traversed by a hole. The measurement of the total density of a rock, with the density profile, is made through a monoenergetic beam of gamma rays that bombard the walls of the hole.

8.5. Qualified person’s opinion on sample preparation, security, and analytical procedures

The sample preparation, analysis, quality control, and security procedures applied in Serra Norte Complex have changed over time to meet industry practices and frequently were industry-leading practices.

The Qualified Person´s opinion is that the sample preparation, analysis, quality control, and security procedures are sufficient to provide reliable data to support estimation of mineral resources and then mineral reserves.

9. Data verification

9.1. Internal data verification

9.1.1. Data collection and storage

The mineral exploration management responsible for geological description, data collection, and QA/QC has daily checks procedures from the drilling to the reception of chemical results from the laboratory analyses.

During the drilling process, several processes are checked by the drilling inspectors, from the depth of the hole, recovery in each maneuver, until the transportation of the core boxes to the core shed. After the hole is drilled, the spatial trajectory deviation logging is carried out followed up by the drilling inspector and with validation of the obtained data.

For the receiving, checkout, and arrangement of the boxes in the core shed, there is a quality management protocol aimed at physical integrity, identification of the boxes, arrangement of the boxes on the pallets (lined for plastic boxes or stacked for wooden boxes), strapped boxes, unlocked pallets, checkout of the head sign, correct numerical sequences, depth, progress and recovery of the maneuvers.

The hole is exposed in the numerical sequence of each box and photographed. Geotechnical description, geological description, elaboration of the sampling plan for chemical analysis, elaboration of the sampling plan for density, and collection of samples are carried out. The core samples collected for physical and chemical analysis are placed in plastic bags properly labeled with barcode labels.

The boxes with half-core or non-sampled intervals are archived as defined in the core disposal procedure.

Vale has consistent QA/QC programs, including robust quality procedures and protocols, where precision and accuracy are assessed in most preparation and chemical analysis stages of the geological samples. Twin samples and field duplicates are used to monitor sampling errors. Crushed and pulverized material duplicates for assessment of the physical preparation (subsampling error). External duplicates and standards for chemical analysis (analytical error). For mitigation and possible reanalysis, the pulverized material residual is kept in identified plastic boxes. Continuous inspections are carried out in non-commercial, internal and external commercial laboratories, thus guaranteeing effective process improvement.

Processes aimed at quality control and assurance and data integrity are under development and used in topographical data validation, spatial trajectory logging, geological description, sample collection and density tests. Among them, we can highlight peer reviews of the information generated, data validations, and error and mitigation reports.

All technical records related to the borehole, spatial and geophysical trajectory logs, photographs of core boxes, description, density tests, samples, petrography, physical and chemical results, among others, which constitute a source of data and information, are kept in the repository(ies) and - or information technology system(s) adequate and accessible for check and - or investigation, whenever necessary. There are operating procedures for all these processes, which are under the responsibility of the data acquisition team in the ferrous mineral exploration management. Vale staff also conduct regular laboratory reviews and audits.

9.1.2. Mineral resource and mineral reserve estimates

We work based on a line of defense structure for governance of our estimation and reporting of mineral reserves and resources, with the purpose of promoting transparency, consistency, professional competence, and the reliability of all information prepared for internal purposes and public reporting. Qualified/competent persons from different areas and departments (resources, reserves, mineral processing, geotechnical engineering (pit, project, and tailings dam) hydrogeology, production, strategy, environment, speleology, finance, mining rights, future mine use, and engineering) approve or certify the assumptions for the work related to the preparation of mineral resource and reserve estimates.

Mineral Reserves and Mineral Resources are estimated in accordance with Global and Vale Ferrous Guidelines and Standards for Mineral Resource and Mineral Reserve Reporting protocols. The guidelines may be subject to be review throughout the year, based on certain circumstances, such as external opinions or amendments to external regulations.

The people in charge of operations are responsible to assure that the mineral reserve and mineral resource estimates, technical documents, and other scientific and technical information for their operation are consistent with Vale´s Global and Ferrous Guidelines. Other experts include individuals in marketing, legal, corporate affairs, finance (tax), strategic and business planning and sustainability (environment, social, governance). These experts are responsible for providing the information that may be required by the ferrous committee of Qualified Persons to ensure that the reports supporting mineral resource and mineral reserve disclosure contain all pertinent information.

Local short term mine planning and mining geology staff are typically responsible for coordinating with other specialists to obtain all information necessary to prepare the estimates. The specialists are knowledgeable in areas such as geostatistics, block modeling, sampling and assaying procedures, diamond drilling, geotechnical, geomechanical, hydrogeology, hydrology, scheduling, cost estimation, lands administration, economic analysis, finance, law, and environment.

The mineral resource and reserves qualified persons are responsible for developing and maintaining mineral resource and mineral reserve estimation and reporting standards, ensuring that such standards and guidelines follow the best practices of the industry, and meet Vale's corporate requirements, as well as the legal requirements.

Technical reviews of the mineral reserve and mineral resource estimates are made by qualified persons annually (or as needed) for each operation and mine. Theyprepare and issue a technical review report to each mine and operation with identified risks. All identified risks require mitigation and addressing, consistent with the risk rating attributed thereto, to be consistent with the disclosure requirements of SK1300, and to be compliant with Vale Global Guidelines for Mineral Resources and Mineral Reserves Management.

9.1.3. Studies

Vale staff perform several internal studies and reports to support the Serra Norte Mineral Resource and Mineral Reserve estimation. These include reconciliation studies, mineability and dilution evaluations, investigations of grade discrepancies between model assumptions and drilling data, drill hole density evaluations, long-term plan reviews, and mining studies to meet internal financing criteria for the project progress.

9.1.4. Reconciliation

The Serra Norte short-term staff perform monthly, quarterly, and yearly reconciliation evaluations. Long-term Mineral Resource staff perform quarterly and annual evaluation, long-term mine planning/reserves perform annual reconciliation. The annual consolidated results report comparison of short-term model, mineral resource, and reserves model, furthermore, production grades and tons are discussed in annual technical meeting to promote continuous improvement of all involved areas. The results indicate that the ore tonnages and grades of the long-term model are controlled within acceptable limits.

9.2. External data verification

The Serra Norte complex was audited in 2008 and again in 2010 when the N5 deposit was included in the mineral reserves. The previous audits included a technical site visit, audit and review of drilling, sampling and assay practices; development of the geologic model; interpretation of grade variations, validation of resource and reserve calculations, mining and processing costs, regulatory permits and approvals. In 2016, these deposits were submitted to another audit process, where Runge Pincock Minarco (RPM) reviewed the mineral resource and reserves estimation techniques and concluded that they comply with the industry standards for iron deposits. In 2019, the N4 and N5 deposits were audited by RPMGlobal, which highlighted, in addition to the quality of the geological models and the resource estimation, the quality of the geological descriptions and the preservation of the drill cores in the conclusion of their report. The most recent external data verification programs for each deposit are summarized in the Table 9-1 below.

Table 9-1 - External data verification, Serra Norte Operations.

Deposit	Auditor	Year
N1	WSP Golder	2023
N2	WSP Golder	2023
N3	WSP Golder	2023
N4	WSP Golder	2023
N5	WSP Golder	2023

9.3. Qualified person's opinion on data suitability

Data verified on upload to the database, and checked using the layered responsibility protocols, is acceptable for use in Mineral Resource and Mineral Reserve estimation.

10. Mineral processing and metallurgical testing

10.1. Summary

In Serra Norte there are three plants: Usina I, Usina II, and Usina III. Together, the three facilities can produce approximately 130 Mtpa of iron ore products, including lump ore, sinter feed, and pellet feed. Process is carried out in both natural moisture and wet circuits, with mass recoveries ranging from 93% to 100%. The plants natural moisture are typical crushing and screening facilities and plant wet have additional stages of classification, magnetic concentration, thickening and filtering.

In addition to these plants, there is a circuit for processing material from the Gelado dam. This circuit has an installed capacity of 14 Mta dry basis. The material from the dam is extracted by dredging and directed to a plant consisting of a protective screening system and a slurry pipeline that conveys the material to the same magnetic concentration as the wet plant. The concentrate from this circuit is the Pellet Feed product.

Serra Norte of a high iron content homogeneous deposit and requires little metallurgical testwork to determine the process route and monitor the operation.

Most of the tests are carried out in Vale's laboratory, with the possibility of carrying out specific tests in external laboratories.

10.2. Metallurgical Testing of Serra Norte

The most recent metallurgical testwork carried out for Serra Norte is related to the pellet feed quality improvement, which is shipped to São Luis pelletizing plant owned by VALE. Magnetic concentration test was evaluated to reduce the alumina content of the pellet feed product. Through of the magnetic concentration route the alumina content was reduced to levels below 1.65%, with a mass recovery of around 61% Considering alumina content in feed is up to 3.5%. For the validation of the process route, a pilot-scale magnetic concentrator was installed in plant 1 of Serra Norte to concentrate the fine fraction of the ore (< 0.15 mm). More than 100 magnetic concentration tests were performed over a period of 6 months and the test analyzes were carried out in the Serra Norte laboratory. The results are shown in Figure 10-1.

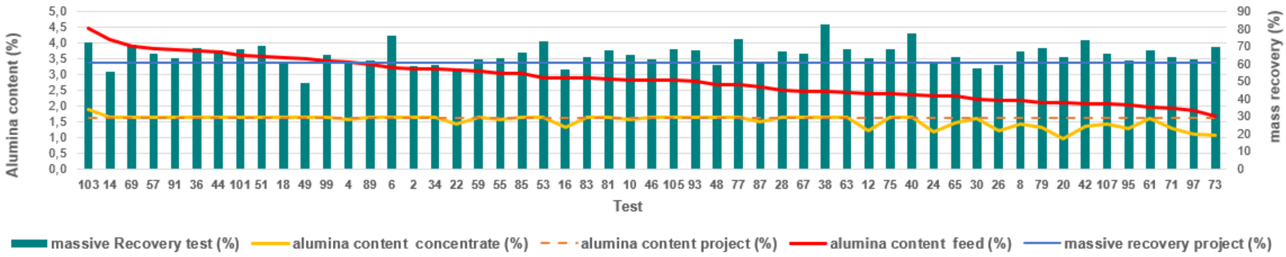


Figure 10-1 - Pellet Feed Magnetic Concentration Testwork Results.

The average results considering alumina content in feed < 3,5% are shown in Table 10-1.

Flow	Mass (%)	Content (%)					
		Fe	SiO_2	P	Al_2O_3	Mn	PPC
Feed	100	62,84	3,45	0,080	2,60	0,338	3,06
Concentrate	61,5	65,12	2,04	0,063	1,61	0,281	2,37
Reject	38,5	59,19	5,71	0,107	4,18	0,430	4,15

Table 10-1 - Test results considering alumina content in the feed < 3.5%

For industrial operation, a mass recovery of 50% is being considered due to chemical and granulometric variability.

10.3. Recovery Estimates

The current global recovery of the 3 plants is between 95 and 97%. After the conversion of plant 1 after 2027 for natural moisture processing, the recovery will be 100%.

10.4. Metalurgical Variability

ROM variability tends to be low due to the homogeneity of the deposit. There may be slight variations between the contents over the years, between the percentage of hydrated ores and between the percentage of jaspelite, but this will have no impact on the process route.

Regarding variations in the content and particle size of the magnetic concentration feed are expected,but these variations will not affect the process of magnetic concentration. Throught operational adjustments in magnetics concentrators it is possible to absorb the variations. After the conversion of plant 1 after 2027 for natural moisture processing, the recovery Metallurgical will be 100%.

10.5. Current Performance

Serra Norte Historical Performance is summarized in Table 10-2

Table 10-2 - Production, recovery and quality carried out

year	Production (Mt)	Products type	Proportion Production (%)	Fe (%)	SiO_2 (%)	Al_2O_3 (%)	P (%)	Mn (%)	PF (%)	Mass recovery (%)
2.019	115,3	Granulado	3,4	62,93	3,43	2,11	0,087	0,423	3,23	95,3
		Sinter Feed	92,4	65,54	1,80	1,38	0,055	0,306	2,29	
		Pellet Feed	4,2	64,61	1,91	2,05	0,062	0,294	2,79	
2.020	109,1	Granulado	3,1	62,37	4,09	2,40	0,067	0,345	3,18	95,3
		Sinter Feed	92,1	65,36	2,16	1,40	0,044	0,273	2,16	
		Pellet Feed	4,7	64,32	2,11	2,18	0,058	0,310	2,84	
2.021	109,3	Granulado	2,2	61,90	4,43	2,41	0,056	0,597	3,18	96,2
		Sinter Feed	93,7	65,70	2,21	1,27	0,035	0,305	1,86	
		Pellet Feed	4,1	64,87	2,23	1,84	0,047	0,292	2,35	
2.022	96,3	Granulado	2,3	61,44	5,55	2,16	0,045	0,575	3,00	97,2
		Sinter Feed	93,7	65,36	2,63	1,23	0,031	0,281	2,01	
		Pellet Feed	4,0	65,34	2,25	1,47	0,034	0,222	2,17	
2023	91,3	Granulado	2.8%	61.32	5.91	2.21	0.058	0.467	2.85	93,7
		Sinter Feed	92.6%	64.95	3.09	1.29	0.032	0.275	1.98	
		Pellet Feed	4.6%	65.07	2.43	1.61	0.044	0.323	2.02	
2024	87,6	Granulado	2.5%	60.57	5.88	2.74	0.046	0.529	3.13	94,1
		Sinter Feed	93.1%	63.82	3.82	1.48	0.029	0.344	2.22	
		Pellet Feed	4.5%	64.59	2.40	1.70	0.038	0.388	2.35	
2025	78,1	Granulado	1.8%	58.91	8.74	2.58	0.030	0.368	2.99	93,6
		Sinter Feed	94.3%	62.99	5.08	1.56	0.024	0.293	2.33	
		Pellet Feed	3.9%	65.22	2.30	1.35	0.032	0.374	2.28	

10.6. **Deleterious elements**

The chemical contents of Serra Norte products are shown in Table 10-2.

The key deleterious elements for iron ore products are silicon, alumina, phosphorus, and manganese. The Serra Norte mine is characterized as a high-purity iron ore producer, with lower contaminant levels, as a corrective for other Vale products. Due to its high quality, there is no commercial penalty for this type of ore.

10.7. Qualified person's opinion on mineral processing and metallurgical testing

The performance of ore bodies in beneficiation plants is well known. Production experience provides a solid basis to forecast production.

As geological knowledge advances, from time to time this can lead to requirements to adjust cut off grades, modify the process flowchart or change plant parameters to meet quality, production and economics targets.

11. Mineral resource estimate

11.1. Summary

Resource estimation includes geological modeling, grade estimation, and mineral inventory classification. This details the nature of the deposit and the reliability of the geological information with which the lithological, structural, mineralogical, alteration, or other geological, geotechnical, and geo-metallurgical characteristics used in typological domains are recorded.

Once the deposit geological modeling step is completed, using explicit, implicit, or hybrid techniques (combining the two methods), this information is interpolated in the block model. The lithological variable is assigned to the block using indicator kriging estimates (explicit modeling) or attributed (*flagged*) from 3D solids (implicit modeling). For both cases, the majority lithology is assumed. This variable is used as mandatory in the grades interpolation and classification of mineral inventory.

Grade interpolation uses multivariate estimation methods by ordinary (co)kriging based on intrinsic correlation models (ICM). The estimate is attributed to the lithological domains using the hard boundary principle. That is, blocks belonging to one domain can be estimated only with samples from the same domain.

The mineral inventories of the block models are classified based on the calculation of the “Risk Index” (RI), which follows the classification method originally proposed by Amorim and Ribeiro (1996) and later reformulated by Ribeiro et al. (2010).

The following flowchart presents the main macro steps from the database, geological modeling, grade estimation, and classification of the mineral inventory of Vale´s iron ore deposits (Figure 11-1).

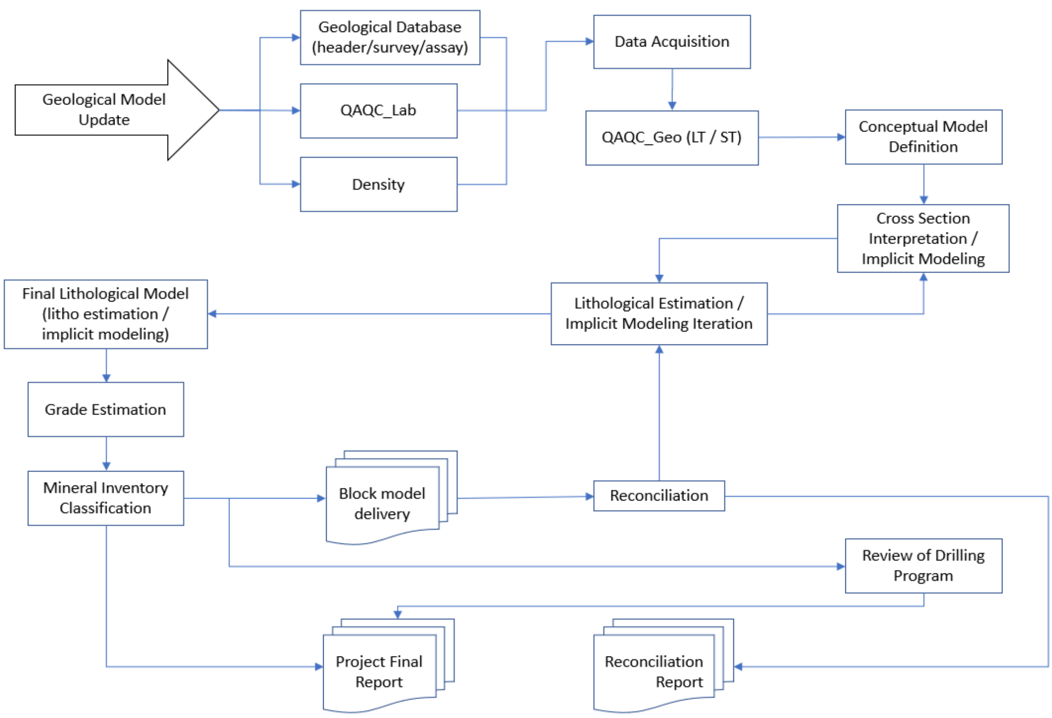


Figure 11-1 - Macro processes flowchart of modeling, grade estimation, and classification of mineral inventory of ferrous deposits

The Serra Norte Complex is composed of the following different mines/deposits listed as: N1, N2, N3, N4, N5 and Gelado. The N4 deposit is composed of N4E deposit and N4W deposit. Those mines share the same logistic facilities and have operational integrations and synergies. The procedures for Mineral Resources Estimation are standardized in Vale´s Ferrous Department. They will be described as a single process to avoid repetition. Wherever necessary, the differences or particularities in the procedures of the mines that comprise the Serra Norte Mining Complex will be highlighted and listed in this section of the Technical Report.

11.2. Resource database

The database used to estimate the grades of the Serra Norte deposits is composed of chemical assays of Fe, SiO_2, P, Al_2O_3, Mn, LOI, TiO_2, MgO, and CaO. These elements were assayed in different fragment size fractions and later grouped into 4 fractions, G1A (+ 19 mm), G1B (-19 + 8 mm), G2 (-8 + 0.15 mm) and G3 (-0.15 mm). The update of the geological and block models of the Serra Norte deposits was completed after extensive review of the entire database.

11.2.1. Database verification

The main database verification points are as follows:

- Chemistry data grouping: with the inclusion of the chemistry data for the different fragment size fractions, the global grades of many samples were recalculated using this information, so it was necessary to consolidate the calculated and assayed global chemistry data into a single group of variables;
- Exclusion of intervals without chemistry (FEGL = -99). Number of excluded samples: 2,325.
- Exclusion of samples without global SiO_2 and Al_2O_3 (SiO_2 and Al_2O_3 = -99): 356 samples that contain only global chemistry information and do not present SiO_2 and Al_2O_3 results were discarded;
- Exclusion of samples without phosphorus (01 samples), alumina (12 samples), managanese (20 samples), and LOI (08 samples);
- Samples with poor global chemical closure, below 94% or above 105%, were discarded. Five samples with closure less than 94% were excluded. A value of 94%, not 95%, was used in this analysis to preserve FM samples;
- The samples that presented a recovery result by interval were evaluated, and intervals with recovery less than 60% were discarded. 10 samples were eliminated in this condition;
- The formula for closure calculation for global chemistry and fragment size fractions, considering only elements that participated in the estimate, is:

$$FQGL = FEGL*1.4297 + SIGL + PGL*2.2913 + ALGL + MNGL*1.2912 + PFGL + TIGL + MGGL + CAGL$$

11.3. Geological interpretation

The geological modeling of the lithotypes is based on the chemical, granulometric, and/or mineralogical homogeneity that differentiates them from each other. In addition, they must have well-defined contacts, with relatively sharp passages in between. The genetic nature of the contact must also be understood for its continuity in-depth to be modeled. The models were completed from vertical geological sections, with their interpretation supported by drill holes and subsurface mapping.

The geological model for mine N1 was built based on 52 vertical geological sections in NE-SW direction, with 48 vertical sections with 200 m spacing and 4 sections spaced 100 m apart (Figure 11-2). The model satisfactorily reproduces the continuity of the mineralized bodies, their host rock, overburden, and intrusive rocks present in the N1 deposit. This model was audited by RPMGlobal in 2016.

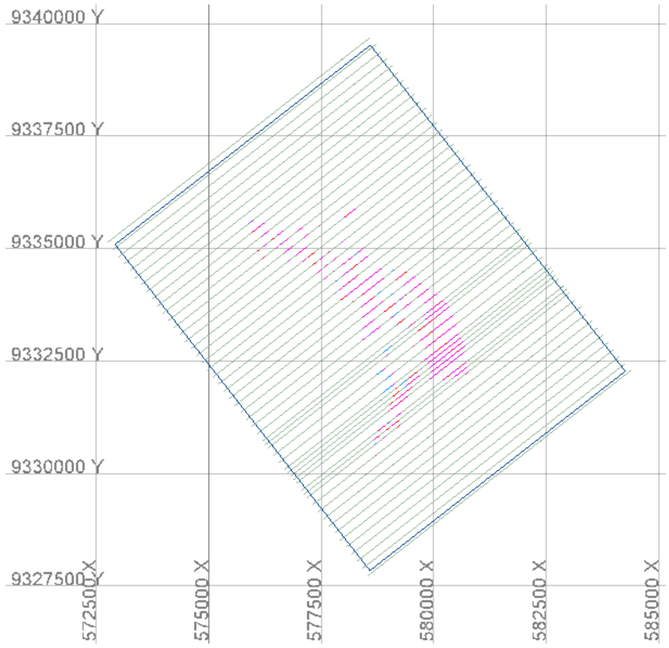


Figure 11-2 - Arrangement of vertical geological sections interpreted in the N1 Model

In the geological model of N2, 14 vertical sections spaced 200 m apart, and 3 intermediate sections were interpreted, totaling 17 vertical sections with NS direction.

In the geological model of N3, 19 vertical sections were interpreted, with 18 spaced 200 m apart and 1 intermediate section. The N3 model has been supported by several drilling campaigns carried out by different companies since 2002. It satisfactorily reproduces the continuity of the mineralized bodies, their host rock, and overburden.

As this is an active mine, most of the information for the model of the N4 deposit was obtained by geological mapping on a 1:2,000 scale, carried out along the mine benches by the Short-Term Geology team. Interpretation was also supported by diamond drill cores. 167 vertical geological sections of E-W direction were interpreted in the geological model of N4, as follows:

- N4W: 106 vertical sections spaced 100 m apart and 7 intermediate sections in the center pit, spaced 50 m apart.
- N4E: 54 vertical sections with 100 m spacing. In the north and central portions of the pit, the vertical sections are displaced 25 m to the south with respect to the set of N4W sections mentioned above. This displacement justifies better positioning of the sections with the drilling grid, avoiding projecting drill holes onto distant sections.

For the geological model of the N5 mine, 145 vertical geological sections were interpreted, in E-W direction, with spacing of 100 x 100 m, locally concentrated to 50 x 50 m, as it can be seen in Figure 11-3.

The geological model supported the mine planning and was audited in 2016 by RPMGlobal. This model satisfactorily reproduces the continuity of mineralized bodies, their host rocks, and overburden.

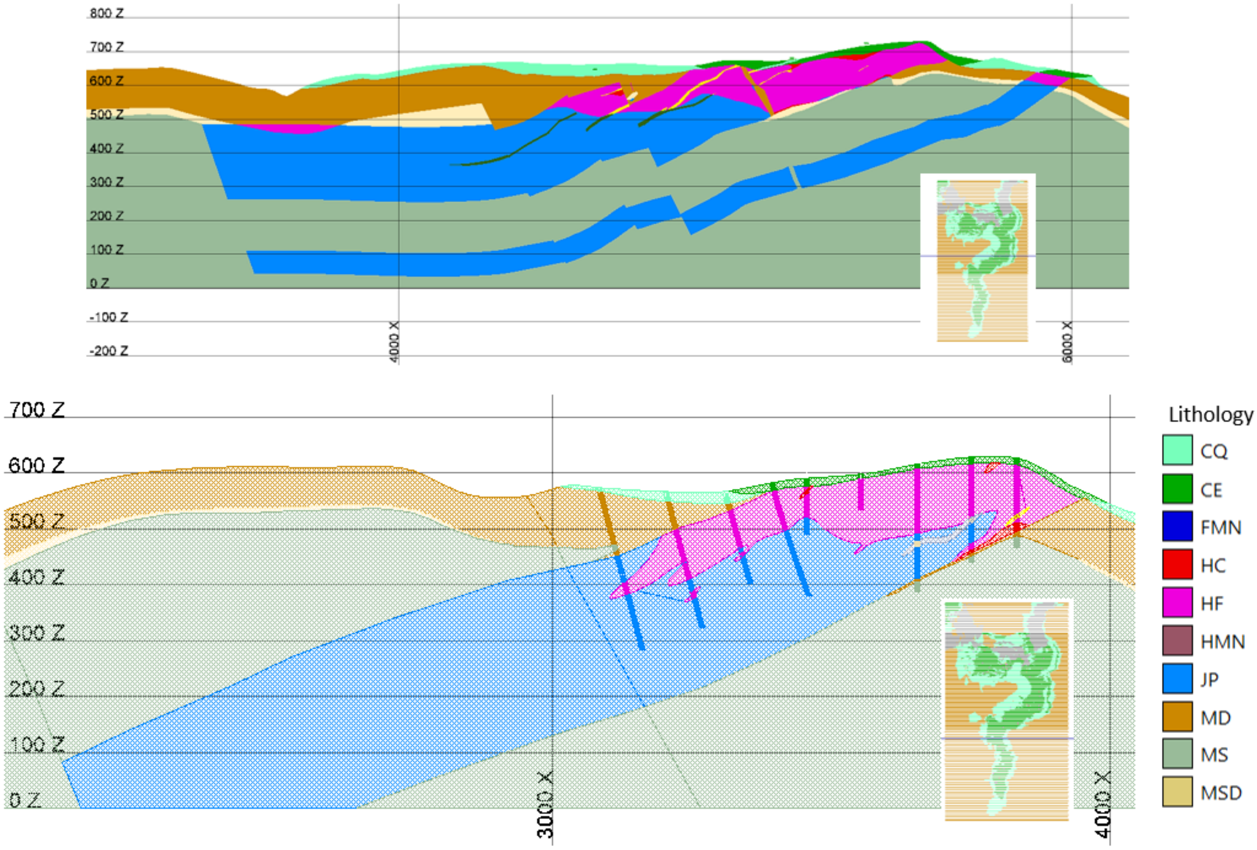


Figure 11-3 - Typical vertical geological sections of the northern portion of the N5 Mine

11.4. Geological modelling

11.4.1. Geological modeling methodology

The construction of mass models at VALE Ferrosos is done using a mixed method that combines geostatistical estimation of categorical variables and 3D modeling. The method of estimating these categorical variables combines the use of direct data (description of drill cores) and indirect data (geological map and geological interpretations). Lithological estimation aims to transfer the geological continuity interpreted during modeling (two-dimensional sections) to a three-dimensional space represented by block models.

The geological modeling of the geometry of the bodies is responsible for predicting the tonnages to be mined. The spatial modeling of the grade distribution is carried out by mathematical and geostatistical methods and is strongly linked to the definition of lithotypes and the geometric modeling strategy (Guimarães et al., 2005).

Explicit modeling with indicator estimation

Explicit modeling from the interpretation of vertical sections is generated with the help of Vulcan® software. Vertical sections are preferably perpendicular to the mineralized bodies. The spacing between sections will depend on the spatial arrangement of the drilling information, which can normally vary between 50 m and 100 m. As an exception, places that lack this information may have their sections more spaced, but this will impact the efficiency/robustness of the interpolator directly. The interpretation is made using half of the space between sections that influence the section, in which each drill hole belonging to this corridor is projected into the section, or in case of divergent information, the closest to the section prevails.

The geological interpretation in sections is materialized directly in the block model using the indicator kriging method (IK). This method consists of transforming a set of lithological data into indicator variables, respecting the procedures of ordinary kriging. These spatially distributed and spatially dependent variables are transformed into binary variables (0 or 1), where the probability of each variable belonging or not to a lithological group in each spatial position is calculated. This methodology was developed by Journel (1983), where the author proposed a conditional cumulative distribution function for estimating spatial data.

The methodology adopted in this work was developed by Ribeiro and Carvalho (2002) and modified by Roldão et al. (2006). The authors propose the combination of conventional modeling methods with the indicator kriging estimation method, in which the interpreted sections are gridded and used in the estimation process together with the drilling database and short-term information (maps and/ or samples). The allocation of the lithologic variable is based on pseudo-probability calculated for each lithologic indicator, assuming the majority value. Figure 11-4 presents a flowchart with the steps for the acquisition, estimation, and validation of the lithological variable.

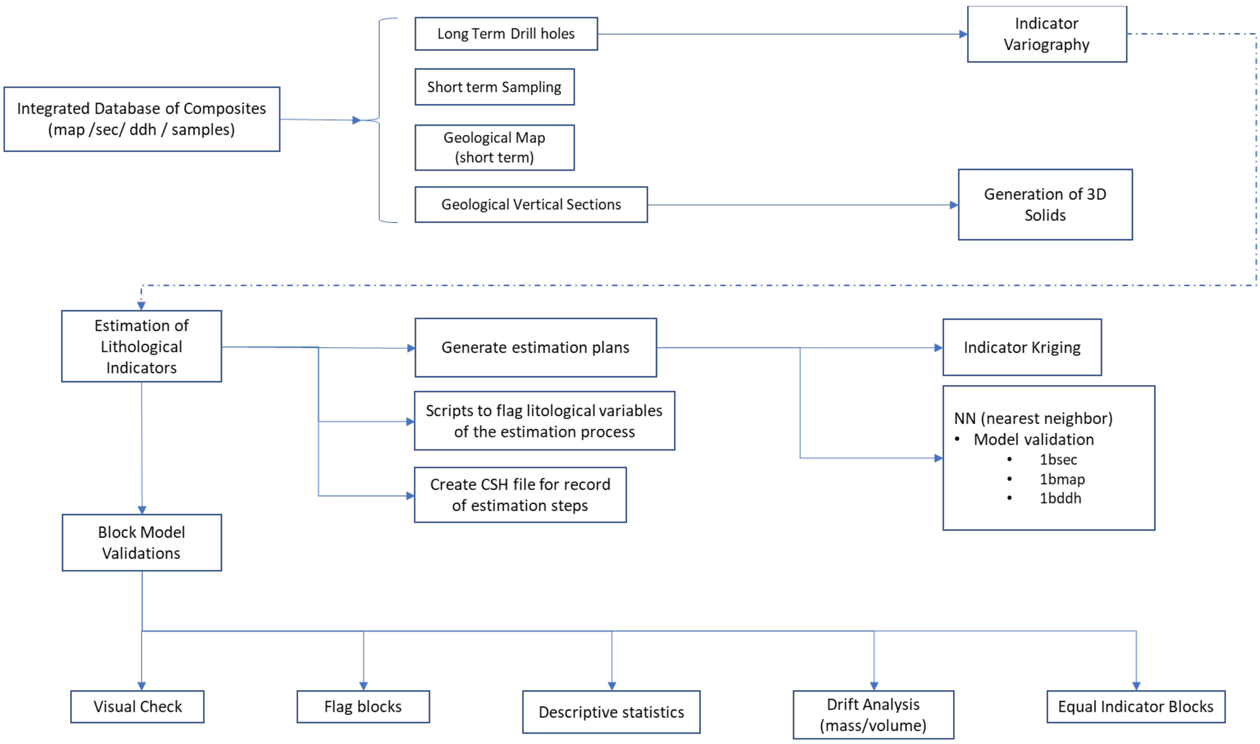


Figure 11-4 - Flowchart of macro-processes for modeling and estimation of grades and classification of the mineral inventory of iron ore deposits

11.4.2. Serra Norte lithological estimation

The Serra Norte models were built using the Indicator Kriging (IK) method (Ribeiro and Carvalho, 2002; Roldão et al., 2006).

The IK lithology estimation method was adopted in this work to reduce the time spent in the generation of horizontal sections ("mechanical" work). The method was validated by Roldão et al. (2006), and the authors present IK as an effective and more agile technique than the conventional methods used in the past (extrusion method of horizontal sections).

Lithology Indicators Database

The geostatistics process for the estimation of lithotypes considers long-term and short-term information, and for this purpose, the binary indicator variable **V_IND** was created, which represents the presence of the lithotype in the regularized sample (1 if present and 0 if absent). Other V_IND variables are usually created (V_IND1, V_IND2, V_IND3, etc.) to test different distributions of indicators, aiming to find the one that best represents the spatial continuity of the lithotypes to be estimated.

Indicator variables are attributed to the geocode field (lithotype). For example, a regularized HF geocode sample will have value "1" attributed to its indicator variable "IHF", while the value "0" will be attributed to the other indicator variables (for the other lithotypes). For lithotypes that will not be estimated by IK, value "–99" is attributed to the fields of the indicator variables.

11.4.2.1. N1 – Lithotypes

Variographic Analysis of Indicators

The variographic study of the N1 model was carried out from the analysis of a single variogram for all indicators, based on the hypothesis that the indicators would have intrinsic correlation, that is, their variograms would have the same range and would vary only in the vertical scale (sill). All variography steps were performed with the help of Vulcan® and Isatis® software. Long-term and short-term database samples/intervals (N1flp_1215_var_entry.csv) were used for the variographic analysis.

The choice of the lithotypes of the composites that participated in the variography as a binary variable was: 1 for lithotypes HF, HC, and HMN and 0 for lithotypes CE, CQ, FM, JP, MS, MSD, MS. The three types of mafic lithotypes are different in the form of occurrence, whether dyke (DK: MDDK, MSDDK, MSDK) or sill (SL: MDSL, MSDSL, MSSL), in addition to the occurrence as host rock (top and base of the iron formation, MD, MSD, MS). However, for the lithological estimation, the mafic groups are consolidated. Thus, we have the decomposed mafic (MD) group, which comprises MD, MDDK, MDSL, the semi-decomposed mafic (MSD) group, which comprises MSD, MSDDK, MSDSL, and the fresh mafic (MS) group, which comprises MS, MSDK, MSSL.

Structural sectors

The N1 model was divided into 7 structural sectors as a function of variations in the dip and the directions of the layers of the ore bodies. These sectors were important to represent the differences in the attitude of the ore bodies and add better lithological representation of the deposit. Structural Sectors were applied throughout the N1 model for the lithology estimation.

Indicators interpolation

In the construction of the block model of the lithological indicator, the initial step is the generation of the model of waste lithologies blocks from the construction of 3D solids based on the vertical sections. After this step, the estimation of lithological indicators is carried out within the limit defined as iron formation. Ordinary kriging was used to estimate the lithological indicators, with each lithotype estimated by IK representing an indicator variable, totaling 10 variables (icq, ice, ihf, ihc, ihmn, ifm, ijp, imd, imsd, ims).

The NN method was adopted to validate the kriging estimate. At this stage, the same parameters used in kriging were reproduced in NN estimation. Estimation plans were created so that the block model would honor the interpreted section (1bsec) and the drilling information (1bflp). These plans are explained in Table 11-1.

Table 11-1 - Parameters used in lithotype estimation plans

Parameters	Kriging	NN	1bflp	1bsec
Group	15MFLP/SEC		15MFLP	SEC
Min. samples	1	1	1	1
Max. samples	16	1	1	1
Octant	2	-	-	-
Block discretization	1 x 1 x 1	1 x 1 x 1	1 x 1 x 1	1 x 1 x 1
Search range	450 x 150 x 50		15 x 15 x 9	

Validation

To validate the variable "litho" estimated by IK, a series of checks is performed:

Estimate Summary – evaluates the number of blocks estimated for each kriging plan. For kriging plans with the same estimation parameters, it is mandatory to have the same number of estimated blocks.

Visual check – is defined as the main validation, in which it is visually assessed block by block whether the IK managed to reproduce the continuity of the geological interpretation proposed by the geologist, Figure 11-5. The visual validation is carried out in vertical, horizontal, and longitudinal sections. This validation is always done together with the modeling geologist, and the need to generate sections in different orientations to reproduce the geological continuity interpreted by the geologist is evaluated.

Empty blocks – 60 empty blocks were identified in the estimation process. This was fixed by applying NN estimate to these blocks.

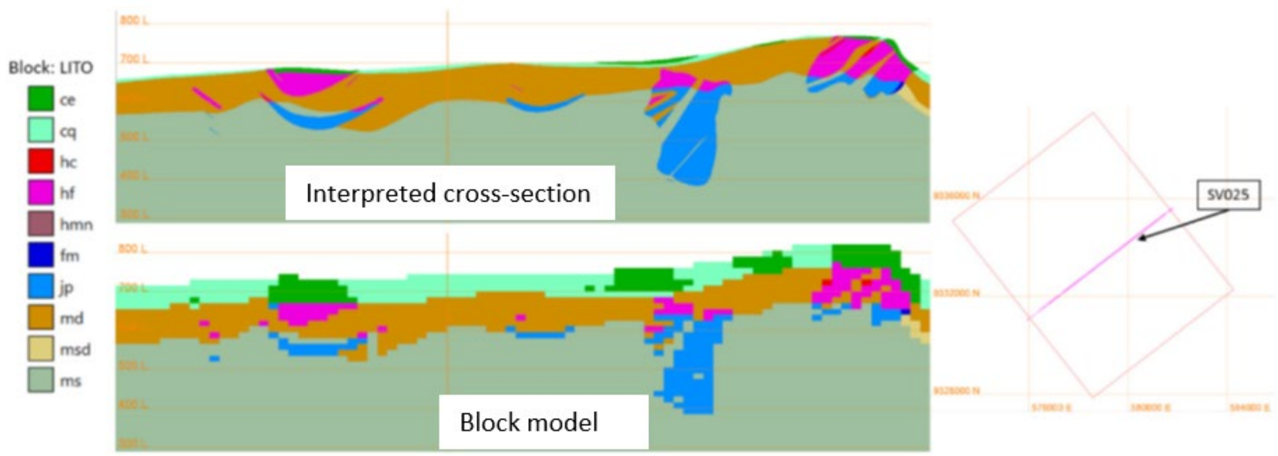


Figure 11-5 - Comparison between interpreted geological vertical section (SV_025) and block model section

Flag blocks – The objective of this check is to validate the adherence between the lithotype of the samples and the lithology of the block model. The procedure consists of attributing the sample with the lithology of the block to which it belongs and comparing this attribute with the lithology of the sample in the database. In general, the discrepancies are related to samples of short length (much smaller than the size of the block) in which it is possible to find more than one sample within the block.

Drift Analysis (Nearest Neighbor (NN)) – Drift analysis is made to assess whether the estimation process is biased with respect to the samples. Among the ore lithotypes, the comparison between the proportions presented by the different methods for HF and JP lithotypes showed good results. On the other hand, the FM, HMN, and HC lithotype graph showed greater relative bias. This is due to the small amount of FM, HMN, and HC in the model, in addition to the fact that the IK process has a smoothing character. However, due to the better continuity of the estimate by IK, it was decided on the result of the kriging of the lithological indicators.

11.4.2.2. N2 – Lithotypes

Variographic analysis of indicators

The variographic study of the N2 model was carried out from the analysis of a single variogram for all indicators based on the hypothesis that the indicators would have intrinsic correlation, that is, their variograms would have the same range and would vary only in the vertical scale (sill). All variography steps were performed with the help of Vulcan® and Isatis® software. Only long-term database samples/intervals (N2flp_var_entry.csv) were used for the variographic analysis.

The choice of the lithotypes of the composites that participated in the variography as a binary variable was: 1 for lithotypes HF, HC, HMN, CE, CQ, FMN, and JP and 0 for lithotypes MS, MSD, MS, and QT.

Structural sectors

The model was estimated as a single sector. Structural Sectors were not applied in the estimation of lithologies, as the structure of the rocks does not present abrupt changes in direction and/or dip.

Indicators interpolation

In the construction of the block model of the lithological indicator, the initial step is the generation of the model of waste lithologies blocks from the construction of 3D solids based on the vertical sections. After this step, the estimation of lithological indicators is made within the limit defined as iron formation.

Ordinary kriging was used to estimate the lithological indicators, with each lithotype estimated by IK representing an indicator variable, totaling 12 variables (icq, ice, ihf, ihc, ihmn, ifmn, ijp, imd, imsd, ims, iqt, iin).

Table 11-2 presents the relation of the lithotypes modeled by 3D and those estimated by IK.

To validate the kriging estimate, the NN method was adopted. At this stage, the same parameters used in kriging were reproduced in NN estimation. Estimation plans were created so that the block model would honor the interpreted section (1bsec) and the drilling information (15bflp).

Table 11-2 - Parameters used in lithotype estimation plans

Parameters	Kriging	NN	1bflp	1bsec
Group	15MFLP/SEC		15MFLP	SEC
Min. samples	1	1	1	1
Max. samples	16	1	1	1
Octant	2	-	-	-
Block discretization	1 x 1 x 1	1 x 1 x 1	1 x 1 x 1	1 x 1 x 1
Search range	400 x 200 x 50		15 x 15 x 9	

Validation

To validate the variable “litho” estimated by IK, the same procedures as in N1 are used: estimate summary, visual check (Figure 11-6), empty blocks, flag blocks, and drift Analysis NN (Figure 11-7).

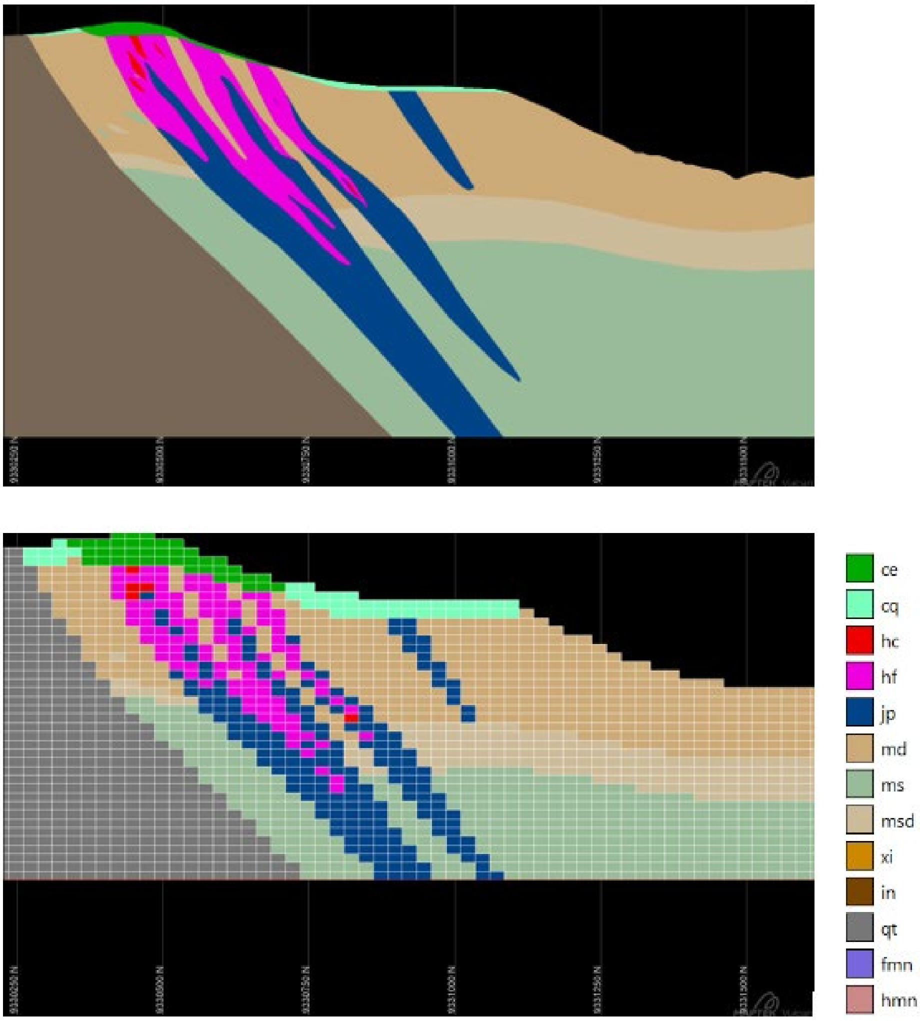


Figure 11-6 - Comparison between interpreted geological vertical section (SV_10) and block model section

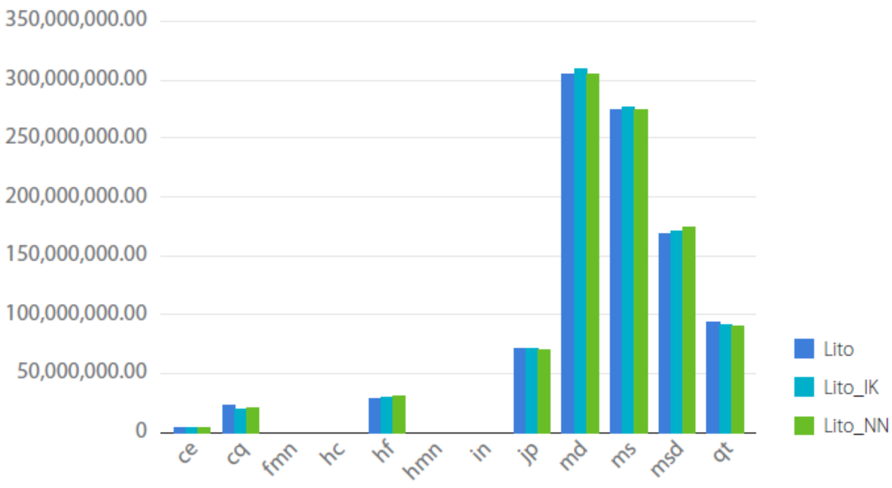


Figure 11-7 - Drift analysis

11.4.2.3. N3 – Lithotypes

Variographic analysis of indicators

The variographic study of the N2 model was carried out from the analysis of a single variogram for all indicators, based on the hypothesis that the indicators would have intrinsic correlation, that is, their variograms would have the same range and would vary only in the vertical scale (sill). All variography steps were performed with the help of Vulcan® and Isatis® software. Only long-term database samples/intervals (n3_n3flp_var_entry.csv) were used for the variographic analysis.

