Technical Report Summary

Serra Sul Complex
Brazil

Report current as of: December 31, 2023

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1. Executive Summary

1.1. Introduction

VALE S.A. (VALE) prepared this Technical Report Summary on the Serra Sul Mine Complex, located in the state of Pará, Brazil. This report is intended to support the disclosure of Mineral Resource and Mineral Reserve estimates for the Serra Sul Complex as of December 31, 2023. This Technical Report Summary complies with the United States Securities and Exchange Commission'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.

VALE is one of the largest mining companies globally, a prominent Brazilian exporter, and one of the major private companies in Brazil. Operating in five continents, the company has a global and diversified shareholder base, with shares traded on the main stock exchanges around the world.

A world leader in iron ore pellet and nickel production, VALE also produces manganese, ferroalloys, copper, gold, silver, cobalt, and platinum group metals. Our top-quality ores are produced to meet customers' needs in steel mills worldwide.

To optimize product delivery, VALE operates a globally integrated and efficient logistics chain that includes railways, maritime terminals and ports, in addition to floating transfer stations and distribution centers.

VALE also invests in the energy and steel industries, both directly and through affiliates and joint ventures.

The Serra Sul Complex is part of VALE’s Northern System in the southeast of the State of Pará in Northern Brazil. This region underwent various geological processes, resulting in large deposits of iron but also 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 and location

The Serra Sul Complex is included in mining right 813.684/1969, which is in the Mining Concession phase. Part of the mining operations are located within the National Forest of Carajás (FLONACA) and the Campos Ferruginosos National Park. The other part of the mining process, where the beneficiation plant and facilities are located, is mostly in properties owned by VALE. Only two surface real properties are not owned by VALE, but both are covered in the mining easement report issued by the National Mining Agency (ANM). These surface properties are owned by the Brazilian Government.

The Serra Sul Complex includes three contiguous easement areas which form a single perimeter encompassing all current and future industrial installations required for the Serra Sul life of mine.

1.3. History

Geological surveys in Serra dos Carajás began in 1922, but iron formations were not mentioned until 1933. In *Carta do Brasil ao Milionésimo*, published by IBGE in 1960, Serra Sul orebodies C and D can be seen in the aerial photograph, but they were initially misinterpreted as “limestone plateaus with elevated lakes in the south of Pará”. From 1967 onwards, several detailed surveys were undertaken on the different areas known as Serra Norte, Serra Sul, and Serra Leste.

In 1977, VALE (at the time Companhia Vale do Rio Doce – CVRD) acquired the shares held by United States Steel (USS) and became the sole shareholder of the Carajás project. In 1979, the construction of the complex began, including the mine, railroad, and port for the Carajás Iron Project. In February 1985, the São Luiz–Carajás railroad was completed. Iron ore production began in 1985 in the Serra Norte Complex, while mining operations in the Serra Sul complex started in 2016.

1.4. Geological setting and mineralization

The main Carajás iron ore deposits are associated with plateaus, usually on elevated areas at 650-800 meters of altitude along two main morphological lines called Serra Norte and Serra Sul. These lineaments are the limbs of the Carajás Syncline.

The Serra Sul Complex corresponds to the normal limb domain of the Carajás Syncline, characterized by a lower degree of deformation when compared to the inverse limb, which is reflected in the greater continuity of the iron formations.

The S11 deposit corresponds to the largest plateau and the main mineralized body of Serra Sul. This plateau extends for 28 km NW-SE. It is segmented with sharp variations between N-S and E-W, which configures a kink-type pattern. The deposit includes bodies A, B, C, and D, the latter of which is the one with the highest economic interest. The rock types in the plateaus are mainly from the Carajás and Igarapé Cigarra formations, interfacing with the Parauapebas Formation to the south and the Águas Claras Formation to the north. The layers present variable dips and azimuths shifting between north and east orientation, in a normal stratigraphic stacking.

At the eastern portion of the S11 plateau, where the active part of the S11D mine is located, geological data was obtained from mapping on a 1:2,000 scale, diamond drilling, trenches and channels.

Therefore, most of the geological information on the plateau was obtained from diamond drill cores and surface mapping of weathered materials. Due to the strong/deep weathering and the absence of cuts and excavations, outcrops were scarce.

The Carajás Formation corresponds to the thickest domain of the iron formations. It coincides with the highest elevations. The iron formations in the Carajás Formation domain occur in a tabular layer with medium to low dip angle to the north in the EW-oriented bodies, such as S11D, and medium to high-dip angle to the east and northeast in the NS-oriented bodies, such as SSC. Actual thickness has not been determined; however, it can exceed 450 m depth (section) and vary between 200 and 1,200 m (plan).

The S11 iron formation layout presents strong structural control. Faults and folds condition the thickness and continuity of the iron formations. The structures correlate with the Transamazonian and Braziliano tectonic events, such as: the nucleation of the Carajás Syncline, folds with sub-horizontal axes of NW-SE orientation verging towards SW, the development of faults that created the kinked segmentation of the SS11 plateau, the formation of discontinuities filled by mafic dikes with NW-SE orientation, and the establishment of normal faults that generated a horsts and grabens system, lifting localized jaspilite bodies.

Friable hematite is the most representative lithology of the mineralization, occurring from near the surface to depths greater than 450 m with average Fe grades around 68.8%, with relatively low levels of phosphorus, silica, alumina, and loss on ignition.

Canga soils occur widely on the surface of Plateau SS11 as a result of weathering of different rocks in the region. Thus, they differ depending on the substrate and can be split into chemical canga, which includes mafic rocks, enclosing or intrusive in the iron formation; and structured canga, which develops directly over the iron formations and is economically viable. Fe content of this lithotype is 64.2% in average, and the main contaminants are alumina and phosphorus in addition to high values of loss on ignition.

1.5. Exploration

1.5.1. Exploration

Exploration work was initially based on details of a regional mapping on a scale of 1:100,000 produced by the Geological Survey of Brazil (CPRM). VALE's team develops in-depth work with mapping at different scales and drilling.