The choice of the lithotypes of the composites that participated in the variography as a binary variable was: 1 for the iron formation lithotypes (HF, HC, HMN, CE, FMN, JP) and 0 for the waste lithotypes (XI, MS).

Structural sectors

Initially, the structural sectors for the estimation of lithological indicators were defined in the block model. These sectors are intended to represent the interpreted geological continuity. Two structural sectors were created: 1) north (Azimuth 60°/ Plunge 0°/Dip -60°); 2) south (Azimuth 85°/ Plunge 0°/ Dip -50°). The boundaries between the north and south sectors were defined by solids created from the interpreted vertical sections.

Indicators interpolation

The first step in the construction of the block model of the lithological indicator is the generation of a model of waste lithology blocks from the construction of 3D solids based on vertical sections. After this step, the estimation of lithological indicators is made within the limit defined as iron formation.

Ordinary kriging was used to estimate the lithological indicators, with each lithotype estimated by IK representing an indicator variable, totaling 11 variables.

To validate the kriging estimate, the NN method was adopted. At this stage, the same parameters used in kriging were reproduced in NN estimation. Estimation plans were created so that the block model would honor the interpreted section (1bsec) and the drilling information (1bflp). These plans are explained in Table 11-3 and Table 11-4.

Table 11-3 - List of lithotypes modeled by solid (3D) and/or estimated by IK

Modelled Lithotypes	3D Modelling	File Name	Indicator Kriging	Lithotype Indicator
CE	x	solido_3d_n3_ce.00t solido_3d_n3_ce1.00t solido_3d_n3_ce2.00t		ice
CQ	x	solido_3d_n3_cq.00t solido_3d_n3_cq1.00t		icq
HF			x	Ihf
HC			x	Ihc
HMN			x	Ihmn
JP			x	Ijp
FMN			x	Ifmn
MS	x	solido_3d_n3_ms.00t		ims
MSD	x	solido_3d_n3_msd.00t		Imsd
MD	x	solido_3d_n3_md.00t		Imd
XI	x	solido_3d_n3_xi.00t		ixi

Table 11-4 - Parameters used in lithotype estimation plans

Parameters		Kriging	NN	1bflp	1bsec
Samples	Database	N3_n3.cik.isis			
	Group	15MFLP/SEC		15MFLP	SEC
	Min. samples	1	1	1	1
	Max. samples	16	1	1	1
	Octant	Yes	-	-	-
Blocks	Discretization	1 x 1 x 1	1 x 1 x 1		
	Search range	400 x 180 x 30		15 x 15 x 9	15 x 15 x 9

Validation

To validate the variable “litho” estimated by IK, the same procedures as in N1 are used: estimate summary, visual check (Figure 11-8), empty blocks, flag blocks, and drift Analysis NN (Figure 11-9).

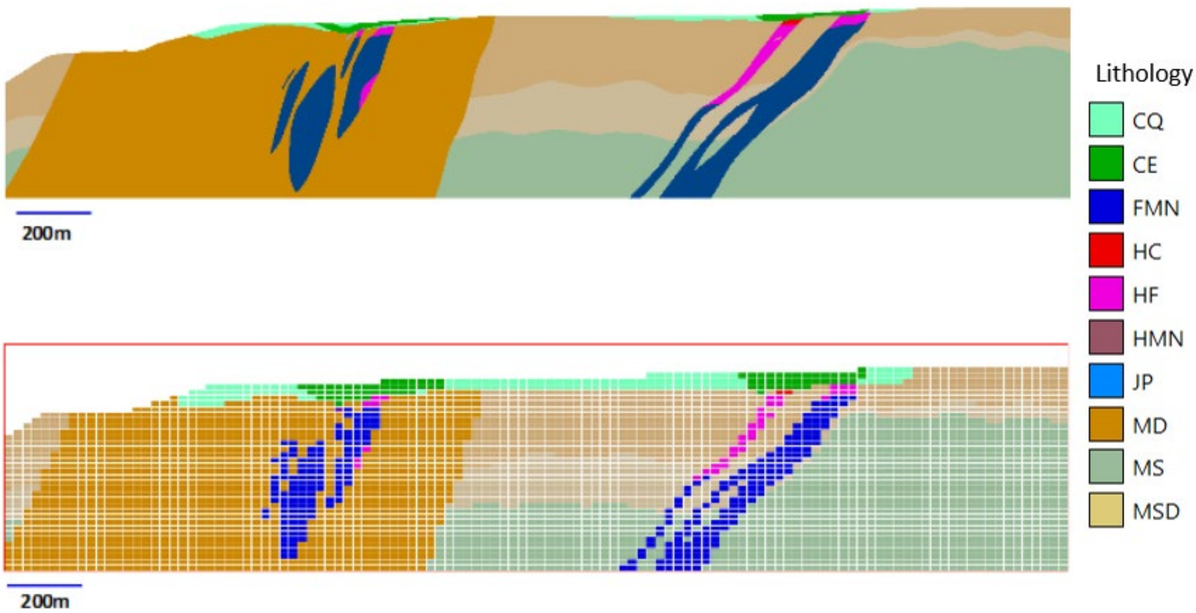


Figure 11-8 – Comparison between the interpreted geological vertical section (SV_13) and the same section in the block model

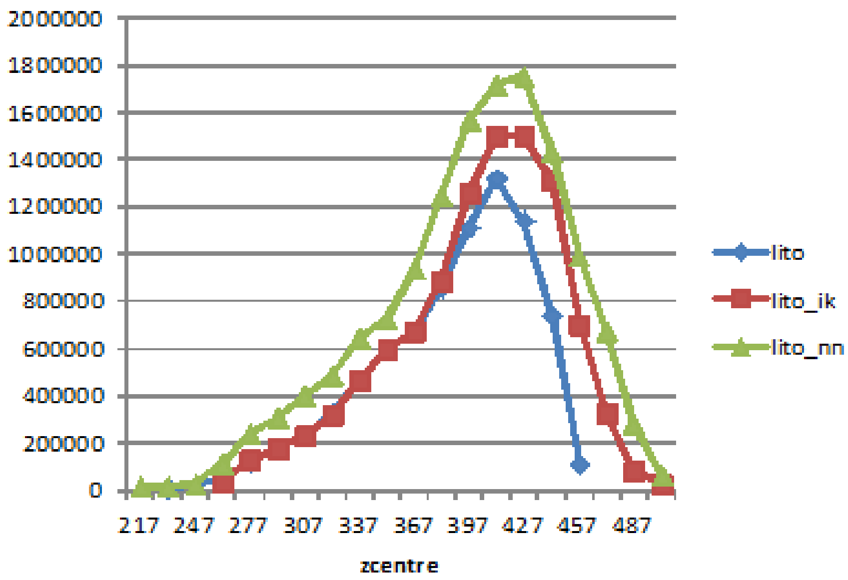


Figure 11-9 – Volumetric comparison between lito (final lithotype attribute), Lito_ik (estimate by IK), and Lito_nn (estimate by NN) of friable hematite from the N3 model

11.4.2.4. N4 – Lithotypes

Variographic analysis of indicators

The variographic study of the N1 model was carried out from the analysis of a single variogram for all indicators, based on the hypothesis that the indicators would have intrinsic correlation, that is, their variograms would have the same range and would vary only in the vertical scale (sill). All variography steps were performed with the help of Vulcan® and Isatis® software. Exploration and ore control database samples/intervals were used for the variographic analysis.

The choice of the lithotypes of the composites that participated in the variography as a binary variable was: 1 for lithotypes HF, HC, and HMN and 0 for lithotypes CE, CQ, FMN, JP, MS, MSD, and MS. The three types of mafic lithotypes are different in the form of occurrence, whether dyke (DK: MDDK, MSDDK, MSDK) or sill (SL: MDSL, MSDSL, MSSL), in addition to the occurrence as host rock (top and base of the iron formation, MD, MSD, MS). However, for the lithological estimation, the mafic groups are consolidated. Thus, we have the decomposed mafic (MD) group, which comprises MD, MDDK, and MDSL, the semi-decomposed mafic (MSD) group, which comprises MSD, MSDDK, MSDSL, and the fresh mafic (MS) group, which comprises MS, MSDK, MSSL.

Structural sectors

For the N4 mine model, four structural sectors were created, which were attributed to the block model, numbered 1 to 4. Sectors 1 and 2 represent the main structure of the N4E body, and sectors 3 and 4, are the main structure of the N4W. In the estimation, horizontal search ellipsoids were used for the mafic host rocks and overburden. The orientation of the ellipsoids varies according to the sector, with different dip for iron formation lithotypes and mafic sills. For the dikes, azimuth 310° and 75° dip were used.

Indicators interpolation

In the construction of the block model of the lithological indicator, the initial step is the generation of the model of waste lithology blocks, from the construction of 3D solids based on the vertical sections interpreted using Vulcan® software. Solids were built using Leapfrog® software. After this step, the estimation of lithological indicators is carried out within the limit defined as iron formation

To validate the kriging estimate, the NN method was adopted. At this stage, the same parameters used in kriging were reproduced in NN estimation. Estimation plans were created so that the block model would honor the interpreted section (1bsec) and the drilling information (1bflp). These plans are explained in Table 11-5 and Table 11-6.

Table 11-5 - List of lithotypes modeled in 3D and those estimated by IK

Lithotype	3D Modelling	IK	Indicator Lithotype
AG	x		
CQ	x	x	icg
CE	x	x	ice
HF		x	ihf
HC		x	ihc
HMN		x	ihmn
FMN		x	ifmn
JP		x	ijp
MD	x	x	imd
MDDK	x	x	imddk
MDSL		x	imdsl
MSD	x	x	imsd
MSDDK	x	x	imsddk
MSDSL		x	imsdsl
MS		x	ims
MSDK	x	x	imsdk
MSSL	x	x	imssl

Table 11-6 - Lithological indicator estimation parameters

Parameters		Kriging	NN	1bflp	1bfcp	1bsec
Samples	Database	Sn4sn4.cik.isis				
	Group	15MFLP/15MFCP/SEC		15MFLP	15MFCP	SEC
	Min. samples	1	1	1	1	1
	Max. samples	16	1	1	1	1
	Octant	Yes	-	-	-	-
Blocks	Discretization	1 x 1 x 1	1 x 1 x 1	-	-	-
	Search range (m)	400 x 300 x 100		12.5 x 12.5 x 7.5		
	Sectoring	Yes		-	-	-

Validation

To validate the variable "litho" estimated by IK, the same procedures as in N1 are used: estimate summary, visual check (Figure 11-10), empty blocks, flag blocks, and drift Analysis NN (Figure 11-11).

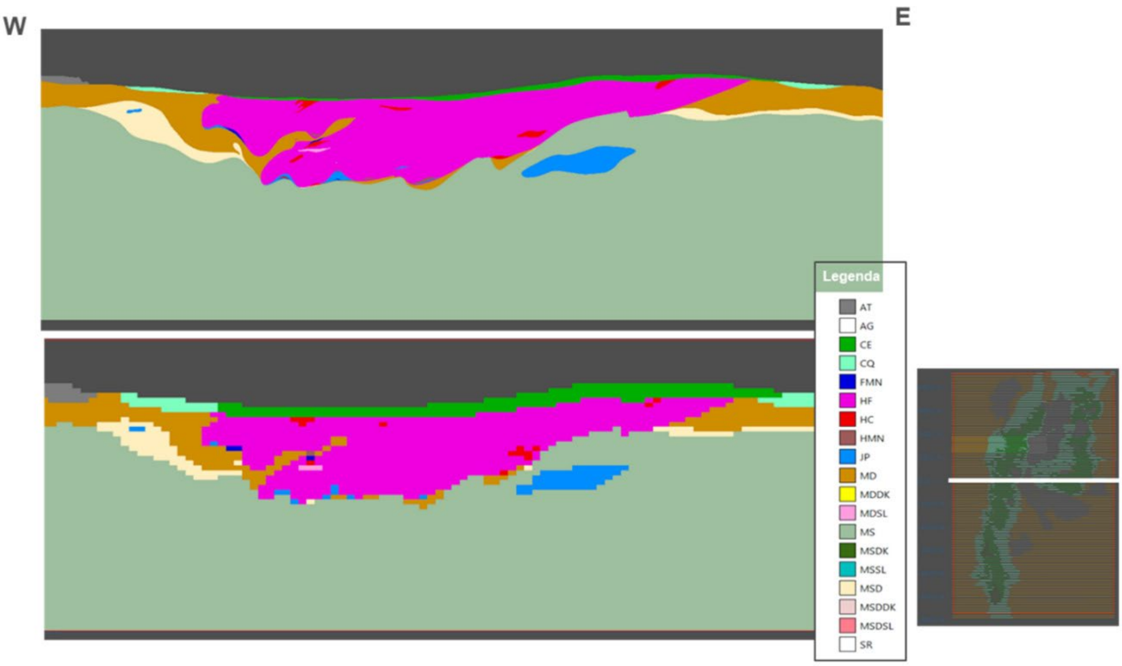


Figure 11-10 - Comparison between interpreted geological vertical section (SV_0100N) and block model sec

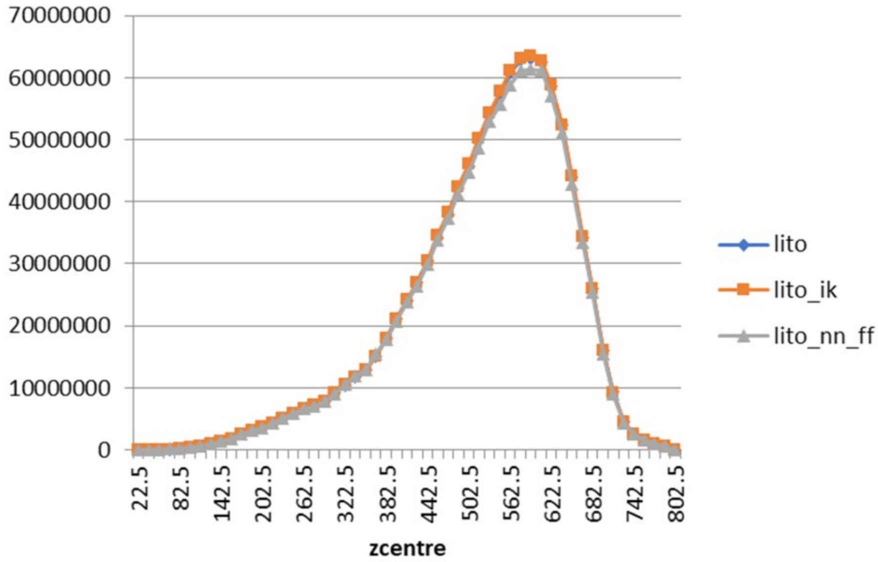


Figure 11-11 – Volumetric comparison between litho (final flagged lithotype), lito_ik (estimate by IK), and litho_nn (estimate by NN) of the friable hematite of the N4 mine model

11.4.2.5. N5 – Lithotypes

Variographic analysis of indicators

The variographic study of the N5 model was carried out from the analysis of a single variogram for all indicators, based on the hypothesis that the indicators would have intrinsic correlation, that is, their variograms would have the same range and would vary only in the vertical scale (sill). All variography steps were performed with the help of Vulcan® and Isatis® software. Long-term and short-term database samples/intervals were used for the variographic analysis.

The choice of the lithotypes of the composites that participated in the variography as a binary variable was: 1 for lithotypes HF, HC, HMN, FMN, JP, CE and 0 for lithotypes MS, MSD, MD, MDDK, MSDDK, MSDK, MDSL, MSDSL, MSSL, CQ, CQL. The three types of mafic lithotypes are different in the form of occurrence, whether dyke (DK: MDDK, MSDDK, MSDK) or sill (SL: MDSL, MSDSL, MSSL), in addition to the occurrence as host rock (top and base of the iron formation, MD, MSD, MS).

Structural sectors

Due to the complexity of the lithological contacts, the conventional search strategy, which considers fixed search angles, was not applied. The dynamic anisotropy method was selected to estimate the N5 model whose search ellipsoid orientation follows different azimuths and dips that best represent the lithological behavior. Three domains were identified: a structural, a supergene, and the external sector. For the structural and supergene sectors, the surfaces that best represent the lithological behavior interpreted in the vertical sections were used as a basis. For regions outside the control surfaces, the general direction of the variogram was used.

The information that allows for dynamic anisotropy, azimuth, and dip values for each block is obtained using guide surfaces. These surfaces are composed of a high number of small triangles and with the help of scripts, it is possible to calculate the vector components of each one, creating a database whose coordinates of the points are the central points of each triangle and the variables are the vector components. These components are estimated in the blocks and a calculation is made to convert the values of the vector components into azimuths and dips. Finally, at the time of estimation, the software identifies which azimuth and dip values are present in the block to be estimated and applies them in the estimation process. Azimuth and dip information is recorded in the block model as a guide variable with the prefix “dyna” followed by the abbreviation that represents the control surfaces.

Indicators interpolation

Ordinary kriging was used to estimate the lithological indicators with each lithotype estimated by IK representing an indicator variable, totaling 17 variables (icgl, ice, icq, ifmn, ihc, ihf, ihmn, ijp, imd,imddk, imdsl, imsd, imsddk, imsdsl, ims, imsdk, imssl). Only the dump lithologies (AT) and the iron formation that came from N4 were attributed by solids, all the others were estimated using indicator kriging.

To validate the kriging estimate, the NN method was adopted. At this stage, the same parameters used in kriging were reproduced in NN estimation. Estimation plans were created so that the block model would honor the interpreted section (1bsec) and the drilling information (1bflp, long-term drilling; 1bfcp, short-term drilling) in addition to the short-term maps (1bmap). These plans are explained in Table 11-7.

Table 11-7 - Lithological indicator estimation parameters

Parameters		Kriging	NN	1bflp	1bfcp	1bsec	1bmap
Samples	Database	N5N5.cik.isis					
	Group	15MFLP/15MFCP/SEC/MAP		15MFLP	15MFCP	SEC	MAP
	Min. samples	1	1	1	1	1	1
	Max. samples	16	1	1	1	1	1
	Octant	Yes	-	-	-	-	-
Blocks	Discretization	1 x 1 x 1	1 x 1 x 1	-	-	-	-
	Search range (m)	540 x 490 x 45		15 x 15 x 9			
	Sectoring	Yes		-	-	-	-

Validation

To validate the variable "litho" estimated by IK, the same procedures as in N1 are used: estimate summary, visual check (Figure 11-12), empty blocks, flag blocks, and drift Analysis NN (Figure 11-13).

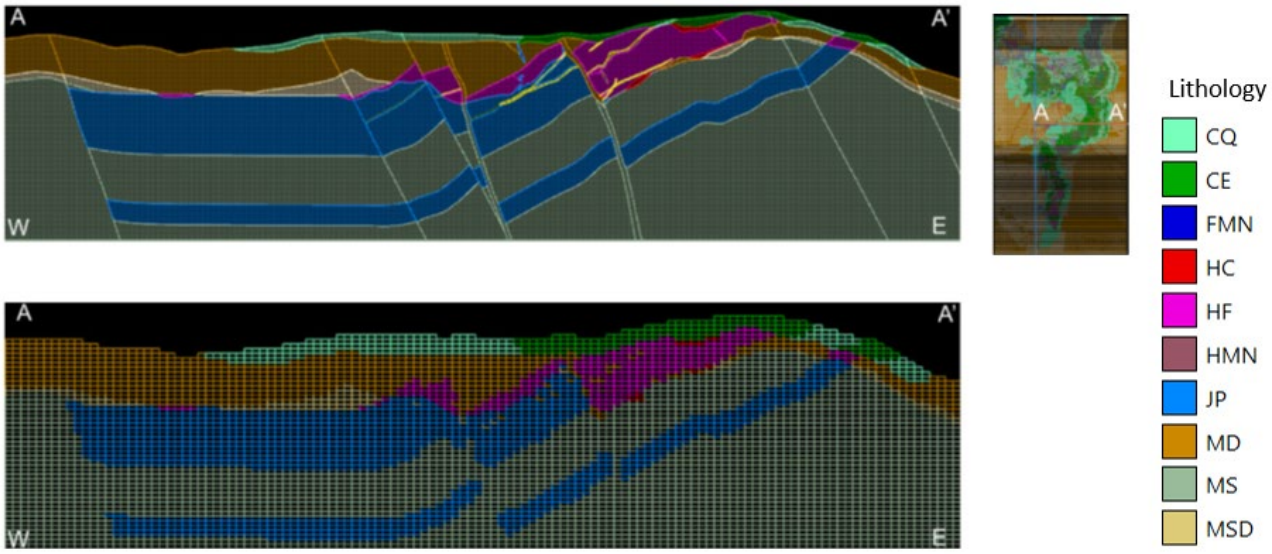


Figure 11-12 – Comparison between interpreted geological vertical section and section of the block model

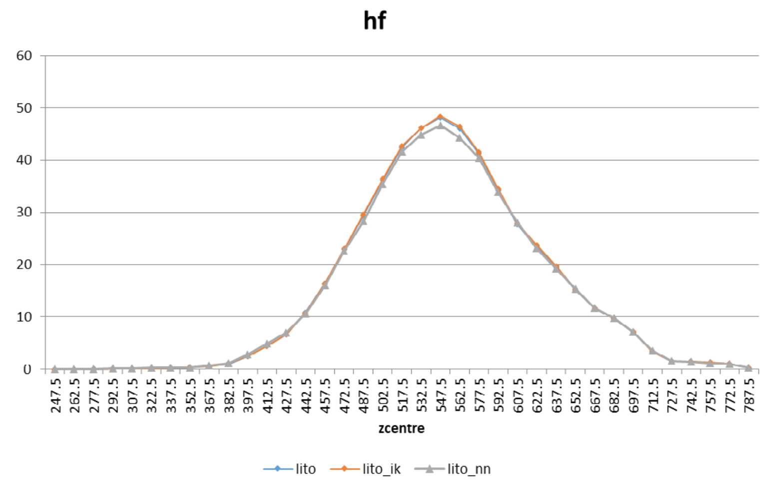


Figure 11-13 – Volumetric comparison between litho (final lithotype flag, in the block model), litho_ik (IK estimate), and litho_nn (NN estimate) for friable hematite of the N5 mine model

11.5. Domain modelling

11.5.1. Methodology

For domain modeling, a definition of lithotypes is considered using geological databases, geological mine maps, and regional mappings as references.

The database contains information referring to drill holes with macroscopic visual geological descriptions of the drill cores and a variable of visual classification (CLV), as per Vale internal standards. The same criteria are used for geological description in databases that include mine sampling.

From the visual description (CLV) of the intervals that make up the geological database and the lithotypes macroscopically identified in the mine, from surface mappings, the definition of the lithotypes that will be modeled is made. In the modeling stage, the definition of relatively homogeneous geological zones is carried out in which the contacts are well defined and marked by mineralogical, chemical, and/or granulometric discontinuities.

A mathematical classification key (CLM) is generated to define the lithotypes that will be modeled based on visual, mineralogical, chemical, and granulometric characteristics, looking for the signature of each lithotype. Studies are carried out with statistical analysis (histograms, cluster analysis, contact analysis, etc.) to define the mathematical classification.

An example of a mathematical classification key for Serra Norte is shown in Table 11-8 and Figure 11-14.

Table 11-8 - Serra Norte mathematical classification key

Lithotype		Iron grade	Manganese grade	G1 (>8mm)
CE – Ore cover		>=55%		
CQ – Chemical cover		<55%		
HF – Friable hematitite		>=60%	<2%	<50%
HC – Compact hematitite		>=60%	<2%	>=50%
HMN – Manganiferous hemtitite		>=55%	>=2%	
JP – Jaspilite		<60%	<2%	
FMN – Iron-manganese		<55%	>=2%	

The contacts between the types of iron formation are generally well defined, with sharp differences in grades and/or compactness that define the lithotypes. Figure 11-14 shows a detail of a vertical geological section with an example of the differences in grades and particle sizes of the lithotypes.

Figure 11-15 shows a contact analysis between two lithotypes (HF and JP), in which the average of the Fe contents relative the distance to contact is calculated.

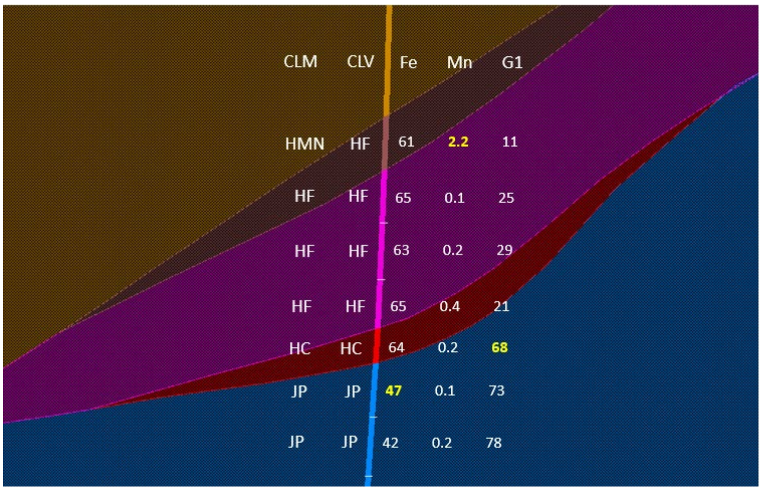


Figure 11-14 - Drillhole detail in vertical geological section showing visual (CLV) and mathematical (CLM) classifications, iron (Fe) and manganese (Mn) contents and retained mass percentages in G1 (>8 mm), in the different lithotypes (sudden changes in values indicate the presence of contact).

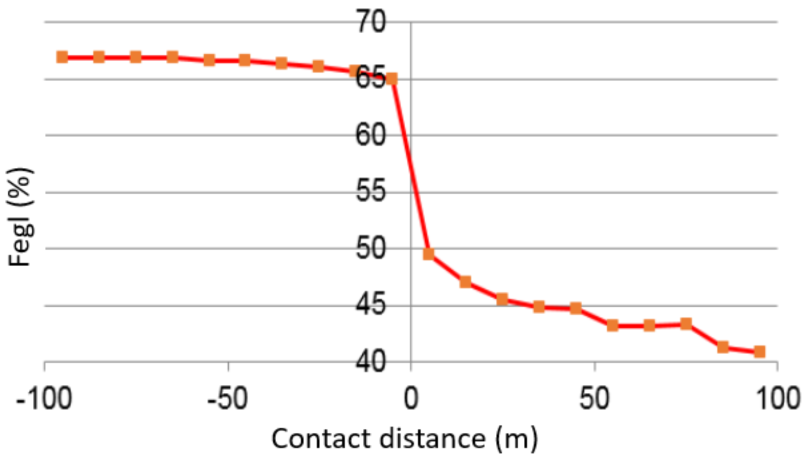


Figure 11-15 - Global Fe mean contents in the contact region between friable hematite (HF) and jaspilite (JP)

From the compatibility of the visual classification of the lithotypes (CLV), their chemical and granulometric characteristics (CLM), and the geological context of each interval, the lithotypes are modeled and classified under an “interpreted classification” code, called CLI. CLI represents the lithotype classification according to the interpretation of the geological model, considering visual, mineralogical, chemical, and granulometric characterization, in addition to the geological context.

Figure 11-16 shows the interpreted (CLI), mathematical (CLM), and visual (CLV) classifications, the iron (Fe) and manganese (Mn) contents and the percentages of mass retained in the G1 grain size fraction (> 8 mm), in drill holes of a vertical geological section. The Interpreted Classification (CLI) corresponds to the final classification of each interval/sample with identification of the lithotype, as interpreted in the model.

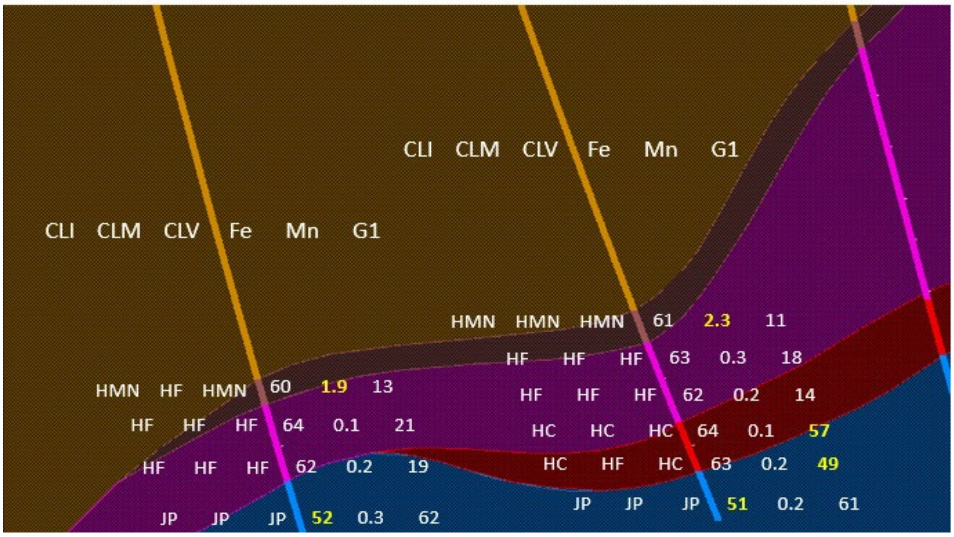


Figure 11-16 - Detail of a vertical geological section showing the interpreted (CLI), mathematical (CLM), and visual (CLV) classifications, in addition to iron (Fe) and manganese (Mn) contents and percentages of mass retained in G1 (> 8 mm).

11.5.2. Serra Norte modeled lithotypes

The different types of iron formation and host rocks of the Serra Norte district are described below. The mean grades mentioned refer to the average grades of the samples (weighted by length) of each lithotype modeled in this review, considering the interpreted classification (CLI).

The cangas represent a product of weathering on the rock sequences typical of the region. For modeling, they are divided into two different types: structural canga (CE) with iron contents greater than or equal to 55%, products of the weathering of iron formation, and chemical canga (CQ), which occurrence is covering the mafic rocks.

Chemical canga (CQ) – represents the iron-aluminous crusts that usually cover the decomposed mafic rocks. It has a colloform texture and high porosity. It often has a high content of Al_2O_3, evidenced by the light coloring of gibbsite and clay minerals. Hematite fragments are scarce or absent. In general, the iron content is under 55%, with high phosphorus and Al_2O_3.

Structural canga (CE) – term commonly used by Vale to designate ferruginous lateritic crusts. It is usually located over iron ore outcrops *in situ*. It also occurs as transported canga, but at a short distance from the source area, being a good indicator of the location of ore bodies. The thickness is variable, reaching more than 20 meters. It has iron content above 55% and relatively low Al_2O_3 and phosphorus grades, thus allowing its potential use as iron ore.

Jaspilite (JP) – banded iron formation, usually of the oxide facies, composed of alternating bands of opaque minerals, such as hematite (predominantly), magnetite or martite, and reddish or white bands composed of jasper and/or chert. Hematite crystals occur mainly in the form of microcrystalline and lamellar hematite, in addition to martite and magnetite, magnetite is uncommon and generally martitized, with kenomagnetite relicts (Lobato et al. 2005). The jaspilite is reddish-gray and represents the ore protolith of the Carajás iron deposits. It occurs predominantly at the base of the iron formations, in contact with mafic rocks or as lenses, immersed in large mass of friable hematite. The thickness of the lenses is usually small (a few meters), ranging from centimeters to about 20 m. The jaspilite in the basal portion can reach up to 350 m in thickness, the continuity in-depth in some regions of the mine is unknown. In the large mass of jaspilite, which constitutes the base of the iron formation, hematite lenses, more commonly friable hematite, are observed in regions close to the jaspelite/hematite top contact.

Friable hematite (HF) – is the predominant type of ore, occurring throughout all Serra Norte mines. It is commonly banded, locally showing primary lamination planes. It consists of a gray friable hematite material with a metallic luster with high porosity. It can be powdery or disaggregate into small fragments (placoid or not).

Hematite crystals occur mainly in the form of microcrystalline, lamellar, anhedral-subhedral, and euhedral-subhedral hematite, in addition to martite, as magnetite pseudomorphs (Lobato et al. 2005). It is predominantly formed by the supergenic enrichment of the ore protolith (jaspilites). It has variable thickness in the enrichment profile, reaching up to 350 m and great continuity throughout the dip.

Compact hematite (HC) – a material rich in iron and, like HFs, generated from the weathering alteration of jaspilite. Its color varies from black to reddish-brown, the latter is typical for goethite/limonite cementation, which is understood to be responsible for the high compactness of this lithotype. HC occurs subordinately throughout the entire deposit, like lenses inside the large friable hematite mass, usually with thicknesses around 5 to 10 m, without considerable lateral continuity (few tens of meters). Locally, it can reach thicknesses of up to 50 m. The color of HC is bluish-gray color with metallic luster. It is dense, with low porosity, and it can be banded, characterized by the original banding of the preserved jaspilite, defined by compact layers alternating with porous or brecciated layers. This lithotype can also be massive, with the original texture destroyed, composed of aggregates of hematite crystals. The Fe contents are between 59 and 69%. Al_2O_3 represents an important contaminant in this lithology.

Manganese hematite (HMN) – The color of manganese hematite is dull dark gray, occurring in lenses with thicknesses ranging from 5 to 10 m, and it may locally reach thicknesses of 60 m, without much lateral continuity, dispersed within the mass of friable hematite. HMN is a material rich in Fe and with Mn contents greater than 2% (global). It is usually positioned at the base of the hematite bodies, a probable zone of accumulation of Mn leached from the weathered horizons.

Iron manganese (FMN) – It is a material that represents an intermediate product of the weathering alteration of jaspilite, enriched in Mn. It occurs as small lenses (usually a few meters thick, reaching up to 30 m), with little lateral continuity, within the mass of friable hematite.

Mafic rocks – They are the host rocks of the iron formation, occurring both at the base and at the top of it. They are represented by the mafic rocks of the Grão Pará Group, the Parauapebas (bottom) and Igarapé Cigarra (top) formations, according to Macambira (2003). Mafic rocks mainly correspond to basalts. For geological modeling purposes, they were not classified in the mentioned stratigraphic units, being considered only as mafic rocks, discriminated into decomposed mafic (MD), semi-decomposed mafic (MSD), and fresh mafic (MS). In addition to their occurrence as host rock (top and base of the iron formation), they also occur as sills and mafic dykes in iron formations.

Decomposed mafic (MD) – It presents a high degree of alteration, poorly structured, with color ranging from reddish to yellowish, clayey, with predominantly soft consistency.

Semi-decomposed mafic (MSD) – It is an intermediate term between MS and MD, sometimes still showing relicts from the original texture of the rock, but already with deep mineralogical transformation, and consequently, in its color.

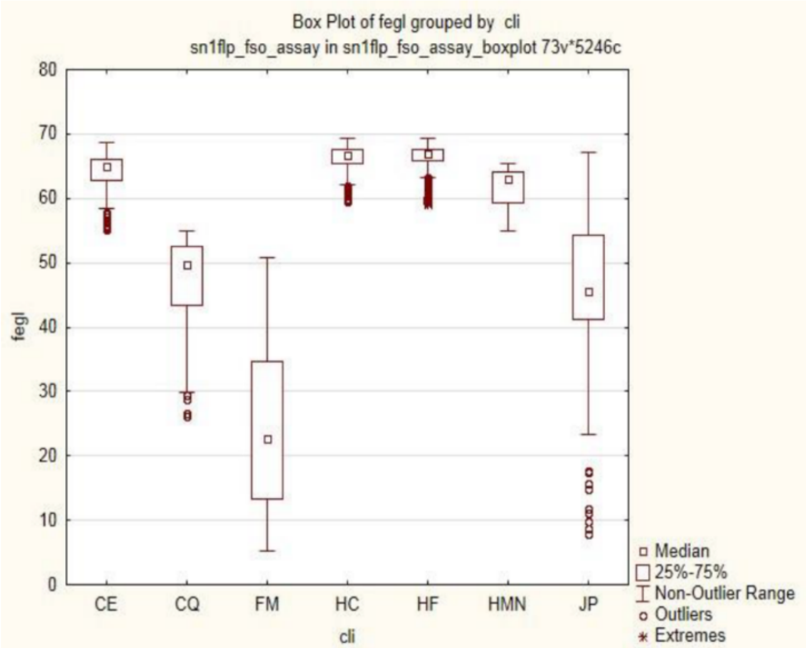
Fresh mafic (MS) – rock not affected by weathering, systematically chloritized, and corresponding to the product of the hydration of basalts and diabases. Its color is dark green, sometimes with typical volcanic structures such as quartz amygdules. Compositional variations and even non-ferrous clastic and chemical sediments were grouped under this name to simplify the geological interpretations.

11.6. Resource assays

11.6.1. Exploratory data analysis

Vale performed exploratory data analysis (EDA) for each estimation domain, including univariate statistics, histograms, cumulative probability plots; box plots to compare geology domain statistics, and contact plots to investigate grade profiles between estimation domains.

The box-plot showing the distribution of global iron (FEGL) and descriptive statistics of the main lithotypes modeled in the N1 deposit is presented below (Figure 11-17) as an example.



LITO	CE	CQ	FM	HC	HF	HMN	JP
Valid N	1528.00	55.00	10.00	321.00	1528.00	54.00	99.00
Mean	66.58	47.18	24.50	66.22	66.58	61.76	44.34
Median	66.90	49.74	22.78	66.61	66.90	62.95	45.50
Minimum	59.12	26.10	5.27	59.61	59.12	55.00	7.90
Maximum	69.43	54.94	50.80	69.30	69.43	65.48	67.15
Variance	2.49	59.45	199.93	4.12	2.49	10.24	173.00
Std.Dev.	1.58	7.71	14.14	2.03	1.58	3.20	13.15
Coef.Var.	2.37	16.34	57.71	3.07	2.37	5.18	29.67

Figure 11-17 - Box-plot graph and descriptive statistics of global Fe grades

11.7. Treatment of high-grade assays

Anomalous values were handled separately in the estimation process. For this purpose, a cut of outliers in the database was applied from the statistical analysis of the distribution of grades (histograms, cumulative frequency plots). The blocks estimated as outliers were those located within the ellipsoid of size 150 x 75 x 15 meters for HC and 200 x 100 x 15 meters for HF. The orientation of the ellipsoid respected the orientation defined for the domain containing the block. For blocks attributed as outliers, the estimation process uses the entire database (no database restriction), but for blocks that were not attributed as outliers, only samples characterized as “OUT” were used.

11.8. Compositing

For the variographic analysis and grade estimation processes, the database was submitted to an isotopy process and subsequent regularization in composites of 15 m. The drilling intervals are regularized respecting the height of the mine bench and the lithological contacts. The method adopted for regularization (composites) is the Vulcan standard, which respects the pre-established constant length and lithological contacts. The acceptance limit of broken intervals (residuals) during regularization in the grade estimation step is 30% of the bench height. The sum of all broken intervals is less than 2% of the total meters in the database.

11.9. Trend Analysis

11.9.1. Grades spatial continuity analysis – N1

Variographic analyses were made to acquire the necessary parameters to estimate grades via the Intrinsic Correlation Model (IMC). For this purpose, the FEGL experimental variogram was calculated, and from the variogram model of this variable, the parameters (variance and ranges) for the IMC were obtained, assuming that the variables have intrinsic correlation.

Then, the following cross experimental variograms were obtained, as well as their respective models:

- Global grades (Fe, Si, P, Al, Mn, and LOI), totaling 36 cross and direct variograms.
- Fractions (retained percentage) + accumulated values of Fe, Si, P, Al, Mn, and LOI of the fractions G1A, G1B, G2, and G3, totaling 28 variables that result in 784 cross and direct variograms.

After the 784 variographic models were created, they were adjusted based on the ranges and proportions of the variances obtained in the FEGL variographic model. The adjusted variographic models were later graphically checked for validation and verification of any impacts this procedure may result in. The following are the Isatis® parameters used in experimental variograms and variographic models:

- Database;
- Selection;
- Isatis parameter files of the experimental variogram;
- Isatis variographic model parameter files;
- Direction of experimental variograms and variographic models (specific for each deposit):
  - Azimuth, Dip and Plunge;
  - Angular tolerance;
  - Lags;
  - Number of lags.

Figure 11-18 shows an example, with the FEGL variogram model used for IMC of hematites in N1. This variographic model was used to estimate the lithotypes: CE, CQ, HF, HC, HMN, FM, JP, MD, MS. The MSD lithotype was not estimated, as there were not enough analytical results to estimate this lithology.

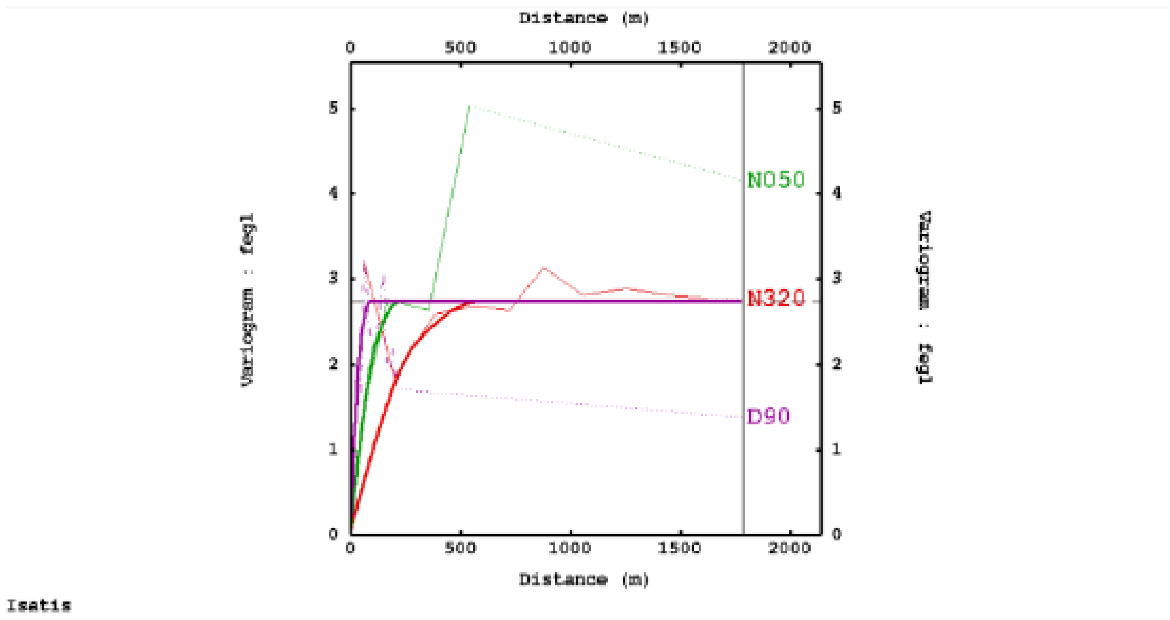


Figure 11-18 - FEGL variographic model for grade estimation, example of N1 deposit

11.10. Search strategy and grade interpolation analysis

11.10.1. Grade interpolation

The interpolation of grades was performed using the principle of ordinary (co)kriging of intrinsic correlation variographic models (ICM). As explained above, based on the method, both the independent kriging of the variable and the (co)kriging have the same results since the variograms are proportional. For the estimate, normalized sills were used. This standardization of the sills is a simplification of the method that makes the estimation process feasible for software based on basic geostatistics modules. The N1 model was estimated in the Geostats module (GSLIB algorithms) of the Vulcan software.

Nine global variables (Fe, SiO_2, P, Al_2O_3, Mn, PF, TiO_2, MgO, and Cao) and 36 granulochemical variables accumulated by the 4 fragment size fractions were estimated. Also, the 4 fragment size fractions (G1A (+19 mm), G1B (-19+8 mm), G2 (-8+0.15 mm) and G3 (-0.15 mm) were estimated.

Although lithological grouping was used to adjust the variographic model, the lithological units were respected in the kriging process; that is, composites of certain lithotype estimate only blocks of the same lithotype.

In the N1 model, 09 distinct lithological domains were estimated: CE, CQ, HF, HC, HMN, FM, JP, MD, and MS.

In the N2 model, 09 distinct lithological domains were estimated: CE, CQ, HF, HC, HMN, JP, FMN, IN, and MD. For MD, the estimated blocks are limited to the contacts with the iron formation, as they are intended to be used only in the dilution calculation. Thus, an auxiliary database was generated with the centroids of the hematite and jaspilite blocks, and from this grid, the decomposed mafic blocks (MD) within a radius of 60 x 60 x 30 m were attributed with the NN estimated grade.

In the N3 model, 7 separate lithological domains were estimated: CE, CQ, HF, HC, HMN, JP, and FMN. Due to the small number of mafic rock samples, these were not estimated.

In the N4 and N5 models, 08 distinct lithological domains were estimated: CE, CQ, HF, HC, HMN, FMN, JP, and MD.

In Gelado Dam only one mineralized zone was considered for interpolation.

Estimation parameters

Table 11-9 presents the list of parameters adopted for the estimation of grades of the N1 model. For all iron formation lithotypes (hematites, jaspilites, and cangas), the estimated blocks are 25 x 25 x 15 m, but for the waste mafic lithotypes, some blocks of size 100 x 100 x 15 m were estimated. Table 11-10 presents the list of parameters adopted for the estimation of grades of the N2.

Table 11-9 - Parameters used in estimating the global grades and granulo-chemistry of the N1 model

<table>
<tr><th colspan="2" rowspan="2">Parameters</th><th colspan="2">(co) Kriging Global and granulo-chemistry</th><th colspan="2">Nearest Neighbor Global and granulo-chemistry</th></tr>
<tr><th>P1</th><th>P2</th><th>P1</th><th>P2</th></tr>
<tr><td rowspan="6">Samples</td><td>Database</td><td colspan="4">Sn1flp_1215.cac.isis</td></tr>
<tr><td>Min. samples</td><td colspan="2">1</td><td colspan="2">1</td></tr>
<tr><td>Max. samples</td><td colspan="2">16</td><td colspan="2">1</td></tr>
<tr><td>Octant</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td>Weight</td><td colspan="2">Length >= 4.5 m</td><td colspan="2">Length >= 4.5 m</td></tr>
<tr><td>Outliers treatment</td><td colspan="2">Yes</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="4">Blocks</td><td>Discretization</td><td colspan="2">5 x 5 x 2</td><td colspan="2">1 x 1 x 1</td></tr>
<tr><td>Search range (m)</td><td>450 x 150 x 50</td><td>4500 x 1500 x 500</td><td>450 x 150 x 50</td><td>4500 x 1500 x 500</td></tr>
<tr><td>Block size</td><td colspan="2">25 x 25 x 15</td><td colspan="2">25 x 25 x 15</td></tr>
<tr><td>N° of structural sectors</td><td colspan="2">7</td><td colspan="2">7</td></tr>
</table>

P1 – First pass of the estimate–; P2 - Second pass of the estimate

Table 11-10 - Parameters adopted in the estimation of N2 model grades

<table>
<tr><th colspan="2" rowspan="2">Parameters</th><th colspan="2">(co) Kriging Global and granulo-chemistry</th><th colspan="2">Nearest Neighbor Global and granulo-chemistry</th></tr>
<tr><th>GL + P1</th><th>P2</th><th>GL + P1</th><th>P2</th></tr>
<tr><td rowspan="6">Samples</td><td>Database</td><td colspan="4">N2_flp.fac.isis</td></tr>
<tr><td>Min. samples</td><td colspan="2">1</td><td colspan="2">1</td></tr>
<tr><td>Max. samples</td><td colspan="2">16</td><td colspan="2">1</td></tr>
<tr><td>Octant</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td>Weight</td><td colspan="2">Length >= 4.5 m</td><td colspan="2">Length >= 4.5 m</td></tr>
<tr><td>Outliers treatment</td><td colspan="2">Yes</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="4">Blocks</td><td>Discretization</td><td colspan="2">5 x 5 x 2</td><td colspan="2">1 x 1 x 1</td></tr>
<tr><td>Search range (m)</td><td>200 x 100 x 30</td><td>2000 x 1000 x 300</td><td>200 x 100 x 30</td><td>2000 x 1000 x 300</td></tr>
<tr><td>Block size</td><td colspan="2">25 x 25 x 15</td><td colspan="2">25 x 25 x 15</td></tr>
<tr><td>N° of structural sectors</td><td colspan="2">1</td><td colspan="2">1–</td></tr>
</table>

GL - Estimate of global chemistry; P1 – First pass of the estimate–; P2 - Second pass of the estimate

For N3 model, two sectors were defined for the grade estimation as a function of the geometry of the deposit: one in the E-W direction and the other, NE-SW. The variograms and search ellipsoids for each sector are rotated following the main directions of continuity (Figure 11-19).

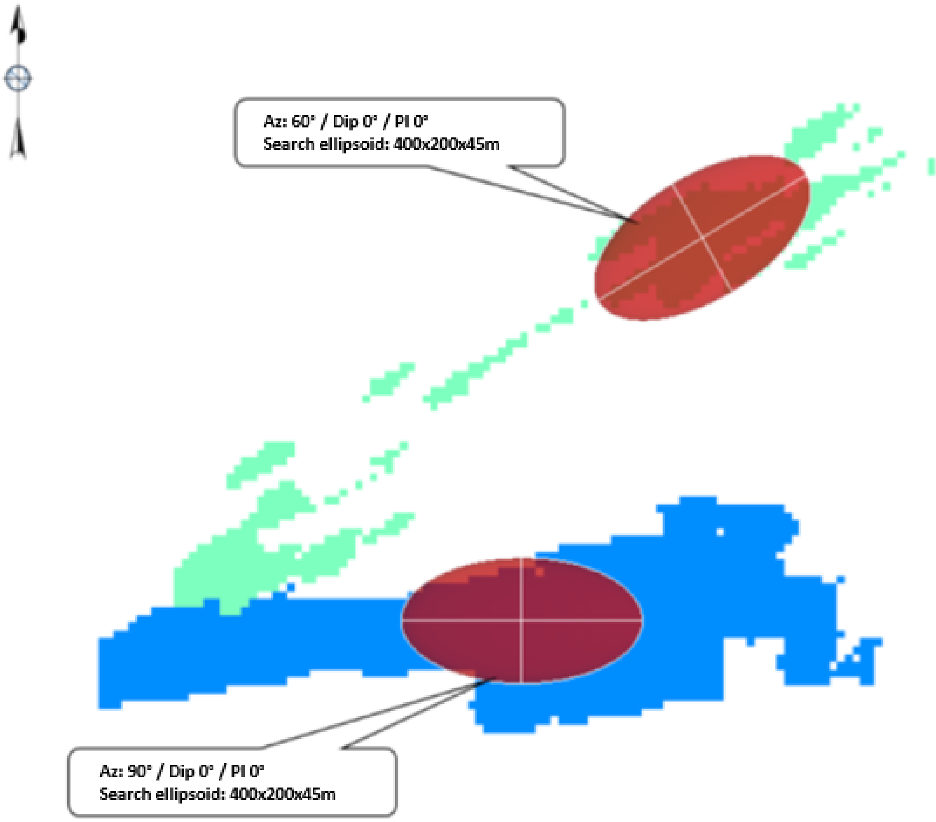


Figure 11-19 - Search parameters for N3 model

Table 11-11 presents the list of parameters adopted for grade estimation of the N4 model, Figure 11-20 illustrates the orientation of the search ellipsoid for grade estimation.

Table 11-11 - Parameters used in estimating the global content and granulochemistry of the N4 model

Parameters		(co) Kriging Global and granulo-chemistry		Nearest Neighbor Global and granulo-chemistry	
		GL + P1	P2	GL + P1	P2
Samples	Database	Sn4sn4.cac.isis			
	Min. samples	1		1	
	Max. samples	16		1	
	Octant	Yes		No	
	Weight	Length >= 4.5 m		Length >= 4.5 m	
	Outliers treatment	Yes		Yes	
Blocks	Discretization	5 x 5 x 2		1 x 1 x 1	
	Search range (m)	400 x 250 x 50	4000 x 2500 x 500	400 x 250 x 50	4000 x 2500 x 500
	Block size	25 x 25 x 15		25 x 25 x 15	
	Sectoring	Yes		Ye–	

GL - Estimate of global chemistry; P1 – First pass of the size fractions chemical estimat–; P2 - Second pass of the size fractions chemical estimate

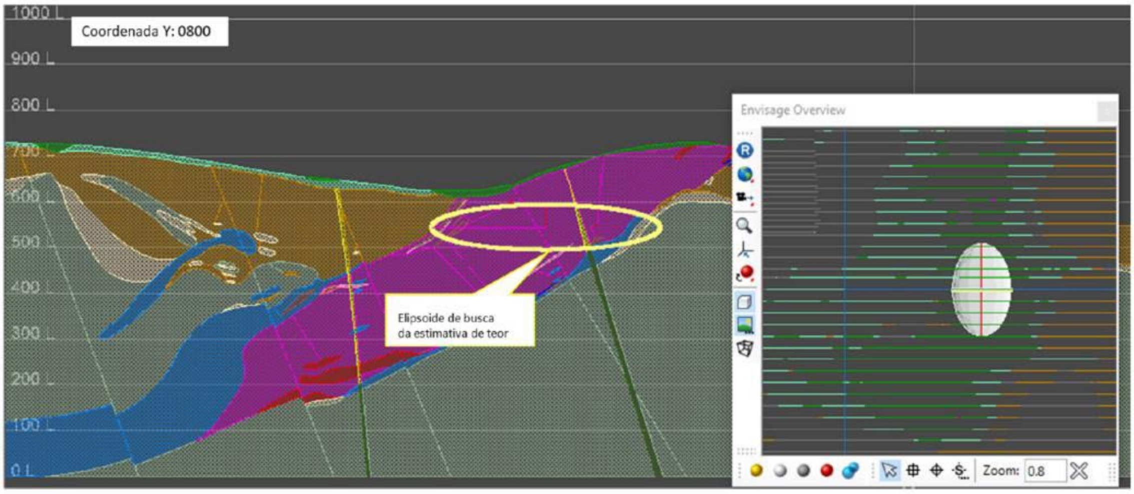


Figure 11-20 - Search ellipsoid for estimating N4 mine grades

Table 11-12 presents the list of parameters adopted for the estimation of grades of the N5 model, and Figure 11-21 illustrates the orientation of the search ellipsoid for grade estimation.

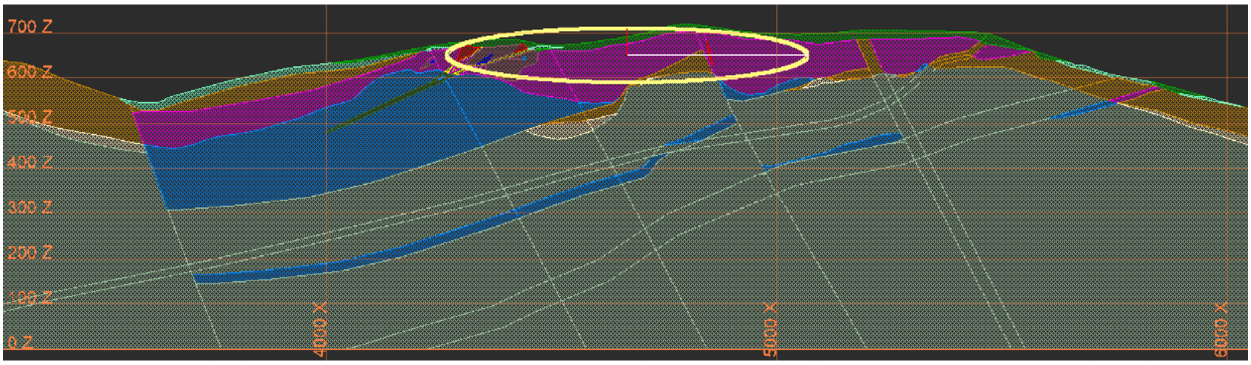


Figure 11-21 - Search ellipsoid of the estimated grades of the N5 mine, North-4200

Table 11-12 - Parameters used in estimating the global grades and granulochemistry of the N5 model

Parameters		(co) Kriging Global and granulo-chemistry		Nearest Neighbor Global and granulo-chemistry	
		GL + P1	P2	GL + P1	P2
Samples	Database	n5n5.cac.isis			
	Min. samples	1		1	
	Max. samples	16		1	
	Octant	Yes		No	
	Weight	Length >= 4.5 m		Length >= 4.5 m	
	Outliers treatment	Yes		Yes	
Blocks	Discretization	5 x 5 x 2		1 x 1 x 1	
	Search range (m)	400 x 200 x 60	4000 x 2000 x 600	400 x 200 x 60	4000 x 2000 x 600
	Block size	25 x 25 x 15		25 x 25 x 15	
	Sectoring	Yes		Yes–	

GL - Estimate of global chemistry; P1 – First pass of the size fractions chemical estimate–; P2 - Second pass of the size fractions chemical estimate

Table 11-12 presents the list of parameters adopted for the estimation of grades of the Gelado Dam model, and Figure 11-21 illustrates the orientation of the search ellipsoid for grade estimation.

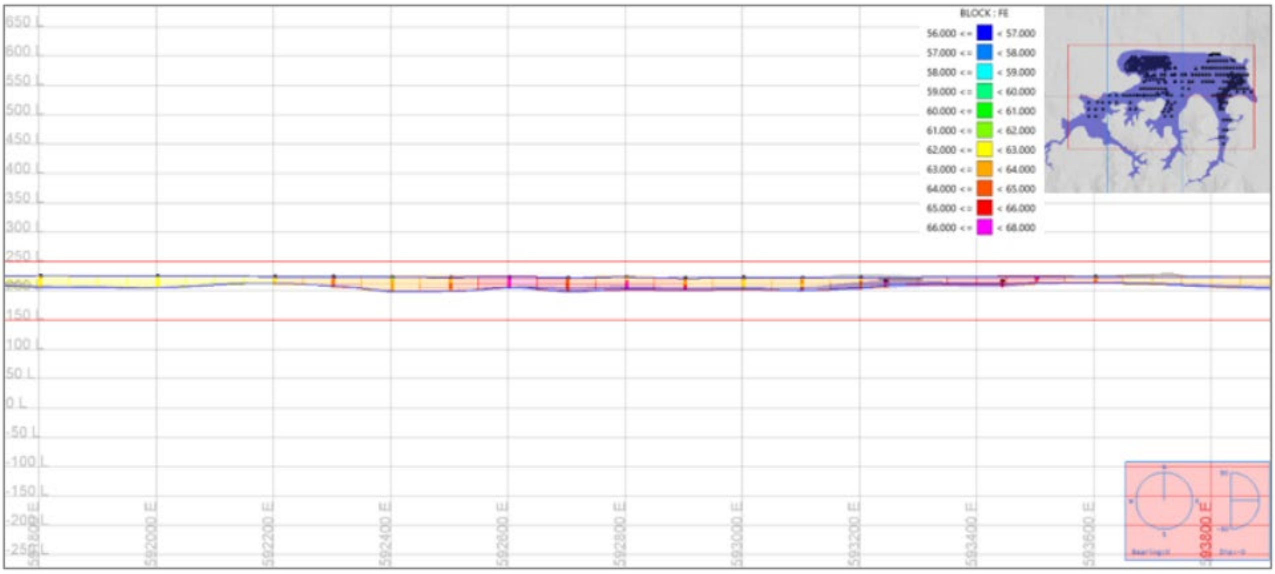


Figure 11-22 - Estimated grades of the Gelado Dam

Table 11-13 - Parameters used in estimating the global grades of the Gelado Dam model

Estimation Method	**IDS**	**OK**
Azimuth/Plunge/Dip	90/0/0	90/0/0
Search Radius Pass 1 (major/semi-major/minor)	1,000/390/35	1,750/630/90
Search Radius Pass 2 (major/semi-major/minor)	NA	3,500/1,260/180
Anisotropy	Anisotropic	Anisotropic
Discretisation (X/Y/Z)	4/4/1	4/4/1
Minimum No. Samples (Pass 1/2)	1	2/1
Maximum No. Samples (Pass 1/2)	10	8/24
Maximum No. Samples per octant (Pass 1/2)	NA	3/3
Length-weighting used	Y	Y

Kriging process

A notable feature in the history of data acquisition in the Carajás deposits is the diversity of sample preparation fluxes and the analytical methods adopted. Thus, the disproportion between the amount of global chemistry data, as opposed to the chemistry data by grain size fractions, results in a heterotopic database that requires a series of adaptations to the kriging plans, as well as additional calculations in the post-process stage. In this work, the global chemistry and granulochemistry data were estimated, the latter in two steps: the first pass (P1), performed with the same search radii as the global chemistry estimate, and the second pass (P2), with search radii 10 times larger than the first. This is necessary because there are regions of the model where samples that contain only global chemistry data predominate. Therefore, some blocks have the global grades estimated, but still without particle size and chemistry data by fraction. The reason for the Second Pass (P2) is to complement the particle size data of these blocks.

After the end of the estimation process, the post-processing step was started. Post-processing is done following the flow exemplified in Figure 11-23, where the following checks were made:

- Existence of blocks with negative grades: the correction was to apply the NN estimated grade for the granulochemistry and the detection limit for the negative grades in the global Mn, Ti, Mg, and Ca. The G1A particle size fraction was set to “0”, where applicable;
- Treatment of blocks without CaO, MgO, and TiO_2 estimated grades: as a result of the heterotopic database used in the estimate, blocks had no CaO, MgO, and TiO_2 estimated grades. The correction was made considering the average grades of the blocks estimated for each lithotype and the chemical closure for each fraction. In cases where the chemical closure was equal to or greater than 100%, the laboratory detection limits were applied. When the chemical closure was smaller, the difference was proportionally distributed among the 3 variables;
- Compatibility of the chemistry of the grain size fractions with the estimated global;
- Identification and correction of anomalous stoichiometric closing values: blocks with values less than 95% and greater than 105% were marked. In blocks with deviations concerning the stoichiometric closing for some fraction, the estimated grades in the granulometric fraction were replaced by the global estimated grades;
- Identification and correction of Fe grades above the maximum, by fraction and global grade, of the database were performed.

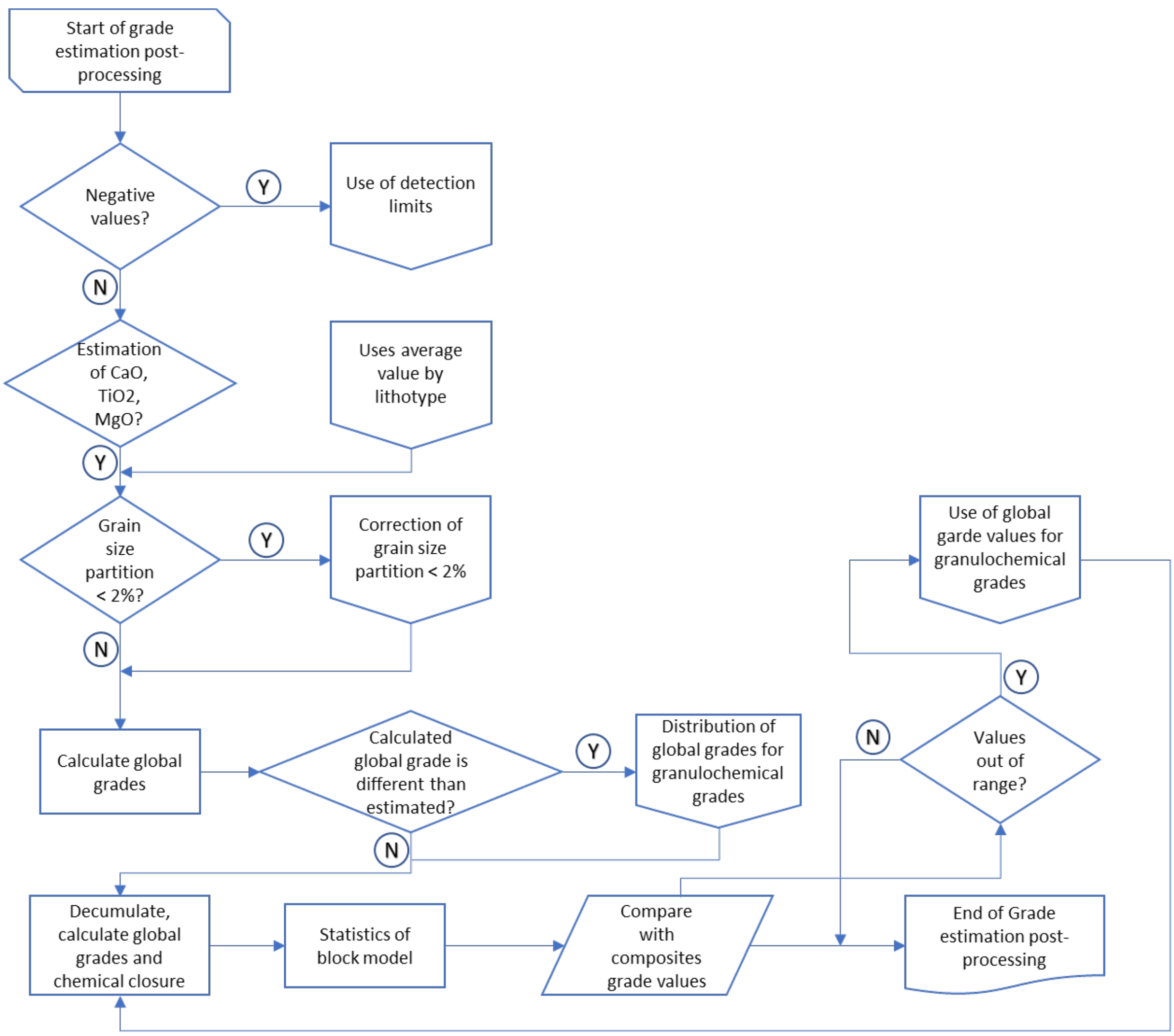


Figure 11-23 - Flowchart of post-processing of grade estimation

11.11. Bulk density

Samples collected by direct methods of conventional density (volume displacement, volume filling, sand flask, and hydrostatic weighing) and gamma-gamma geophysical drill hole logs were used to determine the densities of the different lithotypes of the Serra Norte mines. The gamma-gamma survey data were validated by the geophysics team from the Ferrous Geology and Drilling area and by the Ferrous Mineral Resources area.

The mean values weighted by the number of samples are representative of the density of each lithotype (Table 11-14 to Table 11-19). The weighting considered the results from gamma-gamma geophysical logging and/or conventional direct tests.

Moisture is obtained by drying an aliquot of the sample and comparing the dry and wet mass of the sample. The importance of this determination is that, for evaluations of Vale iron mines, the tonnage measurements are made with the density in the natural base, considering the free water mass obtained from the moisture measurements.

Table 11-14 - Summary of N1 deposit densities

Lithotype	Meters/Samples	Natural Density (g/cm^3)	Method
Structural Canga - CE	3.15 meters	3.32	GG
Chemical Canga - CQ	12.64 meters	2.80	GG
Compact Hematite - HC	12 samples	3.81	DV
Friable Hematite - HF	16.41 meters	3.03	GG
Mn Hematite – HMN	4.13 meters	3.24	GG
Jaspilite – JP	38.24 meters	2.92	GG
Iron Manganese – FM	17.42 meters	3.20	GG
Weathered Mafic – MD	177.33 meters	2.67	GG
Semi-weathered Mafic – MSD	39.86 meters	2.87	GG
Mafic - MS	302.98 meters	2.91	GG

Methods: GG – Gamma-gamma geophysical profiling; DV – Volume displacement. / Note: Humidity determined only for HC (0.29%).

Table 11-15 - Summary of densities and moistures of the N2 deposit

Lithotype	Meters/Samples	Natural Density (g/cm^3)	Moisture (%)	Method
Structural Canga - CE	25.84 meters	3.17	3.47	GG
Chemical Canga - CQ	8.87 meters	2.66	9.21	GG
Compact Hematite - HC	25 samples	3.90	1.17	DV
Friable Hematite - HF	74.97 meters	3.28	6.92	GG
Mn Hematite – HMN	19 samples	3.15	7.10	PV
Jaspilite – JP	49.53 meters	3.32	0.33	GG
Iron Manganese – FM	5.24 meters	3.14	10.18	GG
Weathered Mafic – MD	211 samples	1.88	22.02	PV
Semi-weathered Mafic – MSD	25 samples	2.35	11.01	PV
Mafic - MS	156 samples	2.89	0.10	DV
Quartizite - QT	316.02 meters	2.38	0.10	GG

*Methods: GG – Gamma-gamma geophysical profiling; DV – Volume displacement; PV –Volume Filling / Obs.: * Quartzite: The average values of the N2 Mine – Model N4_0316 were considered, except for Quartzite (QT): gamma-gamma geophysical survey in a drill hole at N2 deposit*

Table 11-16 - Summary of densities and moistures of the N3 deposit

Lithotype	Meters/Samples	Natural Density (g/cm³)	Moisture (%)	Method
Structural Canga - CE	25.84 meters	3.17	3.47	GG
Chemical Canga - CQ	8.87 meters	2.66	9.21	GG
Compact Hematite - HC	25 samples	3.90	1.17	DV
Friable Hematite - HF	74.97 meters	3.28	6.92	GG
Mn Hematite – HMN	19 samples	3.15	7.10	PV
Jaspilite – JP	49.53 meters	3.32	0.33	GG
Iron Manganese – FM	5.24 meters	3.14	10.18	GG
Weathered Mafic – MD	211 samples	1.88	22.02	PV
Semi-weathered Mafic – MSD	25 samples	2.35	11.01	PV
Mafic - MS	156 samples	2.89	0.10	DV
Schist - XI	-	1.88	22.02	PV

*Methods: GG – Gamma-gamma geophysical profiling; DV – Volume displacement; PV –Volume Filling / Obs.: * shale: adopted the same value as decomposed mafic (MD). / The average values of the N4 mine – Model N4_0316 were considered.*

Table 11-17 - Summary of densities and moistures of the N4 mine

Lithotype	Samples	Natural Density (g/cm³)	Moisture (%)
Structural Canga - CE	399	3,.22*3	4.39
Chemical Canga - CQ	137	2.71*3	7.18
Compact Hematite - HC	1,008	3.59*3	1.01
Friable Hematite – HF	7,827	3.24*3	6.15
Mn Hematite – HMN	283	3.16*3	7.14
Jaspilite – JP	4,524	3.10*3	0.22
Iron Manganese – FM	11	3.06*3	10.53
Weathered Mafic – MD	3,551	2.27*3	22.51
Semi-weathered Mafic – MSD	621	2.39*3	0.10
Mafic - MS	7,361	2.73*3	0.10
Clay – AG*1	-	2.27	-
Landfill – AT*2	-	2.00	-

**1 Adopted the lithotype MD value. / *2 Historical Value. / *3 Weighted average of values obtained by gamma-gamma geophysical survey and conventional density methods, using the number of samples/composites as a weight.*

Table 11-18 - Summary of densities and moistures for the N5 mine

Lithotype	Samples	Natural Density (g/cm³)	Moisture (%)
Structural Canga - CE	176	2.96	4.82
Chemical Canga - CQ	495	2.62	10.47
Compact Hematite - HC	170	3.65	0.82
Friable Hematite - HF	151	3.30	8.22
Mn Hematite – HMN	24	3.00	11.06
Jaspilite – JP	3,357	3.43	0.10
Iron Manganese – FM	1	3.01	10.49
Weathered Mafic – MD	4,257	2.23	18.36
Semi-weathered Mafic – MSD	181	2.32	-
Mafic - MS	777	2.85	0.10
Landfill – AT*1	-	2.00	-
Conglomerate*2	-	2.48	10.47

*1 Considered historical values. / *2 Value relative to CQ by conventional methods.

Table 11-19 - Summary of densities for the Gelado Dam

Material	No. of Samples	"In loco" Density (g/cm³)	Moisture (%)	Dry Density (g/cm³)	Analytical Method*
Tailings Mineralisation	10	2.52	17.95	2.07	PV

Note: *PV: "Preenchimento de Volume" (Water filled pit).

11.12. Block models

N1 wireframes were filled with blocks in Vulcan software. The block model was sub-celled at wireframes boundaries with parent cells measuring 100 m by 100 m by 100 m and minimum sub-cell sizes of 25 m by 25 m by 15 m. The block model setup is shown in Table 11-20.

Table 11-20 - N1 Block Model Setup

Parameter	X	Y	Z
Origin (m)	578,584	9,327,842	10
Bearing/Dip/Plunge	52	0	0
Block Size (m)	100	100	15
Min.Sub Block size (m)	25	25	15
Number of blocks	72	92	66

N2 wireframes were filled with blocks in Vulcan software. The block model (SN2_0616_LP.BMF) was not sub-celled at wireframes boundaries in a single scheme with parent cells measuring 25 m by 25 m by 15 m. The block model setup is shown in Table 11-21.

Table 11-21 - N2 Block Model Setup

Parameter	X	Y	Z
Origin (m)	582,163	9,329,760	150
Bearing/Dip/Plunge	90	0	0
Block Size (m)	25	25	15
Min.Sub Block size (m)	25	25	15
Number of blocks	95	78	56

N3 wireframes were filled with blocks in Vulcan software. The block model was sub-celled at wireframes boundaries with parent cells measuring 25 m by 25 m by 15 m and minimum sub-cell sizes of 12.5 m by 12.5 m by 15 m. The block model setup is shown in Table 11-22.

Table 11-22 - N3 Block Model Setup

Parameter	X	Y	Z
Origin (m)	584,738	9,331,110	200
Bearing/Dip/Plunge	90	0	0
Block Size (m)	25	25	15
Min.Sub Block size (m)	12.5	12.5	15
Number of blocks	174	116	40

N4 wireframes were filled with blocks in Vulcan software. The block model was sub-celled at wireframes boundaries with parent cells measuring 100 m by 100 m by 15 m and minimum sub-cell sizes of 25 m by 25 m by 15 m. The block model setup is shown in Table 11-23.

Table 11-23 - N4 Block Model Setup

Parameter	X	Y	Z
Origin (m)	588,420.02	9,331,110.7	10
Bearing/Dip/Plunge	82.64	0	0
Block Size (m)	100.04	100.04	15
Min.Sub Block size (m)	25.01	25.01	15
Number of blocks	65	103	60

N5 wireframes were filled with blocks in Vulcan software. The block model was not sub-celled at wireframes boundaries in a single scheme with parent cells measuring 25 m by 25 m by 15 m. The block model setup is shown in Table 11-24.

Table 11-24 - N5 Block Model Setup

Parameter	X	Y	Z
Origin (m)	593,799.21	9,320,695.16	10
Bearing/Dip/Plunge	83.64	0	0
Block Size (m)	25.01	25.01	15
Min.Sub Block size (m)	25.01	25.01	15
Number of blocks	212	376	60

RPM reviewed the block model in 2016 and opined that the block sizes are appropriate, based on the drill spacing and proposed mining method, and are suitable to support the estimation of Mineral Resources and Mineral Reserves.

Gelado Dam wireframes were filled with blocks in Vulcan software. The block model was not sub-celled at wireframes boundaries in a single scheme with parent cells, a summary is shown in following table.

Table 11-25 – Gelado Dam Block Model Setup

Direction	Origin (m)	Extent (m)	Range (m)	Parent Block Size (m)
Easting (X)	590,600	596,000	5,400	50
Northing (Y)	9,335,984	9,338,984	3,000	50
RL (Z)	150	250	100	5

11.13. Net value return and cut-off value

The calculation of the economic cut-off grade considers the sale price of the metal, mineral processing, commercial, mining, processing, transport and marketing costs, grade, and process plant recovery. The cut-off grade is not defined as a matter of the iron grade itself but as a technological approach at each processing plant recovery and productivity stage to estimate Mineral Resources and Mineral Reserves. The decision to mine a specific block will be determined in the final pit generation due to product price and all related costs.

Each ore lithology destination and recovery are defined by processing equations that will search for lithotypes totally or partially routed to the operational processing route of Vale site or that had a processing route successfully tested at the project/study level.

11.14. Classification

11.14.1. Mineral inventory classification

The mineral inventories of the block models for Vale iron ore deposits are classified based on the calculation of the “Risk Index” (IR), which follows the classification method originally proposed by Amorim and Ribeiro (1996) and later reformulated by Ribeiro et al. (2010).

Risk index methodology

The Risk Index method uses a single index, combining geological continuity, measured by the “ore” kriging indicator (IK), and estimation error, measured by the variance of the indicator kriging (σ^2IK), to classify the blocks into measured, indicated, and inferred. IR is calculated by the following equation, which represents simplification of the original 1996 equation:

$$IR(u) = \sqrt{[1 - I_k(u)]^2 + [\sigma_{IK}^2(u)]^2}$$

where:

$I_K - (u)$ - is the indicator estimated by kriging, associated with the support of given block, located at position u;
$\sigma_{IK}^2\,(u)$ -– is the variance of the kriging indicator of the block at position u, using a normalized semivariogram model, with unitary sill.

The graphic representation of IR can be seen in Figure 11-24. The horizontal axis represents the geological continuity as $1 - I_k(u)$. The vertical axis is the estimation error, $\sigma_{IK}^2(u)$. The vector IR and the limits used for the classification, into Measured, Indicated, and Inferred blocks.

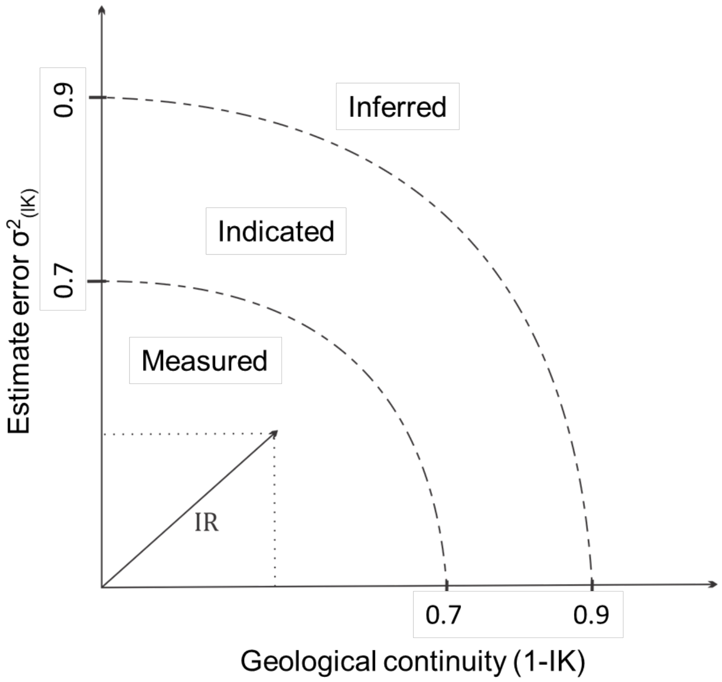


Figure 11-24 –– Graphic representation of the IR calculation and class limits

The validation of the method (IR), including the chosen Risk Indices, is carried out by comparing it with another classification method: the dilation and erosion method. The dilation and erosion method is a geometric method in which, in general, blocks belonging to a 100 x 100 m mesh are considered as measured, indicated for a 200 x 200 m mesh, and the other blocks with estimated grades are considered as inferred.

11.14.2. Classification of the Serra Norte mineral inventory

Serra Norte deposits use a binary code, attributing 1 (one) to the regularized drilling intervals considered “ore” (cangas and hematites) and 0 (zero) for the lithotypes considered “waste.” In the N2 and N3 deposits, although jaspilite and iron-manganese lithotype are not currently ore, they received indicator 1 for the variographic analysis due to the small number of samples in the database. For the estimation, the indicators of these lithotypes were attributed with zero (Table 11-26).

Table 11-26 -– Indicators used to characterize the lithologies considered as waste and ore from the Serra Norte deposits

Deposit	Indicator 1 (ore)	Indicator 0 (waste)
N1	CE, HF, HC, HMN	CQ, FM, JP, MD, MSD, MS
N2	CE, HF, HC, HMN, JP, FMN	CQ, MD, MSD, MS, IN, QT
N3	CE, HF, HC, HMN, JP, FMN	CQ, MD, MSD, MS, XI
N4	CE, HF, HC, HMN	CQ, FMN, JP, MD, MDSL, MDDK, MSD, MSDSL, MSDDK, MS, MSSL, MSDK, AG
N5	CE, HF, HC, HMN	CQ, FMN, JP, MD, MDSL, MDDK, MSD, MSDSL, MSDDK, MS, MSSL, MSDK, AG

Block kriging and classification according to the Risk Index were performed using Vulcan® software. The radii of the sample search ellipsoid for the construction of the block kriging matrix were 450 x 150 x 50 m for N1, 200 x 100 x 30 m for N2, 400 x 200 x 45 m for N3, 400 x 250 x 50 m for N4 and N5, in the three main directions of continuity. These distances correspond to a maximum acceptable grid for exploring iron ore resources in the horizontal plane and approximately three benches of extrapolation in the vertical direction. For the estimation, the composites of the exploration and ore control drill holes databases for N4 and N5 were used. For N1, N2, N3 deposits, still under project development phase, only exploration drill holes databases were used. The ellipsoids search directions were the same directions used for grades estimation.

The minimum and maximum samples were 1 and 16, respectively, considering two samples per octant as optimal, and the discretization of the blocks was 4 x 4 x 2.

After estimating the IK variable (Risk Index indicator) and during the process, the IK variance for the kriged blocks (var_ik) was obtained. From these variables, the Risk Index is calculated using a script. The classification follows these criteria: measured for IR up to 0.6, indicated for IR between 0.6 and 0.9 (in general) and inferred for IR above 0.9. The indexes are defined by analyzing the textures (visual) of the block model and comparing them with an auxiliary method (dilation and erosion method).

The final classification of measured, indicated, and inferred were conditioned to contain valid grade values; otherwise, the block is attributed as “n” (potential). Blocks classified as measured but estimated by a single drill hole were downgraded to indicated.

11.14.3. Validation of Serra Norte mineral inventory classification

The validation of the classification of the mineral inventory is done mainly through visual inspection, throughout the model, in vertical and plan sections, to notice possible inconsistencies and distortions of the method. Another validation technique used is the comparison of classification by the Risk Index method with the traditional classification by dilation/erosion, from the drilling grid, as can be observed in one example, for N5 (Figure 11-25).

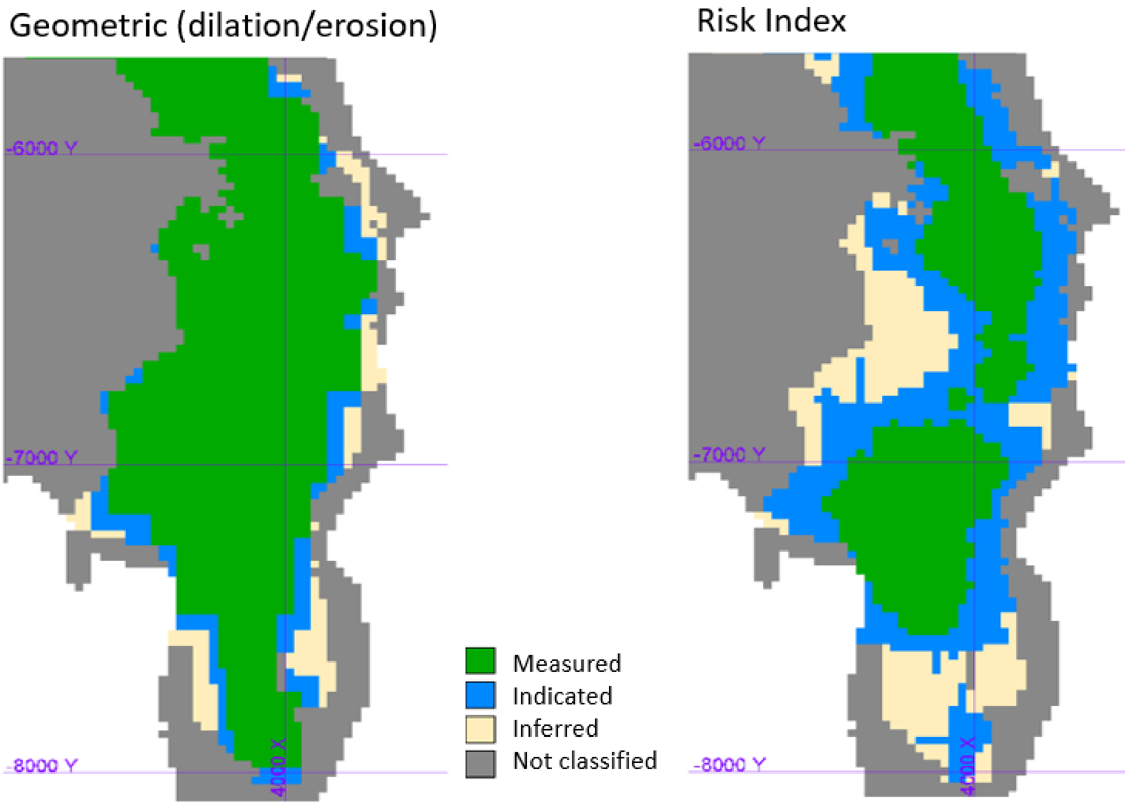


Figure 11-25 -– Visual comparison between classification methods at elevation 525 in the N5 mine, Morro1 region: dilation/erosion (left) and Risk Index (right).

11.14.4. Serra Norte mineral inventory

The Classified Mineral Inventory corresponds to the set of geological blocks of iron formation in the mineral inventory that was classified into measured, indicated, and inferred using the Risk Index methodology, representing the lower geological uncertainty for the measured inventory and the higher for the inferred one.

11.15. Block model validation

11.15.1. Grades validation

Block model grade validation follows Vale internal procedures, for all deposits at Serra Norte. The main validation steps are described below.

- Estimation plans summary – this check identifies whether there are any problems with the estimation that have led to estimating a different number of blocks for the same process.
- Block Length – checks whether all blocks with estimated grades have the same dimensions (25x25x15m), proving that the block model has not been corrupted during the estimation process.
- Sampling range – is done through the statistical analysis of the kriged grades compared to the regularized samples file (Table 11-27).

Table 11-27 – Comparison between kriging estimated grades and regularized samples for N2

Lithotype	Variable	Database			Block Model			Differences	
		N°	Min.	Max.	N°	Min.	Max.	Min.	Max.
CE	FEGL	22	55680	66720	1270	55680	66720	0	0
CQ	FEGL	9	39668	53472	756	42173	53472	2505	0
HC	FEGL	20	61519	68062	107	62748	67814	1229	247
HF	FEGL	112	60767	68545	2294	60767	68533	0	12
HMN	FEGL	11	55293	64599	34	55293	63687	0	913
JP	FEGL	7	30157	59890	526	30157	59890	0	0
FMN	FEGL	3	30240	52430	6	30240	49477	0	2953

Drift analysis – is a local and global bias check, in which a "Nearest Neighbor" estimation model is generated, and the results are compared globally by 15 m levels (bench height). Some examples of this validation are presented below (Figure 11-26).

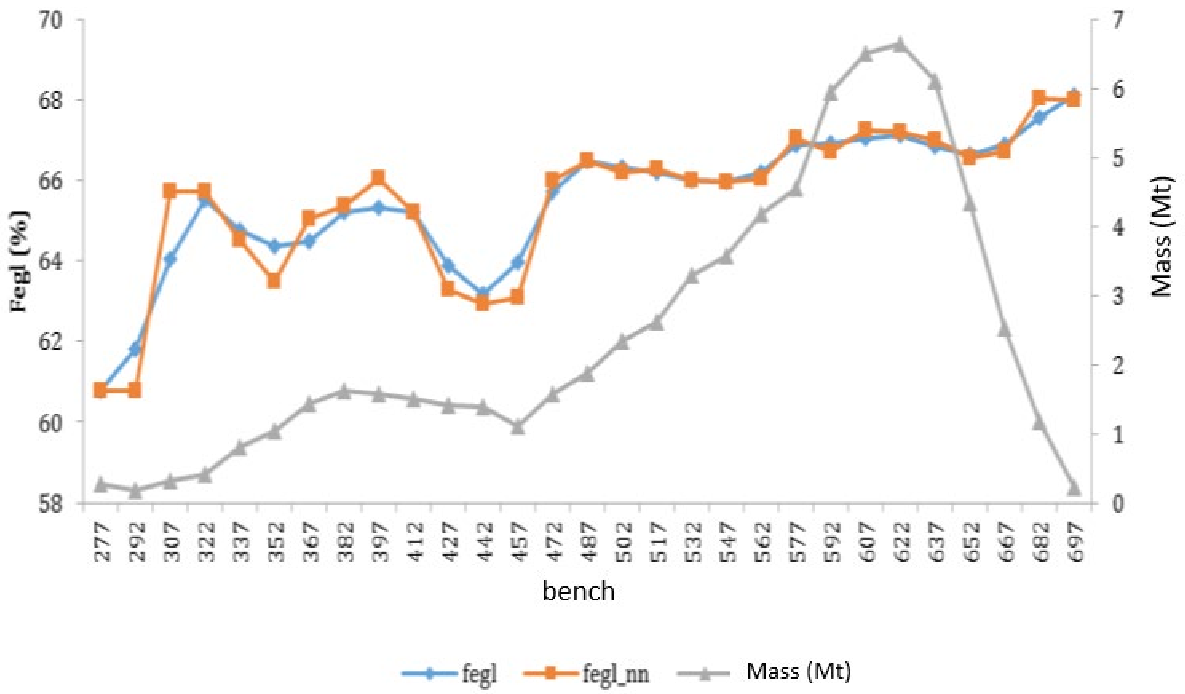


Figure 11-26 – Global iron bias check of friable hematites (HF) for N2

In addition to the global comparison, visual inspections were also performed on the estimated block model (Figure 11-27).