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

1.5.2. Drilling

The exploration work 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 iron ore.

Recent works in Serra Sul incorporated approximately 82,000 meters of drilling in 2017 and 79,000 meters in 2020. There is a 200 by 200 m grid for S11C which defines the optimal drilling grid for resource definition. In S11D, long-term and short-term drilling programs were performed with the purpose of defining the resources (100x100 m) and ore control (50x50 m).

A summary of drilling per area is presented in Table 1-1.

Table 1-1 - Summary of drilling in the Serra Sul Complex

Orebody	# Drillholes	Meters (m)
S11D	1,901	326,313.83
S11C	188	40,375.01
TOTAL	**2,089**	**366,688.84**

1.5.3. Hydrology

Groundwater models were prepared using industry-standard water modelling software to support dewatering permits. Hydrogeological models are tools used to simplify the representation of groundwater dynamics and enable the simulation of different scenarios.

The numerical model developed in MODFLOW (MDGEO, 2020) and revised by the VALE team in 2022 was used for drawdown simulation. The simulated outflow is estimated at 1,032 m^3/h, of which 215 m^3/h come from the pit in orebody C and 817 m^3/h from the pit in orebody D. To calibrate the model, 92 instruments were used, and the resulting root mean square error (nRMS) was 4.4%.

The database was deemed satisfactory for its main purpose, which was to build, calibrate and simulate future mining scenarios in a groundwater numerical model, providing water level data to be inputted into the geotechnical stability analysis to guarantee dry mining operations and depressurized slopes.

1.5.4. Geotechnics

The final slope design geotechnical assessment is conducted by VALE's geomechanical and hydrogeological teams in accordance with the procedures expounded in Section 14.4.1. To substantiate the Serra Sul project geotechnical assessments, a compendium of previous studies has been drawn upon, including those conducted by VALE (2022), VOGBR (2008), Golder (2012 and 2013), Geominas (2017), SRK (2020), MDGEO (2020), and TEC3 (2020).

1.5.5. Sampling

Core sampling follows corporate governance procedures and mining industry standards. The efficiency of sampling and laboratory analysis processes applied in the Serra Sul Complex operations is ensured by periodic reviews and/or audits.

1.5.6. Density Determinations

The density database comprises 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 with normative mineralogical calculation techniques to assign the final density values to the geological model.

The Serra Sul Complex mines tonnage is reported in wet basis, so it is very important to determine the average moisture values for each lithology. Such values are obtained by drying a fraction of the sample and comparing the dry and wet sample masses.

1.5.7. Sample preparation and analyses

The 1970s drill holes were prepped and assayed at the Serra Norte laboratory and the Companhia Vale do Rio Doce laboratory in Belo Horizonte. Only global assays were done for Fe, SiO_2, P, Al_2O_3, Mn, FeO and LOI (Loss on ignition). Measurements of magnetite percentage in the ore were also taken using Satmagan equipment.

The assay of RC drilling programs from 2003 to 2005 was undertaken by the GADIN Chemical Analysis Laboratory of the Carajás Iron Mine, Brazil. In 2005 and 2006, VALE engaged the ALS Chemex Laboratory in Vancouver, Canada exclusively for the analysis of 5% checks on duplicates of pulverized material to evaluate the performance of the GADIN Chemical Laboratory. The following analytes were assayed: Fe%, SiO_2%, Al_2O_3%, P%, Mn%, MgO%, TiO_2%, CaO% and Cu ppm.

Starting in 2013, Fe assays are wet for all fractions. The other analytes are determined by X-ray fluorescence, except for Loss on Ignition, for which gravimetry was used. From 2009 onwards, no more assays were made for Cu.

1.5.8. Quality Assurance and Quality Control

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

Upon assessment of QA/QC results from 2012 to 2019, sampling/chemical assay accuracy is good and analytical biases/flaws are small or insignificant when compared to the grade ranges involved. The accountable teams (geology teams and laboratories involved) have already been requested to investigate the most relevant points of attention. Non-compliance, precision, and accuracy indicators from QA/QC data were generally deemed satisfactory and not compromising to their respective databases.

1.6. Data verification

VALE had data collection procedures in place that included several verification steps to ensure database integrity. VALE staff also conducted regular logging, sampling, laboratory, and database reviews. All technical records related to borehole, spatial and geophysical trajectory logs, core box photographs, descriptions, density tests, samples, petrography, physical and chemical results, among others, are kept in adequate repositories and/or information technology systems and available for checks and/or investigations whenever necessary.

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

Alongside mining operations activities, each site conducts periodic reconciliations. Annual consolidated results reports comparing short-term models, mineral resources and reserves models, production grades and tonnage are discussed in annual technical meetings to promote continuous improvement for all functions involved.

1.7. Mineral resource estimates

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 within the domain(s); compositing of drill hole information on a consistent support size (length, density, recovery), statistic validation of lengths and variables before and after compositing; comprehensive understanding of the variables' statistical characters in each estimation domain and at the contacts between domains; characterization of the spatial continuity of each modelled variable (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, post-processing methods); validation of the estimates (visual inspection, global and local bias checks, kriging plan confirmation, 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 in estimation include Vulcan, Leapfrog Geo and Isatis.

Block grades were estimated using ordinary kriging (OK) in Vulcan software whilst the variography is performed in Isatis 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. Classification of blocks was based on the Risk Index methodology, which combines orebody continuity and estimation error. Blocks that estimated from a single drillhole were downgraded to indicated blocks. Subsequently, this automated classification was compared with a regular geometric classification method to better assess the classification.

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), suitability of the current waste piles projected capacities. Pit inter-ramp slope angles varies according to lithology and range from 22-40°.

VALE established the commodity pricing forecasts using a consensus approach based on long-term analyst and bank forecasts, supplemented with research by VALE's internal specialists. This approach is considered reasonable for 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 the mineral resources converted into mineral reserves.

A summary of the mineral resource estimates exclusive of reserves is provided in Table 1-2 and Table 1-3. Mineral resource estimates are in metric million tons including moisture and dry %Fe grade.

Table 1-2- Measured and indicated mineral resources exclusive of mineral reserves

Complex / Deposit	Measured		Indicated	
	Tonnage (Mt)	Grade (%Fe)	Tonnage (Mt)	Grade (%Fe)
Serra Sul	542.5	66.1	407.0	64.8

Notes to accompany mineral resources tables:
1. The effective date of the estimate is 2023/Dec/31.
2. Tonnage stated as metric million tons inclusive of 6.6% of moisture content and dry %Fe grade. The point of reference used is in situ tons.
3. The mineral resource prospects of economic extraction were determined based on a long-term price of USD93/dmt for 62% iron grade.
4. Numbers have been rounded.

Table 1-3 - Inferred mineral resources exclusive of mineral reserves

Complex / Deposit	Inferred	
	Tonnage (Mt)	Grade (%Fe)
Serra Sul Complex	123.7	64.6

Notes to accompany mineral resources tables:
1. The effective date of the estimate is 2023/Dec/31.
2. Tonnage stated as metric million tons inclusive of 6.67% of moisture content and dry %Fe grade. The point of reference used is in situ tons.
3. The mineral resource prospects of economic extraction were determined based on a long-term price of USD93/dmt for 62% iron grade.
4. Numbers have been rounded.

The mineral resource estimate has changed since the previous Serra Sul Complex Technical Report Summary was filed, having increased by 82 million tons (corresponding 8% of the exclusive mineral resource) due to partial incorporation of downgraded material in mineral reserve mine design review.

Areas of uncertainty that may materially impact the mineral resource estimates include: changes in long-term metal prices and exchange rates 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, permitting and social license assumptions.

1.8. Mineral reserves estimate

The Serra Sul ore body is divided into four bodies: A, B, C and D. A and B are potential bodies currently under study. Only bodies C and D have estimated and officially declared models, and body D is currently in operation. Measured and indicated resources of these deposits (C and D) are converted into proven and probable after the reserves have been estimated. More details about the resources can be seen in chapters 6 and 7.

The optimized pit considered environmental constraints and some large physical structures already established in the area, processing and mining costs that take into account additional deepening increments, sales costs, commodity price curves, geotechnical parameters, mine recovery and dilution.

The cost methodology defined two phases within the optimal pit; one uses the mobile crushing method and the second uses conventional shovels and trucks. This enabled us to separate the costs for each method. A certain pit geometry was established for mobile crushing to separate this phase, and all blocks below this geometry are assessed with the conventional mining methods.

Finally, these parameters were applied to generate a family of pits and the optimal pit was picked based on the best possible economic criteria (see further details in chapters 12 and 13). After this first step, the pit was submitted first to geotechnical evaluation and again to post optimization to incorporate some geotechnical parameter corrections. Only after this second round of optimization the pit is submitted to the implementation team and a final geotechnical analysis for final corrections according to the implementation geometry, to ensure slope safety and stability. Table 1-4 presents the results of proven and probable reserves.

Table 1-4 - Proven and Probable Mineral Reserve Statement 2023

Pit/Operation	Classification	Tonnage (Mt)	Grade
			Fe (%)
S11CD	Proven	1,506.6	65.7
	Probable	1,924.3	65.2
	Total Proven + Probable	**3,430.8**	**65.4**

Notes to accompany mineral reserves tables:
1. The effective date of the estimate is Dec 31, 2023.
2. Tonnage stated as metric million tons inclusive of 6.79% of moisture content and dry %Fe grade. The point of reference used is in situ metric tons.
2. The mineral reserve economic viability was determined based price curve with the long-term price being USD79.62/dmt for 62% iron grade.
4. Numbers have been rounded.

The mineral reserve estimate has changed, in comparison to the previous Serra Sul Complex Technical Report Summary filed due to a review study on the environmental protection buffer. This review aimed at safeguarding some maximum relevance caves, Violão and Amendoim lakes and their respective hydrological contribution area.. Therefore, we expanded our environmental constraints for pit generation, increasing the protection buffer, which resulted in a decrease in mineral reserves at Serra Sul by 418 million tons (-10%). We have reasonable expectation of the permit being granted, however, the final impact on the mineral reserve and mineral resource will depend on the size of buffer area approved by Brazilian federal environmental agencies. Additionally, the mineral reserve at Serra Sul was further reduced by 75 million tons (-2%) due to mine depletion and by 269 million tons (-6%) due to changes in mining recovery assumptions and mine design reviews. Despite these reductions, the expected exhaustion date for the Serra Sul Complex has not significantly changed after adjusting the production plan, with the impact deferred to the final years of production.

1.9. Mining methods

The Serra Sul mine uses the open pit method. The mine operation is split into favorable mining zones, belt operations and high geometric complexity zones operated by the conventional Truck and Shovel system.

In the areas that allow belt operations, mining is carried out by electric rope/hydraulic shovels that feed the mobile crushers. These materials, whether ore or waste, are reduced to particle sizes that can be fed into the belt conveyors and taken to the processing plants or waste piles. Materials are separated in transfer houses and placed on the belts that correspond to their destination.

In addition to rope/hydraulic shovels and mobile crushers, flexibility in operations is ensured by wheel loaders and various cleaning and backup jobs for the shovels, when necessary. A fleet of haul trucks is used for situations where truckless mining is not possible. Bulldozers are in charge of clearing production areas and benches. Wheel tractors, graders and water trucks make up the remaining auxiliary fleet.

The current estimated production target is 90 Mtpy; planned expansions should raise this to 120 Mtpy, considering that is necessary to implement a semi mobile crusher and the new long distance conveyor belt from the mine to the plant.

The geotechnical parameters used in the pits are validated and provided by the contracted and in-house geotechnical teams. Periodic inspection procedures verify the stability of slopes, waste rock piles, dams, dikes and drainage systems in order to guarantee the safety and continuity of operations.