Figure 11-27 — Visual comparison of the geological model (left) with the estimated global iron grades (right) for bench 622.5

Sample density by mineral inventory class – the evaluated values are the average number of samples used in the block grades estimate, by mineral class (Figure 11-28).

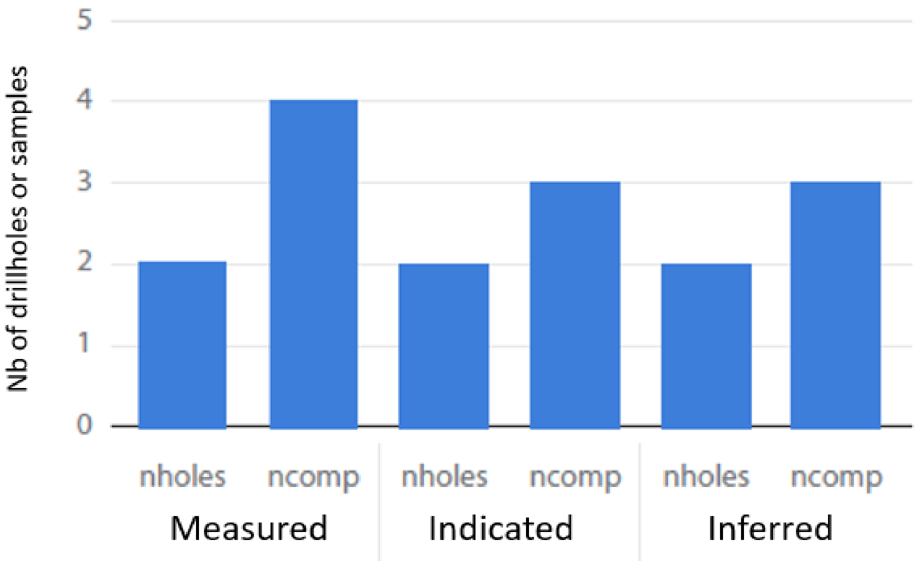


Figure 11-28 — Average number of samples per mineral inventory class of model N2

11.16. Mineral resource reporting

11.16.1. Assessment of the reasonableness for eventual mineral extraction of mineral resources in the northern logistic corridor

The Mineral Resource is not the inventory of all drilled or sampled mineralization, regardless of cut-off grades, likely mine dimensions, location, or continuity. It is a realistic mineralization inventory that, depending on assumed and justified technical and economic conditions, could become economically mineable, in whole or in part.

For this evaluation, some technical parameters were applied to the Classified Mineral Inventory (mining method, geotechnical, process engineering, restrictions of conservation units, hydrogeological, speleological and surficial restrictions, mining rights, among others) and economic (cost and price) for delimitation of the mass that will be declared as a Mineral Resource.

The NPV Scheduler (Datamine ®) software was adopted for optimization of the open pit through the Lerch-Grossman optimizing algorithm, in which the generated mathematical pits search for all classified iron formation (measured, indicated, and inferred) that presents reasonableness of mineral processing, mining method, and infrastructure associated with any mineral project at a minimum level of conceptual study (FEL 1). In addition, analyses of masses blocked by the main restrictions existing in this deposit were made. Before, during, and after carrying out all these optimization steps, statistical validations of the lithotypes, mineral processing destinations, geotechnical parameters, costs, prices, recovery equations, and product quality are carried out, in addition to 2D and 3D visual validations.

11.16.2. Assessment of reasonableness for eventual mineral extraction for Serra Norte mineral resources (N1, N2, N3, N4, N5 and Gelado)

The Mineral Resource is not the inventory of all drilled or sampled mineralization, regardless of cut-off grades, likely mine dimensions, location, or continuity. Instead, it is a realistic mineralization inventory that, depending on assumed and justified technical and economic conditions, could become economically mineable in whole or in part.

For this evaluation, some technical parameters were applied to the Classified Mineral Inventory (mining method, geotechnical, process engineering, restrictions of conservation units, hydrogeological, speleological and surficial restrictions, mining rights, among others) and economic (cost and price) for delimitation of the mass that will be declared as a Mineral Resource.

The NPV Scheduler (Datamine ®) software was adopted for optimization of the open pit using the Lerch-Grossman algorithm. Before, during, and after all these optimization steps, statistical validations of the lithotypes, mineral processing destinations, geotechnical parameters, costs, prices, recovery equations, and product quality are carried out, in addition to 2D 3D visual validations.

Price and cost parameters

As a general assumption, Vale long-term CIF price curves (price delivered in China), adjusted for moisture content, were adopted, according to the long-term pricing policy of the company. The considered average moisture of the product was 6.74% in this price analysis.

- The prices of products from these deposits were regularized only with the Fe grades curves above 60%, considering that Vale uses blending centers in Asia to sell its products (BRBF – Brazilian Blend Fines);
- Mine costs were defined as the average cost per mined ton (ore+waste) calculated from the assumptions of mine costs and mine movements used in the Strategic Planning Cycle/Master Plan;
- Mineral processing costs were defined by the average cost per ton of ROM fed into the long term mine planning of the deposit, recorded in the Strategic Planning Cycle/Master Plan;
- Commercial costs, including logistics, administration, etc., were calculated by the average current costs and investments per ton of product from the stockpiles of the mineral processing

plants to the port in China and were properly used to build the final pit to define the mineral resources of each deposit of Serra Norte Complex.

Mineral process parameters

The block model was populated with a value “NSR” which represents the qualities and respective mass recoveries, block by block. These are obtained from equations provided by the Vale process engineering team. Due to the quality of the material and as the processing will be based on natural moisture, the mass recovery was inferred at 99.5%, which is the standard for the current processing plants at the Serra Norte Mining Complex.

The equations search for lithotypes that are routed, totally or partially, to the operational processing route of a Vale site, or that had a processing route successfully tested at the project/study level, that is:

- ce: structural canga;
- hc: compact hematite;
- hf: friable hematite;
- hmn: manganese hematite;
- Such lithotypes are grouped into the following groups:
    - Hematites (HEM): hc, hf, hgo, and hmn;
    - Rolled (ROL): ce.

Mining method parameters

Due to the characteristics of the deposit, which presents superficial to subsurface iron mineralization, low ore/waste ratio, and similarity to deposits that are already mined at the Carajás Mining Complex, the open-pit mining method was chosen. Based on internal reconciliation and operation studies, it was adopted that mining recovery is 96% and the operational dilution was established at 1.35%. As for the optimization of reserves, the additional cost of deepening of US$ 0.0045/m was considered.

The suggested ore and waste method of transport is by trucks. However, further engineering studies of the mineral project will be necessary to assess crushing plants closer to the pits (semi-mobile crushing), to reduce DMT and its related operating costs.

Geotechnical parameters

The slope stability evaluations have the geomechanical model as their starting point considered for the mine rock mass, based on geological and structural database. This information is mainly collected in the geological-geotechnical description of drilling cores and surface mapping. Detailed information regarding to geotechnical procedures is presented in section 7.4.

The NPV Scheduler software requires geotechnical inputs from individual "slope region", which defines the geotechnical parameters for each lithology and geotechnical domain. The values of the inter-ramp slope angles (grouping by lithologies) applied in each block were assigned, grouping the lithologies according to Table 11-28.

Locally, the operational reserves pit may exceed the resource pit, which is perfectly acceptable due to the definitive geotechnical sectors of the mines, the geomechanical and structural characteristics of the materials, and the final design of ramps and accesses for this pit.

The demand for water in this mining complex is supplied by surface and underground sources. Surface water is collected at the Igarapé Gelado dam and used as raw water for the industrial process of the iron ore processing plant. Underground water is collected through deep tubular drill holes drilled in mines N4 and N5, being destined for industrial use, supplying WTP, spraying roads, water replenishment in the Jacaré and Buriti streams. The remainder is destined for the Pêra and Gelado dams. Table 11-28 shows geotechnical parameters used in generating the resource pit.

Table 11-28 – Geotechnical parameters

Deposit	Lithologies	Overall NPV Angle
N1	AT	22
	MD	31
	MSD	34
	CE-CQ	36
	FM-HF-HMN	41
	HC-JP-MS	46
N2	AT	22
	IN-MD	31
	CE-CQ	33
	QT	36
	FMN-HF-HMN-MSD	41
	MS	46
	HC-JP	48
N3	AT	22
	XI-MD	31
	CE-CQ	36
	FMN-HF-HMN-MSD	41
	MS	46
	HC-JP	48
N4	AT	22
	AG-MD	31
	CE-CQ	36
	FMN-HF-HMN-MSD	41
	HC-MS-JP	46
N5	AT	22
	MD	31
	CE-CGL-CQ	36
	MN-FF-HF-HMN-MSD	41
	HC-MS-JP	46

Waste/tailings disposal parameters

The waste generated by the resource pit are contained in the Northern Corridor Waste and Tailings Master Plan, whose projects are at a conceptual development level, requiring additional studies to define their technical, economic, and environmental feasibility for their implementation as needed in the Ferrous Master Plan and the LOM of that deposit.

Mining/surficial rights parameters

Vale mining rights (DM) cover the entire area of the model box, therefore it is not a restriction for the development of mineral resource pits (Figure 11-29).

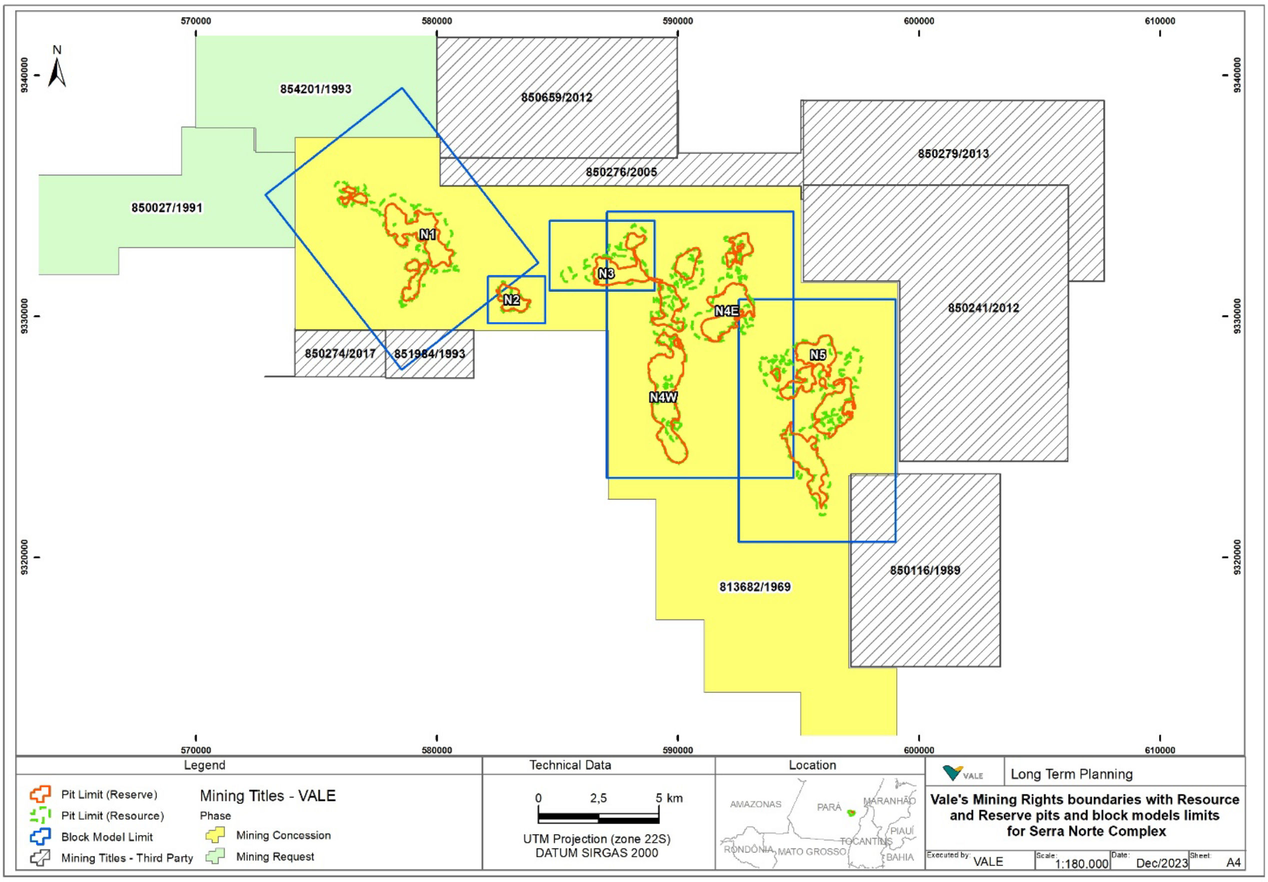


Figure 11-29 – DMs Vale boundaries and Serra Norte geological model box boundaries (blue polygons), Vale´s mining concession in yellow.

Environmental / sustainability / speleological parameters

The deposits covered in this report are located in the Carajás National Forest (FLONACA). This conservation unit was approved by Ordinance No. 45 on 04/28/2004 and reviewed on May 9, 2016.

Currently, the N4 and N5 mines operate under environmental licenses LO 267/2002, which allow the exploitation (exploration, mining, and processing) of iron ore from existing pits and expansions, as well as LP 488/2014, which allows for the expansion of the mines in the bodies named N4WS and N5S (2nd stage), Morro 1 and Morro 2, as well as the use of some pits for disposal of waste. The N1, N2, and N3 deposits are waiting for the approval from the respective environmental agencies. There is a reasonable expectation to obtain all environmental licenses (prior, installation, and operation) for these projects in the next 5 years. Licenses for possible expansions of pits in operation and pits of resources and reserves of the deposits with a project completed at a FEL2 level will be requested within the time required for the mining of these respective areas, according to the Ferrous Production Plan (Master Plan).

The Mining Zone of this conservation unit includes licensed (N4 and N5) and licensing in process (N1, N2, and N3) iron ore deposits. The northwestern region of N1 and N5 (an area called Morro 2) was kept outside the mining zone (considered a sustainable management zone). The purpose of this zone is to concentrate mining activities, minimizing the impact on adjacent areas and other zones (Carajás National Forest Management Plan – ICMbio-2016). Primitive Zones in which no mining and processing activities are allowed were considered absolute restrictions in N4 and N5.

The buffers with a radius of 150m around the most relevant iron ore caves, categorized as maximum relevance with low probability of change.

Physical structure constraint parameters

Mobile or semi-mobile primary crushing, TCLDs, offices, and plant feed internal piles were not considered as restrictions for the Serra Norte deposits, as these structures can be relocated and have little or no interference with the resource pit. Only the 100 m protection polygon around Plant 2 on N4 was considered as a definitive restriction.

11.16.3. Mineral resource definitions

The resource pit was unable to reach the entire classified inventory.

Due to the restrictions imposed by the environmental limits described and the economic reasonability, not all the mineral inventory was converted to mineral resources.

For all Serra Norte deposits, the mathematical pit of the NPV Scheduler with the price factor of 110% was used for each deposit in a more flexible approach compared to mineral reserves.

Table 11-29 shows the tonnage/grade numbers of the Mineral Resources (exclusive of Reserves) for the N1, N2, N3, N4E, N4W, N5 and Gelado deposits, respectively, considering the optimized Resource pits.

Table 11-29 – Mineral Resources (exclusive of Mineral Reserves)

Target	Classification	Tonnage (Mt)	Fe (%)

N1	Measured	183.4	66.4
	Indicated	138.2	66.4
	Measured + Indicated	321.6	66.4
	Inferred	157.5	66.3
N2	Measured	3.0	65.9
	Indicated	10.2	65.2
	Measured + Indicated	13.2	65.4
	Inferred	22.4	65.3
N3	Measured	15.0	65.8
	Indicated	45.9	65.2
	Measured + Indicated	60.9	65.3
	Inferred	48.8	65.8
N4W	Measured	196.2	66.3
	Indicated	31.1	66.1
	Measured + Indicated	227.2	66.3
	Inferred	5.9	65.9
N4E	Measured	130.9	66.1
	Indicated	17.7	65.9
	Measured + Indicated	148.6	66.0
	Inferred	5.2	65.1
N5	Measured	318.0	66.9
	Indicated	176.3	66.7
	Measured + Indicated	494.3	66.8
	Inferred	56.0	67.3
Gelado	Measured		
	Indicated	85.6	63.8
	Measured + Indicated	85.6	63.8
	Inferred	7.0	63.6
Total	**Measured**	846.4	66.5
	Indicated	505.1	65.9
	Measured + Indicated	1,351.5	66.3
	Inferred	302.7	66.2

Notes to accompany mineral resources tables:

1. *The estimate has an effective date of 31/Dec/2025.*
2. *Ferrous Mineral Resources estimates stated as metric million tonnage inclusive moisture and dry %Fe grade; following moisture contents: 7.77% Serra Norte;. Gelado density is dry bases.*
3. *Serra Norte integrated operation includes N3, N4W, N4E and N5 mines, N1, N2 projects and Gelado tailings dam.*
4. *The mineral resources prospects of economic extraction were determined based on a long-term price of US$92.3/dmt for 62% iron grade.*
5. *Numbers have been rounded.*
6. *Product Recovery: for Gelado Tailings was considered 50%, so the overall processing recovery for Serra Norte Complex is 97.3%.*

The Mineral Resources estimate (exclusive of Mineral Reserves) is effective as of December 31, 2025 of in situ. The estimate of Mineral Resources (exclusive of Mineral Reserves) is between the minimum topographic bases between May/2024 and December/2024 for the operating mines of N4 and N5. For N1, N2, and N3 (projects under development) laser aerial survey, delimited by resource pits with economic reasonableness. The iron grades are expressed on a dry basis and the mass is on a natural basis.

The generation of Resource pits was completed using economic, legal, geotechnical, and environmental assumptions and other modifying factors.

The totals in the table are rounded to reflect the uncertainty of the estimate. Total numbers of tons and grades may differ due to this rounding.

The Mineral Resources are following the United States Securities and Exchange Commision's (SEC) Modernized Property Disclosure Requirements for Mining Registrants as described in Subpart 229.1300 of Regulation S-K, Disclosure by Registrants Engaged in Mining Operations (S-K 1300) and Item 601 (b)(96) Technical Report Summary.

11.16.4. Conclusions and recommendations of the technical responsible

Regarding the geometry of the resource pit, the pit shape is fully adherent to the resource classification and is only limited by environmental and social constraints (primitive zone of the Carajás National Forest Management Plan). Despite these restrictions, there is potential for the conversion of Inferred to Measured or Indicated Resources and an increase in Mineral Resources, especially in the northern portion of the N5W pit and in the deposit called Morro 2. The development of mineral processing studies for marginal materials (jaspelites, chemical canga, manganese, and decomposed mafic formations) should continue aiming at evaluating the impact of these materials on current processing plants and future adaptations.

Condemnation studies and drilling must be carried out in the vicinity of the mineralized bodies to characterize potential areas for waste piles, crushing, and TCLDs for possible expansion of current operations.

11.16.5. Uncertainties that may affect the mineral resource estimate

- Areas of uncertainty that may materially impact all the mineral resource estimates include:
- Changes to long term metal price and exchange rate assumptions;
- Changes in local interpretations of mineralization geometry with additional drillings campaigns; faults, dykes and other structures; and continuity of ore bodies;
- Changes to geological and grade shape, and geological and grade continuity assumptions;
- Changes to variographical interpretations and search ellipse ranges that were interpreted based on limited drill data, when closer-spaced drilling becomes available;
- Changes to metallurgical recovery assumptions;
- Changes to the forecast dilution and mining recovery assumptions;
- Variations in geotechnical, hydrogeological and mining method assumptions;
- Changes to environmental, permitting and social license assumptions.

12. Mineral reserve estimates

12.1. Introduction

The Serra Norte Complex is divided into five bodies: N1, N2, N3, N4, and N5. In addition to this, we also reprocess material from the Gelado dam. Currently, the N4 and N5 orebodies are in operation, along with the Gelado dam.

The measured and indicated mineral resources of these deposits were converted into proven and probable mineral reserves after applying the modifying factors, and are reported using the mineral reserve definitions set out in S-K 1300.

The mineral reserve estimate has been adjusted compared with the previously presented Serra Norte Complex Technical Report Summary. The changes result from the revision of the block model, new mine designs, long-term commodity price assumptions, the conversion of mineral resources into mineral reserves, and changes to restrictive mine design parameters.

The mineral reserves at Serra Norte remained stable, as depletion was offset by reserve gains resulting from the revisions performed.

The expected depletion date for the Serra Norte Complex did not change significantly after these revisions.

Table 12-1 summarizes the Mineral Reserve estimate effective as of December 31, 2025.

Table 12-1 – Mineral reserve estimate

Pit/Operation	Classification	Tonnage (Mt)	Fe (%)
N1	Proven		
	Probable	388.1	64.3
	Subtotal Proven + Probable	388.1	64.3
N2	Proven		
	Probable	44.5	63.6
	Subtotal Proven + Probable	44.5	63.6
N3	Proven		
	Probable	114.8	63.7
	Subtotal Proven + Probable	114.8	63.7
N4W	Proven	192.9	64.9
	Probable	117.9	65.1
	Subtotal Proven + Probable	310.8	65.0
N4E	Proven	150.1	65.3
	Probable	8.4	64.8
	Subtotal Proven + Probable	158.5	65.3
N5	Proven	31.1	64.5
	Probable	367.9	65.1
	Subtotal Proven + Probable	399.0	65.0
Gelado	Proven		
	Probable	96.6	63.7
	Subtotal Proven + Probable	96.6	63.7
Total	**Proven**	**374.0**	**65.0**
	Probable	**1138.3**	**64.5**
	Total Proven + Probable	**1512.3**	**64.6**

1. The estimate has an effective date 31/Dec/2025.
2. Iron Ore Reserve estimates stated as metric million tonnes inclusive moisture and dry %Fe grade (Fe2O3); Serra Norte moisture of 7,46%. The point of reference used is in situ tons. Gelado is reported on dry basis.
3. The mineral reserve economic viability was determined based price curve with the long-term price being US$84.3/dmt for 62% iron grade
4. The estimate assuming open pit mining methods uses the following key input parameters: mining cost from 3.02 up to 3.96US$/t mined; process cost from 1.89 up to 2.78US$/t feeded to plant; other cost include sells cost from 34.11 up to 37.46US$/t product. Mining recovery of 92% and dilution of 5%.
5. Numbers have been rounded.

The Mineral Reserves were estimated by Vale and reviewed by Vale QP. Measured and Indicated Mineral Resources were used as inputs for conversion into Proven and Probable Mineral Reserves respectively.

Reserve modifying factors were first added to the optimization software. The software NPVScheduler® was used to generate the pit shell but there is no economic cut-off grade applied to the mineral reserve and this is mainly because of the grade of the resource, which has an average of 60% Fe and the recovery factor is 100%, thus all material is handled as ore. The surface wireframe from December 2025 was used to deplete the resource block model. Environmental constraints, the presence of iron ore caves and the limits to mining concessions are also uploaded to NPVScheduler® before pit optimization.

The economic value of each block is calculated by the software using mining, procession and G&A costs, recovery factor, selling cost and commodity selling price. The pit shells are generated, and the final pit shell is chosen based on technical and economic criteria, which can vary between mines, from the characteristic of a specific mine, NPV maximization if the pit has a higher strip ratio or in some cases, the pit shell of revenue factor equal to 1 for a lower strip ratio.

An ultimate pit is designed and then returned into NPVScheduler® and the pit optimization is re-run. Economic phases are generated and afterwards, a production schedule. Mineral Reserves are reported as diluted. Vale QP certifies that these were fully scheduled in an appropriate LOM plan and applied to a discounted cash flow model. The Mineral Reserve estimate has demonstrated viable economic extraction.

Vale QP is not aware of any risk factors associated with or changes to any aspect of the modifying factors, such as mining, metallurgical, infrastructure, permitting, or other relevant factors that could materially affect the Mineral Reserve estimate.

12.2. Methodology

12.2.1. Dilution

Dilution is estimated by the reconciliation between what was fed into the plant and what was planned, over a year. The grade is assayed every two hours from the sampling of the crusher feed and consolidated for the entire current year to date and compared with the grade estimated from the short-term mining plan. From this comparison, the dilution factor for pit optimization is defined.

12.2.2. Mining Recovery

The calculation of mine recovery is obtained through the reconciliation between the mass fed into the plant and the planned mass for each year. The crushed mass is provided by date from the scales at the plant and consolidated by month. The production for the year is compared with the short-term plan and the mining recovery factor is determined comparing the production plan to the actual achieved.

12.2.3. Net value return and cut-off value

An NR cut-off value is determined using the Mineral Reserve metal prices, metal recoveries, transport, treatment, and mine operating costs. The metal prices used for the Mineral Reserves are based on a market estimated model, upon which are considered clients characteristic, offer and demand for exported iron ore, bonus and penalties according to the quality of the product.

The cut-off value used for the reserves is based on a positive profit of the block.

Costs and other parameters used to calculate the cut-off grade are shown in Table 12-2. The cut-off grade is 37.08% considering Serra Norte plants parameters. There is no economic cut-off grade applied to the mineral reserve, and this is mainly because of the grade of the resource, which has an average of 60% Fe and is above an estimate of the cut-off grade. The cutoff is not material to the estimate of the Reserves. Nevertheless, a check is performed.

Table 12-2 - Cut-off grade parameters for Serra Norte plant

Item	Units	Parameters
Metallurgical Recovery	%	100
Mining Cost	US$/t rock.	3.67
Processing Cost	US$/t fed	2.78
Selling Cost	US$/t product	37.46

12.2.4. Costs

The cost was based on the operations and base projection of the operational indicators, which includes support infrastructure, environmental studies and continued operational feasibility. Table 12-3 presents the costs used in the pit optimization.

Table 12-3 - Modifying factors for pit optimization

Item	Unit	Costs
Mining	US$/$t_{mined}$	3.02 to 3.96
Processing Plant	US$/t crusher feed	1.89 to 2.78
Other costs	US$/t product	34.11 to 37.46
Vertical rate cost	US$/m	0.0045
Mining recovery	%	92
Mining dilution	%	5

12.2.5. Price

The price curves are provided by Vale Market department and elaborated from a market estimated price model, upon which client characteristic, offer and demand for iron ore transoceanic, bonus and the deleterious according to the quality of the product are considered. As a reference price it was used US$70 up to 84.2/dmt (62% Fe) which varies according to the iron ore grades.

12.2.6. Caves

Iron ore cave limits are updated in a special database. The classification of these caves is regulated by Brazilian Federal law. A stand-off distance of 150 m as an exclusion zone for caves of maximum relevance.

12.2.7. Mass Recovery

For the open pit mines a constant recovery factor of 100% was used as the process does not have concentration. It uses historical data based on mass balance in and out. In case of Gelado process the recovery factor of 51.6% for pumped material, was applied.

12.2.8. Wall Slope Angles

The pits are generated with the overall slope angles provided for each lithology. The company policy considered two factors safety:

- 1.3 in other areas of the pit;
- 1.5, in regions where there are structures, such as piles, industrial facilities, railways, highways, etc.

After the pit optimization, the results are sent to the geotechnical team that proceeds with the geotechnical sectoring which will then be used in the operation of the pits.

12.3. **Factors, which might affect the mineral reserve estimate**

The following factors may affect the results of the obtained Mineral Reserves:

- Prices of the iron commodities.
- American dollar exchange rate.
- Brazilian inflation rate.
- Geotechnical assumptions (including seismicity) and hydrogeological.
- Changes in the capital input and operating costs estimate.
- Change in the operating cost assumptions.
- Stockpile assumptions.
- Capacity of the mining operation to fulfill the annual production rate.
- Recoveries of the process plant and the capacity to control levels of deleterious elements within the expectations of the LOM plan.
- Capacity to meet and keep environmental licenses and permits, and capacity to maintain a social license to operate.

According to the knowledge of QP, there are no other environmental, licensing, legal, title, tax, social-political or marketing issues that could affect the mineral reserve estimate materially, which have not been discussed in this Report.

13. Mining methods

13.1. Summary

Serra Norte has been operating since 1985, with production rates of approximately 100 Mtpa in recent years. The mine is an open pit by berms and benches and uses large truck and shovel equipment. Mining is carried out in five separate orebodies.

N4 and N5 mines, currently in operation, utilize open pit mining and are operated by large loading and hauling equipment, namely, hydraulic excavators with loading capacity up to 80 ton, cable excavators with loading capacity up to 109 ton and front-end-loader with loading capacity of 72.6 ton. The haulage is carried out by truck with payload capacity of 400, 320 and 240 short tons.

In some regions of these mines, where maximum relevant iron ore caves are presented, continuous miners are utilized, which eliminates drilling and blasting thereby reducing ground vibrations caused by blasting and avoiding damage to the caves near the mining areas.

Gelado tailings dam, reserve is managed based on scheduling and constraints parameters to achieve the optimal results. It is operated by large electric dredges that pump slurry to treatment plant.

13.2. Mine design

The mine design includes benches with heights 15m, berms with widths of 12m, face angles between 26 and 85 degrees, all according to the lithology in the mine. Ramp access is 40m wide with 10% gradient. The ore is either hauled to stockpiles or dumped straight into the crusher bins. The open-pit designs are presented in

Figure 13-1 to Figure 13-6.

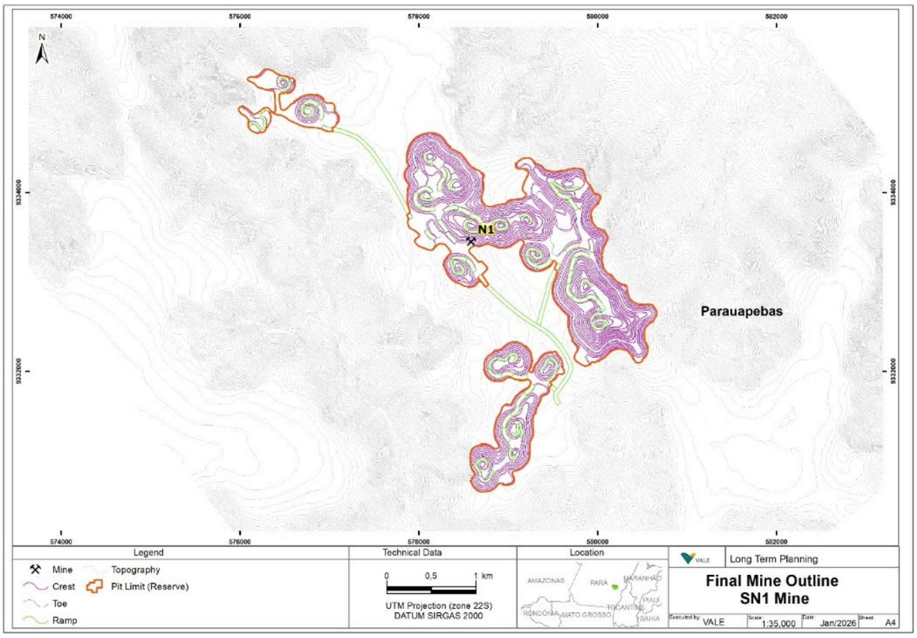


Figure 13-1 - Plan view of N1 open pit mine design.

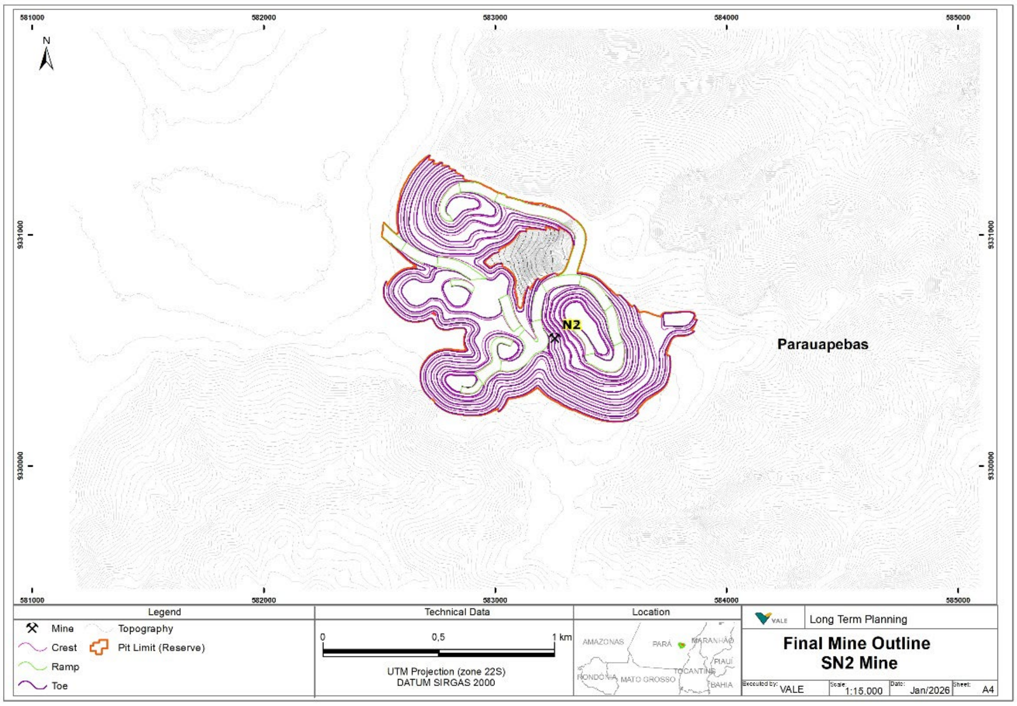


Figure 13-2 - Plan view of N2 open pit mine design.

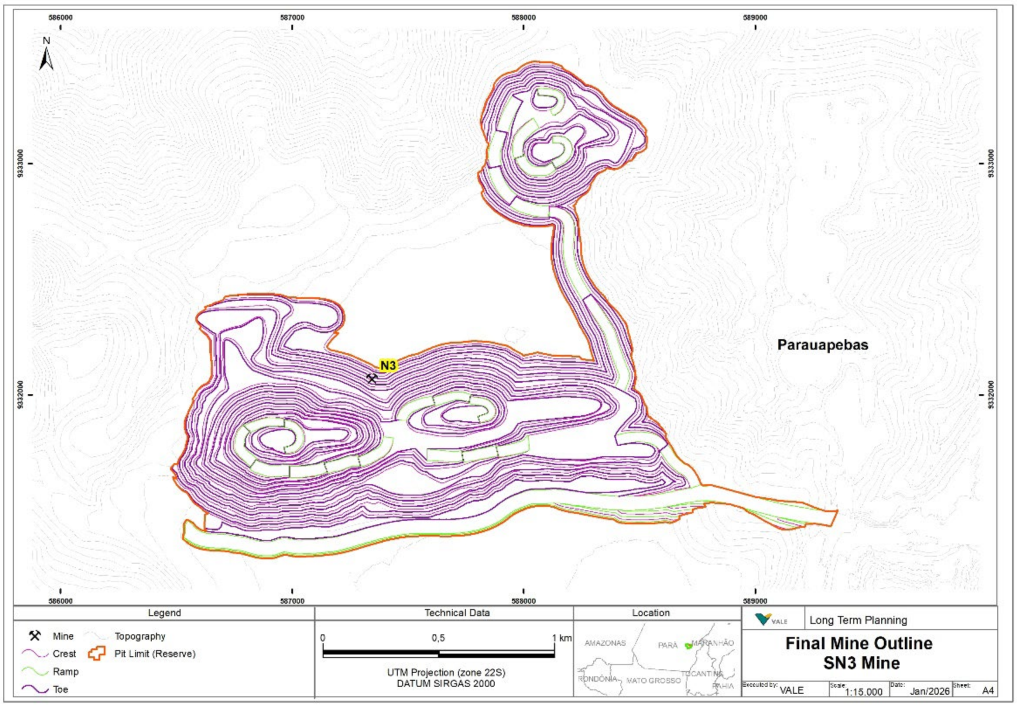


Figure 13-3 - Plan view of N3 open pit mine design.

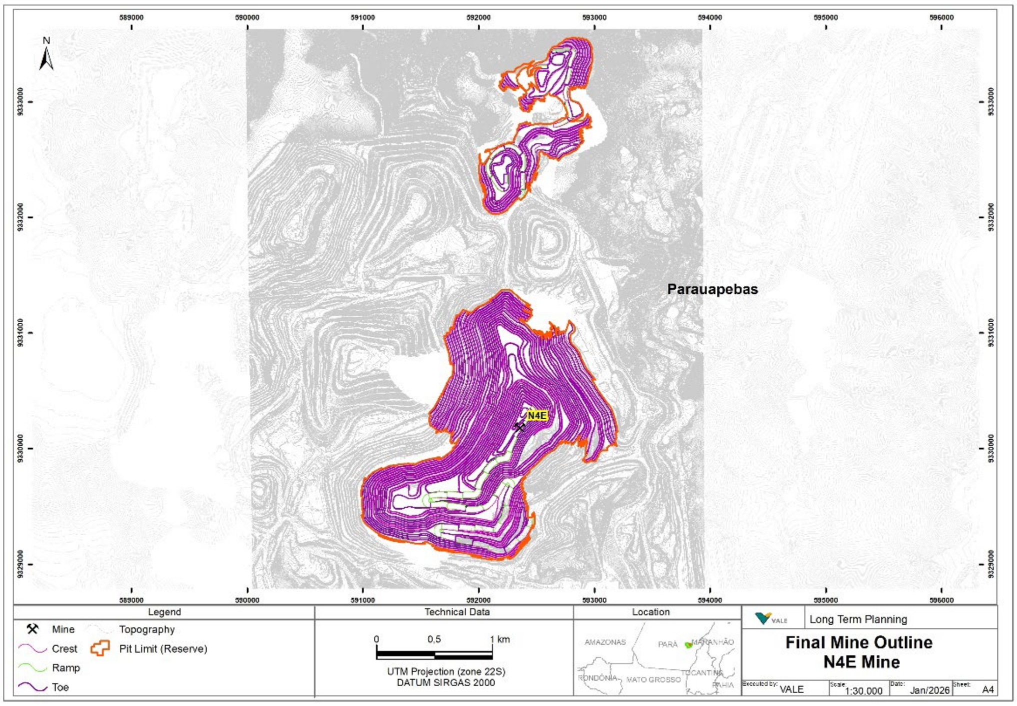


Figure 13-4 - Plan view of N4E open pit mine design.

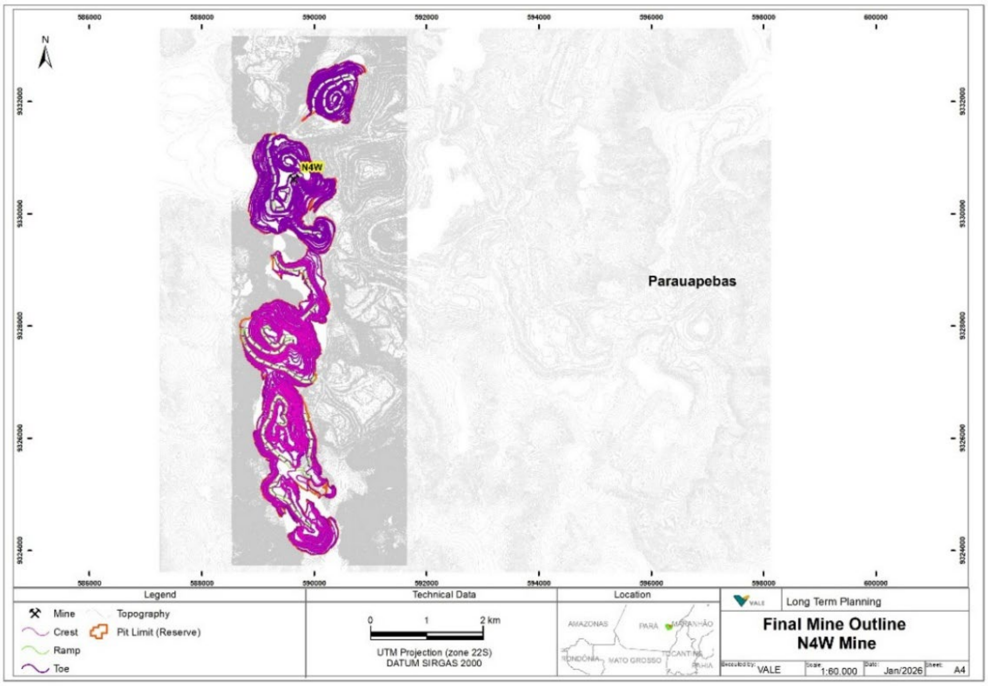


Figure 13-5 - Plan view of N4W open pit mine design.

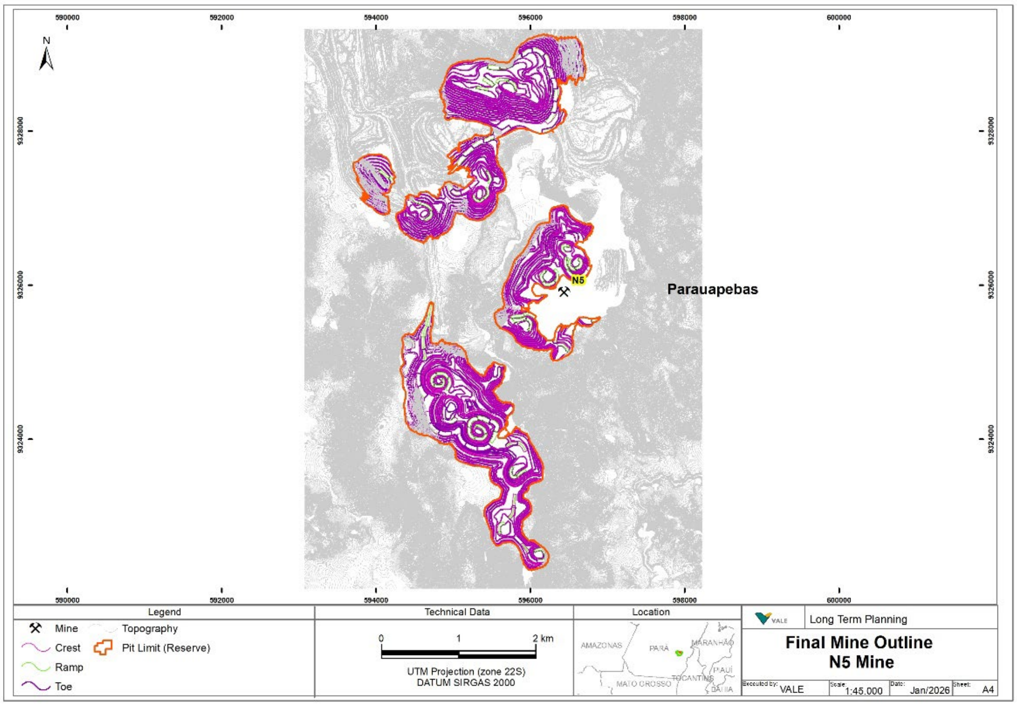


Figure 13-6 - Plan view of N5 open pit mine design.

13.3. Mine method

The mining method at Serra Norte is open pit, as a normal standard operation adopted across the mining industry. Part of the material is free digging and other parts require blasting. The ore is loaded into the haul road trucks and dumped directly to the crusher. Blending is required to adjust the average Fe grade.

At Gelado dam, the reserves are reclaimed primarily through dredging.

13.4. Geotechnic

13.4.1. Introduction

The geotechnical assessment for the final pit is undertaken by a multidisciplinary team comprising geotechnical, hydrogeological, geological, and long-term mine-planning professionals, who collectively contribute to the final evaluations. This activity depends on coordinated teamwork, beginning with the definition of the mathematical pit surface and extending through to the operational implementation of the final geometry. As illustrated in Figure 13-7, the workflow is organized into four phases (rows) and corresponding responsibilities (columns):

- Phase 1 – Lithogeometric parameters definition supporting the mathematical pit.
- Phase 2 – Development of the geotechnical model.
- Phase 3 – Operational pit assessment.
- Phase 4 – Final approval and verification for closing conditions.