1.10. Processing and Recovery Methods

The Serra Sul mill is a conventional crushing and screening facility with 90 Mtpa installed capacity. The expansion of the S11 project to 120 Mtpy includes the implementation of new crushing and screening stages, as well as a new long distance conveyor belt for transporting ore from extraction points to processing. All ROM is processed at natural moisture. There is no concentrator, and all plant throughput is recovered as final product. The primary operations include:

- Primary cone crushing.
- Primary vibrating banana-type screen.
- Secondary cone crushing.
- Secondary vibrating banana-type screen.
- Tertiary cone crushing.

Ore is crushed in three stages to 100% passing (P_{100}) 19 mm using cone crushers with vibrating screens.

Secondary crusher throughput and primary screen undersize are collected in an intermediate stockpile with a total capacity of 1 Mt, or three days' normal operation. The ore from this stockpile is reclaimed and fed to the tertiary cone crushers. The final product is shipped by railway to the São Luiz port.

1.11. Infrastructure

Most of the support infrastructure for mining operations is in place. There is a temporary accommodation camp on site to accommodate workers involved in expansion projets. Most of the workforce resides in Canaã dos Carajás.

Water can be abstracted from permitted streams and downgradient wells. The process replacement water comes from the same sources already mentioned in the text. Potable water also comes from wells located in the mine and is treated onsite at a WTP - Water Treatment Plant. The Serra Sul operations team monitors water level, flow and balance regularly.

Electric power is supplied by the NIS - National Interconnected System at 230 KV. Part of the power (around 6% of energy consumption) is captured from the belt conveyors' regeneration system.

The internal distribution system runs through VALE's own 34.5 kV electrical networks.

In 2023, the plant and mine consumed about 303,301MWh, 56% of which fed the mineral processing plants, 35% were consumed at the mine and the remaining 8% were consumed by other supporting facilities.

1.12. Market studies

Iron ore is one of the core products sold by VALE globally. Its price and premiums can fluctuate along the year following supply and demand balance and short-term market sentiment trends.

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.

VALE established the commodity pricing forecasts using a consensus approach based on long-term forecasts by analysts and banks. The sole purpose these figures is to demonstrate the economic viability of the mineral reserve, therefore they can differ from other data we publish and should not be construed as guidance.

At the time this report was prepared, the analyst consensus price for 62% Fe iron ore in 2023 was USD114/t, trending downward until prices reach the long-term level of around USD80/t; the analyst consensus price for 65% Fe iron ore in 2023 was USD126/t, trending downward until prices reach the long-term level of around USD90/t. Additionally, we believe that the production our iron ore reserves predict for the future can be absorbed by the market in the long term if we consider the demand expected by market analysts.

1.13. Environmental, Permitting and Social Considerations

Serra Sul has been granted the required operating permits. Environmental monitoring protocols include biological, air quality, soil, climate, iron ore pits, surface and groundwater, dust control, and other protocols required to meet regulatory compliance.

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

The permitting process to increase production capacity from 90 to 120 Mtpa is underway with the Brazilian regulatory agency. The Installation Permits (LI) for both projects S11D +10 Mtpy and +20 Mtpy were obtained. A revision of the Carajás National Forest Management Plan to allow mining in certain areas is under discussion.

1.14. Capital and operating costs

1.14.1. Capital costs estimates

Economic valuations cash flows include sustaining CapEx, necessary for maintaining existing assets / operations, and capital projects to maintain and/or increase productive capacity. Sustaining CapEx can be classified into routine and non-routine.

Routine sustaining CapEx is related to projects to maintain operational capacity of the assets, including acquisition and replacement of equipment and readjustment of operating structures. It is estimated based on the Engineering team's assessments of the asset base, on a maintenance backlog and investment targets the company has established for future years.

Non-routine sustaining CapEx refers to projects that support the business strategy, ensuring compliance with the production plan, but which do not occur frequently. These include pit, waste and tailings disposal expansion projects, process and technology changes in the plants, among others. It is estimated based on the expected needs of each operation or production complex over the Horizon being assessed. After considering those needs, VALE's multidisciplinary teams estimate the cash flow investments of the economic evaluations.

The sole purpose of these figures is to demonstrate the mineral reserve economic viability. They can differ from other information published by VALE and should not be construed as guidance.

Additionally, economic assessments of reserves consider capital projects that aim to maintain and/or increase productive capacity. The overall LOM or assessed period capital cost estimate is USD15,573 million, as shown in Table 1-5.

Table 1-5 – LOM capital cost estimate

Capital Cost Type	Unit	Value
Sustaining CAPEX	US$M	***10,816***
Non-routine	US$M	**940**
Mine and plant	US$M	915
Waste and tailings piles	US$M	25
Routine	US$M	**9,876**
Capital projects CAPEX	US$M	**4,757**
Mine and plant	US$M	903
Logistics and Other	US$M	3,822
Waste and tailings piles	US$M	33
TOTAL	US$M	**15,573**

Note: numbers have been rounded.

1.14.2. Operating costs 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 projects are undergoing implementation.

In summary, the mining OpEx considers the cost of the operation or similar operations in previous years and their respective operational indicators as a reference. Thus, future operational indicators of operations are estimated, based on long-term mine planning. In this way, estimated costs take future changes in the operational indicators of operations into account.

LOM average unit operating cost and expenses:

- Mine and plant: 6.7USD/ton of product.
- Logistics and Distribution: 17.3USD/ton of product.
- Royalties: 4.9USD/ton of product.
- Sales expenses, R&D, others: 0.2USD/ton of product.

Total average unit operating costs and expenses: 29.1USD/ton of product.

The sole purpose of these figures is to demonstrate the economic viability of the mineral reserve; they may differ from other information VALE publishes and should not be construed as guidance.

The overall costs and expenses estimate for LOM, or the assessed period, is USD99,988 million, as shown in Table 1-6.

Table 1-6 – Operational Costs and Expenses

Type of costs and expenses	Unit	Value
Mine and plant	US$M	23,006
Logistics and Distribution	US$M	59,419
Royalties	US$M	16,939
Sales expenses, R&D, others	US$M	624
TOTAL	**US$M**	**99,988**

Note: numbers have been rounded.