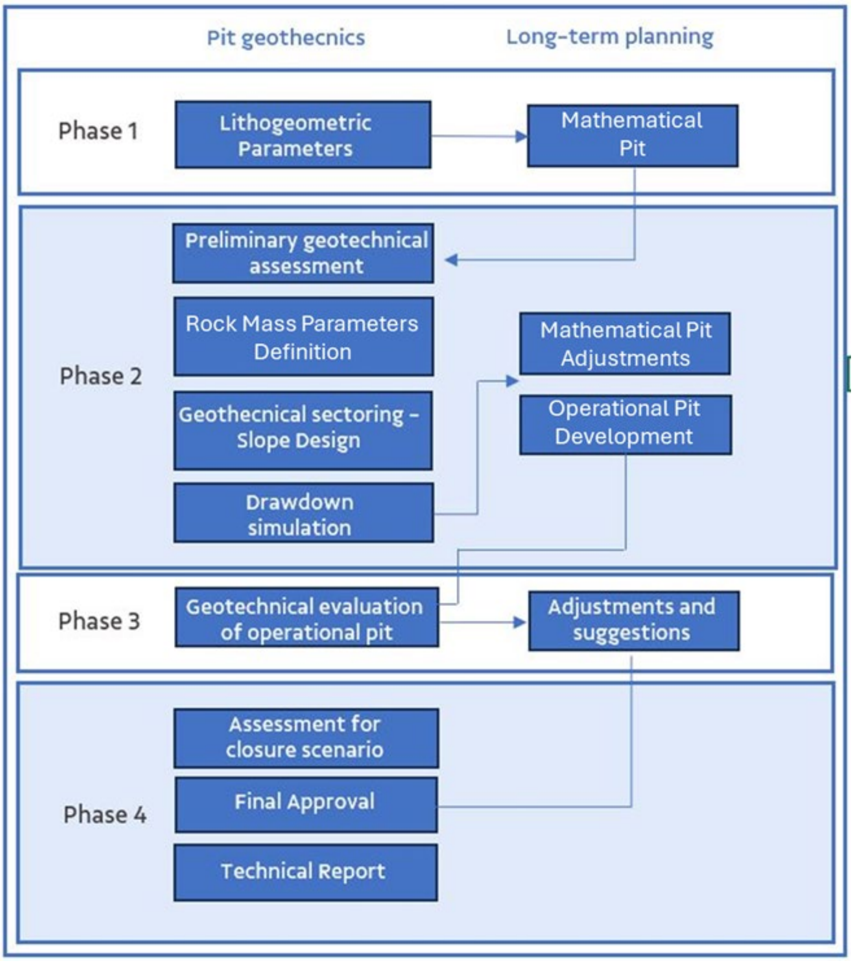


Figure 13-7 - Process of geotechnical evaluation of the final pits.

13.4.2. Geotechnical Assessment

The criteria used for the approval of the slope designs adhere to international standards and to the best practices recommended by Read & Stacey (2009). The acceptance criteria are based on slope-stability analyses using deterministic Factor of Safety (FoS) approach, which must comply with the indicative minimum values presented in Table 13-1.

Table 13-1 – Typical FoS acceptance criteria values. Source: Modified from Read & Stacey (2009).

Slope Scale	Consequences of Failure	Acceptance Criteria[a]	
		$FoS_{(min)}$ (static)	$FoS_{(min)}$ (dynamic)
Bench	Low-high[b]	1.1	NA
Inter-ramp	Low	1.15–1.2	1.0
	Moderate	1.2	1.0
	High	1.2–1.3	1.1
Overall	Low	1.2–1.3	1.0
	Moderate	1.3	1.05
	High	1.3–1.5	1.1

[a] *Needs to meet all acceptance criteria.*
[b] *Semi-quantitatively evaluated.*

Limit-equilibrium analyses were performed to evaluate the potential development of failure surfaces, incorporating the geotechnical models, appropriate failure mechanisms, and corresponding rock mass parameters. These analyses were systematically applied across the entire pit, with emphasis on critical sections used to assess inter-ramp- and overall-slope-scale failure mechanisms.

The identification of critical analysis sections was guided by the following criteria:

- Segments with the highest slope heights.
- Maximum bench stacks heights without ramps or geotechnical ramps.
- Inter-ramp angle variations associated with notably weak materials.
- Areas composed of materials with the lowest rock mass parameters.
- Slope sectors exhibit the steepest overall slope angles.
- Interfaces between lithotypes characterized by significant contrasts in strength.
- Presence of industrial facilities or other geotechnical structures near the pit crest.
- At least one section representative of each geotechnical sector is considered relevant.
- Geological or structural features contributing to potential instability, such as shear zones, discontinuities, or strongly oriented structural anisotropy.
- Areas indicating high pore-pressure conditions.

The evaluation of slopes and the determination of the FoS were based on the following assumptions:

- Stability analyses were performed using the Limit Equilibrium Method (LEM) for each most-probable failure mechanism identified in the geotechnical model, under static loading conditions.
- The groundwater levels and piezometric surfaces used in the analyses were derived from hydrogeological models specifically developed for the final-pit configuration, supplemented by data from local hydrogeological instrumentation.

The stability analyses were conducted using SLIDE2 (Rocscience Inc.®). The Limit Equilibrium Method (LEM) was applied employing the GLE/Morgenstern-Price formulation, with search algorithms such as Cuckoo Search, Auto-Refine Search, and Path Search evaluated for the identification of critical failure surfaces. The selected results correspond to those most consistent with the geological and geomechanical conditions of each analyzed section.

Approval of the pit geometry is dependent on meeting the acceptance criteria established for the corresponding Factor of Safety (FoS) values obtained in each section. The detailed assessment results for each operational pit are presented in Section 13.4.5.

13.4.3. Geotechnical Overview

The geotechnical assessment for the final slope design was carried out by Vale's geomechanical and hydrogeological teams, in accordance with the procedures described in Section 13.4.1. To support the geotechnical evaluations for the Serra Norte project, a comprehensive set of previous studies was consulted, including several internal reports and external technical studies developed between 2014 and 2023.

The lithological units have been described and modeled to provide adequate support for geotechnical characterization and for the evaluation of geohazards associated with mining activities. In the context of the open-pit mining method, the rock mass conditions are well understood and are considered suitable for the current mining depths, the local rock reinforcement practices, and the geotechnical requirements of the mining process.

The geotechnical mapping and data-analysis protocols follow standard industry practices, including detailed characterization of structural domains and their attributes, based on field mapping, geological modeling, and geotechnical core-drilling data.

13.4.4. Geotechnical and Rock Mass Models

The geomechanical model employed for the Serra Norte Mine Complex incorporates Rock Mass Rating (RMR) and Weak Rock classifications. The rock mass is systematically categorized into distinct classes denoted as I, II, III, IV, Weak, Very Weak, and Extremely Weak. Concurrently, Table 13-2 provides a comprehensive summary of the geotechnical data gathered for the Serra Norte mine sites.

Table 13-2 - Summary reports used to build structural and geomechanical model.

Serra Norte Mine Complex	Year of Structural Mapping / Year of Geomechanical Model	Drillholes with geotechnical assay		Surface Mapped Points
		Amount of drillholes	Total drilled (m)	
N1	2014 / 2023	124	30,760	217
N2	2014 / 2023	41	7,286	99
N3	2014 / 2020	80	17,205	137
N4	2011 & 2019 / 2023	2,920	406,742	8,450
N5	2011 & 2019 / 2023	1,401	191,108	3,460

The determination of geotechnical parameters was conducted based on lithological units and weathering grades derived from the geological and geomechanical models, in addition to structural features, such as anisotropies and discontinuities, identified through detailed structural mapping and geological cross-sections. The strength tests supporting the definition of the geotechnical parameters employed in the slope-stability analyses for the Serra Norte Complex are summarized in Table 13-3. In cases where specific lithotypes lacked corresponding laboratory test data, parameters established for adjacent mining operations with comparable lithostratigraphic, tectonic, and geomechanical characteristics were adopted, following standard industry practice.

Table 13-3 - Geotechnical laboratory tests reports– Serra Norte Mine Complex

Laboratory Test	Year	Number of Tests
Consolidated Drained Triaxial Shear Test (CD)	2006	4
Consolidated Undrained Triaxial Shear Test (CU)	1991	2
	1996	12
	2006	20
	2012	1
	2017	4
	2018	13
Direct Shear	2006	8
Unconfined Compressive Strength (UCS)	1991	3
	2012	5

13.4.5. Slope Stability Analysis

Multiple geotechnical sections were compiled and systematically evaluated across the mines of the Serra Norte Complex. Using the final pit design in conjunction with the geological and geomechanical model, Vale conducted comprehensive assessments to identify potential failure mechanisms based on the adopted geotechnical parameters. These evaluations were performed on selected cross-sections along the final pit limits to determine the FoS associated with slope-stability conditions in each mine.

Deterministic limit-equilibrium analyses were based on the geotechnical model and incorporated the hydrogeological conditions described in Section 14.5. The analyses covered the entire pit and were performed using representative cross-sections, as illustrated in Figures 13-8 through 13-14.

A summary of the results from the slope-stability analyses, including FoS, the incorporation of near-mine boundary interferences for each section, and other relevant considerations, is presented in Tables 13-4 through 13-8.

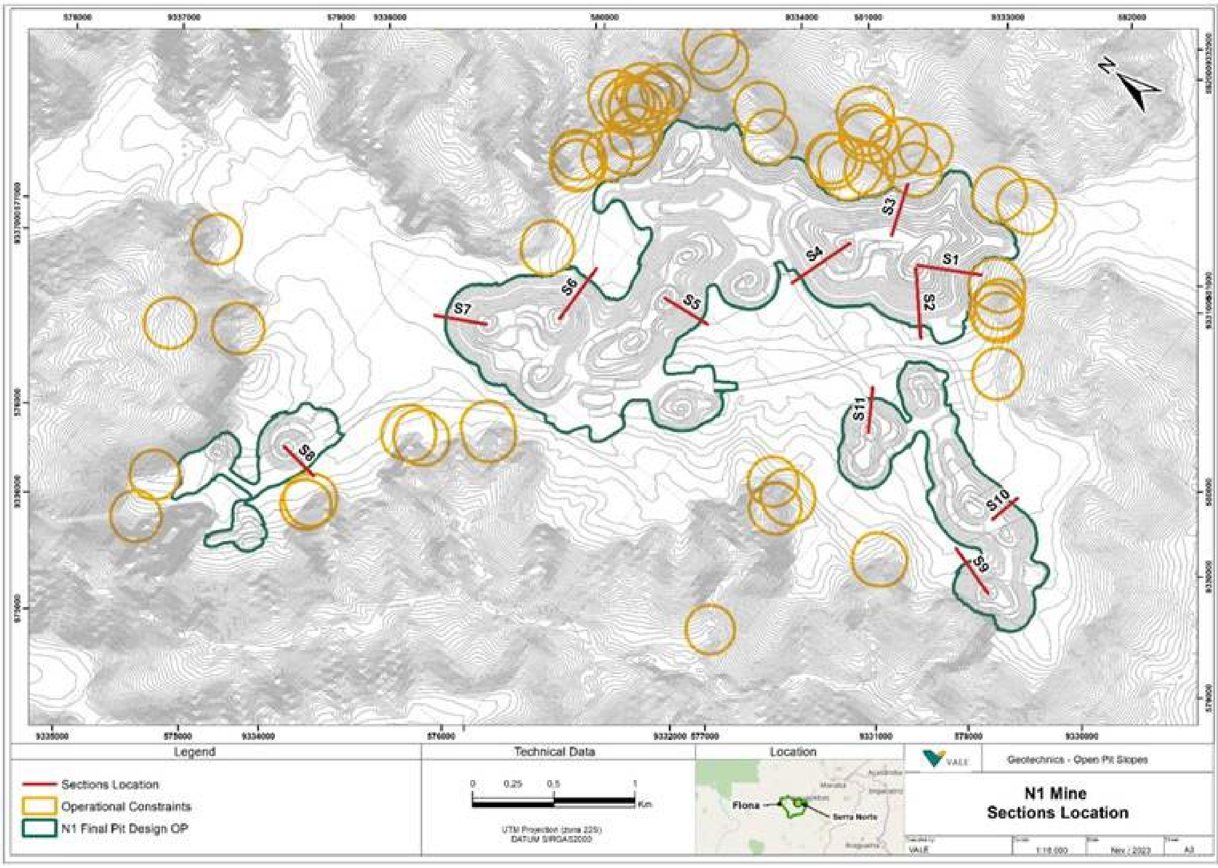


Figure 13-8 - Slope stability analysis cross section location – N1 Mine.

Table 13-4 – Safety Factor and other information from N1 final pit slope design

Pit	Section	Acceptable criteria		Results	
		FoS (required)	Near mine border interference	FoS	Failure Scale
N1	S01	1.30	Cave	1.43	Overall
	S02	1.30	-	1.30	Inter-ramp
	S03	1.30	-	1.40	Overall
	S04	1.30	-	1.74	Inter-ramp
	S05	1.30	-	1.34	Inter-ramp
	S06	1.30	-	1.31	Inter-ramp
	S07	1.30	-	1.32	Inter-ramp
	S08	1.30	Cave	1.68	Overall
	S09	1.30	-	1.39	Overall
	S10	1.30	-	1.30	Inter-ramp
	S11	1.30	-	1.38	Inter-ramp

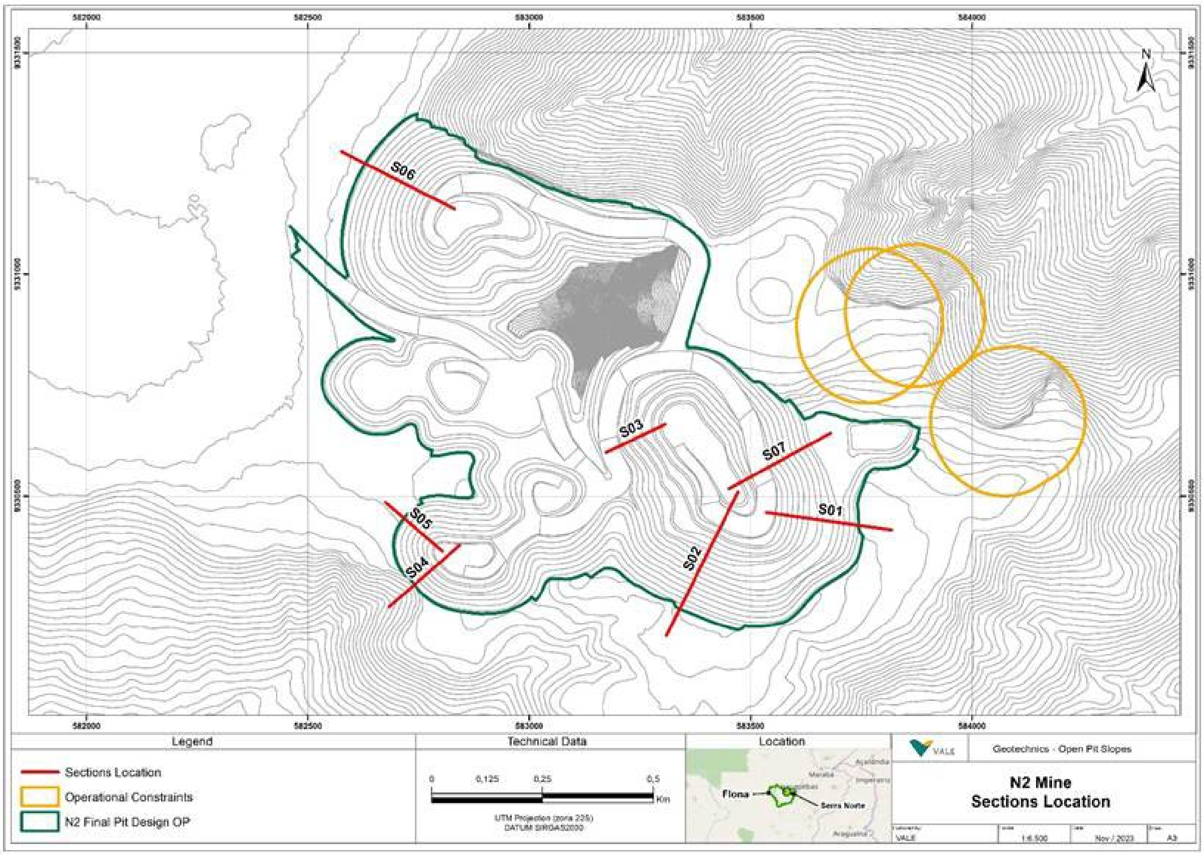


Figure 13-9 - Slope stability analysis cross section location – N2 Mine.

Table 13-5 – Safety Factor and other information from N2 final pit slope design.

Pit	Section	Acceptable criteria		Results	
		FoS (required)	Near mine border interference	FoS	Failure Scale
N2	S01	1.30	-	1.47	Overall
	S02	1.30	-	1.30	Overall
	S03	1.30	-	1.52	Overall
	S04	1.30	-	1.66	Inter-ramp
	S05	1.30	-	1.90	Inter-ramp
	S06	1.30	-	1.43	Overall
	S07	1.30	-	1.40	Inter-ramp

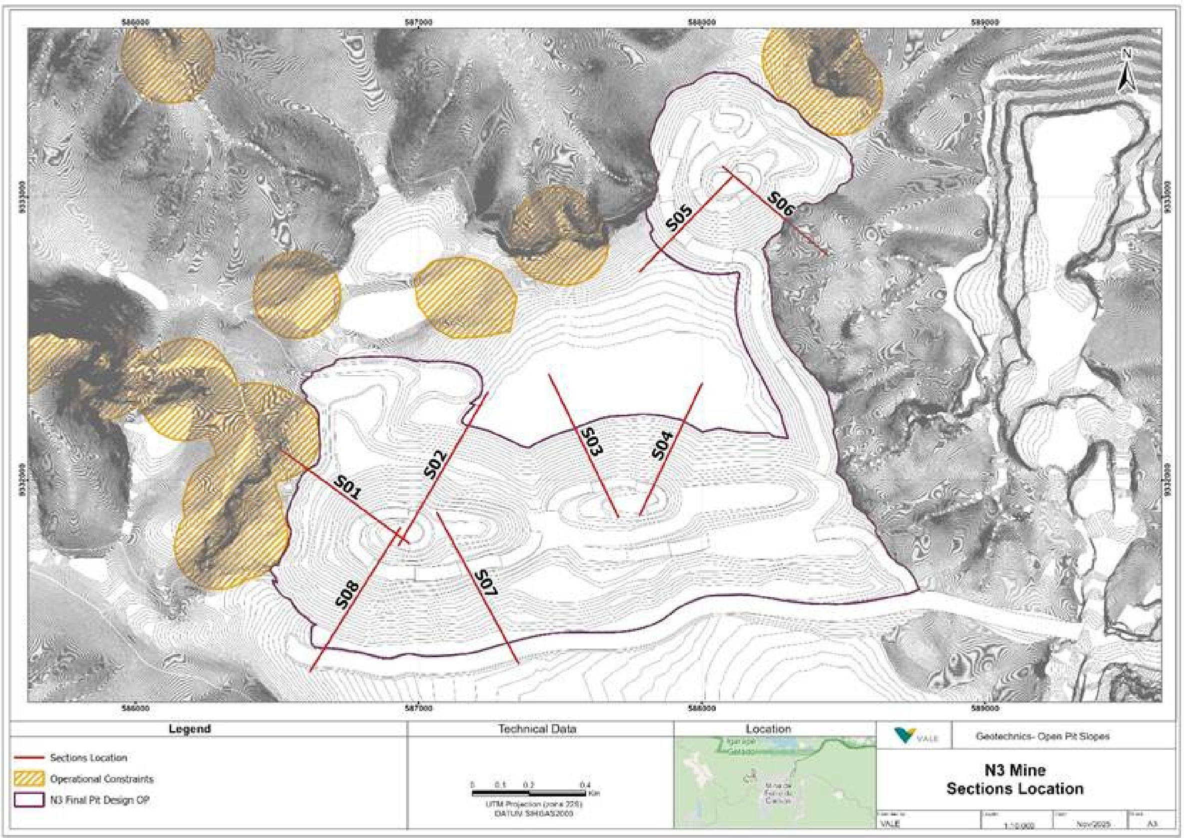


Figure 13-10 - Slope stability analysis cross section location – N3 Mine.

Table 13-6 – Safety Factor and other information from N3 final pit slope design

Pit	Section	Acceptable criteria		Results	
		FoS (required)	Near mine border interference	FoS	Failure Scale
N3	S01	1.30	Cave	1,7	Inter-ramp
	S02	1.30	-	1,5	Overall
	S03	1.30	-	1,5	Overall
	S04	1.30	-	1,4	Overall
	S05	1.30	-	1,8	Inter-ramp
	S06	1.30	-	1,7	Inter-ramp
	S07	1.30	Intern road	1,5	Inter-ramp
	S08	1.30	Intern road	1,5	Inter-ramp

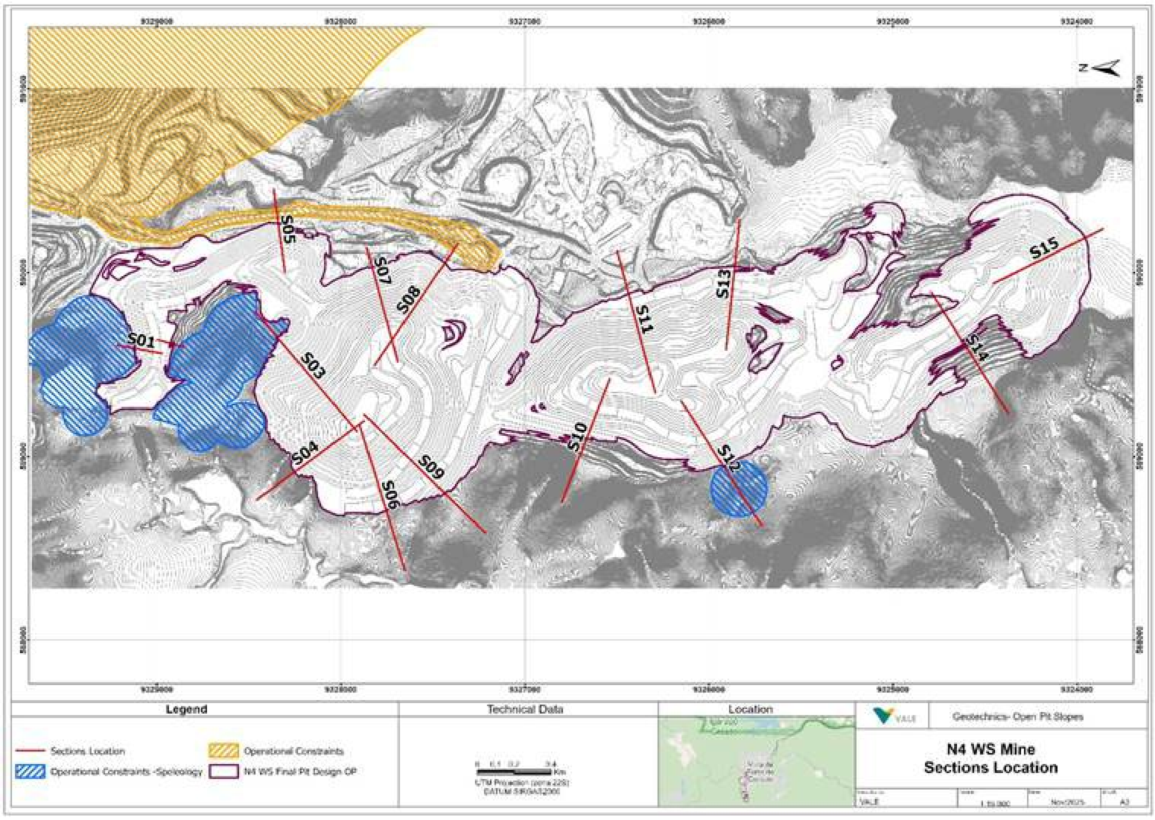


Figure 13-11 - Slope stability analysis cross section location – N4WS Mine

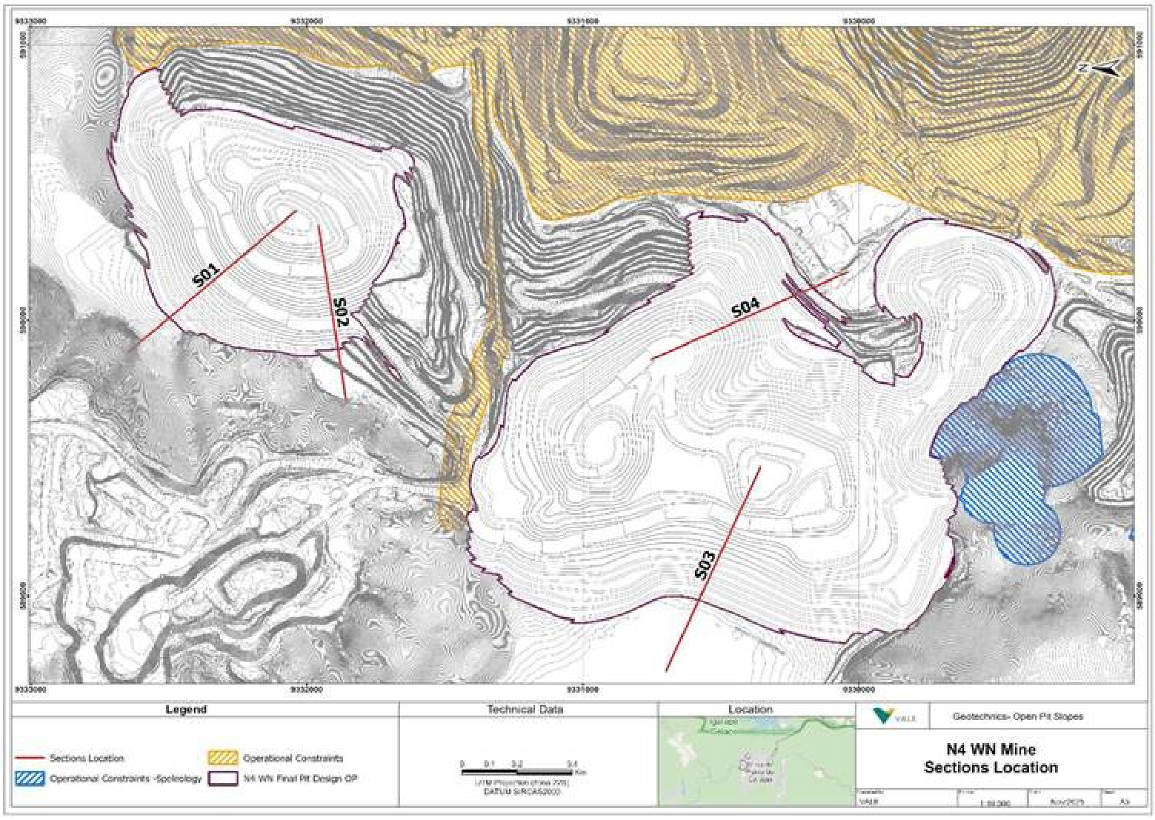


Figure 13-12 - Slope stability analysis cross section location – N4WN Mine.

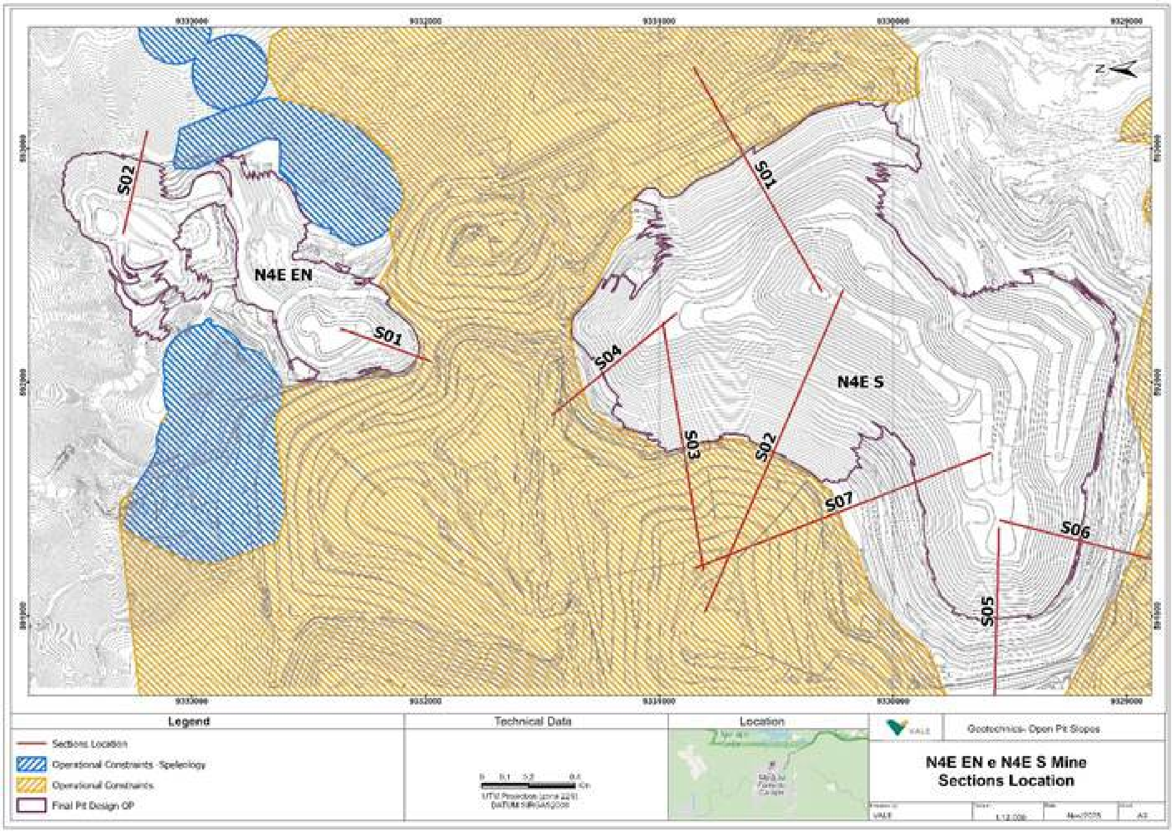


Figure 13-13 - Slope stability analysis cross section location – N4E Mine.

Table 13-7 - Factor of safety and other information from N4 final pit slope design

Pit	Section	Acceptable criteria		Results	
		FoS (required)	Near mine border interference	FoS	Failure Scale
N4WS	S01	1,3	Cave	1,7	Overall
	S02	1,3	Cave	1,8	Overall
	S03	1,3	Cave	1,3	Inter-ramp
	S04	1,3	-	1,3	Overall
	S05	1,5	LDC*	1,7	Inter-ramp
	S06	1,3	-	1,4	Overall
	S07	1,3	-	1,7	Overall
	S08	1,5	LDC*	1,5	Overall
	S09	1,3	-	1,5	Inter-ramp
	S10	1,3	-	3,9	Inter-ramp
	S11	1,5	LDC*	1,5	Overall
	S12	1,3	Cave	1,3	Inter-ramp
	S13	1,5	-	2,5	Overall
	S14	1,5	LDC*	1,5	Inter-ramp
	S15	1,3	-	1,3	Overall
N4WN	S01	1,3	-	1,3	Inter-ramp
	S02	1,3	-	1,6	Inter-ramp
	S03	1,3	-	1,5	Inter-ramp
	S04	1,5	Industrial Facilities	1,5	Inter-ramp
N4EEN	S01	1,5	Waste Dump	1,9	Inter-ramp
	S02	1,3	-	1,3	Inter-ramp
N4ES	S01	1,5	Industrial Facilities	1,5	Inter-ramp
	S02	1,5	Waste Dump	1,5	Inter-ramp
	S03	1,5	Waste Dump	1,5	Inter-ramp
	S04	1,3	-	1,3	Inter-ramp
	S05	1,3	-	1,3	Inter-ramp
	S06	1,3	-	1,5	Inter-ramp
	S07	1,5	Waste Dump	1,5	Inter-ramp

*Long distance conveyors

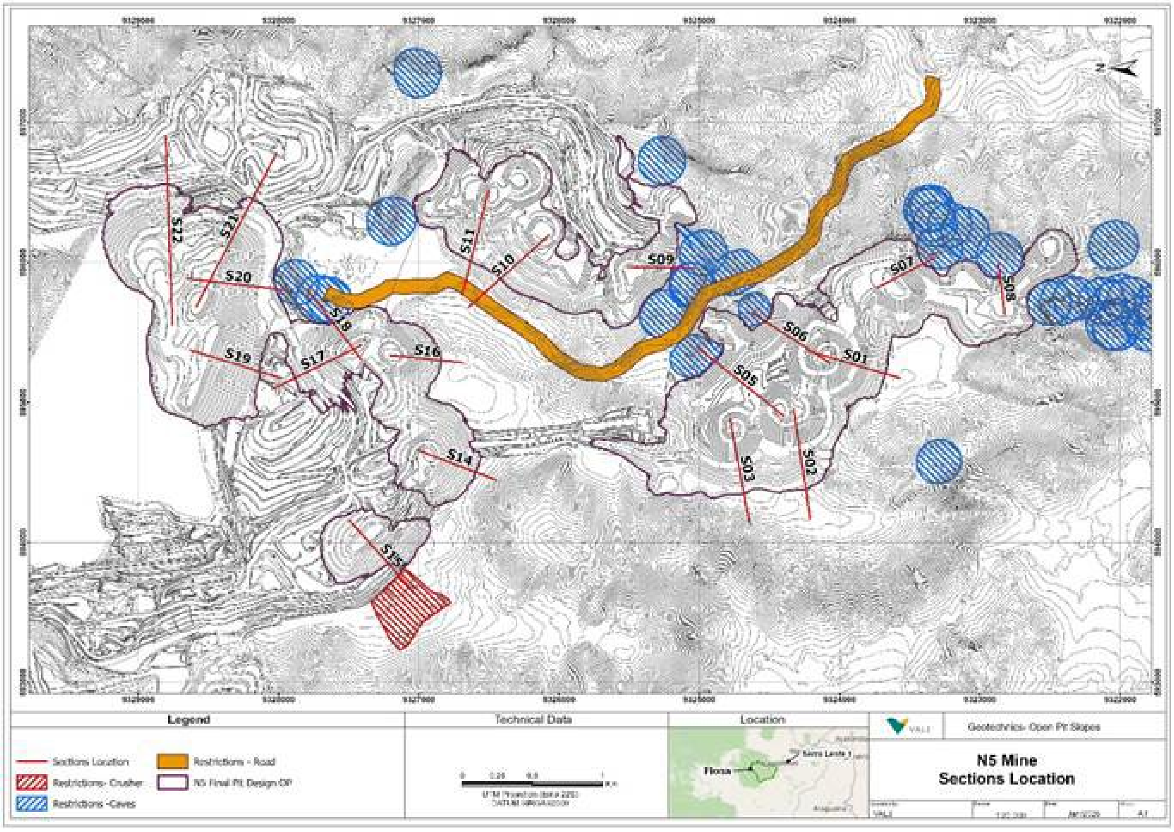


Figure 13-14 - Slope stability analysis cross section location – N5 Mine.

Table 13-8 - Factor of safety and other information from N5 final pit slope design

Pit	Section	Acceptable criteria		Results	
		FoS (required)	Near mine border interference	FoS	Failure Scale
N5	S01	1,3	-	1,8	Overall
	S02	1,3	-	1,3	Overall
	S03	1,3	-	1,8	Overall
	S05	1,3	Cave	1,7	Overall
	S06	1,3	Cave	1,5	Overall
	S07	1,3	Cave	1,7	Overall
	S08	1,3	Cave	1,7	Inter-ramp
	S09	1,3	Cave	1,5	Inter-ramp
	S10	1,5	Internal road	1,6	Inter-ramp
	S11	1,5	Internal road	1,8	Overall
	S14	1,3	-	1,6	Overall
	S15	1,5	Crusher	1,6	Inter-ramp
	S16	1,3	-	1,6	Inter-ramp
	S17	1,5	Waste Dump	1,6	Inter-ramp
	S18	1,3	Cave	1,6	Overall
	S19	1,5	Waste Dump	1,5	Inter-ramp
	S20	1,3	Cave	1,6	Inter-ramp
	S21	1,5	Waste Dump	1,5	Inter-ramp
	S22	1,5	Waste Dump	1,5	Inter-ramp

13.5. Hydrogeological considerations

13.5.1. N1 Hydrogeological Models

A numerical groundwater flow model was employed to simulate the drawdown of the water table in the N1 area. The estimated outflow from the simulation is 662 m^3/h. A total of 16 instruments were utilized to calibrate the model, resulting in a root mean square error (nRMS) of 2.32%.

Figure 13-15 illustrates the equipotential contours (at 20-meter intervals) generated during the simulation under maximum dewatering conditions, along with the direction of groundwater flow. These surfaces were utilized as input data for the stability analysis detailed in Section 13.4.4.

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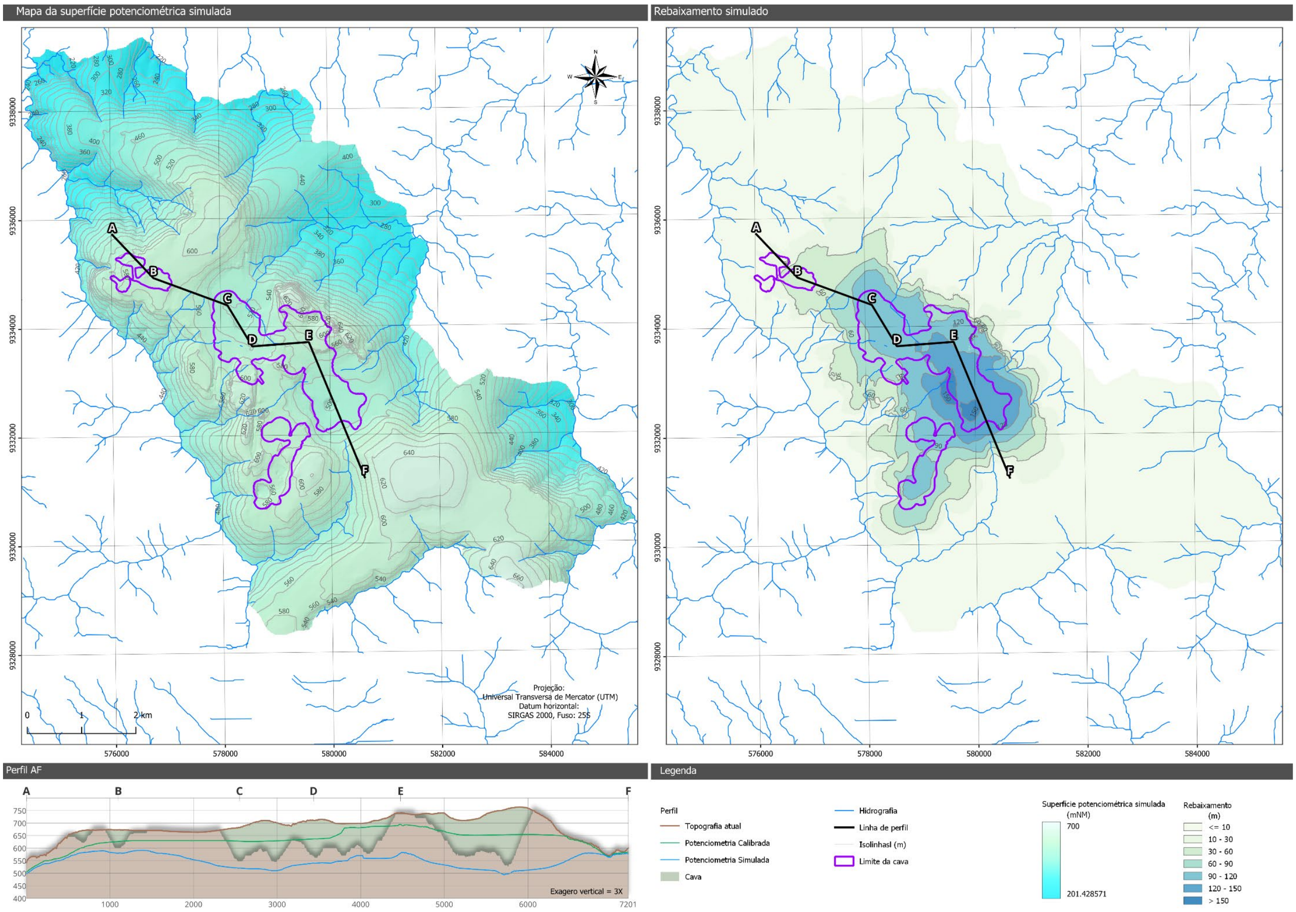

Figure 13-15 - Maximum drawdown equipotentials at N1 mine.

13.5.2. N2 Hydrogeological Model

A numerical groundwater flow model was employed to simulate the drawdown of the water table in the N2 area. The simulation estimated an outflow rate of 164 m³/h. A total of 16 monitoring instruments were used for model calibration, resulting in a normalized root mean square error (nRMS) of 2,32%, which is considered acceptable for regional scale hydrogeological modeling.

The groundwater level surface generated at the end of the drawdown simulation is presented in Figure 13-16. These hydrogeological results were subsequently incorporated as boundary conditions for the slope stability analyses described in Section 13.4.4, consistent with standard geotechnical and hydrogeological engineering practices.

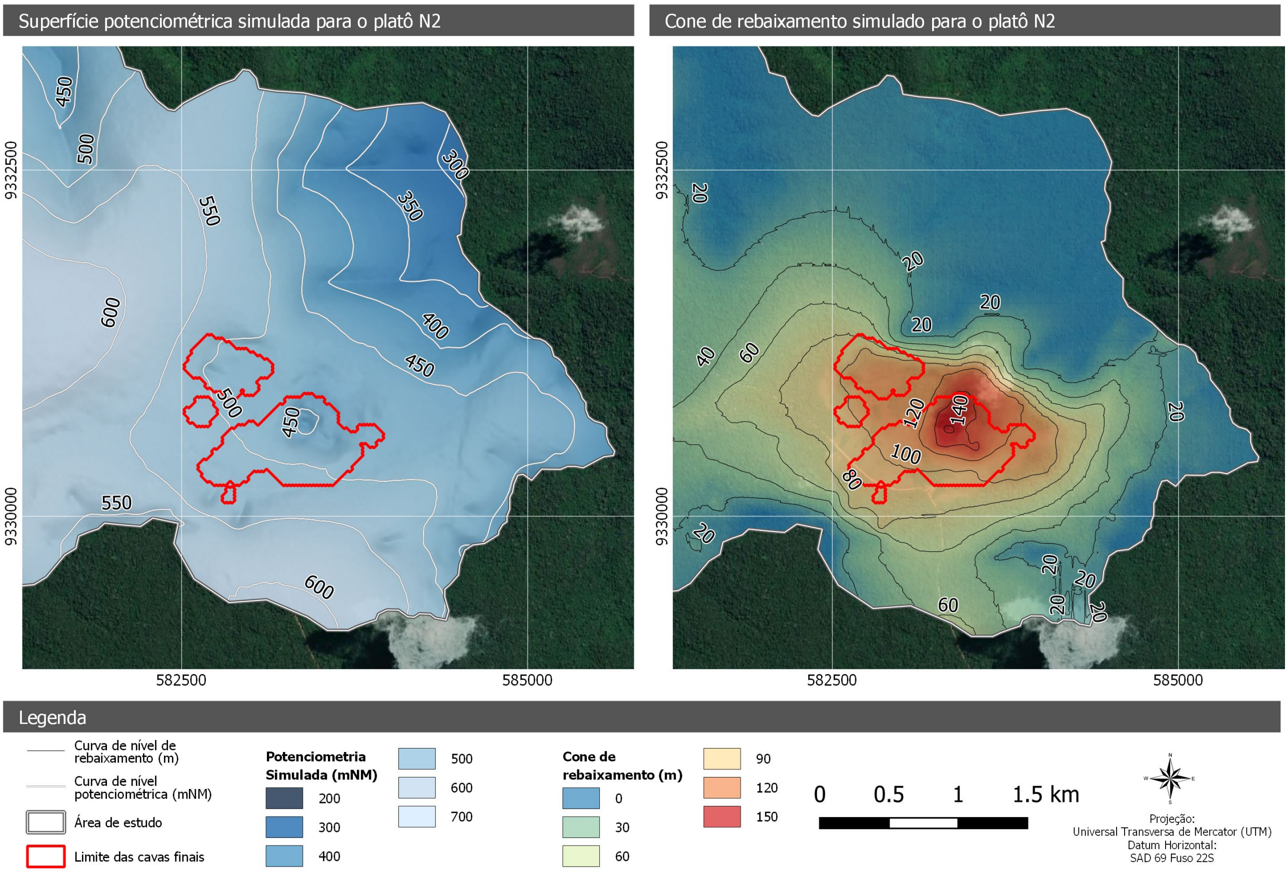

Figure 13-16 - Maximum drawdown equipotentials at N2 mine.

13.5.3. N3 Hydrogeological Models

A numerical groundwater flow model was employed to simulate the drawdown of the water table in the N3 area. The simulation estimated an outflow rate of 294 m³/h. A total of 63 monitoring instruments were used for model calibration, resulting in a normalized root mean square error (nRMS) of 3,6%, which is considered acceptable for regional scale hydrogeological modeling.

The ground water level surface generated at the end of the drawdown simulation is presented in Figure 13-17. Figures 13-18 through 13-19 illustrate the principal vertical sections, demonstrating that the simulated ground water level drawdown meets the dewatering requirements for the planned mining horizon under the modeled final pit configuration. These hydrogeological results were subsequently incorporated as boundary conditions for the slope stability analyses described in Section 13.4.4, consistent with standard geotechnical and hydrogeological engineering practices.

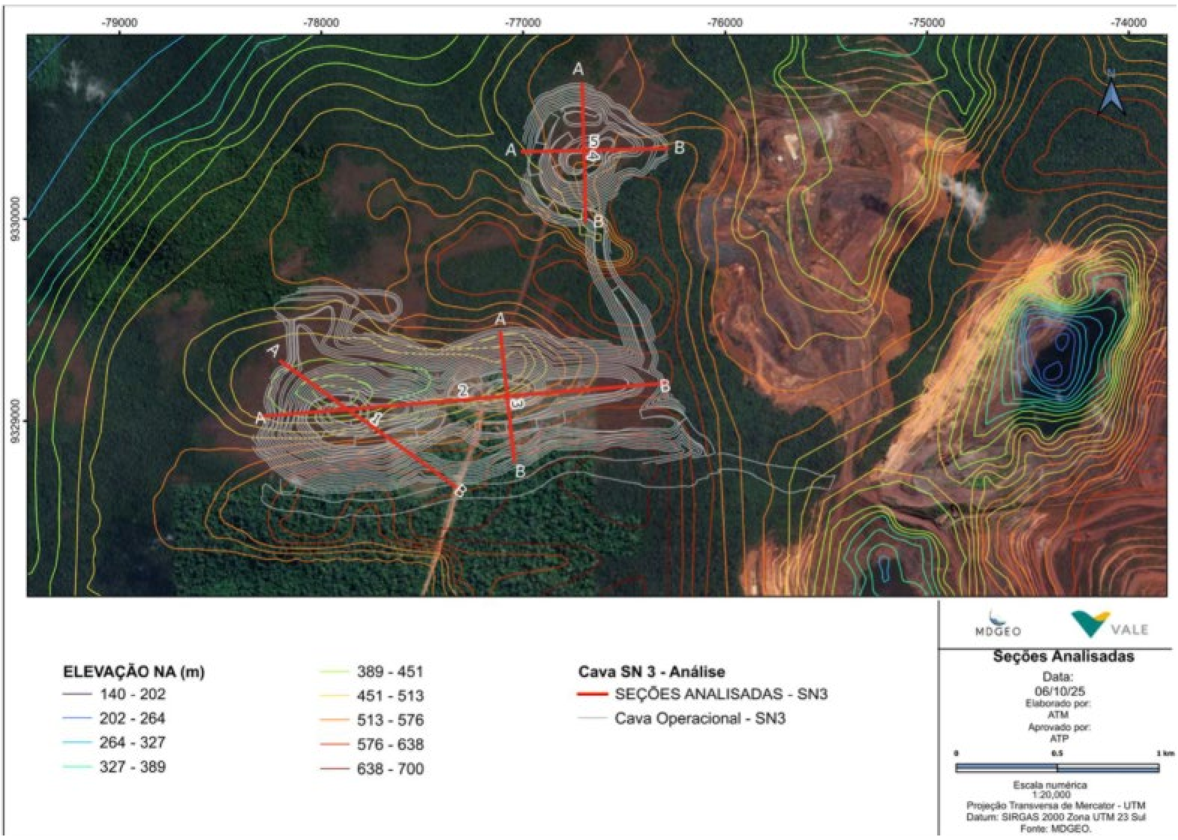

Figure 13-17 - Maximum drawdown equipotentials at N3 mine.

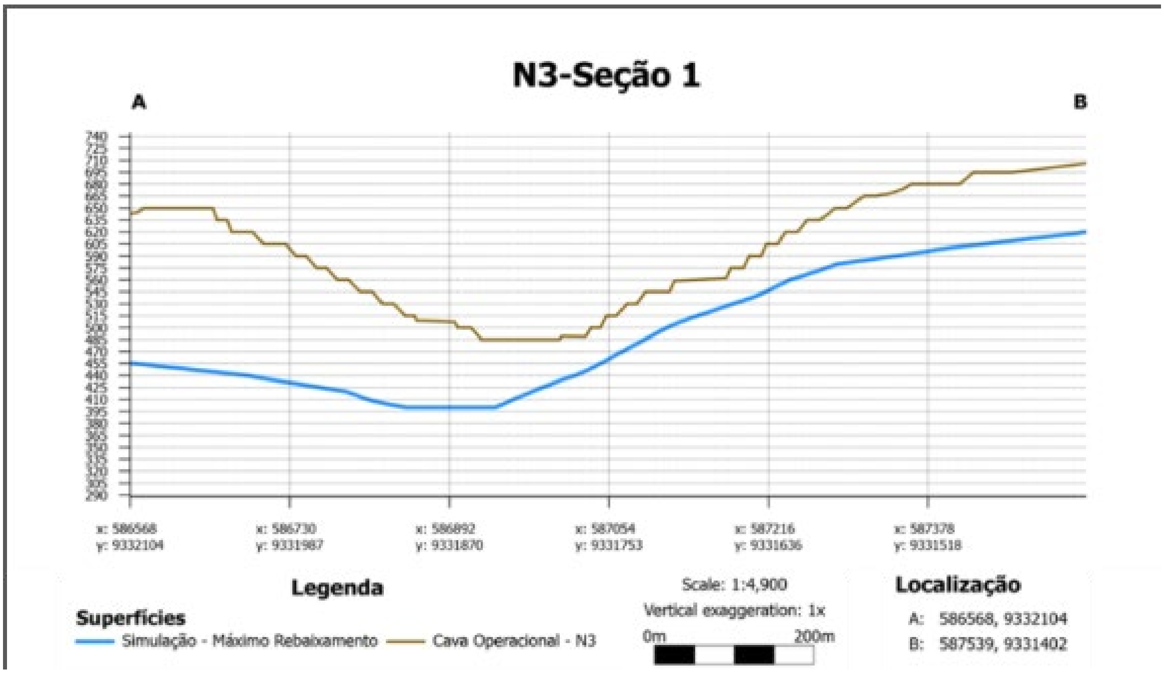

Figure 13-18 - Crosssection 1, intersecting at the bottom of the N3 Mine pit.

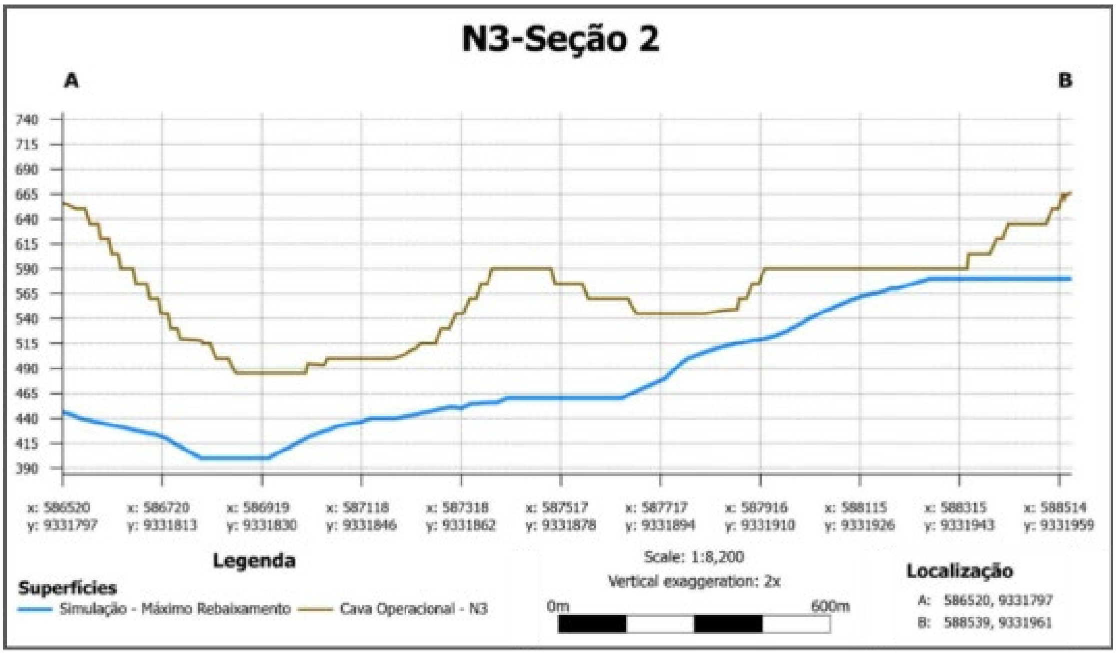

Figure 13-19 - Crosssection 2, intersecting at the bottom of the N3 Mine pit.

13.5.4. N4 Hydrogeological Model

A numerical groundwater flow model was employed to simulate the drawdown of the water table in the N4 area. The simulation estimated an outflow rate of 2,900 m³/h. A total of 63 monitoring instruments were used for model calibration, resulting in a normalized root mean square error (nRMS) of 3,60%, which is considered acceptable for regional scale hydrogeological modeling.

The groundwater level surface generated at the end of the drawdown simulation is presented in Figure 13-20. Figures 13-21 through 13-23 illustrate the principal vertical sections, demonstrating that the simulated groundwater level drawdown meets the dewatering requirements for the planned mining horizon under the modeled final pit configuration. These hydrogeological results were subsequently incorporated as boundary conditions for the slope stability analyses described in Section 13.4.4, consistent with standard geotechnical and hydrogeological engineering practices.

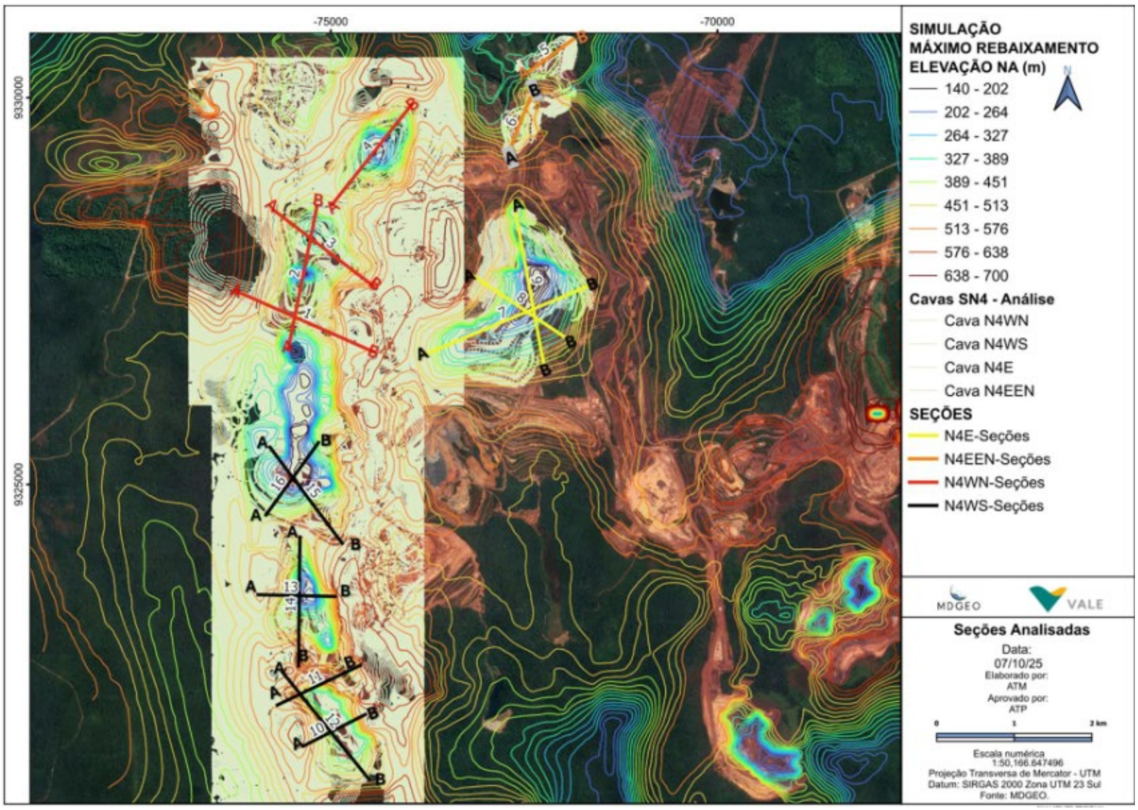

Figure 13-20 - Equipotential surfaces correspond to maximum drawdown conditions at the N4 Mine.

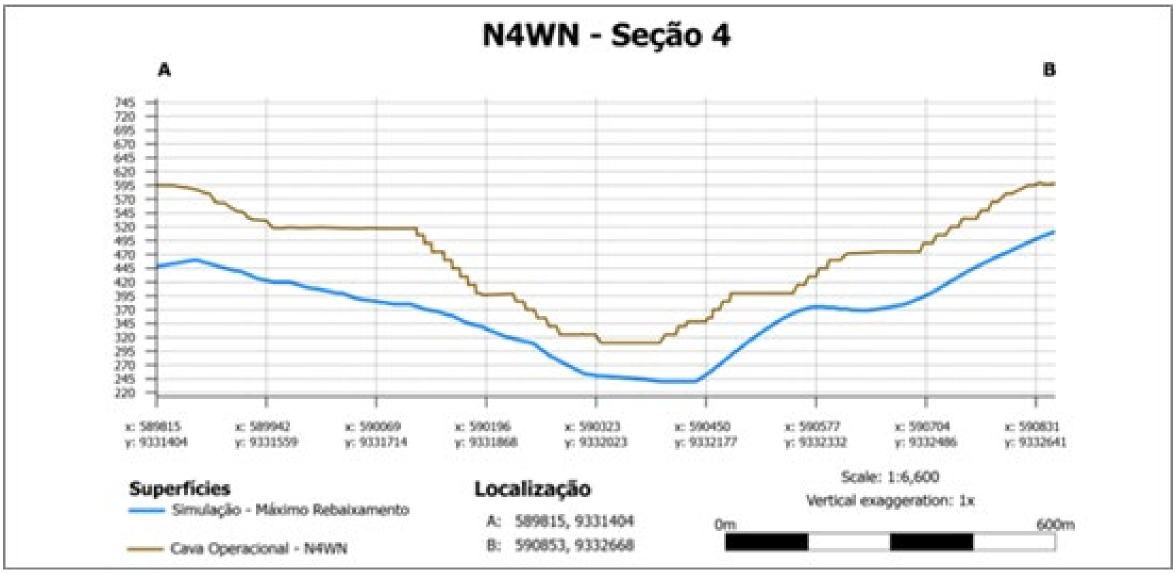

Figure 13-21 - Crosssection 4, intersecting at the bottom of the N4WN Mine pit.

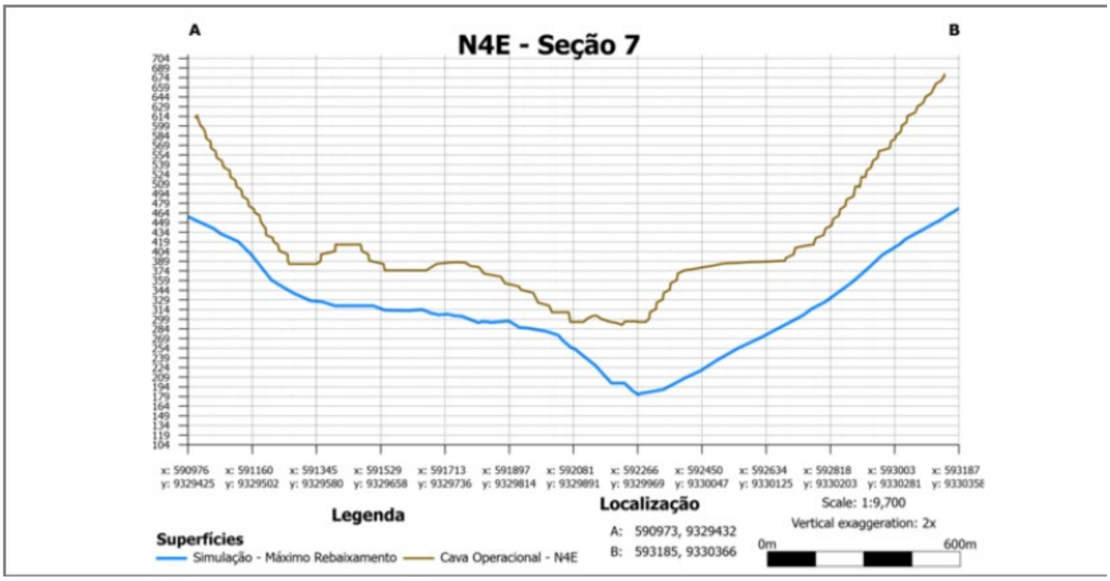

Figure 13-22 - Crosssection 7, intersecting at the bottom of the N4E Mine pit.

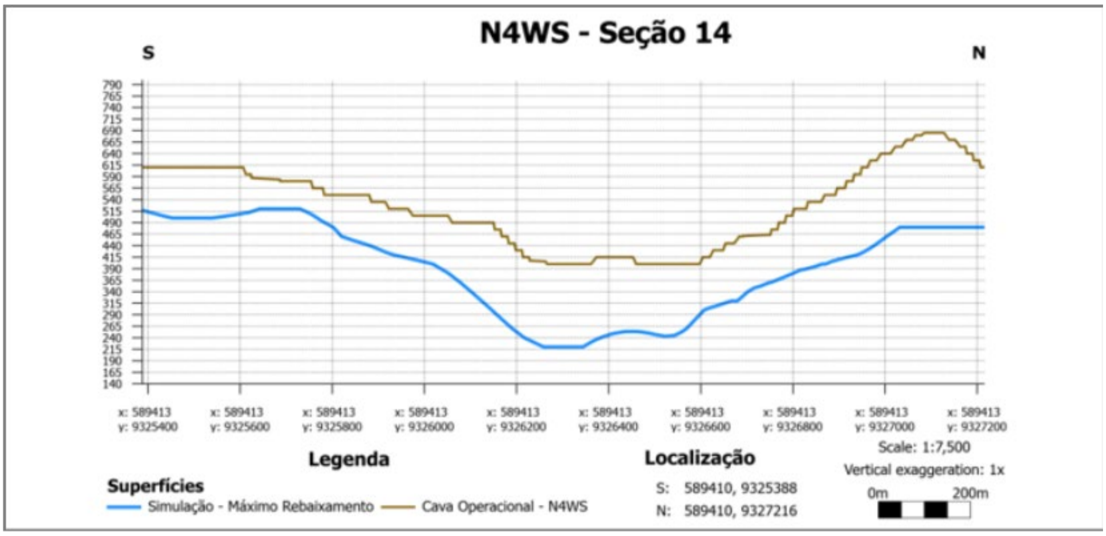

Figure 13-23 - Crosssection 14, intersecting at the bottom of the N4WS Mine pit.

13.5.5. N5 Hydrogeological Model

A numerical groundwater flow model was employed to simulate the drawdown of the water table in the N5 area. The simulation estimated an outflow rate of 726 m³/h. A total of 35 monitoring instruments were used for model calibration, resulting in a normalized root mean square error (nRMS) of 8.42%.

Figure 13-24 presents the equipotential contours, at 20meter intervals, generated under maximum dewatering conditions, as well as the inferred groundwater flow directions. The corresponding cross sections, illustrated in Figures 13-25 through 13-27, refer to the locations indicated on the map and depict the hydraulic responses along the modeled sections. These hydraulic surfaces were subsequently incorporated as input conditions for the slope stability analyses described in Section 13.4.4.

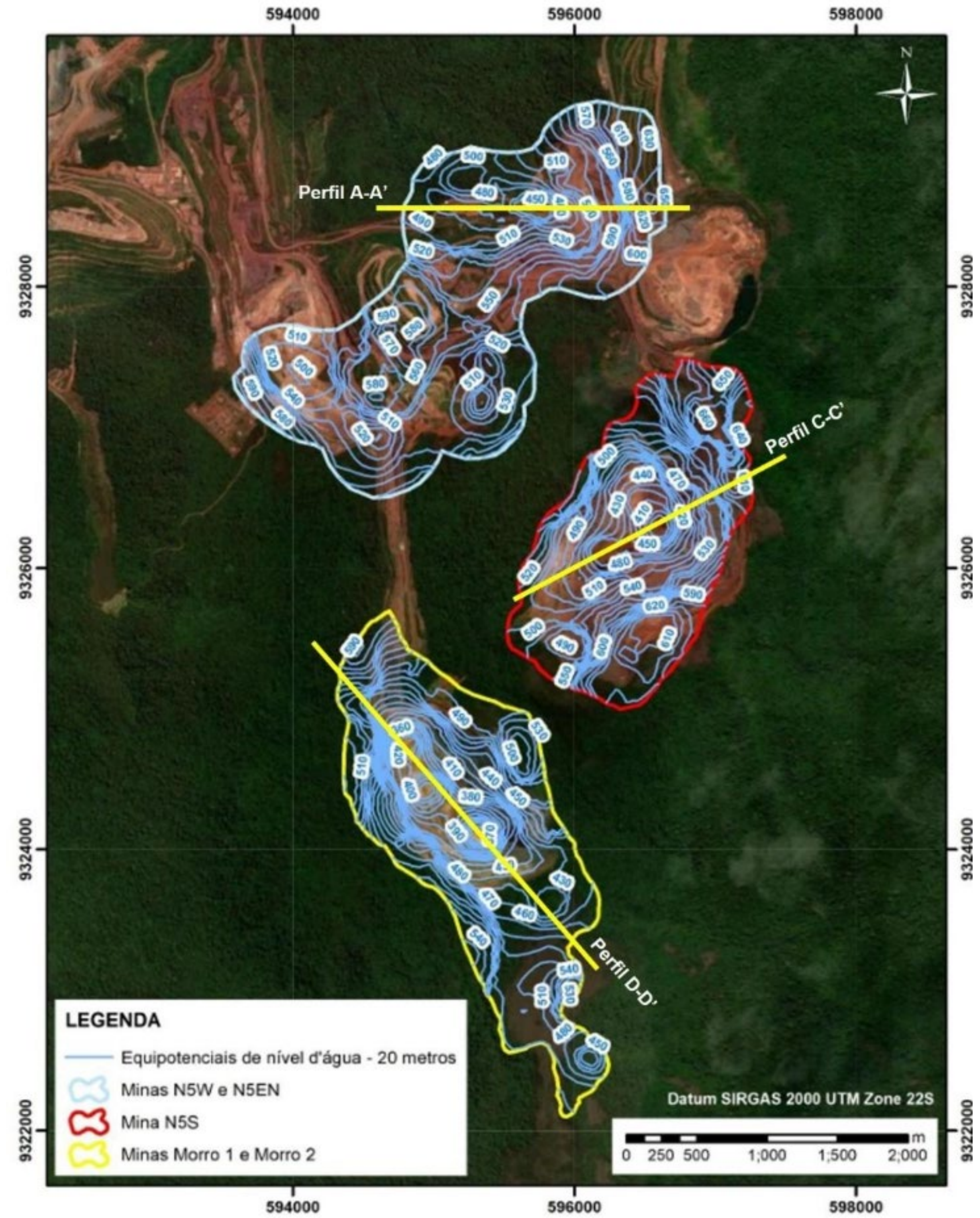

Figure 13-24 - Equipotential surfaces corresponding to maximum drawdown conditions at the N5 Mine.

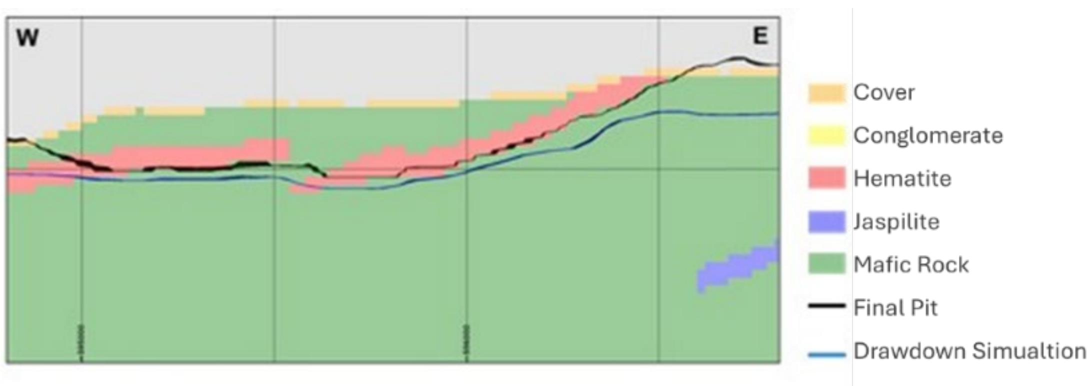

Figure 13-25 - A–A' crosssection (west–east orientation) intersecting at the bottom of the N5EN Mine pit.

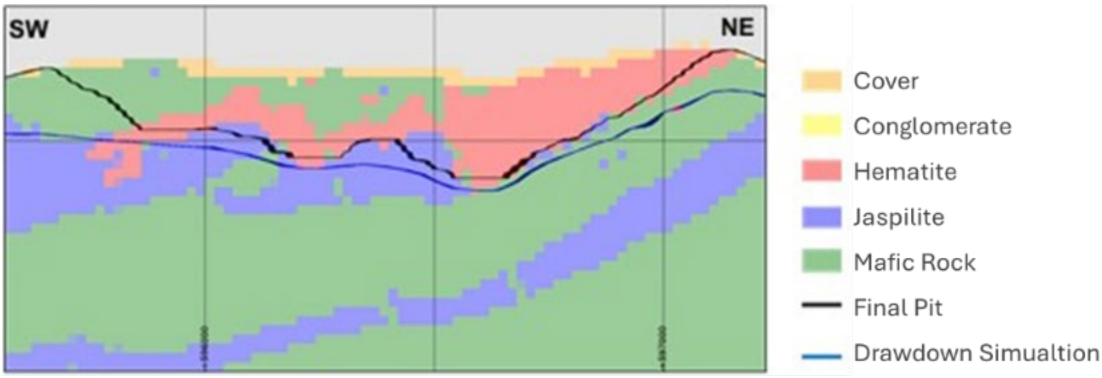

Figure 13-26 - C–C' crosssection (southwest–northeast orientation) intersecting the bottom of the N5S Mine pit.

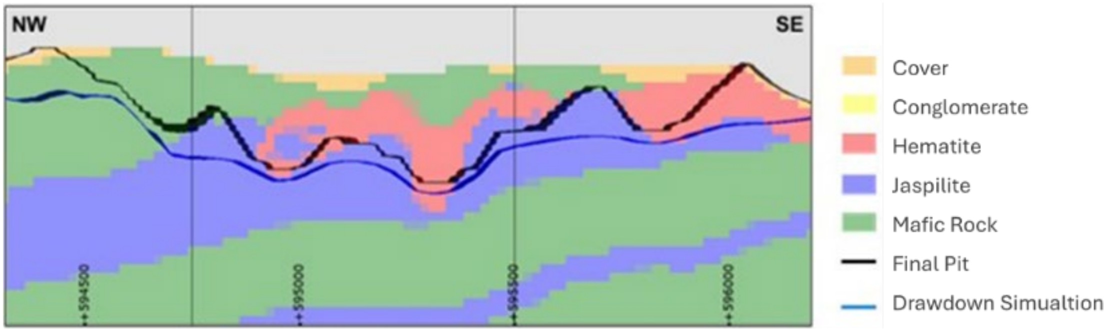

Figure 13-27 - D–D' crosssection (northwest–southeast orientation) intersects at the bottom of the Morro 1 Mine pit.

13.6. Life of mine plan

The life of mine production plan is shown in Figure 13-28. The production from 2026 through 2048 will include approximately 1.5 Bt with average grades of 65 % Fe, 2.1 %SiO2, 1.7 % Al2O3, 0.047 %P, 2.4 % LOI. Stripping ratio for the LOM is 1.4.

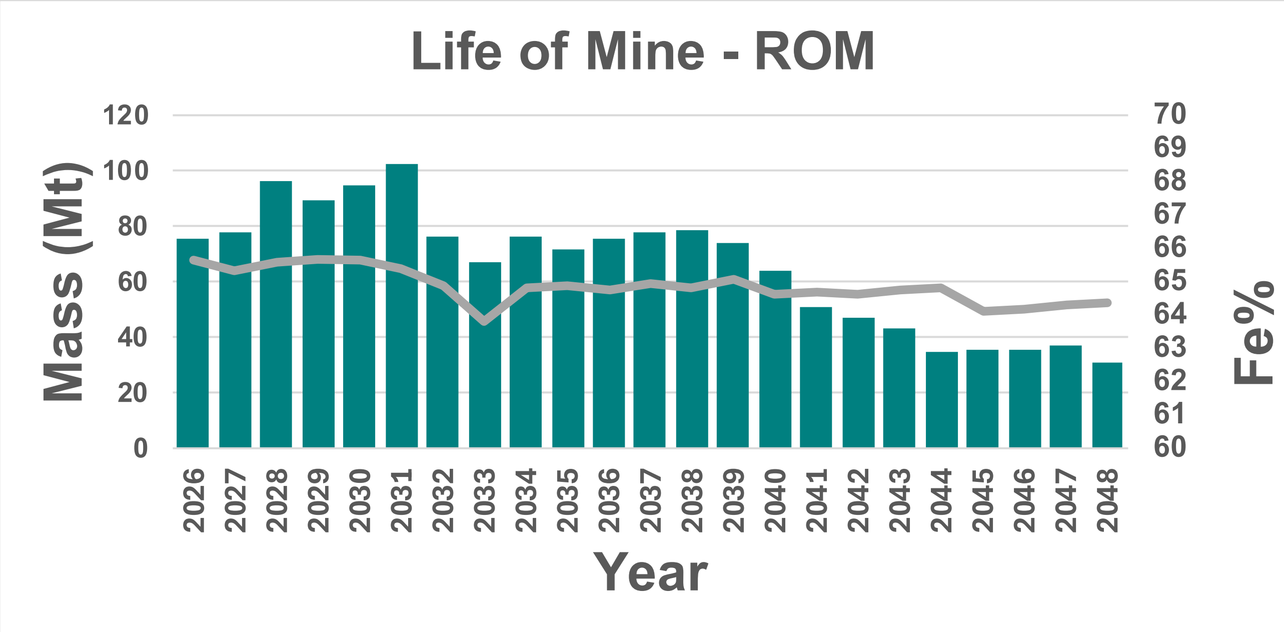

Figure 13-28 - Life of Mine vs Fe grades

13.7. Infrastructure

13.7.1. Workshops

In the Serra Norte area, there is a complete Maintenance Workshop (three units located in the N5, N4W, and Central mines) equipped with bays for large mobile equipment, as well as workshops for machining, maintenance of diesel generators, electrical, electronics; warehouse, and tooling. It is build of a metallic structure and there is an office and a locker room attached to the shed, made of masonry. In areas adjacent to the General Maintenance Workshop shed, there are the Lube Bay, the Vehicle Washing Bay, the Tire Shop, the Heavy and Light Vehicle Refueling Station, the Parking Lot, and the patio.

13.7.2. Laboratory

All quality control of the ore is carried out using the structures of the Carajás Iron Mine Laboratory, where physical tests and assays of the entire production chain are carried out.

13.7.3. Offices

Masonry offices are grouped in the administrative areas of Vale S.A. and its contractors. It is made up of offices for senior management, management, coordination, meetings, technicians, files, reception, and restrooms, which serve all administrative personnel.

13.7.4. Warehouses

The warehouse, built partly of masonry and partly of metallic structure, is surrounded by an outdoor area surrounded by gates. The covered area includes service desks, offices, and restrooms, and the external area for storage of materials currently includes annexes for the storage of lubricants, fuels, and tires. The fuel storage is equipped with horizontal tanks for filtered diesel, with drainage basins and a water-oil separation system.

13.7.5. Meal room

There is a canteen that serves all staff, both in-house and outsourced, and provides lunch, dinner, and snacks. Its operation is outsourced by Vale as in other operating units of the company.

13.7.6. Clinic

The clinic is installed in masonry construction and is intended to house a small office for first aid care and a restroom. The clinic is equipped for first aid care, and the more serious cases are sent to the existing hospital in the urban center, in which case an ambulance is available, parked next to it with a driver on permanent standby.

13.7.7. Firefighting system

The firefighting water is stored in concrete tanks, divided into two compartments that allow the tank to be cleaned, keeping half of the fire water reserve available for use.

13.7.8. Housing

Part of the company's staff resides in the urban center of Carajás and part in the city of Parauapebas, with no need to build new accommodation in the industrial area.

13.7.9. Mine equipment

The peak requirement for primary and auxiliary mining equipment is provided in Table 13-9.

Table 13-9 - Mining equipment

Equipment	Units
Loading	30
Hauling	116
Drilling	17
Auxiliary Equipment	97

13.7.10. Workforce

The workforce of Serra Norte consists of company personnel and contractors. The Vale personnel and the lists of main contractors for mining operations are presented in Table 13-10 and Table 13-11, respectively. The number of Vale employees required for the mining operations is not expected to change significantly for the foreseeable future. The number of contractors varies month by month depending on labor requirements at the mine site.

Production is carried out by the company mine personnel, while contractors carry out the auxiliary services. Administrative staff works on 5x2 roster in 8 hours shift, and operation and maintenance either on a 3x3 roster in 11h shift or 4x2 roster in 10h shift.

Table 13-10 - Vale's Workforce

Serra Norte	Manager	Supervisor	Coordinator	Staff and Technical Specialist	Total
Mine	18	103	14	3,536	3,671
Plant	11	108	13	2,152	2,284
Others	9	23	13	764	809
Total	38	234	38	6,452	6,764

Table 13-11 - Contractor's Workforce

Serra Norte (Contractors)	Permanent	Project	Part time	Total
Mine	442	178	75	695
Plant	591	51	23	665
Others	1,347	1,714	214	3,275
Total	2,380	1,943	249	4,635

14. Processing and recovery methods

14.1. Summary

There are three processing plants on Serra Norte for ROM processing: Plant I, Plant II, and Plant III. Together, the three facilities can produce about 130 Mtpa of iron ore products, including lump ore, sinter feed, and pellet feed. In addition, there is a plant for recovery of the tailing from Gelado Dam.

Plant I has an installed production capacity of 85 Mtpa. Ore feeds the plant from the semi-mobile crushers 2, 3, 4, 6, 7 and the primary crusher. Part of the ore is treated at natural moisture and part wet to produce lump ore, sinter feed, and pellet feed products, with a mass recovery between 93% to 97%. Modifications are on course to allow Plant I to process 100% of the ore at natural moisture by 2026.

Plant II has an installed production capacity of 33,4 Mtpa. All throughput is treated at natural moisture, and the plant receives ROM from the semi-mobile crusher 5 and alternatively from the semi-mobile crusher 2.

Plant III has an installed production capacity of 20,4 Mtpa. Ore is treated at natural moisture through a screening arrangement to produce fines, with an average mass recovery of 100%.

The plant for recovery tailings from Gelado Dam has installed production capacity of 9,5 Mta through wet processing,

Products are shipped by railway to São Luiz port. The pellet feed product feeds VALE's pelletizing plant located in São Luiz city.

The Serra Norte average recovery, utilization, and capacity are shown in Table 14-1.

Table 14-1 - Plant Recoveries, Utilization, and Capacities

Plant	Metallurgical Recovery (%)*	Physical Utilization (%)*	Nominal Capacity (Mta)
Plant 1	96.2	89.6	85.0
Plant 2	100	89.3	33.4
Plant 3	100	74.9	20.4

*average of the last five year

14.2. Plant I

Plant Plant I is the largest processing facility in Carajás, with a production capacity of 85 Mta. It consists of crushing, screening, classification and magnetic concentration, and produces Lump ore, Sinter Feed and Pellet Feed products.

The primary crushing is based on a fixed crusher and five semi-mobile crushers, called BSM 2, 3, 4, 6 ,7 and alternatively, BSM 5.

After primary crushing, the material is directed to the primary screening. The oversize (+ 70 mm) is directed to the secondary crushing. The product of secondary crusher returns to primary screening, closing the circuit. The undersize (-70 mm) is sent to the secondary screening, with 17 lines, 11 operating in wet, and 6 in natural moisture.

In the natural moisture lines the undersize (-19 mm) is considered the Sinter Feed product, and the oversize (+19 mm) is directed to the tertiary crusher. The product of the tertiary crusher is directed to the tertiary screening. The oversize returns to the tertiary crushing and the undersize is considered Sinter Feed product.

In the wet screening, the material retained in the first deck (+31.5 mm) is sent to the same tertiary crusher previously described. The material between 31.5 mm and 19 mm is considered the Lump ore product, and the material below 19 mm is directed to the quaternary screening. At the quaternary screening, the fraction above 1 mm is considered Sinter Feed product. The fraction below 1 mm is targeted for classification using spiral classifiers.

The underflow of spiral classifiers (-1 mm + 0.15 mm) is considered Sinter Feed, and the overflow is directed to the magnetic concentration. There is the option of directing overflow of the classification to desliming stage. The concentrate of the magnetic concentration or underflow of the desliming, after a thickening stage, is directed to disc filtering and press filters and the Pellet Feed product is generated. The tailing (reject and overflow of desliming) are pumped to the dam after thickening stage. Figure 14-1 shows Plant I flowsheet. The current mass recovery of Plant I is between 93% to 97%.

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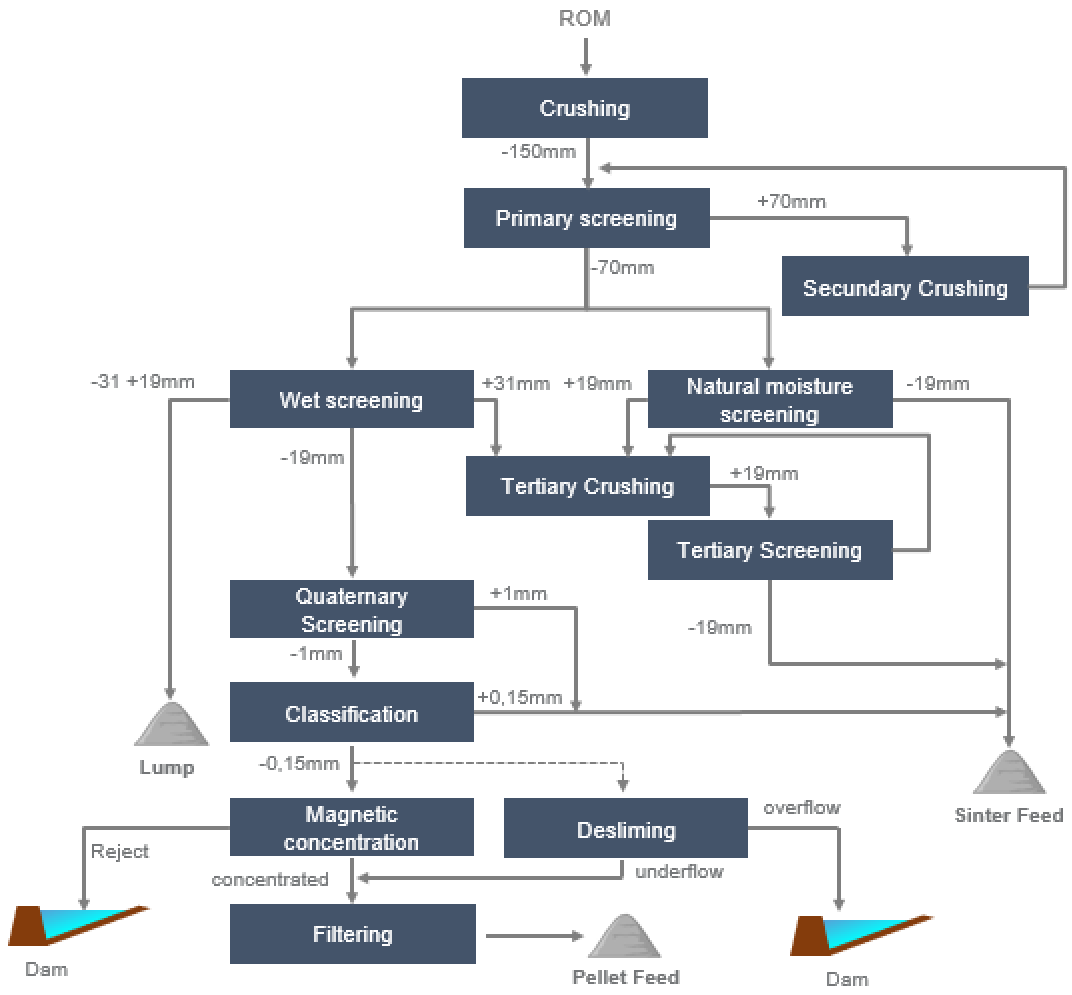


Figure 14-1 - Plant I Flowsheet

14.3. **Plant II**

The Plant II has a capacity of 33,4 Mtpa and consists of crushing and screening operations to produce Sinter Feed product with 100% mass recovery.

Plant II is fed through the semi mobile crusher 5 (BSM 5) and alternatively, BSM 2.

After primary crushing, the ore is directed to the secondary screening and the material greater than 90mm (oversize) is directed to the secondary crusher. The product of the secondary crusher and the undersize of the secondary screening is directed to the homogenization yard through four long distance conveyor belts. After the homogenization the ROM is directed to the tertiary screening. The oversize (+19 mm) is directed to the tertiary crusher in which the product of the crushing returns to the tertiary screening. The undersize is considered Sinter Feed product. Plant II flowsheet is shown in Figure 14-2.

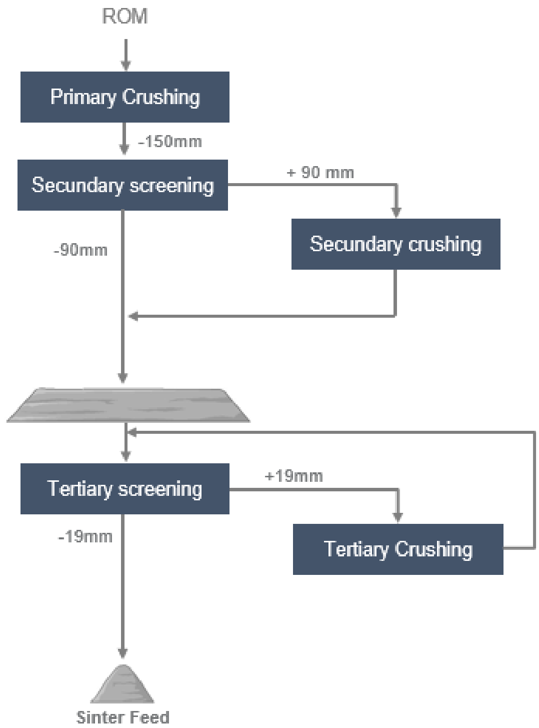


Figure 14-2 - Plant II Flowsheet

14.4. **Plant III**

Plant III consists of two plants, called Re-Screening 2 and Re-Screening 6. The joint production capacity of these two plants is 20,4 Mtpa. The material less than 19 mm is considered Sinter Feed product, and the material greater than 19 mm feeds Plant of recrushing consisting of stage of crushing and screening. In the plant of recrushing the material below 19 mm is considered Sinter feed and the material > 19 mm return to secondary screening. Figure 14-3 shows Plant III flowsheet, both plants have the same flowchart.

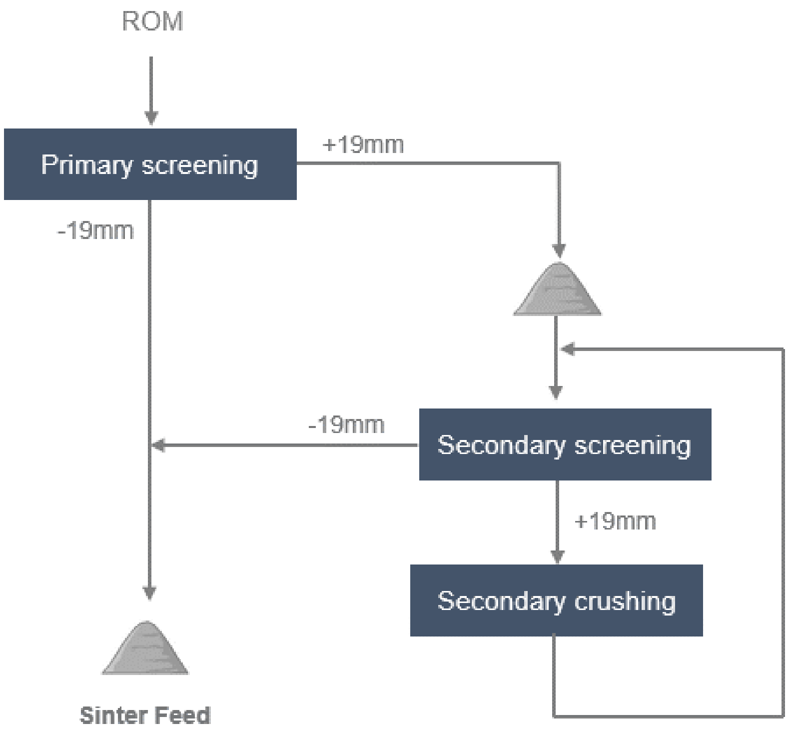


Figure 14-3 - Plant III Flowsheet

14.5. Plant for recovery Gelado tailings dam

The mining of the dam is carried out through dredging that directs the material to the protection screening where the undersize from the screening is sent to the thickener. After the thickener, there is a pipeline that sends the material to the magnetic concentration of the plant I. The concentrate is sent to disc and press filters and the reject returned to a specific point in the dam. This project will reach full capacity only after the conversion of plant 1 to natural moisture processing, because the magnetic concentration and filtration circuit is being used to process the fines from plant 1. Figure 14-34 shows the flowsheet.