1.15. Economic analysis

1.15.1. Introduction

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

1.15.2. Methodology and Assumptions

We applied the Discounted Cash Flow (DCF) economic evaluation methodology, which is widely used by companies, investment banks and consultancies to evaluate companies, projects, operations, etc.

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

To evaluate reserves, we forecasted the cash flows a given mass of product would be able to generate. To estimate potential yearly revenues from the mining of this resource, we took into account annual processed tonnages and grades, associated process recovery and metal prices. Operating costs, logistics costs, royalties, taxes, and capital expenditures required for economic exploitation were also estimated. If the forecasted 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 cash flow is documented in USD and all costs and prices are in unescalated 'real' dollars.

The forecasted exchange rate for the long term (LT) is shown in Table 1-7.

Table 1-7 – Long Term Exchange rate.

Exchange rate – real terms	2024	2025	2026	2027	2028	LT
R$ / USD	5.00	5.04	5.02	4.93	4.86	4.81

The evaluated cash flow period runs through the end of reserves for the operation or project. 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.

When assessing pellet feed (PF) operations and projects that supply our own pellet plants, we assumed that the product would be sold to third parties at market price, without taking the pelletizing process into account, that is, without the costs of pellet processing and the pellet premiums in revenue.

In summary, the planned mining OpEx considers the costs of the operation or similar operations in previous years and their respective operational indicators. That is how future operational indicators are estimated for long-term mine planning. In this way, the estimated costs are forecasted considering future changes in the operational indicators of the operations.

The overall costs and expenses estimate for LOM, or the evaluated period is USD99,988 million, as per Table 1-8.

Table 1-8 – Operational Costs and Expenses

Type of costs and expenses	Unit	Value
Mine and plant	US$M	23,006
Logistics and Distribution	US$M	59,419
Royalties	US$M	16,939
Sales expenses, R&D, others	US$M	624
TOTAL	**US$M**	**99,988**

Note: number have been rounded.

VALE's discount rates are re-calculated annually by the Treasury and Corporate Finance Department. To support mineral reserve statements, VALE WACC must be used. In 2023, a 7.0% WACC was calculated for VALE and used to demonstrate economic viability of mineral reserves.

1.15.3. Economic Analysis

The discounted cash flow method was used for the economic valuation model of reserves, including annual processed tonnages and grades. The associated process recovery, metal prices, operating costs, logistics costs, royalties, and capital expenditures were also considered. Economic analysis confirmed that Serra Sul is economically viable. The after-tax NPV at a 7.0% discount rate and following a mid-year convention is USD44,505M. A summary of the cash flow analysis results can be seen in Table 1-9.

Table 1-9 – Economic Evaluation.

Net present value of overall cash flow	Unit	Value
Total revenue	**US$M**	**111,117**
Total costs and expenses	US$M	-41,402
Mine and plant	US$M	-9,085
Logistics and Distribution	US$M	-24,880
Royalties	US$M	-7,159
Sales expenses, R&D, others	US$M	-266
Closure costs	US$M	-13
Income Tax and working capital change	US$M	-17,509
Operational Cash Flow	**US$M**	**52,205**
Total CAPEX	US$M	-7,700
Free Cash Flow	**US$M**	**44,505**

1.15.4. Sensitivity Analysis

Price and VIU cause the most impact in the sensitivity analysis, followed by mine, plant, logistics and distribution OpEx, exchange rates and total capex.

When the main variables are subject to a sensitivity analysis, NPV remains positive, which confirms the robustness of these reserves.

2. Introduction

2.1. Terms 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, including its material changes, for the Serra Sul Complex in Vale’s Form 20-F for the year ending 31 December, 2023, 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 new SEC rules align disclosure requirements with global regulatory practices and standards, as incorporated to the standards developed by the Committee for Mineral Reserves International Reporting Standards (CRIRSCO), which VALE is accustomed to using.

The effective date of this Technical Report Summary is December 31st, 2023.

The assumptions adopted in the preparation of this report involve inherent uncertainties and risks, and the information herein does not guarantee future performance. This report contains estimates, projections, and forward-looking statements, which can be identified by the use of words related to future projections, such as 'anticipate', 'believe', 'may', 'expect', 'should', 'plan', 'intend', 'estimate', 'will be', and 'potential', among others. These estimates, projections, and statements involve some known and unknown risks and uncertainties. VALE and the QPs cannot guarantee that such forward-looking statements will prove to be accurate. The risks and uncertainties related to our estimates and projections include, without limitation, factors related to (a) economic, political and social issues in the countries in which 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 by nature, and their reliance on global industrial production, which is also cyclical; (e) 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 preparing the forward-looking statements and (j) data provided by external sources.

VALE and the QPs emphasize that the actual results of VALE's mineral resources and reserves may materially differ from the plans, objectives, expectations, estimates, and projections expressed herein. VALE does not undertake any obligation to publicly update or review any forward-looking statement, whether as a result of new information or future events or for any other reason.

2.2. The Company

VALE is one of the largest mining companies in the world, a leading Brazilian exporter and one of the main private companies in Brazil. Operating on all five continents, the company has a global and diversified shareholder base, with shares traded in the main global stock exchanges. A world leader in the production of iron ore, pellets and nickel, VALE's portfolio also includes manganese, ferroalloys, coal, copper, gold, silver, cobalt, and platinum group metals. VALE's ores are of high quality and produced to competitively meet the needs of worldwide customers in the steelwork industry. To optimize product delivery, VALE operates a globally integrated and efficient logistics chain, 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 B3.