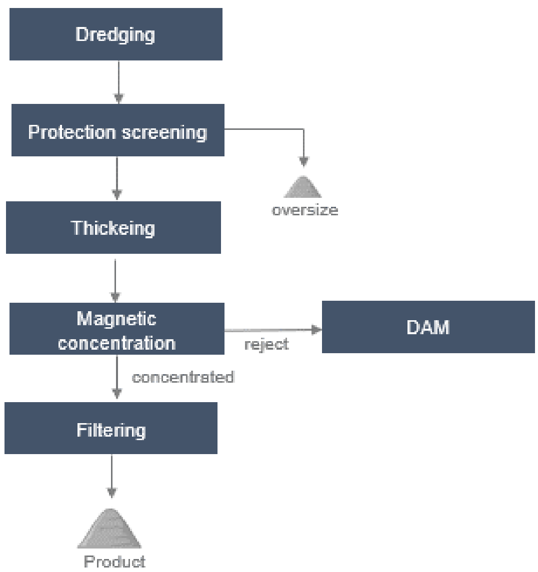


Figure 14-4 – Gelado Dam Plant

14.6. Equipment

The main process equipment is summarized in Table 14-2.

Table 14-2 - Equipment list of Plants I, II and III

Plant	Unit operation	Quantity	Type of Equipment	Dimensions/Model
BSM 2	Primary Crushing	1	Jaw crusher	DB18-14
BSM 3	Primary Crushing	1	Jaw crusher	C160
BSM 4	Primary Crushing	1	Jaw crusher	CJ815
BSM 5	Primary Crushing	1	Jaw crusher	CJ 815
BSM 6	Primary Crushing	1	Jaw crusher	CJ815
BSM 7	Primary Crushing	1	Jaw crusher	CJ815
Plant I	Primary Crushing	1	Gyratory crusher	48" x 74"
Plant I	Primary Screening	8	Vibrating screen	8' x 21'
Plant I	Secondary Crushing	4	Cone crusher	17" x 84" (3) CS660 (1)
Plant I	Secondary Screening	17	Vibrating screen	8' x 21'
Plant I	Tertiary Screening	6	Vibrating screen	10 x 20 (2), 8 x 20 (1) e 8 x 21 (3)
Plant I	Tertiary Crushing	6	Cone crusher	HP500
Plant I	classification	6	Spiral classifier -	84"
Plant I	Magnetic concentrator	8	WHIMS	GX300
Plant I	Desliming rougher	100	Hydrocyclone	10"
Plant I	Desliming scavenger	500	Hydrocyclone	4"
Plant I	Tailing Thickening	2	Thickener	Diameter: 80 m
Plant I	Concentrate Thickening	3	Thickener	Diameter: 26 m (2) Diameter: 34 (1)
Plant I	Filter	8	Disc Filter	Area 100 m^2
Plant I	Filter	12	Press Filter	10 (132 m^2)
Plant II	Secondary Screening	1	Roller screen	RS8R300-90
Plant II	Secondary Crushing	1	Cone crusher	CH890

14.7. Logistics

Serra Norte mine is integrated with a mine-railroad-port system.

The EFC ("Estrada de Ferro Carajás") railroad connects the productive complexes of Serra Norte (Mina de Carajás), Serra Sul (Mina do S11D) and Serra Leste, all located in the Brazilian state of Pará, to the Ponta da Madeira port complex, in São Luís, State of Maranhão. The trains are loaded at Carajás terminal or Serra Sul terminal. The unloading process takes place at the Ponta da Madeira terminal.

Connected to EFC, the Ponta da Madeira Maritime Terminal (TMPM) is located near the city of São Luís, in the State of Maranhão. The port configuration enables operation of high-capacity vessels, such as Valemax.

15. Infrastructure

15.1. Introduction

A surface plan showing the mine site infrastructure is provided in Figure 15-1. The in-situ and operating infrastructure at Serra Norte includes the following:

- Three open-pit mines which are accessed by approximately 10 main ramps;
- Surface ore stockpiles and waste rock dumps;
- Three processing plants with a total of 130Mtpa of crusher feed;
- One TSF;
- Main site power supply;
- Site access roads;
- Mine shops, offices, warehouse facilities.

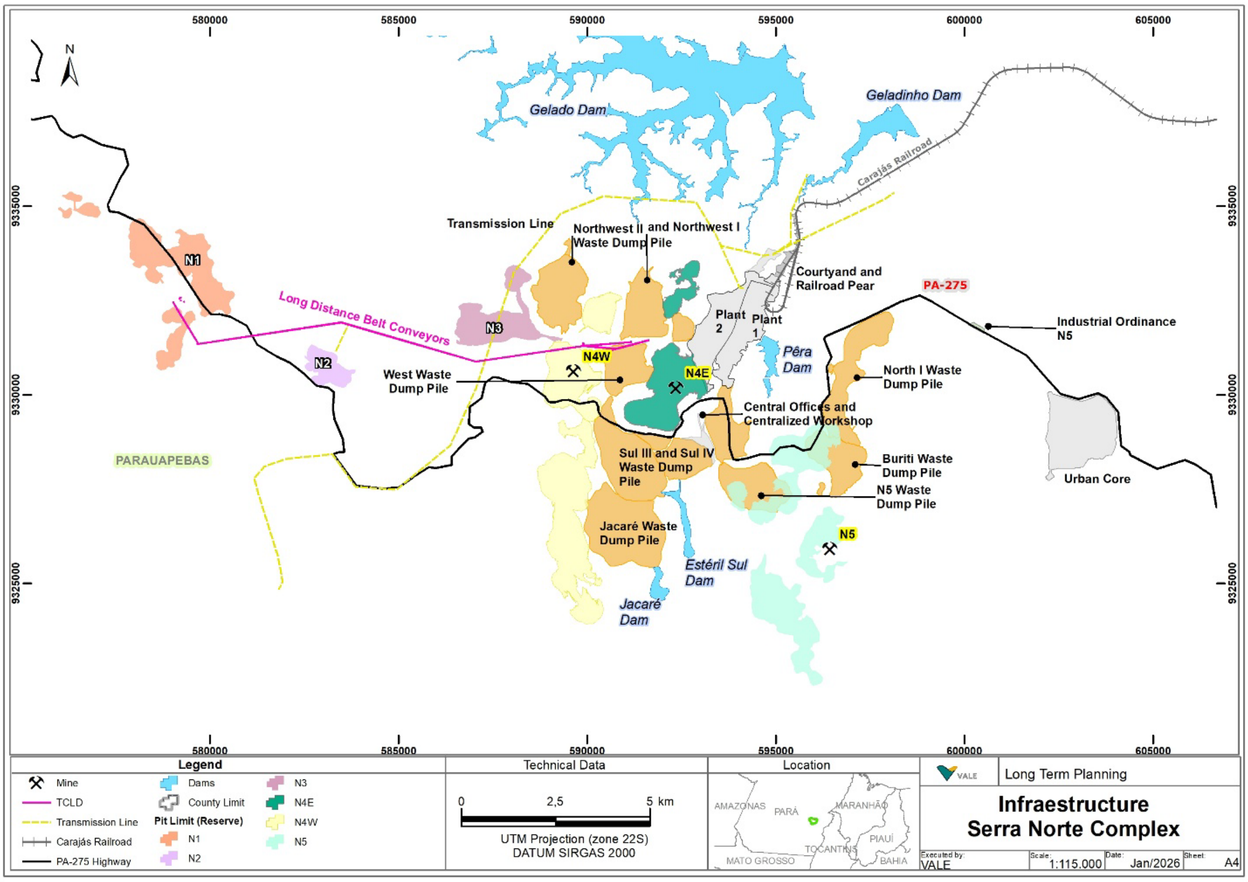


Figure 15-1 – Infrastructure map.

15.2. Site access

Provided on chapter 3.

15.3. Power supply

The Serra Norte operational complex (Carajás) fully provided by Sistema Interconectado Nacional (SIN) and is connected by 230kV via two transmission lines to the Carajás Substation owned by Eletronorte (Eletrobrás).

The internal distribution system is carried out through Vale´s 34.5KV networks. Consumption in 2024 was about 494,563 MWh, 70.9% of which fed the mineral processing plants and dredges in Gelado tailings dam, 25.9% was distributed to the N4/N5 mines and the remaining 3.2% was consumed by the Urban Center and other support structures.

15.4. Water supply

Currently, in the N4E, N4W, and N5 mines there are 54 downgradient wells in operation conditions with flow capacity of around 4,000 m³/h, with 10,000 m³/h licensed by the state environment agency – SEMAS-PA. The main purpose of pumping is to lower the water levels of the mines, 90% of the pumped volume is released into the drainages around the mines and the other 10% is used in the industrial process, human supply, and dust control. Industrial water collection and supply

Water consumption is estimated at 0.0374m³/ton of ROM with a reuse rate of 91,78%. The water catchment sites come from the Gelado and Pera dams.

15.4.1. Drinking water supply system

All drinking water used to supply the mines comes from mine downgradient wells. The water, after treatment at the Water Treatment Plant (ETA), is sent to the consumption units through pumping and a pressure network, stored in reservoirs which are periodically cleaned.

The water from the downgradient wells is used to wash floors and equipment and for human consumption, used in bathrooms and canteens. Vale also uses water in its industrial process, and this water is collected directly from the Igarapé Gelado and Pêra Dams.

15.5. Site buildings

Site facilities are distributed around the mines at Serra Norte. Facilities include offices, warehousing and storage areas, maintenance shops, fuel station, processing plants, canteen and locker room.

15.6. Mine waste and tailing management

15.6.1. Introduction

The operation and the development of projects for disposal of waste dumps and tailings follow the best national and international practices. In this report, the waste rock dumps will be represented by the acronym “PDE”.

15.6.2. Tailings management

Plant 1 generates 3 to 4Mton of tailings per year at Serra Norte. The Tailings pass through a thickener before pumping to TSF to facilitate reuse of the process water.

15.6.3. Tailings storage facility

Gelado dam is located at Serra Norte Mine, Carajás Complex, in the town of Parauapebas (PA). On the left bank of the reservoir, there is also the saddle dike 06. Gelado dam was built to provide process water for the Iron Ore Processing Plant, to contain tailings from the mine processing plants of N4 and N5, and to contain sediment from waste rock dumps.

Gelado dam was implemented in three stages. Based on the Periodic Dam Safety Review (RPSB) conducted in Nov/2025, the total reservoir volume is 163.40 Mm³.

For the geotechnical monitoring of the dams, field inspections are carried out every two weeks, automatic monitoring with piezometers, water level gauge, prisms, surface marks, inclinometer, orbital radar and CCTV cameras are used.

15.6.4. Waste dumps

15.6.4.1. Waste dumps in operation

The Waste rock from the open pit mining operations is deposited on the locations at the mine site:

Table 15-1- Waste Dump in operation (Updated 2025/2026 RAL)

Waste Dump	Volume Mm³
PDE JACARÉ	136.31
PDE N5W	45.24
PDE NOROESTE 1	131.03
PDE NOROESTE 2	76.80
PDE SUL 3	83.12

The PDE N4EN, PDE N5E and PDE Norte I (CCI) waste dumps are in operation, however, as they are nearing their maximum capacity, they have no material impact on reserves.

15.6.4.2. Waste dumps in design

The structures in design are detailed as follows:

PDE Jacaré Expansão is located at Serra Norte Mine, in the Carajás Complex – city of Paraupebas, in the State of Pará, Brazil. The pile is going to be formed of waste rock from the N4WS pit, with a disposal volume of 93.0 Mm³ in a 250 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

PDE Sudeste N5 is located at Serra Norte Mine, and it is going to contribute to the operational continuity of Carajás Complex, with waste rock disposal from the M1, M2, N5EN, and N5W pits. Its capacity of disposal is 120.9 Mm³ in a 371.7 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

PDE Sudoeste N4W is located at Serra Norte Mine, and it is going to contribute to the operational continuity of Carajás Complex, with waste rock disposal from the N3, and N4WN pits. Its capacity of disposal is 122.7 Mm³ in a 285.2 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

PDE N1 (SN-PDE-25) is located at Serra Norte Mine, and it is going to contribute to the operational continuity of Carajás Complex, with waste rock disposal from the N1 pit. Its capacity of disposal is 128.4 Mm³ in a 209.8 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

PDE N2 (SN-PDE-26) is located at Serra Norte Mine, and it is going to contribute to the operational continuity of Carajás Complex, with waste rock disposal from the N1 pit. Its capacity of disposal is 32.4 Mm³ in a 60.4 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

PDE Nova 1 (SN-PDE-09) is located at Serra Norte Mine, and it is going to contribute to the operational continuity of Carajás Complex, with waste rock disposal from the N1 N5EN, N5W pits, with a disposal volume of 74.9 Mm³ in a 176.4 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

PDE Nova 1 (SN-PDE-28) is located at Serra Norte Mine, and it is going to contribute to the operational continuity of Carajás Complex, with waste rock disposal from the N5EN, N5W pits, with a disposal volume of 85.5 Mm³ in a 164.8 hectares area. The presented design and correspondent quantities are based on a technical report developed in 2025.

It is important to highlight that a volume reduction factor is applied to the volume report according to the design phase they are in. Piles in Conceptual Design Phase have a 13% volume reduction factor and piles in Feasibility Design Phase have a 30% volume reduction factor.

Other projects under development are presented in Table 15-2.

Table 15-2 - Waste Dump under development

Waste Dump	Volume Mm³
PDE Jacaré Expansão	93.0
PDE N1 (SN-PDE-25) ~~- Fase 02 (Eng.)~~	128.4
PDE N2 (SN-PDE-26)	32.4
PDE Sudoeste N4W	122.7
PDE Sudeste N5	120.9
PDE Nova 1 – SN-PDE-09	74.9
PDE Nova 1 – SN-PDE-28	85.5

16. Market studies

16.1. Markets

16.1.1. Introduction

Iron ore is one of the core products that Vale commercialize globally. Its price and premiums can fluctuate throughout the year according to changes in the balance between its supply and demand and short-term trends due to the market's sentiment.

Vale operates three systems in Brazil for producing and distributing iron ore, which we refer to as the Northern, Southeastern, Southern Systems. Each of the Northern and Southeastern Systems is fully integrated, consisting of mines, railroads, maritime terminals and a port. The Southern System consists of two mining complexes and two maritime terminals.

In 2025, iron ore prices have held steady, traversing within a $96–$110/t range since late 2024, despite geopolitical tensions, tariffs, and trade disputes causing sharp swings in other commodities. China's latest efforts to address overcapacity and target ruinous competition, known as "anti-involution," had gained momentum, and propped up the steel industry, which had been operating in weak margins conditions in 1H25. This has translated to an improved but cautious optimism in the iron ore sector and supported market sentiment. While such measures could limit iron ore usage, they may enhance steel sector profitability, indirectly supporting prices.

16.1.2. Demand

China has been the main driver of global demand for minerals and metals over recent decades. In 2024, Chinese demand represented 75% of global demand for seaborne iron ore. Therefore, any contraction of China's economic growth or change in its economic profile could result in lower demand for our products, leading to lower revenues, cash flow and profitability.

In 2024, China's crude steel production (CSP) was 1,005Mt, a decrease of 1.2% YoY. In the first 11M25, China's CSP was 891.7Mt, a decline of 4% YoY. During the first 3 quarters of 2025, China's GDP grew by 5.2% YoY. The decent GDP growth in Jan-Sep of 2025 was driven by solid export and strong industrial production, combined with decent investment demand in non-property sectors, despite ongoing challenges in the property sector.

In the rest of the world, global GDP excluding China is to grow at an annualized average rate of nearly 3% in 2025. This growth trajectory has defied prior gloomy expectations, reflecting a resilient though noticeably slowing economy which in 1H25 was mainly driven by front-loading of trades and production, thereafter, followed by waning of the front-loading impulse as supply chain disruptions ripple through. For developed countries, U.S. has surprised on the upside, with turnaround in growth strongly attributed to accelerated AI-related investment, easing interest rates and continued fiscal support. In the Euro area, GDP expanded by 1.4% YoY in 3Q25, driven by investment and government spending, despite weaker private consumption and net exports. However, the growth distribution in Europe was skewed, as major economies like Spain and France saw expansion, contrasting with stagnation in Germany and Italy.

Growth for the group of emerging market economies excluding China was stronger than expected in the 1H25, thanks in part to robust service sector expansion in India, record agricultural output in Brazil, and resilient domestic demand in Türkiye. On a more somber note, global economic growth has remained below pre-pandemic averages due to lingering structural challenges, higher borrowing costs and geopolitical uncertainties.

Looking beyond 2025, it is projected that major economies are losing growth momentum. External conditions are becoming more challenging, and in some cases, the trajectory of domestic demand is slowing. Specter of a slowdown induced by tariffs and immigration policy in U.S. have led markets to speculate on further Fed rate cuts in 2026, while manufacturing activity in developed economies such as Europe, Japan and Korea could see uneven sectoral growth. EU's CBAM, with compliance obligations and fees starting on 01 January 2026, is set to transform global commerce.

During 11M25, global CSP, as published by World Steel Association, has declined by 2.0% YoY to 1,662Mt. For Ex-China, there is an encouraging lift of 0.5% YoY to 771Mt. Steel production outside China has shown disparate performance, with modest growth in some regions and declines in others. The laggards are Europe, South America and CIS countries. Europe woes are dominated by weak construction and faltering manufacturing demand, while Brazilian steel industry has been compromised by record-high imports from China and high interest rates. For CIS, this is mainly due to a combination of structural problems in Russia's economy, amid low oil prices as well as war and sanctions pressures. Anticipating the full year 2025, steel production in Ex-China is poised for robust growth, with a projected 0.5% YoY increase. This expansion is primarily driven by strong investments in India, and some ASEAN and MENA countries. India retains its position on the leaderboard, with CSP growing 10.3% YoY in 11M25.

World Steel Association (worldsteel) Short Range Outlook, released in October 2025, projects global steel demand in 2025 to be flat YoY, reaching about 1,749Mt, while in 2026, there was a modest rebound of 1.3% to 1,772Mt. China's demand is projected to fall by 2.0% in 2025, driven by continued downtrend in real estate sector. In contrast, India is expected to maintain strong momentum, with robust steel demand growth of ~9% expected in 2025, underpinned by infrastructure development, urbanization and rising steel intensity. Overall, economies excluding China are forecast to grow by 1.9% in 2025.

The projected global steel demand growth at 1.3% YoY in 2026 is driven by a mix of powerful regional trends. A slowdown in the decline of steel demand from China, coupled with stronger demand in developing economies like India, Vietnam, Egypt, and Saudi Arabia look to be a continuing trend in the horizon. Steel demand in Africa, and the United States is also highlighted, being poised for growth of 4.7% and 1.8% in 2026. Critically, the market is anticipating the long-awaited sustainable return of steel demand growth in Europe.

In China, weakness in real estate sector continue to weigh on steel demand in 2025, while the decline in housing demand may narrow in 2026 as property market gradually stabilizes, as per WSA view in Short Range Outlook and market consensus in China. In 2025, manufacturing and export-related steel demand continued to outperform and partly offset the downward pressure brought by property sector. While demand deceleration in China can present a downside risk, tempering of inflationary pressures and easing interest rates on major markets in Ex-China could lead to improved industrial production and sustain demand in good levels. Underlying risks which will continue to splinter the market are trade wars triggered by tariffs and the volatile geopolitical conflicts.

For the longer term, the slowdown on China's economic growth and construction demand might impact iron ore demand, which needs to be closely monitored.

16.1.3. Supply

The global iron ore and iron ore pellet markets are highly competitive. The main factors affecting competition are price, quality and range of products offered, reliability, operating costs and shipping costs.

Our main competitors are in different locations than our own sites and compete with Vale mainly in their regional markets. For the Asian market, our main competitors are in Australia and include subsidiaries and affiliates of BHP, Rio Tinto Ltd ("Rio Tinto") and Fortescue. For the European market our main competitors are Luossavaara Kiirunavaara AB ("LKAB"), ArcelorMittal Mines Canada Inc., Iron Ore Company of Canada, a subsidiary of Rio Tinto, Kumba Iron Ore Limited, and Société Nationale Industrielle et Miniére (SNIM) as well as Simandou as it ramps up to full capacity in 30 months, as targeted from full commissioning. Vale also has competitors within the Brazilian market. Several small iron ore producers, and some steel companies, including Gerdau S.A. ("Gerdau"), Companhia Siderúrgica Nacional ("CSN"), Vallourec Tubos do Brasil S.A., Usiminas and ArcelorMittal, compete to feed iron ore for the local steel production.

In 2025, there were no major shifts in global iron ore supply, though there is incoming supply in the pipeline. Rio Tinto's Western Range officially opened in June 2025, adding capacity of 25 Mtpa, and previously mentioned Simandou started their first shipment in November 2025. The majors, including Vale, had a strong year with record exports for BHP and Fortescue, despite cyclone disruptions occurring in Australia. In 2025, the CIS region was able to export more volumes of iron ore again due to the opening of some export channels from the slowdown of the Ukrainian War. For the longer term, the global supply remains steady with replacement projects underway, some expansion projects for CSN, ArcelorMittal Liberia and LKAB among others, and in regions such as Africa.

16.1.4. Price outlook

At the beginning of each annual cycle, Vale sets long-term price and exchange rate assumptions used to estimate Mineral Resources and Mineral Reserves.

The company uses a consensus-based approach to forecast iron ore price and exchange rate assumptions. This includes long-term forecasts published by analysts and financial institutions, supplemented by research from Vale's internal experts and adjustments in accordance with the company's pricing policy.

The iron ore price applied to demonstrate the mineral reserve economic viability in based on the average forecast from analysts and financial institutions, considering annual estimates for the period 2026–2031, followed by a long-term constant price from 2031 onward for the remaining life mine.

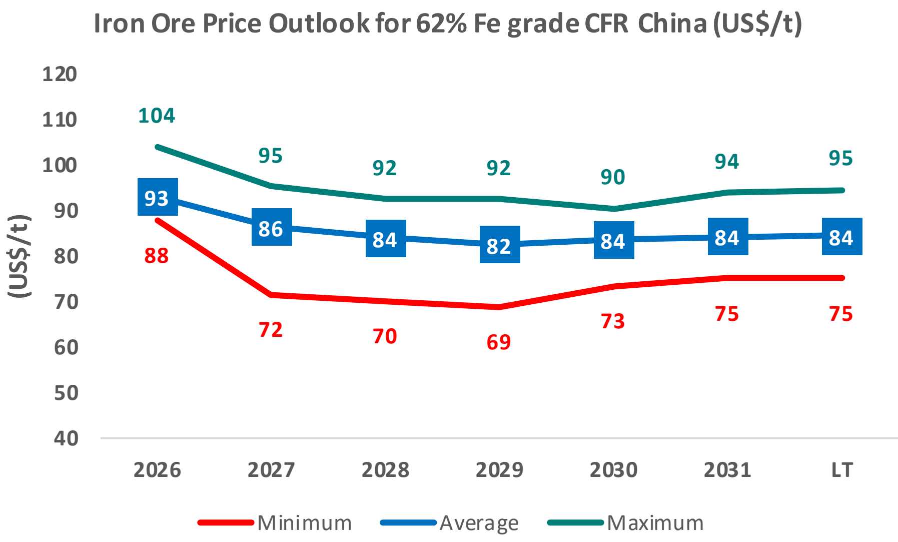
The iron ore price applied to assess reasonable prospects for economic extraction is based on the highest value forecasted by analysts and financial institutions for the long term, limited to 20% above the average.

In 2025, the iron ore average price closed at US$102.2/dmt (Platts IODEX 62% Fe iron ore prices), 6.61% lower than in 2024. During 2025, iron ore prices have had one of the least volatile years since the spot market was developed. Iron ore prices were largely trapped in a narrow corridor of $95-$105/t despite a variety of major drivers to fundamentals and sentiment – both positively and negatively - to the expectations of economic stimulus and rising trade protectionism globally.

Iron ore monthly price traded at around $100/t level between April and August, supported by the very flat movements of iron ore port inventory hovering at around 140Mt level during the period. Iron ore monthly price further stabilized at $105/t in 4Q25.

China steel production remained at moderate levels in 2025 thanks to the healthy domestic manufacturing demand and strong steel export which jumped to the historical highest level that helped to absorb steel production in China. Mandatory steel production cuts still have not substantially materialized in China, and Chinese iron ore imports increased to a new record level in 11M25, +1.4% YoY. As a result, seaborne iron ore markets have proved more resilient to improved seaborne supply than expected.

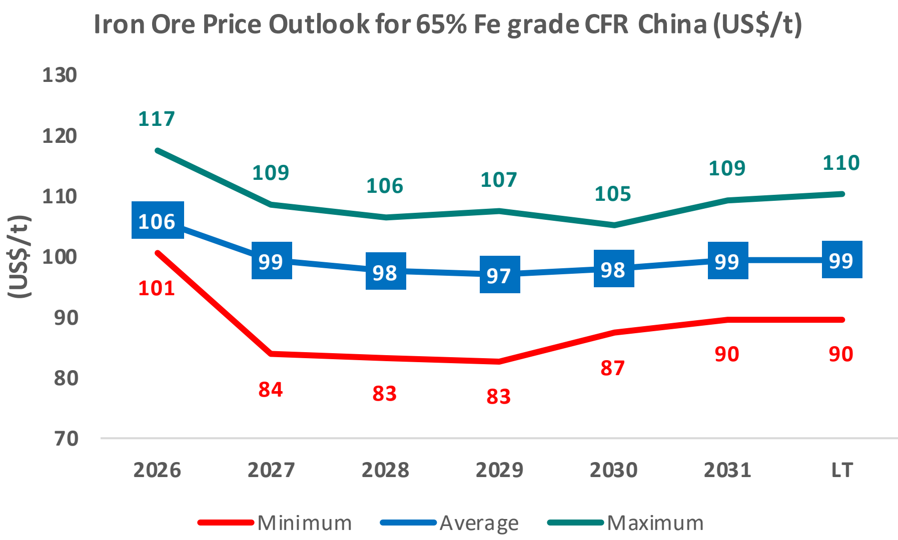
The lower met coal price in the first half of the year and the reduction of steel margins in the fourth quarter both resulted in a decline in high-grade premiums. Nevertheless, the price differentials between high- and low-grade iron ores are a definitive structural change that should continue to impact the market in the coming years. The transition towards a more efficient steel industry, with the enforcement of stricter environmental policies in China and decarbonization pursuit in Europe, should support the demand for high quality ores like pellets, briquettes and Carajás fines, that enable productivity and lower emission levels. By the time this report was prepared, the price consensus for iron ore prices at 62% Fe in 2025 of the analysts was $93/t (table below – prices in USD), with a downward trend going forward until prices reach the long-term level of around $84/t in the long term (beyond 2032). Additionally, we believe that the expected future production, relative to our iron ore reserves, can be absorbed by the market in the long term given the expected demand by market analysts. Figure 16-1 shows the iron ore price for 62% Fe.



Source: Bank reports published between October and December 2025

Figure 16-1 - Iron ore price outlook for 62% Fe grade (US$/dry metric ton).

The price differential between the 65% index and the 62% index is influenced by several market-driven fundamentals. Beyond the environmental advantages of utilizing high-grade ores in steel production, a greater proportion of these ores in the blast furnace enhances productivity by increasing the Fe content in the process and reducing the need for fuel, specifically coke, to convert the ore into iron. Consequently, during periods when mills seek to maximize process efficiency to achieve higher margins or when coke costs rise, the demand for high-grade ores increases, consequently widening the price differential over medium-grade ores. In the coming year, a challenge to the premium is the reduction in steel margins in China, combined with the possible introduction of tariffs, which has diminished the competitive pricing advantage for Chinese steel exports. Nonetheless, the price differential is anticipated to correspond more closely to market fundamentals. By the time this report was prepared, the price consensus for iron ore prices at 65% Fe in 2025 of the analysts was $106/t (table below – prices in USD), with a downward trend going forward until prices reach the long-term level (beyond 2032) of around $99/t.



Source: Bank reports published between October and December 2025

Figure 16-2 - Iron ore price outlook for 65% Fe grade (US$/dry metric ton).

The value-in-use (VIU) per additional percentage point of Fe CFR China was projected by dividing the price presented in the "Consensus / Average" line of the 62% Fe CFR China table by its Fe content (62%). This methodology is robust when comparing historical means. In addition, there are ore sales in the market using this methodology for iron adjustment. The forecast values are in Table 16-1.

Table 16-1 - VIU per additional percentage point of Fe (US$/dry metric ton)

	2026	2027	2028	2029	2030	2031	2032	LT
VIU per additional percentage point Fe	1.50	1.39	1.35	1.33	1.35	1.36	1.36	1.36

For comparison and information only, the table below shows iron ores prices realized over the last 5 years (2021-25) for Platts 62% Fe IODEX CFR China (*Table 16-2*).

Table 16-2 - Platts iron ore for 62% Fe (US$/dry metric ton)

	2021	2022	2023	2024	2025	Average
Platts iron ore 62% Fe IODEX CFR China	160	120	119	110	102	122

16.2. Contracts

16.2.1. Northern System operations TRS: logistics/distribution contracts

We operate the EFC railroad under a concession agreement, which has been recently renewed and will expire in 2057. The EFC railroad links our Northern System mines in the Carajas region in the Brazilian state of Para to the Ponta da Madeira maritime terminal, in São Luis, in the Brazilian state of Maranhão.

We rely on long-term contracts of affreightment to secure transport capacity and enhance our ability to offer our products in the Asian market at competitive costs on a CFR basis. To support our commercial strategy for our iron ore business, we have long-term agreements with seventeen ports in China, which also serve as distribution centers.

16.2.2. Northern System operations TRS: logistics – full

Our production from Serra Sul is transported by railway to the port through Carajas railroad (''EFC''). The EFC railroad links our Northern System mines in the Carajas region in the Brazilian state of Para to the Ponta da Madeira maritime terminal, in São Luis, in the Brazilian state of Maranhão. We operate the EFC railroad under a concession agreement, which has been recently renewed and will expire in 2057. EFC extends for 997 kilometers from our Carajas mines to our Ponta da Madeira maritime terminal complex facilities. Its main cargo is iron ore, principally carried for us. VLI has rights to purchase railroad transportation capacity on our EFC railroad. In 2021, the EFC railroad transported 188,335 thousand metric tons of iron ore. In 2021, EFC had a fleet of 298 locomotives and 21,175 wagons, which were operated by Vale and third parties.

We operate ports and maritime terminals mainly to complete the delivery of our iron ore and iron ore pellets to bulk carrier vessels serving the seaborne market. Production from Serra Sul is exported through Ponta da Madeira maritime terminal. Our Ponta da Madeira maritime terminal is located in the Brazilian state of Maranhão. Pier I can accommodate vessels of up to 420,000 DWT and has a maximum loading rate of 16,000 metric tons per hour. Pier III, where there are two berths and three shiploaders, can accommodate vessels of up to 210,000 DWT at the south berth and 180,000 DWT at the north berth (or two vessels of 180,000 DWT simultaneously), subject to tide conditions, and has a maximum loading rate of 8,000 metric tons per hour in each shiploader. Pier IV (south berth) can accommodate vessels of up to 420,000 DWT and there are two ship loaders that work alternately with a maximum loading rate of 16,000 metric tons per hour. In 2018, Vale received the customs authorization for the operations of Pier IV (north berth). Cargo shipped through our Ponta da Madeira maritime terminal consists of the Northern system production of iron ore, pellets and manganese. In 2021, 182.9 million metric tons of iron ore, pellets and manganese were shipped through the terminal. The Ponta da Madeira maritime terminal has a storage yard with static capacity of 7.2 million metric tons.

We rely on long-term contracts of affreightment to secure transport capacity and enhance our ability to offer our products in the Asian market at competitive costs on a CFR basis. To support our commercial strategy for our iron ore business, we operate two distribution centers, one in Malaysia and one in Oman and we have long-term agreements with seventeen ports in China, which also serve as distribution centers.

In 2015, we launched the Brazilian blend fines (BRBF), a product resulting from blending fines from Carajas, which contain higher concentration of iron and lower concentration of silica in the ore, with fines from the Southern and Southeastern Systems, which contain lower concentration of iron in the ore. In August 2018, Metal Bulletin launched a new index, the 62% Fe low-alumina index, which is based on our BRBF. During 2020, the 62% Fe low-alumina index traded with a premium of US$1.2 per dmt over the 62% Fe index. The resulting blend offers strong performance in any kind of sintering operation. It is produced in our Teluk Rubiah Maritime Terminal in Malaysia and in the seventeen distribution centers in China, which reduces the time to reach Asian markets and increases our distribution capillarity by using smaller vessels. In 2019, we announced the launch of GF88, a new product to supply the growing market of pellet production in China, which consists of Carajas fines (IOCJ) obtained through a grinding process, opening a new market for our high-quality products portfolio.

17. Environmental studies, permitting, and plans, negotiations, or agreements with local individuals or groups

17.1. Introduction

There are different environmental and protected areas located in the vicinity of the Serra Norte complex, such as the National Forests of Tapirapé-Aquiri, Itacaiúnas and Carajás; the Campos Ferruginosos National Park; the Tapirapé Biological Reserve; the Xikrin do Cataté Indigenous Land; and Igarapé Gelado Protected Area. The total area is approximately 1.2 million hectares, relatively well preserved, in contrast to the anthropized regions in the surroundings.

17.2. Environmental aspects

Serra Norte is in Federal Areas, within the Carajás National Forest, established in 1998.

According to Resolution of the National Environmental Council - CONAMA No. 237/1997 and Federal Law LC No. 140/2011, the environmental licensing for mining projects is under responsibility of the corresponding State, except when there is any condition, such as localization in indigenous lands, two or more states or when located in federal lands.

The environmental permit of Serra Norte is issued by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), which evaluates and approves projects for mining activities.

In Brazil, the environmental licensing process allows a company to operate according to the technical and legal aspects established by law. The process has three typical phases:

- Preliminary Permit (LP): This is requested even in the planning phase of the activity or project, approving its location and conception, attesting to the environmental feasibility, and establishing the basic requirements to be fulfilled in the next phase;
- Installation Permit (LI): Authorizes the installation of the project or activity following the specifications in the approved plans, programs, and projects, including environmental restrictions and control measures
- Operating Permit (LO): Authorizes the operation of the project, after verification of effective compliance with the conditions established in the two previous licenses, with environmental restrictions and control, mitigation, and compensation measures determined for the operation;

The N4 and N5 mines received an operating permit in 2002 and its fourth renewal in 2025, the LO nº 267/2002 – 4th renewal. The Environmental Permits placed for Serra Norte are shown in Table 17-1.

Table 17-1 - Environmental Permit in Serra Norte

Authorization / Environmental Permit	Environmental agency	Description	Expiration Date	Status
LP nº 674/2022	IBAMA	N3 Mine Project	09/27/2026	Valid License PS: LI requested
LI nº 1172/2017	IBAMA	Adequacy of the facilities of the beneficiation plant	07/12/2021	License under revalidation (Process No. 02001.002197/2002-15) (1)
LO nº 1710/2025	IBAMA	Reprocessing Project for the Gelado Dam's Tailings	02/06/2035	Valid License (Process 02001.002181/2009-71)
LO nº 1697/2024	IBAMA	Apinha road	08/19/2030	Valid License (Process 02001.002197/2002-15)
LO nº 267/2002 (4th Renewal)	IBAMA	Exploitation of iron ore from bodies N4 and N5 and extensions. Extension of the Conveyor Belt of the Mobile Waste Handling System	02/27/2035	Valid License (Process nº 02001.002197/2002-15)
LO nº 1570/2020	IBAMA	LT 230kV Carajás and Serra Norte Substation	03/27/2021	License under revalidation (Process nº 02001.011540/2020-96) (1)
LO nº 743/2008	IBAMA	Fuel station of N4 Mine	12/23/2023	License under revalidation (Process nº 02001.005618/2003-32) (1)
LO nº 744/2008	IBAMA	Administrative fuel station of N4 mine	04/19/2012	License under revalidation (Process nº 02001.000714/2004-75) (1)
LO nº 745/2008	IBAMA	Railway contour fuel Sation	08/25/2013	License under revalidation (Process nº 02001.000672/2004-72) (1)
LO nº 724/2008	IBAMA	Carajás Urban Fuel Sation	02/12/2020	License under revalidation (Process nº 02001.006407/2004-06) (1)

(1) According to Brazilian legislation we can continue to operate during the renewal process.

The company has also prepared and submitted the necessary environmental and social studies for the continuity of the operations. These processes are in different stages, as shown in Table 17-2:

Table 17-2 - Processes for Serra Norte complex

Project	Process in the Environmental Body	Status	Structures	Process Formalization	Forecast to Obtain the License
N3 Mine	02001.003830/2015-07 IBAMA	LP	N3 Mine	06/30/2023	2026
N1 and N2 Mine	02001.111331/2017-46 IBAMA	EIA	N1/N2 Mining	02/01/2020	2030

- **Conservation units**

Serra Norte is part of the Carajás National Forest, which is part of a group of conservation units designed to protect biodiversity, and therefore qualified as an area of extreme importance. These protected areas include forest reserves and other conservation units, named special-use areas, and indigenous lands. The Carajás National Forest belongs to the "sustainable use" class of protected areas that foresee multiple uses within its limits, including mining.

Currently, discussions are under way with the conservation managing agency to change the zoning of the Carajás National Forest Management Plan, which might reduce mining areas due to occurency of restricted endemic species or allow expansion of mining areas where there is no risk of endemic species extinction. Examples under discussions are N1/N2 and Morro II. The discussions, including different topics (biodiversity (fauna, flora), water resources, socio-environmental and speleology), are in course but if restrictions increase it might affect the reserve.

- **Natural Caves**

Supported by federal legislation and specific normative instructions, it establishes that caves must be classified according to their degree of relevance (Maximum, High, Medium and Low) and defines the necessary studies and compensation possibilities in case of impacts on the caves with High, Medium and Low relevance degree.

The caves with a maximum degree of relevance cannot be subject to irreversible negative impacts around their 250m buffer until their respective areas of influence are validated by the Agency´s licensing bodies corresponding to the respective licensing processes.

In the context of studies and licenses, VALE has been obtaining specific and individual authorizations per cave for controlled mining in areas of influence of less than 250 meters (average of 150 m), where the projects are monitored by the environmental agency through monitoring reports on the physical and biological conditions thereof. Vale has also been successful in claims for reclassification of relevance from maximum to non-maximum degree (High, Medium or Low), and consequently, become eligible for environmental compensation processes in accordance with the law, thus recovering blocked reserves.

Also, regarding cave compensation, in order to obtain a balance of caves suitable to be offered as compensation, Vale carries out campaigns to identify caves in areas without mining interests, seeking greater predictability of their needs and anticipating demands.

17.2.1. Climate

There are two well defined seasons in the region: the rainy season, from November to April, when it rains 80% of the total annual precipitation, and the dry season, between May to October, with the driest three months (June, July, and August) and monthly averages precipitation of 24 mm. The average annual rainfall for the region ranges from 1,500 to 1,900 mm, and the average temperature is between 23.5 and 25.5°C, with the maximum temperature reaching 32.5 and the minimum never lower than 18°C.

Humidity in the region typically ranges from 70% and 85%. In the driest months, humidity can reach minimum of 50%, while in the rainy periods it can exceed 95%.

Serra Norte historical precipitation is shown Figure 17-1.

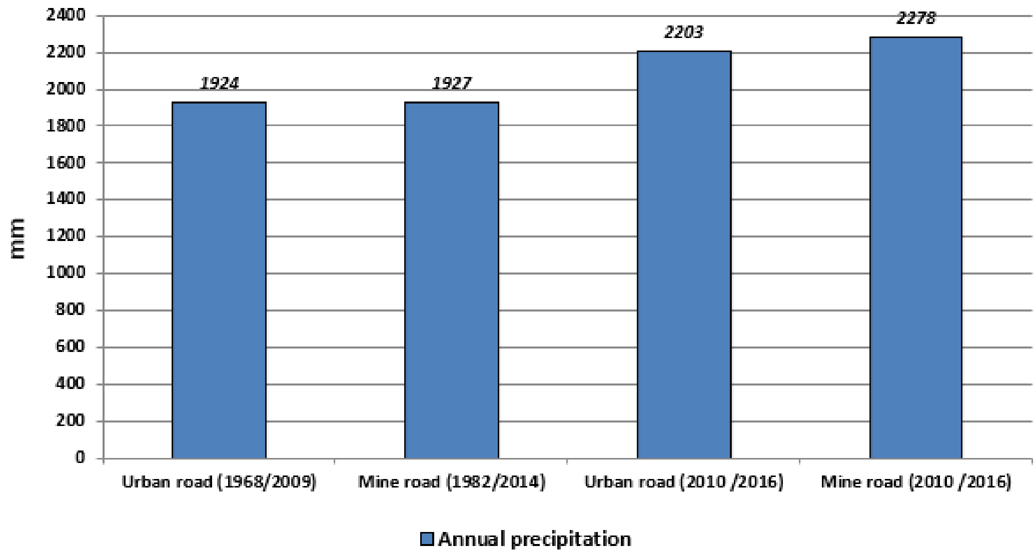


Figure 17-1 - Serra Norte annual precipitation

17.2.2. Hydrology

Serra Norte operations are in the hydrographic basins of the Parauapebas river (eastern portion) and the Itacaiúnas portion (western portion). The Parauapebas River is an important tributary of the Itacaiúnas, which is a tributary of the Tocantins River on its left bank. The Tocantins River flows into the Pará River, which belongs to the Amazon River Basin.

The Serra Norte mines are developed mostly in the sub-basins of the Parauapebas River.

17.2.3. Vegetation

The Serra Norte region is part of the Amazon Biome, where the most common form of vegetation is the Ombrophilous Forests, which are those adapted to humid climates, with rain during most of the year (8 to 9 months of rain and 3 to 4 dry months). They are located mainly on the slopes of the mountains and in the lower parts.

Other types of forests include Deciduous Forests and Transitional Forests. Deciduous Forests or “Dry Forests” are those adapted to drier climates, growing on granitic rocks, and whose crowns lose more than 50% of their leaves in the dry season. They are located in small spots in the middle of the Ombrophilous Forests on the slopes of the Sierras.

Another type of vegetation is the “rupestrian vegetation”, which grow on iron ore (“canga”). Despite receiving a lot of rain, the canga remains dry for most of the year due to the rocky soil. As a result, the plants that grow on the canga must withstand water scarcity and high temperatures.

17.3. Environmental management

The main environmental management programs are described below.

17.3.1. Environmental management system

Vale has an environmental management system to identify non-conformities, develop correction plans and ensure continuous improvement. The management system aims to prevent and control potential environmental and social impacts identified in the impact assessments submitted to the regulatory agencies.

An ISO 14001:2015 certification for N4 and N5 mines has been obtained by 2015 and revalidated year after year since then, with the most recent revalidation obtained in 2022.

17.3.2. Removal and storage of topsoil

The surface soil of suppressed areas, formed by layers with higher organic matter content are stored and used in the process of rehabilitation of degraded areas. This material is rich in nutrients and has propagules from native vegetation, important for the recovery of altered or degraded areas.

17.3.3. Liquid effluent management

Effluents generated in the workshops and fueling stations are treated using water-oil separators. The sanitary effluents generated in the administrative areas are treated in the Sewage Treatment Plant.

17.3.4. Drainage system

Operational areas and access roads are equipped with drainage systems to direct the rainwater to watersheds decantation ponds. Drainage systems are also important to conduct the water and prevent erosion. Those systems are constantly monitored and technically adjusted when necessary.

17.3.5. Solid Waste management

This process establishes a management model based on selective collection segregated at the generating source, safe handling without compromising the health of the employees involved, packaging according to the hazardousness and physical state of the waste, correct temporary storage until the moment of final disposal, which includes control through records, thus covering the conditions of sending, transportation and receipt by the final recipient licensed for such activity.

17.3.6. Air quality

The monitoring of air quality and meteorology in Carajas is carried out by three automated stations that continuously generate data through specific analyzers and sensors, which measures either suspended particulate matter and inhalable particles and meteorological parameters.

Particulate matter and inhalable particles are controlled with mitigation actions as the use of water trucks on unpaved roads, the use of fixed sprinklers, setting vehicle speed limits, washing paved roads, revegetation of waste dumps, stockpiles, and mining areas, and active monitoring.

Combustion gases from mobile sources are monitored using Ringelmann scale and their levels are controlled by carrying out maintenance on machinery and equipment, regularly.

17.3.7. Noise and vibration monitoring

This monitoring aims to assess noise and vibration, through periodic seismographic monitoring, allowing comparison with the standards defined by the current legislation.

At Carajás Mining Complex, this monitoring is carried out periodically through a sampling network, with points distributed at the following locations: mines and plants, highways, natural forests, and dams. The information obtained is stored in a database and submitted annually to IBAMA in a consolidated report. As a complement, Vale is developing the Bioindicators Monitoring Program to assess the noise emission over amphibians and birds communities, with 58 monitoring points.

Vibration inside caves, caused by implementation and operation activities, is measured by specific seismographic monitoring, due to its importance, with the main goal of verify whether it will or won't exceed legal vibration levels.