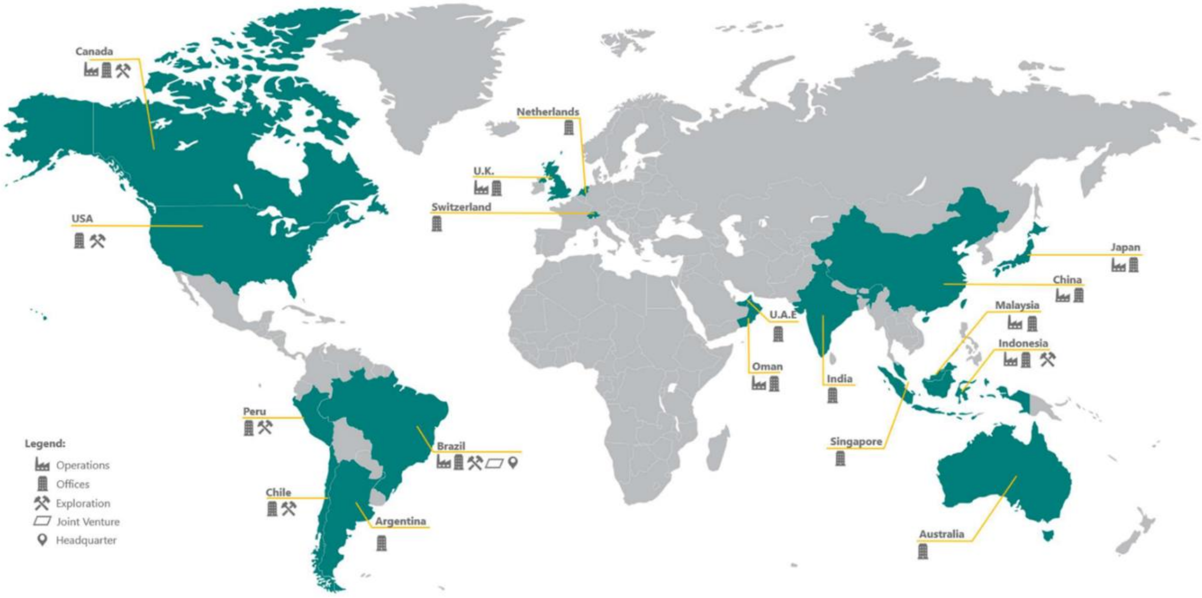

Figure 2-1 - Location of VALE's business segments.

2.3. Qualified Persons Site Visits

Qualified persons (QPs) involved in the estimation of mineral resources and reserves at Serra Sul are professionals with extensive experience in their fields who repeatedly visited the sites described in this report. Table 2-1 shows the latest visits and future schedule.

Table 2-1 - QPs site visits

QP	Last visit	Scheduled visit
Alessandro Gomes Resende	-	First half/2024
Arnor Barbosa de Couto Junior (Mineral Reserves)	October/2023	First half/2024
Evandro Machado da Cunha Filho (Geology / Mineral Resource)	October/2023	First half/2024
Hely Simões Gurgel (Process Development)	-	First half/2024
Luciano Souza Castro (Production Plan)	December/2023	First half/2024
Teofilo Aquino Vieira Costa (Geotechnical)	December/2023	First half/2024
Wagner Castro (Geotechnical)	December/2023	First half/2024

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 Gomes Resende, PQR CBRR	Mining Rights and Mine Closure Manager	1; 2; 3; 20; 21; 22; 23; 24 and 25
Arnor B. Couto Jr., PQR CBRR	Mineral Reserves Specialist	1; 2; 4; 12; 13; 15, 16; 17; 18; 19; 20; 21; 22; 23; 24; and 25
Evandro M. Cunha Filho, MAusIMM	Specialist Geologist	1; 2; 5; 6; 7; 8; 9; 11; 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
Wagner Castro, PQR CBRR	Master Geotechnical Engineer	1; 2; 4; 12; 13; 20; 21; 22; 23; 24; and 25
Hely Simões Gurgel, PQR CBRR	Process Development Specialist Engineer	1; 2; 10;14; 20; 21; 22; 23; 24; and 25
Teófilo Costa, PQR CBRR	Senior Geotechnical Specialist	1; 2; 7; 14; 20; 21; 22; 23; 24; and 25

2.5. 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 (USD) and converted to Brazilian Real per US Dollar.

Unless noted 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 TRS.

Unit	Abbreviation
American Dollar	USD
Bond Ball Mill Work Index (metric)	kWh/t
Brazilian Real	R$ or BRL
Centigrade	°C
Centimeter	cm
Cubic centimeter	cm^3
Cubic meter	m^3
Cubic meters per second	m^3/s
Day	d
Dead weight ton (imperial ton – long	Dwt

Unit	Abbreviation
Dry metric ton	dmt
Gigawatts	GW
Giga Years	Ga/Gy
Gram	g
Gram/liter	g/L
Gram/ton	g/t
Hectare	ha
Hour	h
Hours per Year	h/yr
Kilogram	kg
Kilogram per ton	kg/t
Kilometer	km
Kilopascal	kPa
Kilovolt	kV
Kilovolt amp	kVA
Kilowatt	kW
Kilowatt hour	kWh
Liter	T
Liter per second	L/s
Megawatt	MW
Megawatt per hour	MWh
Meter	m
Meter per hour	m/h
Meter per second	m/s
Metric ton	t
Metric tons per Annum	t/a
Metric tons per day	t/d
Metric tons per hour	t/h
Micron	Mm
Milligram	mg
Milligram per liter	mg/L
Millimeter	mm
Million	M
Million Dollars	USDM
Million short ton	MT
Million short ton per annum	MT/a
Million Years	Ma
Minute	min
Parts per billion	ppb
Parts per million	ppm
Percent	%
Second	s
Short ton	T
Square meters	m^2
Tons per Day	t/d
Troy ounce	Oz.
Wet metric ton	wmt

Unit	Abbreviation
Work index	WI
Year	yr

The following abbreviations are used in this report:

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

Abbreviation	Acronym
AG	Clay Lithotype
ANM	National Mining Agency
BEP	Brazilian Exploration Program
BR	Breccias
BRBF	Brazilian Blend Fines
Bt	Billion Tons
CAPEX	Capital Expenditure
CDM	Mineral Development Center
CE	Structural Canga
CFEM	Financial Compensation for the Exploitation of Mineral Resources
CFR	Cost and Freight
CNM	Mineralogical Normative Calculation
CLI	Interpreted Geological Classification
CLV	Visual Lithological Classification
CO	Colluvium
CQ	Chemical Canga
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
CS	Social Contribution
CPRM	Geological Survey of Brazil
CPT	Technological Research Center
CVRD	Companhia Vale do Rio Doce
DCF	Discounted Cash Flow
DIPM	Department of Mineral Exploration (VALE)
DM	Mining Rights
DNPM	National Department of Mining Production
DOU	Federal Gazette
EBIT	Earnings Before Interest and Taxes
EC	Crystalline Base
EDA	Exploratory Data Analysis
EFC	Carajás Railroad
ELM	Equilibrium Limit Method
FAC	Águas Claras Formation
FAI	Fixed Asset Investments
FEGL	Distribution of global iron grades
FIC	Igarapé Cigarra Formation
FLONACA	National Forest of Carajás
FMN	Manganiferous Iron
FP	Parauapebas Formation
FPIC	Free, Prior and Informed Consent
FOB	Free on board

FoS	Safety Factor
FRX	X-Ray Fluorescence
GDP	Gross Domestic Product
HC	Compact Hematite
HF	Friable Hematite
HGO	Goethitic hematites
HMN	Manganiferous Hematite
IBAMA	Brazilian Institute for the Environment and Renewable Natural Resources
IBGE	Brazilian Institute of Geography and Statistics
ICM	Intrinsic Correlation Models
ICMBio	Chico Mendes Institute
IK	Indicator Kriging
IOCG	Iron Oxide Copper Gold
IOCJ	Iron Ore Carajás
IPCC	In Pit Crusher Conveyor
IR	Income Tax
IRR	Internal Rate of Return
JCS	Joint Compressive Strength
JP	Jaspilite
JRC	Joint Roughness Coefficient
LI	Installation License
LO	Operation Permit
LP	Preliminary Permit
LOI	Loss of Ignition
LOM	Life of Mine
LT	Long Term
MCI	Intrinsic Correlation Model
MD	Decomposed Mafic
MLC	Linear Coregionalization Model
MS	Fresh Mafic
MSD	Semi-decomposed Mafic
NR	Net Value Return
nRMS	Normalized Root Mean Squared
NIS	National Interconnected System
NPV	Net Present Value
OK	Ordinary Kriging
OPEX	Operating Expenditure
PF	Pellet Feed
QA/QC	Quality Assurance/Quality Control
QP	Qualified Person
RI	Risk Index
RMR	Rock Mass Rating
ROM	Run of Mine
RPM	Runge Pincock Minarco
RQD	Rock Quality Designation
SEC	United States Securities and Exchange Commission's
SEMAS-PA	Secretary of State for the Environment and Sustainability
SIN	National Interconnected System

TMPM	Ponta da Madeira Maritime Terminal
TFRM	Control Fee Monitoring and Inspection of Research Activities, Mining, Exploration and Use of Mineral Resources
TTG	Tonalite-Trondhjemite-Granodiorite
UCS	Unconfined Compressive Strength
USS	United States Steel
UTM	Universal Transverse Mercator (coordinate system)
VIU	Value in Use
WSA	World Steel Association
WTP	Water Treatment Plant

The following chemical symbols are used in this report:

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

Element	Symbol
Aluminum	Al
Calcium	Ca
Iron	Fe
Magnesium	Mg
Manganese	Mn
Oxygen	O_2
Phosphorus	P
Potassium	K
Potassium	K
Silica	Si
Titanium	Ti

3. Property Description and Location

3.1. Location

The Serra Sul, Serra Leste, and Serra Norte Mining Complexes are located 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. The approximate coordinates of the Serra Sul Mining Complex are 574,671 E; 9,291,735 N, based on datum UTM_SAD 69.

The Serra Sul Serra Sul Mining Complex, also known as S11, is in the District of Canaã dos Carajás. Access to the site is mainly through the Canaã dos Carajás airport and 66 km along state highways PA-275 and PA-160, as seen in Figure 3-1.

The actual Serra Sul mine site corresponds to orebody S11 and blocks A, B, C, and D. The latter is the current operating mine area, referred to as S11D.