17.3.8. Bioindicators

This monitoring aims to assess how the project affects the dynamics of species or communities of fauna and flora bioindicators, chosen specifically for this purpose, using different biological indicators.

17.3.9. Water resources

The water quality management program is responsible for monitoring underground and surface water and monitoring the potable water and the liquid effluent treatment. The results are consolidated in annual reports and provided to the environmental agencies.

17.3.10. Vegetal Suppression

This program aims to apply the best forest suppression techniques, focusing, either on the worker's safety and to minimize impact on the local fauna and flora due to habitat loss.

17.3.11. Bio-Park Vale Amazônia

Located in the Carajas National Forest, in Para, the BioPark Vale Amazônia is a reference on protecting rare and threatened species, besides promoting knowledge, fostering Vale's purpose of improve life and transform the future, together.

Created in 1985, maintained, and administered by Vale, the BioPark Vale Amazônia is exclusively home to Amazonian native species of fauna and flora. Located within the National Forest of Carajás, in a Federal Conservation Unit, occupies an area of 30 preserved hectares, which allows free circulation of small sized local fauna and, likewise other preserved areas, is suitable for birdwatching practice. The space receives around 100,000 visitors a year.

17.3.12. Degraded areas recovery plan

This program aims to rehabilitate the areas morphologically altered by mining activities, aiming to restore the ecosystem functionality. As the Serra Norte Operation is located inside a federal conservation unit, the process uses only Amazonian native plants, with confirmed occurrence inside Carajas National Forest.

17.3.13. Fire prevention

Vale has its own rangers and works in partnership with federal environmental agencies IBAMA and ICMBio, local military firefighters (CBMPA) and, when triggered, the Brazilian army, to execute fire prevention and firefighting procedures to protect conservation units in Carajas. It´s important to mention that, nowadays, Vale has been satellite monitoring heat focuses throughout its area of activity.

17.4. Social or community requirements

The closest community to the Serra Norte Operation is the municipality of Parauapebas, located approximately 30 km south with population of approximately 305.771 residents (IBGE 2025).

This section describes the main social actions and results related to the operation.

17.4.1. Environmental education program

This program helps increase the critical awareness of the employees (VALE and third parties) and the surround communities, about environmental responsibility, impacts, threats and mitigation.

17.4.2. Recruitment program and workforce training

This program intends to hire the highest possible number of employees residing in the municipality of Parauapebas, where the project operates. Therefore, this program aims to qualify the local workforce through professionalizing technical courses.

17.4.3. Health program

This Program aims to promote community engagement and involve the operation team to define and implement actions to address critical health and safety issues, which are carried out through participatory processes with communities and internal audiences in awareness-raising actions such as campaigns, lectures, and production of graphic material. The topics covered include disease prevention, mental health, and combating violence against women.

17.5. Mine closure and future use

The mine closure plan includes the main infrastructure and natural sites, such as preservation areas, waste piles, containment dykes, basins and sumps, and industrial and administrative infrastructure.

The activities planned for the de-characterization and deactivation of Serra Norte described below, according to their specific characteristics, to adapt them to the required safety standards and the planned closure scenario for the area.

17.5.1. Mine Pits

The activities planned for the closure of the Serra Norte Complex pits are summarized in Table 17-3.

Table 17-3 - Closing activities - Pits

Typology	Structure	Activities
Pit	N3– Projeto N4E – Operação N4WN– Operação N4WS– Operação N5EN– Operação N5S– Operação N5W– Operação Morro I – Operação Morro II – Projeto	- Topographic survey; - Localized slope adjustments; - Localized superficial drainage adjustment; - Geotechnical monitoring system final adjustment; - Water level monitoring system final adjustment; - Localized slope revegetation; - Safety barrier implementation.
	N5E, N5W, N4EN	Waste disposal.

17.5.2. Waste dumps

The activities planned for deactivation of waste dumps are summarized in Table 17-4.

Table 17-4 - Closing activities – Waste Pile

Typology	Structure	Activities
Waste Dump	PDE Oeste - Operação PDE Sul III - Operação PDE Sul IV - Operação PDE Noroeste I – Operação PDE Noroeste II– Operação PDE Sudoeste N4W- Projeto PDE Norte I (CCI) - Operação PDE Leste I - Inativo PDE Jacaré - Operação PDE Sudeste N5 – Projeto PDE N5S – Projeto PDE N5E - Operação PDE N5W - Operação PDE N1 – Projeto PDE N2 – Projeto PDE N4EN - Operação PDE Viaduto - Inativo PDE Sul I – Inativa PDE Sul II – Inativa	- Topographic survey; - Final adjustment of the geotechnical monitoring system; - Localized slope adjustments; - Final adjustments of superficial and belt drainage system; - Vegetation reinforcement of slope and berm.

17.5.3. Sediment Containment System

The activities planned for the closure of the containment dykes in the Serra Norte Mines are summarized in Table 17-5. It is important to highlight that the decommissioning approaches for some containment structures are being reassessed in accordance with new global guidelines on the subject and relevant legal regulations.

Table 17-5 - Closing activities - Sediment Containment System

Typology	Structure	Activities
Dam and Sumps	Gelado Geladinho Estéril Sul Pera Montante Pera Jusante Jacaré Dique PDE Jacaré – Operando Dique PDE Noroeste II – Projeto	- Final adjustment of the geotechnical monitoring system; - Vegetation reinforcement of slope and berm; - Final adjustment of the superficial protection embankment system; - Final adjustment of the localized superficial drainage system; - Spillway final adjustment; - Revegetation; - Safety barrier implementation.

17.5.4. Industrial Facilities and Support Infrastructure

The activities planned for the closure are briefly presented in Table 17-6.

Table 17-6 - Closing activities – industrial facilities and support infrastructure

Typology	Structure	Activities
Industrial Facilities and Structure	Office, storehouse, railway pear, facilities, gas station	- Survey of areas with potential contamination; - Systems Deactivation and Structure Disassembly; - Drainage system final adjustments; - Subsoiling; - Revegetation.

17.5.5. Monitoring and maintenance

As part of the closure plan for the Serra Norte Complex, the need for geotechnical and environmental monitoring and the maintenance of areas in the post closure stage should be considered. Table 17-7 summarizes the main activities proposed to measure the efficiency of the closure actions for all assets and for the area in general.

Table 17-7 - Post-closure monitoring and maintenance.

Activities	Attention points
Post-closure Monitoring and Maintenance	- Revegetation development. - Geotechnical stability; - Superficial and underground water quality.

17.5.6. Future use proposition

Serra Norte Complex is located in the Carajás National Forest, a conservation unit for sustainable use, created on 02/02/98. Its specific objectives follow those of its category and those established in its creation decree.

The Carajás National Forest Management Plan (STCP, 2016) is based on studies of abiotic, biotic, and anthropogenic factors.

The Management Plan includes the following programs: Administration and Communication, Protection and Inspection, Research and Monitoring, Environmental Education, Sustainable Forest Management, Public Use, and Incentive for Sustainable Development in the Surroundings.

Financial provision

The closure of activities in the Serra Norte iron ore mines is foreseen in the project to take place in 2045 and for the manganese mines in 2035, with progressive closure considered, with decommissioning and deactivation actions starting in the operational phase. The description of actions planned for closing is presented in Table 17-8, which refers to the provision of financial resources for the demobilization of assets using the ARO model for 2021.

17.5.6.1. Future Use

As a means of establishing guidelines for the future use of the area and considering the Management Plan of Carajás National Forest the following were identified:

- Research and Development: with the purpose to create a database on flora, fauna, human occupation, and natural resources within its boundaries;
- Training and Biodiversity Conservation: aiming at both the continuity of the preservation of the Carajás National Forest and the development of activities that generate wealth for the region;
- Diversification of Vegetal Agroextractivism: to promote sustainable production, the articulation between a community organization and technological development for the economic autonomy of Carajás National Forest;
- Ecological and Historical Tourism: following the example of the conservation of mining industrial heritage in other countries and similar initiatives in Brazil, and also because the Serra Norte mine is one of the largest in the world, associated with historical and tourist interest in terms of its remaining structures and facilities;
- Environmental Conservation Area: This promotes the connection of preserved vegetation fragments and favours the construction of habitats for different faunal groups, which allows the occurrence of sufficient flora biodiversity to offer important sources of plant propagation and subsequent efforts to recover degraded ecosystems around.

17.5.7. Financial Provision

The closure of activities at Serra Norte Mine is scheduled for 2045, and considers progressive closure activities, with decommissioning and deactivation actions starting during operations. The phased closure is planned in accordance with the useful lives of the assets listed in Table 17-8. The description of the actions planned for closure is shown in Table 17-9, which refers to the provision of financial resources for the demobilization of assets using the ARO model for 2025.

Table 17-8 – Serra Norte Mines Operating Assets 2025

Asset name	Type	Useful Life
Pit N4WN	Pit	2045
Pit N4E	Pit	2045
Pit N5W	Pit	2045
Pit N5EN	Pit	2045
Pit N5S	Pit	2045
Pit N4WS	Pit	2045
Pit Morro 1	Pit	2038
Pit 1	Pit	2026
Pit 2	Pit	2026
Pit 3	Pit	2026
WASTE DUMP Norte I (CCI)	Waste Dump	2028
WASTE DUMP Leste I	Waste Dump	2004
WASTE DUMP Oeste	Waste Dump	2016
WASTE DUMP Noroeste I	Waste Dump	2029
WASTE DUMP Noroeste II	Waste Dump	2027
WASTE DUMP Sul IV	Waste Dump	2020
WASTE DUMP Sul III	Waste Dump	2030
WASTE DUMP Jacaré	Waste Dump	2028
WASTE DUMP N4EN	Waste Dump	2023
WASTE DUMP Viaduto	Waste Dump	2011
WASTE DUMP N5W	Waste Dump	2026
WASTE DUMP N5E	Waste Dump	2030
Waste Dump Sul I	Waste Dump	2012
Waste Dump Sul II	Waste Dump	2012
Waste Dump Pit 1	Waste Dump	2026
Waste Dump Pit 2	Waste Dump	2026
Waste Dump Pit 3	Waste Dump	2026
Gelado	Dam	2034
Geladinho	Dam	2034
Estéril Sul	Dam	2034
Pêra Montante	Dam	2024
Pêra Jusante	Dam	2034
Jacaré	Dam	2034
Kalunga	Dam	2032
Azul	Dam	2032
WASTE DUMP2	Dam	2032 2026
Treatment plant 01 N4N5	Facilities	2045
Treatment plant 02 N4N5	Facilities	2045
Treatment plant 03 N4N5	Facilities	2045
Treatment plant Mn Azul	Facilities	2027
Facilities Azul	Facilities	2027
Facilities N4N5	Facilities	2045

Table 17-9 - Cash Provision for decommissioning (2025, ARO Model)

Asset	Total (US$ M)
Pit	266,78
Waste Dumps	147,13
Dams and Sumps	385,96
Industrial Facilities	154,29
Other structures	43,09
Total	**997,24**

Note: numbers have been rounded

17.5.8. Final remarks

- Mine Closure & Permitting

In alignment with the Brazilian legislation governing the subject, mine closure is an integral part of the permitting process pertaining to mining ventures during the initial phase of implementation and operation permit acquisition. During this phase, the Environmental Impact Assessment is developed, covering the entire life cycle of the project. Environmental and mineral legislation legal interfaces are collectively linked to license for operation. There is no requirement for the acquisition of a separate

mine closure license. This topic comprises the information set that constitutes the overall mineral project. Permitting pertains to the project as a whole, not to a specific phase or theme (despite the fact that the permitting process is split into phases). Therefore, mine closure is understood as a process and not a stage that requires separate permits bound to the overall mineral project.

It is emphasized, however, that determining a future use for the territory after cessation of the mining operation is subject to permitting due to the new scenario in terms of territory use, which requires an assessment of relevant environmental impacts. Notwithstanding, it is not a legal obligation for the mining project to establish the future use of the area in question. According to current legislation, it is the entrepreneur's obligation to deliver a stabilized site in physical and chemical terms at the end of the project lifetime. This aligns with the goal of enabling safe and sustainable future use of the region where the mining project was previously located.hOpinion on Addressing Issues in the Mine Closure Plan

In accordance with Brazilian legislation and market best practices, considering the closure deadline for the Serra Norte site and the application of a progressive closure model, coupled with the existence of a financial provision for asset demobilization—whose values are annually reviewed and adjusted to the current year's reality—and taking into account VALE efforts to use this provision to expedite the elimination of liabilities associated with closure by incorporating progressive closure as a day-to-day practice, it is understood that the company operates in alignment with market best practices regarding mine closure.

18. Capital and operating costs

Vale QP reviewed the capital and operating costs required for mining and processing of Mineral Reserves at Serra Norte. Serra Norte is an operating mine, and capital and operating cost estimates were prepared based on the recent operating performance and the current operating budget for 2026. All costs in this section are expressed in US dollars.

All capital and operating cost estimates are based on recent estimates and actual costs and are at least at a pre-feasibility level of confidence, with accuracy level of ±25% and a contingency range not exceeding 15%.

The sole purpose of the presented figures is to demonstrate the economic viability of the mineral reserve, therefore it can differ from other information Vale publishes and should not be considered as a guidance.

18.1. Capital costs

The total capital costs for Serra Norte Life of Mine are shown in Table 18-1. Capital costs are related to new projects to maintain or increase production. The sustaining capital costs are related to maintaining the current production rate and include the replacement of mine equipment, pit pushbacks, a new waste dump, replacement of plant equipment and instrumentation. Additionally, economic assessments of reserves may consider capital projects that aim to maintain and/or increase productive capacity. The overall capital cost estimate for LOM or evaluation period is US$ 8,062 million as shown in Table 18-1.

Table 18-1 - LOM Capital Cost Estimate

Capital Cost Type	Unit	Value
Sustaining CAPEX	US$ M	**8,062**
Non-routine	US$ M	**3,156**
Mine and plant	US$ M	1,854
Waste and tailings piles	US$ M	1,302
Routine	US$ M	**4,906**
Capital projects CAPEX	US$ M	**0,0**
TOTAL	US$ M	**8,062**

Note: numbers have been rounded

18.2. Operating costs

LOM average unit operating cost and expenses:

- Mine and plant: 16.0 US$/ton of product
- Logistics and Distribution: 22.5 US$/ton of product
- Royalties: 5.5 US$/ton of product
- Sales expenses, R&D, others: 0.2 US$/ton of product
- Total average unit operating costs and expenses: 44.2 US$/ton of product

The overall costs and expenses estimate for LOM or evaluation period is US$ 64,709 million as shown in Table 18-2.

Table 18-2 - Operating Costs and Expenses

Type of costs and expenses	Unit	Value
Mine and plant	US$ M	23,482
Logistics and Distribution	US$ M	32,956
Royalties	US$ M	7,994
Sales expenses, R&D, others	US$ M	276
TOTAL costs and expenses	**US$ M**	**64,709**

Note: numbers have been rounded

The average operating cost is based on a 23-year life of mine from 2026 through 2048. The operating cost inputs including labor, consumables, supplies, selling costs, commercial offices, operational and maintenance research & development, and were based on data from Vale's 2025 budget.

18.2.1. Workforce

The workforce breakdown and main contractors list for the entire operation at Serra Norte are shown in Table 18-3 and Table 18-4, respectively. The main contractors at Serra Norte are related to mining, maintenance of the plant and cleaning.

Table 18-3 - Vale's site workforce

Serra Norte	Total
Mine	2,665
Plant	286
Others	2,741
Total	5,692

Table 18-4 – Contractor´s workforce

Serra Norte(Contractors)	Total
Mine	1,889
Plant	2,395
Others	2,637
Total	6,921

19. Economic analysis

19.1. Forward-looking information caution

The aim of the economic evaluation presented in this chapter is to demonstrate the economic viability of the mineral reserve, therefore the production rates, operating efficiencies, costs and expenditures, taxes and other information presented can differ from other information we publish and should not be considered as a guidance. Note that our planned production extraction may vary due to continuous mineral exploration and technical studies to add new mineral reserves.

19.2. Economic criteria

The economic analysis in this Technical Report Summary is based on the Mineral Reserves, economic assumptions, and the capital and operating costs as presented in Section 18 of this Technical Report Summary.

19.2.1. Physicals

- Open pit ore tons mined: 1,512 Mt (23-year mine life from 2026 through 2048);
- Total ore processed: 1,512 Mt (23-year mine life from 2026 through 2048);
- Mine life: 23 years (between 2026 and 2048);
- Ore grade: 64.9% Fe (average);
- Average LOM Recovery: 96.9%;
- Recovered Iron Ore: 1,465 Mt (23-year mine life from 2026 through 2048).

19.2.2. Revenue

Commodity prices were discussed in Chapter 16.

The average logistics costs considered for this model are: 22.5 US$/ton, over 80% of the total sells during Serra Norte mine life considered as foreign market and CFR (cost and freight) model.

The remaining production volume is delivered to the domestic market or first transferred to our own pelletizing plants and/or sold to the foreign market on a FOB basis (Free on Board), and although not having the associated maritime logistics costs, the net revenue in this case is lower, since discounts are applicable as the reference prices are CFR China.

To support VALE's iron-ore commercial strategy, the company operates two blend and distribution centers, one located in Malaysia and one in Oman. VALE also has long-term contracts with ports in China, which also serve as distribution centers.

The ore of Serra Norte is sold as IOCJ (Iron Ore Carajás), a premium product with pricing based on the 65% Fe product and as an input to BRBF blend.

19.2.3. Operating Costs

- LOM average unit operating cost and expenses:
- Mine and plant: 16.0 US$/ton of product
- Logistics and Distribution: 22.5 US$/ton of product
- Royalties: 5.5 US$/ton of product
- Sales expenses, R&D, others: 0.2 US$/ton of product
- Total average unit operating costs and expenses: 44.2 US$/ton of product
- Overall costs and expenses estimate for the LOM or evaluation period: US$ 64,709 million.

The mine and plant costs include mining, processing, storage, and shipping of the ore to the loading points. Logistics and distribution costs includes railroad, ports, maritime freight, and distribution centers.

19.2.4. Capital Costs

- Overall capital cost estimate for the LOM or evaluation period: US$ 8,062 million
- Sustaining CAPEX : US$ 8,062 million
- Capital projects CAPEX: US$ 0,0 million

19.2.5. Main Taxation and Royalties

- CFEM Royalty rate: 3.5%
- Income tax rate with SUDAM tax benefit: 15.25 % (until end of 2033)
- Income tax rate: 34% (from 2034 onwards)

19.3. Results of economic analysis

19.3.1. Introduction

VALE has prepared the Serra Norte Operation LOM after-tax cash flow model to confirm the economics of the LOM plan. The economic analysis is based on 100% equity financing and is reported on a 100% project ownership basis.

The mineral reserve cashflow for Serra Norte is only used to confirm economic viability. The annual cashflow is presented below, with the inputs presented as averages grouped for the first 6 years, followed by 5 years until end of 2041 and 7 years grouped from 2042 to 2055. The cash flow summary is presented in Table 19-1 and Figure 19-1. We understand that presenting the cash flow summary in a grouped format, as in Table 19-1, can provide stakeholders with a better trend or predictability of future expectations. The currency used to document the cash flow is US$ and the base case economic analysis assumes constant prices with no inflationary adjustments.

Table 19-1 - Cash Flow table results

Cash Flow (Mineral Reserves only)	Unit	2026-31	2032-36	2037-41	2042-48	2049-55
Iron Ore Recovered	Mt	85	75	68	34	0
Total Revenue	US$ million	7,009	6,084	5,529	2,707	0
Operating costs, expenses, royalties and closure costs	US$ million	-3,626	-3,237	-2,820	-1,835	-117
Income Tax and working capital change	US$ million	-765	-664	-618	-138	31
Operational Cash Flow	US$ million	2,618	2,182	2,092	734	-85
Total CAPEX	US$ million	-585	-423	-349	-99	0

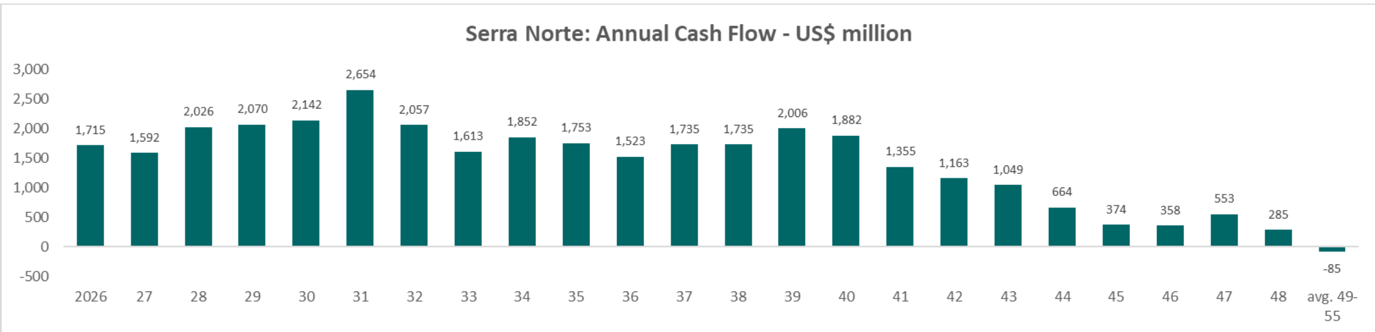


Figure 19-1 - Cash Flow graphic results

19.3.2. Cash flow analysis

The economic valuation model of reserves considered the discounted cash flow method and it took into account annual processed tonnages and grades. The associated process recovery, metal prices, operating costs, logistics costs, royalties, and capital expenditures were also considered. The economic analysis confirmed that Serra Norte are economically viable. The after-tax NPV at a 7.01% discount rate and following a mid-year convention is US$ 19,553 M. The summary of the results of the cash flow analysis is presented in Table 19-2.

Table 19-2 - Cash Flow analysis

Net present value of overall cash flow	Unit	Value
Total revenue	**US$ M**	**67,844**
Total costs and expenses	US$ M	-36,198
Mine and plant	US$ M	-12,483
Logistics and Distribution	US$ M	-18,831
Royalties	US$ M	-4,543
Sales expenses, R&D, others	US$ M	-159
Closure costs	US$ M	-182
Income Tax and working capital change	US$ M	-7,078
Operational Cash Flow	**US$ M**	**24,569**
Total CAPEX	US$ M	-5,016
Free Cash Flow	**US$ M**	**19,553**

For this cash flow analysis, the internal rate of return (IRR) and payback are not applicable as there is no negative initial cash flow (no initial investment to be recovered).

19.4. Sensitivity analysis

Project risks can be identified in both economic and non-economic terms. Key economic risks were examined by running cash flow sensitivities on after-tax NPV at an 7.01% discount rate. The following items were examined:

- Price and VIU;
- OPEX mine, plant and logistics and distribution;
- Exchange rate;
- Total CAPEX;

The sensitivities are shown in Figure 19-2. Upon application of the sensitivity analysis in the main variables, the NPV remains positive, confirming the robustness of the mineral reserves.

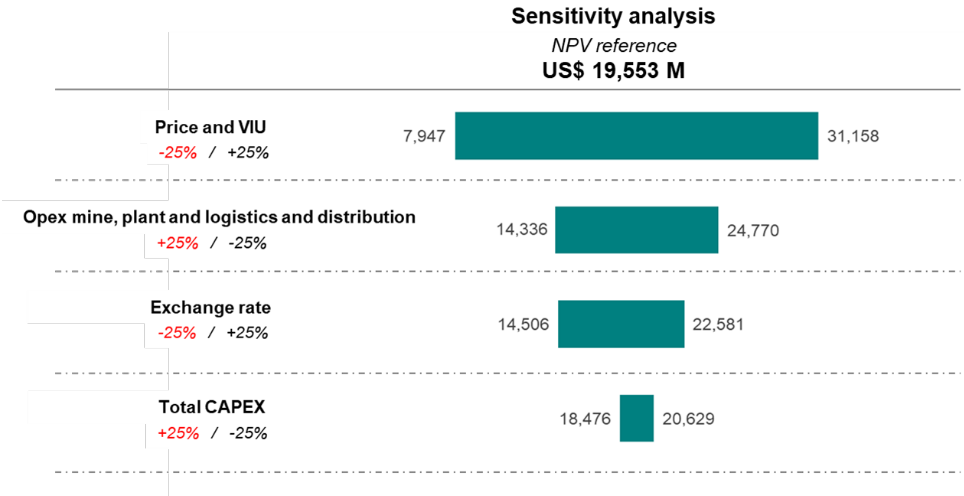


Figure 19-2 - Sensitivity Analysis

20. Adjacent properties

This chapter is not relevant to this Report.

21. Other relevant data and information

This chapter is not relevant to this Report.

22. Interpretation and conclusions

22.1. Property description

The resource and reserve pits of the N1, N2, N3, N4, N5 and Gelado deposits do not appear to be associated with mining processes of other holders or with mining processes of Vale in previous phases. The mines in operation are N4E, N4W and N5 and have mining licenses in force.

The Serra Norte complex has four mining easements that are contiguous and form a unique contour that circumscribes all current and future industrial facilities in the Serra Norte complex. Two of the easements are authorized and two are in the approval stage.

22.1. Exploration, drilling and sampling

All work developed at the Serra Norte follows strict internal standards and the best practices of the mining industry. The various drilling campaigns carried out over the last decades, as well as all geological data, sampling and chemical analysis originated therefrom were extensively discussed among the technical teams involved to ensure the robustness of the geological model.

22.1.1. Hydrogeological and geotechnical settings

The current geotechnical and hydrological database was considered satisfactory (amount and quality) to achieve the main objectives, which were build and calibrate models able to simulate future mining scenarios capable to provide input to slope stability analysis, support failure mechanism evaluation, provide short and long-term geotechnical information, and provide mining and environmental assistance.

The hydrogeological simulations showed reliable and feasible results with operational flow rates for the drawdown of the pits in the Serra Norte Mine Complex. The geotechnical and hydrological data obtained and used in the slope stability analyses has been a reasonable predictor of current conditions and, therefore, satisfactorily supported the mineral reserve estimates. The slope stability analyses obtained reliable and feasible results, with safety factors consistent with the minimal international standards stabled by Read & Stacey (2009). Therefore, the proposed geometry was considered geotechnically practicable.

It is important to emphasize that any changes in the geotechnical and hydrological assumptions could affect mine planning, indirectly affecting capital cost estimates if any major rehabilitation is required due to a geotechnical or hydrological event, affect operating costs due to mitigation measures that may need to be imposed, and impact the economic analysis that supports the mineral reserve estimates.

22.2. Data verification

The data verification programs concluded that the data collected from the Serra Norte adequately supports the geological interpretations and constitute a database of sufficient quality to support the use of the data in mineral resource and mineral reserve estimation.

22.3. Geology and mineralization

The current geological database satisfactorily allows us to set a robust structural and stratigraphic model, like mineralization associations and understandings. Although it is recommended to keep the geological data collection, with mapping, sampling and developing drilling campaigns (short and long terms), to keep improving the knowledge of the high-grade ores, structural and stratigraphy.

All the current geological models were audited and satisfactorily reproduce the continuity of the mineralized bodies, their enclosing and coverings. The models were built by vertical sections or implicit modelling methods, which represents the geological units acceptably.

The presented structural / stratigraphic geometry settings is the result of three successive tectonic events, and post mineralization mainly by supergenic enrichment, developed on jaspilites.

22.4. Mineral resource statement

Mineral resources are reported for Serra Norte Mining Complex which comprises the deposits of N1, N2, N3, N4, N5 and Gelado. Vale has a set of protocols, internal controls, and guidelines in place to support the estimation process, which the estimators must follow. Estimation was made by Vale personnel. The mineral resource estimate is supported by core drilling.

Mineral resources are reported using the mineral resource definitions set out in S–K1300 and are reported without the mineral resources converted into mineral reserves.

Areas of uncertainty that may materially impact the mineral resource estimates include: changes to long-term iron ore price and exchange rate assumptions; changes in local interpretations of mineralization geometry, structures, and continuity of mineralized zones; changes to geological and grade shape and geological and grade continuity assumptions; changes to the input assumptions used to derive the optimized conceptual open pit used to constrain the estimates; changes to the forecast dilution and mining recovery assumptions; variations in geotechnical and mining assumptions; and changes to environmental, permitting and social license assumptions.

Under the assumptions presented in this Report, the Serra Norte Mining Complex has proven to have a reasonable prospect of economic extraction, and therefore the mineral resource estimates can be supported.

22.5. Mineral reserve estimate

Serra Norte mineral reserve estimates follow the definitions established by SEC-SK1300 and were estimated in 2023, 2024 and 2025. For Gelado dam, the reserves were estimated in 2024. Both were depleted in 2025 by qualified Vale personnel. Only part of the measured and indicated mineral resources are converted to proven and probable reserves according to modifying factors. All pits went through a geotechnical validation process and were approved.

Besides the risks associated with prices, costs, process, commodities price volatility as already commented in chapters 11 and 12, we consider as risks the liberation of the radius reductions of caves of maximum relevance in the surroundings of the caverns (N1, N2, N3, N4 and N5), in the necessary time, among other environmental licenses that are beyond our effective control.

As an opportunity we have the cost reduction with the implementation of the Trolley project and increase the use of autonomous trucks. We also have high potential to increase the reserve if the suppression of the caves of maximum relevance adjacent to the caves that today are treated as blocks in the areas where they are located are released.

A combination of pre mining (historical) and current geotechnical data, with the mining site experience of internal teams supported by national and international consultants, is used to establish internal guidelines and procedures in the slope stability design and operation of Vale’s open pit mines. Any changes in the geotechnical and hydrological assumptions could affect mine planning, indirectly affecting capital cost estimates if any major rehabilitation is required due to a geotechnical or hydrological event, affecting operating costs due to mitigation measures that may need to be imposed, and impact on the economic analysis that supports the mineral reserve estimates.

22.6. Mining methods

Mining in Serra Norte uses the open pit mining method and a fleet of conventional equipment. The mine has its own operation, except in some specific areas, such as re-slope areas.

The production plans aim at average annual production of around 100Mt. It may vary according to the company's production plan throughout the life of the mine.

22.7. Processing and recovery methods

For the processing of ROM with natural moisture, there is no need for process tests for operational control, as it is a technique dominated in the beneficiation of ore, where traditional equipment from the mining industry is used. For the plants to achieve the best performance, it is necessary to ensure that ROM is within the established limits of granulometry, the percentage of lithologies and the quality of each plant, and this procedure is already applied in this complex. Screening at natural moisture requires attention in the rainy season, once ROM with higher moisture generates drop in productivity, in addition to handling problems. During this period, a production drop is already considered in production planning and an attempt is made to reduce the percentage of hydrated ore, as this type of ore presents greater difficulty in processing.

For the wet plant, there is a routine chemical analysis of the main magnetic concentration fluxes that will allow the necessary operational adjustments to be made. The magnetic concentrators applied for this project are well-known equipment at Vale and allow for the optimization of mass recovery or quality through simple changes in operating parameters. The mass recovery of the magnetic concentration will depend on the contents of the feed. If there is any deviation that cannot be resolved through adjustments to the operating parameters, samples will be collected for technological characterization and pilot tests to identify the causes of the problem and propose solutions.

Considering that there is variability in the content and grain size of the material in the Gelado dam, it is essential to carry out detailed sampling at this dam to map the regions and enable the creation of blends to meet the magnetic concentration feed specification.

22.8. Environmental studies, permitting, and plans, negotiations, or agreements with local individuals or groups

The Serra Norte Complex has environmental controls and monitoring that aim to ensure or quickly identify possible operational deviations that could cause damage to the environment or nearby communities. The current production expansions does not require major expansions of controls and monitoring due to the robustness and adequacy of these controls and programs on the site.

Mining close to most restrictive conditions, such as caves, has specific programs and monitoring that aim to ensure production without causing irreversible damage to these environments.

22.9. Capital costs estimate

Economic valuations consider in cash flows sustaining CAPEX, necessary for the maintenance of existing assets / operations, and capital projects that aim to maintain and/or increase productive capacity. Sustaining CAPEX can be classified into routine and non-routine.

Routine refers to projects aimed at maintaining the operational capacity of assets, including acquisition and replacement of equipment and readjustment of operating structures. They are estimated based on a diagnosis made by the Engineering area on the asset base, on a maintenance backlog and on the investment target defined by the company for future years.

Non-routine refers to projects that support the business strategy, ensuring compliance with the production plan, but which do not occur frequently. Included in this list: expansion of pits, waste and tailings disposal projects, changes in processes and technologies in the plants, among others. They are estimated based on the expected needs of each operation or production complex over the evaluated horizon. Based on these needs, Vale's multidisciplinary teams estimate the values of the investments considered in the cash flows of the economic evaluations.

The sole purpose of the presented figures is to demonstrate the economic viability of the mineral reserve, therefore it can differ from other information Vale publishes and should not be considered as a guidance.

Additionally, economic assessments of reserves may consider capital projects that aim to maintain and/or increase productive capacity. The overall capital cost estimate for LOM or evaluation period is US$ 8,062 million.

22.10. Operating cost estimates

Operating costs and expenses are grouped as follows:

- Mine and plant Opex: mine and plant costs include mining, processing, storage, and shipping from the ore to the loading points.
- Logistics and distribution costs: logistics and distribution costs include railroad, ports, maritime freight, and distribution centers.
- Sales, R&D and pre-operational expenses: sales, R&D and pre-operational expenses are related to team expenses with sales and offices, expenses on research and development of solutions for projects and/or the maintenance of operations, and pre-operational expenses, when there are projects in implantation.

In summary, the mining Opex is designed considering as a reference, the costs of the operation or similar operations in previous years and their respective operational indicators. Thus, future operational indicators of operations are estimated, based on long-term mine planning. In this way, the estimated costs are projected considering the future changes in the operational indicators of the operations.

- LOM average unit operating cost and expenses;
- Mine and plant: 16.0 US$/ton of product;
- Logistics and Distribution: 22.5 US$/ton of product;
- Royalties: 5.5 US$/ton of product;
- Sales expenses, R&D, others: 0.2 US$/ton of product;
- Total average unit operating costs and expenses: 44.2 US$/ton of product;
- The overall costs and expenses estimate for the LOM or evaluation period is US$ 64,709 million.

22.11. Economic analysis

The aim of the economic evaluation presented in this chapter is to demonstrate the economic viability of the mineral reserve, therefore the production rates, operating efficiencies, costs and expenditures, taxes and other information presented can differ from other information we publish and should not be considered as a guidance. Note that our planned production extraction may vary due to continuous mineral exploration and technical studies to add new mineral reserves.

The economic analysis confirmed that Serra Norte are economically viable. The after-tax NPV at a 7.01% discount rate and following a mid-year convention is US$ 19,553 million.

For this cash flow analysis, the internal rate of return (IRR) and payback are not applicable as there is no negative initial cash flow (no initial investment to be recovered).

Project risks can be identified in both economic and non-economic terms. Key economic risks were examined by running cash flow sensitivities on after-tax NPV at an 7.01% discount rate. The following items were examined: Price and VIU; OPEX mine, plant and logistics and distribution; Exchange rate; and Total CAPEX.

22.12. Risks and opportunities

22.12.1. Mineral resource estimates

Factors that may affect the mineral resource and mineral reserve estimates were identified in Chapter 11 and Chapter 12, respectively.

Other risks noted include:

- In 2008, a federal decree established a criterion for classification of caves based on their relevance (maximum, high, medium or low). This decree prohibits irreversible negative impacts in maximum relevance caves and, however, it allows impacts on the other caves categories, following proper environmental permit and/or compensation. A regulation defined a 250 meters buffer as the default area of influence to be preserved around caves. Environmental studies can be submitted to the federal environment regulator to re-evaluate and better define the area of influence, allowing its reduction. Specifically for some maximum relevance caves, the Serra Norte mineral reserve estimation considered a 150 meters buffer for their protection, but, in the case of mineral resources, no constraints were considered. The request for alterations on protective influence area needs to be assessed and approved by the Brazilian federal environmental regulators and, depending on the decision, it can have positive or negative impacts on mineral reserves and resources disclosed. In January 2022, a new federal decree was enacted, revoking the regulation of 1990 and its subsequent amendments and establishing new rules for the protection of caves, including with respect to relevance classifications and forms of compensation, and the impact of it on our operations is under review. This 2022 decree, however, is currently being challenged in the STF by a political party on the grounds that such regulation is unconstitutional since it allegedly reduces the legal protection of caves and it has been temporarily suspended until further decision of the court.
- The Carajás National Forest (FLONA Carajás) was created in 1998 as a conservation unit in which the management of natural resources is allowed. FLONA Carajás has an environmental Management Plan, which defines a land zoning, encompassing the "Mining Zone" category. The Management Plan has legal provision to be reviewed, and the last revision was in 2016. A portion of Serra Norte deposit is outside the Mining Zone and depends on the modification of this status to allow mining activities. We have a reasonable expectation that the Management Plan will be revised, depending on the assessment and approval of Brazilian federal environment institutes. If our petition is denied (or partially approved), a portion of the mineral reserves and resources will be affected.
- Geotechnical and hydrological assumptions used in mine planning are based on historical performance, and to date historical performance has been a reasonable predictor of current conditions. As the pit trends deeper; however, additional geotechnical and hydrological data collection is warranted. Any changes to the geotechnical and hydrological assumptions could affect mine planning, affect capital cost estimates if any major rehabilitation is required due to a geotechnical or hydrological event, affect operating costs due to mitigation measures that may need to be imposed, and impact on the economic analysis that supports the mineral reserve estimates.

Opportunities include:

- The mineralization of Serra Norte deposits remains open at depth under the current open pit outline. Additional exploration evaluation is warranted;
- Potential conversion of the measured and indicated mineral resources reported exclusive of mineral reserves, with supporting studies, to mineral reserves;
- Potential conversion of inferred mineral resources, with supporting studies, to higher confidence mineral resource classifications;

22.12.2. Mineral reserves statement

In addition to the risks associated with prices, costs, process, commodity price volatility, as already mentioned in chapters 11 and 12, release of radius reductions in caves of maximum relevance around the pits (N1, N3, N4 and N5), in the necessary time, among other environmental licenses that are beyond our effective control, are considered risks.

As an opportunity, we have the cost reduction with the implementation of the Trolley project and increase the use of autonomous trucks. We also have high potential to increase the reserve if the suppression of the most relevant caves adjacent to the pits, currently treated as blockages in the areas where they are, were released.

In 2022, the ANM issued Resolution No. 95/2022, consolidating the content of various previously created standards related to mining dam safety, and introducing new features under the National Dam Safety Policy. After, in 2025, the ANM issued Resolutions No. 220/25, replacing the prior framework.

With regard to dam safety Res. 220/25 ANM updated its regulations to meet the new parameters and implemented additional changes. The new ANM resolution further tightened restrictions on the presence of workers in the Self-Rescue Zone (ZAS) of dams, excluding from the permitted activities those related to mining operations, ore processing, and the disposal of tailings and waste rock.

The mineral sector is working to promote a more reasonably grounded solution that ensures operational safety and enables continuity of activities. in the worst-case scenario, if the wording of Resolution 220/25 remains unchanged, we could have a temporary suspension of operations and facilities and infrastructure within the ZAS that have fixed workstations will need to be relocated, or containment structures will need to be built. And, if it is not possible to carry out the aforementioned relocation or the construction of containment structures, activities may be temporarily suspended.

23. Recommendations

If applicable, the qualified person must describe the recommendations for additional work with associated costs. If the additional work program is divided into phases, the costs for each phase must be provided along with decision points at the end of each phase.

23.1. Property description

It is recommended to proceed with ANM to issue the report on mining easements under approval.

23.2. Geology and mineralization

It is recommended to keep the routine works of geological data collection with mappings, sampling, and developing drilling campaigns (short and long term), to keep improving the knowledge of the high-grade ores, structural and stratigraphy.

Further work is required to determine the exploration potential below the current open-pit operations and not operated plateaus. The exploration targets are mainly associated with the outcrops of structured cangas, friable hematites and jaspilites, or geophysical anomalies.

23.3. Hydrogeological and geotechnical

Regarding to the geotechnical and hydrogeological considerations, it is recommended to develop an effective Ground Control Management Plan, a complete Quality Assurance and Quality Control Program, and promote continuous increase in database improvement (drillholes and testing) to reduce the identified database backlog and provide information from new areas. This will provide a robust basis for geotechnical and hydrogeological evaluation, modelling and mitigation measures. It’s also suggested to implement deep structural information from down the hole geophysical evaluations and with the geotechnical testing increase probabilistic analyses

To achieve the maturity level of the geotechnical and hydrogeological studies of the mines throughout the project life cycle, it is necessary to refine the hydro and geotechnical database, models, and monitoring programs continuously.

23.4. Mineral resource statement

The continuity of geological drilling annual plans to better assess the geology in depth increases the geological knowledge and the confidence to convert inferred and indicated classes to indicated and measured categories.

23.5. Mineral reserves and mining methods

The mining dilution and recovery rates used in the reserve estimates can be more assertive. For this, Vale should plan drilling to improve geological interpretation and grade estimation and improve the reconciliation process by deploying more samplers that can improve the assertiveness of the dilution and loss assumptions that support the reserves statement.

Search for new technologies to minimize the need for lining, especially in the waste dumps and in the mining fronts that have a floor under soft material (mainly decomposed mafic).

23.6. Processing and recovery methods

Verification of existing process controls to identify opportunities, bottlenecks and/or improvements for process optimization, especially in the rainy season when processing productivity is lower.

QP's opinion: The process route for processing the Serra Norte material is highly reliable because it involves traditional beneficiation equipment where Vale has extensive experience in this type of process. Through this route, it can generate high volume of production with satisfactory quality.

During the rainy season, a drop in production is already expected due to the characteristics of the material. Some controls and actions are being adopted to improve performance during this period, such as automation (hourly rate control based on the electrical current of the screens), optimization of screen parameters, and lower participation of hydrated ore.

In magnetic concentration, it is understood that sampling at the Gelado dam will allow mapping of regions with different characteristics, thus supporting the creation of blends to meet feed specifications.

23.7. Environmental

Continue monitoring and implementing environmental programs to ensure the mitigation of the environmental impact of operations by:

- Benchmarking environmental best practices;
- Developing projects that consider sustainability from the outset and minimize the complexity of permitting processes, as much as possible;
- Continue conducting studies and research, in order to address potential risks related to endemic species and maximum relevance caves, in permitting processes.

23.8. Costs and economics

Maintain the focus on the discipline of capital allocation and the elimination of possible inefficiencies, to guarantee, with operational safety, cost competitiveness, and consequently, healthy margins and balance sheets in any price scenario.

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25. Reliance on information provided by the registrant

25.1. Introduction

QPs fully relied on the registrant for the information used in the areas noted in the following sub-sections. QPs consider it reasonable to rely on the registrant for the information identified in those sub-sections, for the following reasons:

- The registrant has been owner and operator of the mining operations since 1984;
- The registrant has employed industry professionals with expertise in the areas listed in the following sub-sections;
- The registrant has a formal system of oversight and governance over these activities, including a layered responsibility for review and approval;
- The registrant has considerable experience in each of these areas.

25.2. Macroeconomic Trends

Information relating to inflation, interest rates, discount rates, and taxes was obtained from the registrant.

This information is used in the economic analysis in Chapter 19. It supports the assessment of reasonable prospects for economic extraction of the mineral resource estimates in Chapter 11, and inputs to the determination of economic viability of the mineral reserve estimates in Chapter 12.

25.3. Markets

Information relating to market studies/markets for product, market entry strategies, marketing and sales contracts, product valuation, product specifications, refining and treatment charges, transportation costs, agency relationships, material contracts (e.g., mining, concentrating, smelting, refining, transportation, handling, hedging arrangements, and forward sales contracts), and contract status (in place, renewals), was obtained from the registrant.

This information is used in the economic analysis in Chapter 19. It supports the assessment of reasonable prospects for economic extraction of the mineral resource estimates in Chapter 11, and inputs to the determination of economic viability of the mineral reserve estimates in Chapter 12.

25.4. Legal Matters

Information relating to the corporate ownership interest, royalties, encumbrances, easements and rights-of-way, violations and fines.

This information is used in support of the property description and ownership information in Chapter 3, the permitting and mine closure descriptions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.

25.5. Environmental Matters

Information relating to baseline and supporting studies for environmental permitting, environmental permitting and monitoring requirements, ability to maintain and renew permits, emissions controls, closure planning, closure and reclamation bonding and bonding requirements, sustainability accommodations, and monitoring for and compliance with requirements relating to protected areas and protected species was obtained from the registrant.

This information is used when discussing property ownership information in Chapter 3, the permitting and closure discussions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.

25.6. Stakeholder Accommodations

Information relating to social and stakeholder baseline and supporting studies, hiring and training policies for workforce from local communities, partnerships with stakeholders (including national, regional, and state mining associations; trade organizations; fishing organizations; state and local chambers of commerce; economic development organizations; non-government organizations; and state and federal governments), and the community relations plan was obtained from the registrant.

This information is used in the social and community discussions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.

25.7. Governmental Factors

Information relating to taxation and royalty considerations at the Project level, monitoring requirements and monitoring frequency, bonding requirements, violations and fines was obtained from the registrant.

This information is used in the discussion on royalties and property encumbrances in Chapter 3, the monitoring, permitting and closure discussions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.