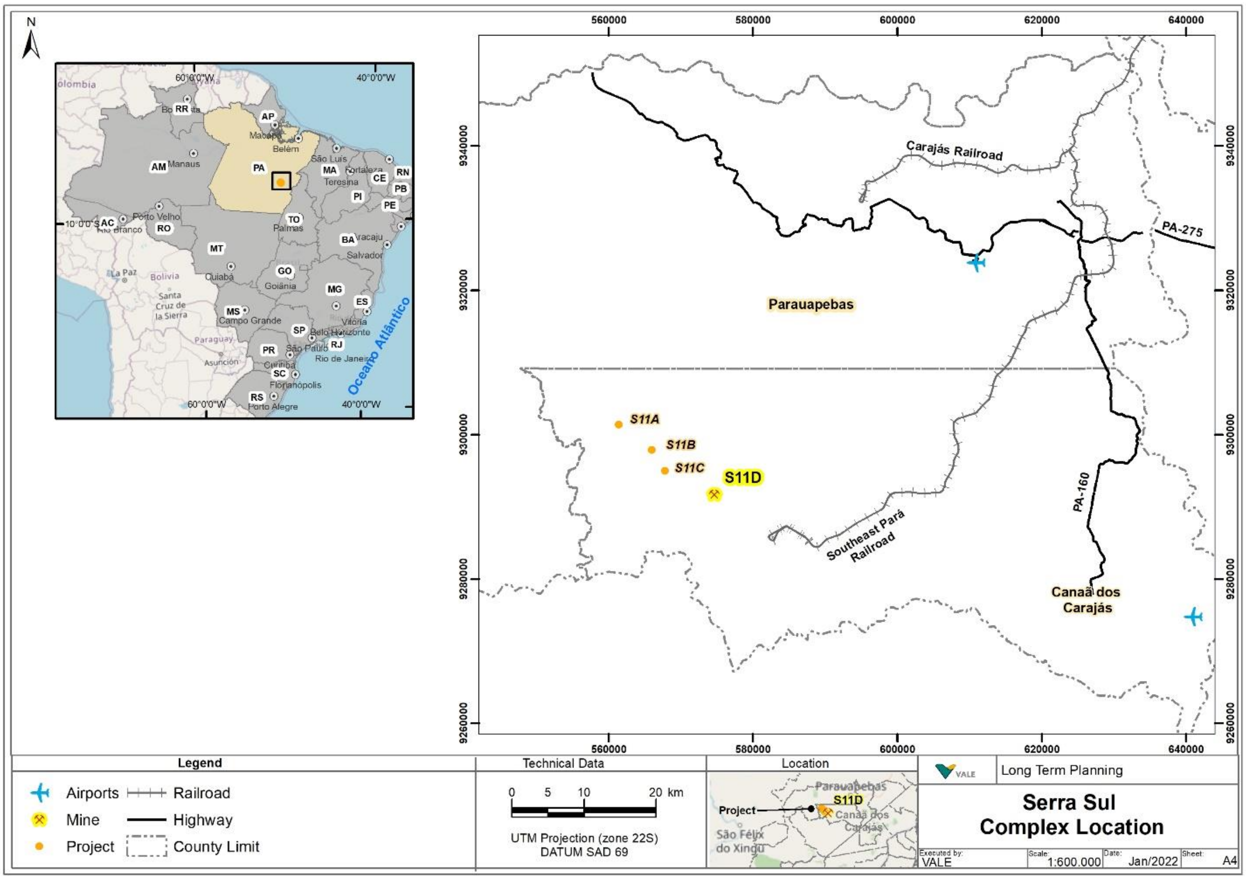

Figure 3-1 - Serra Sul Location Map.

3.2. Mineral and Surface Rights

Mineral Rights in Brazil are typically mineral exploration and mining concessions. In the North System, the original mining concessions were grouped as a single license, referred to as "Mining Group" (GM). This licensing format allows all mineral rights to be managed under one single process. The Serra Sul mineral right consists of a single mining concession (813.684/1969) covering an area of 98,910.42 hectares, as shown in Figure 3-3 and Table 3-1. This mining concession is part of a larger Mining Group right (852.145/1976) which includes Serra Norte and Serra Leste operations.

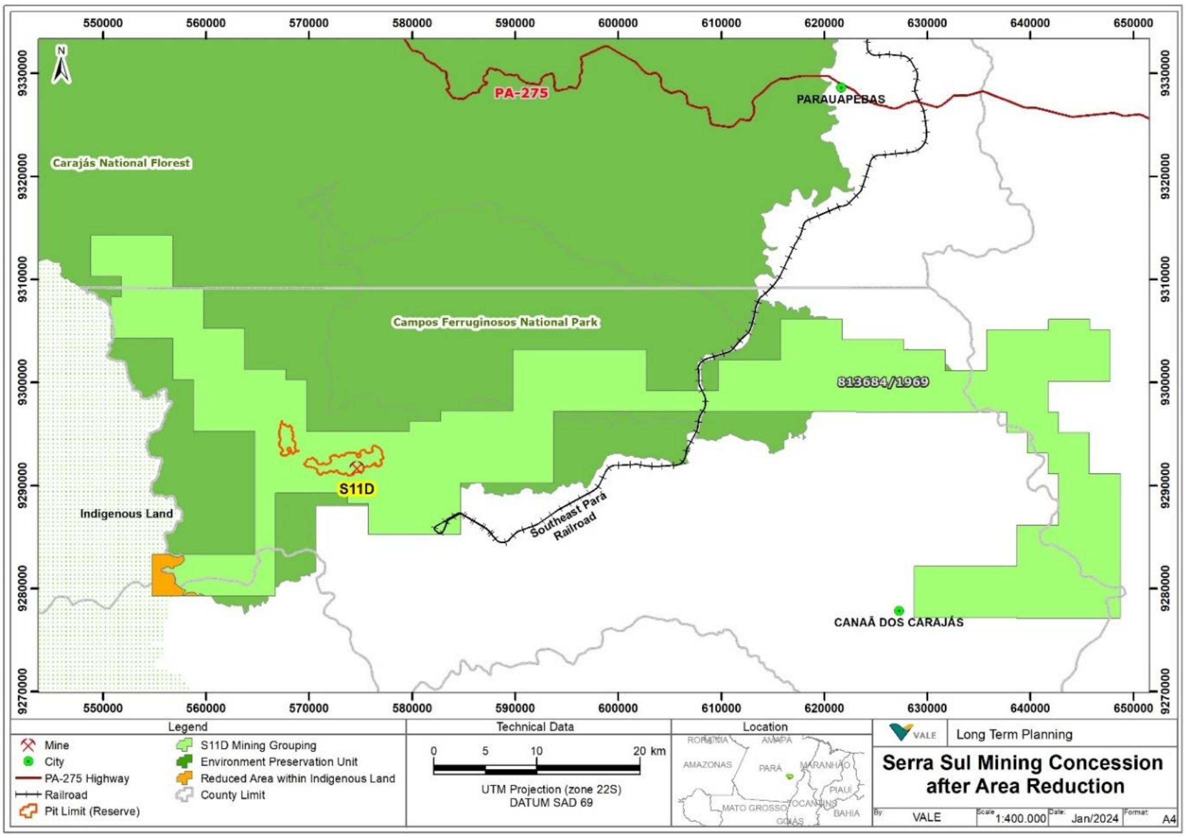

Figure 3-2 – Serra Sul Mining Concession Right which is part of a larger Mining Group.

Table 3-1 – Serra Sul Mining Rights forming the Concession Grouping

813.684/1969	Canaã dos Carajás	98,910.42	Mining concession	06/09/1974	Iron	S11D	813.684/1969

In 2021, VALE decided to relinquish part of the Serra Sul mining concession located in indigenous territory, reducing the area from 100,000 ha to 98,910.42 ha. By the time of this report, this reduction was pending formal acceptance by the public authorities.

According to Brazilian Mining Law, mineral rights are separate from surface real rights and the law requires that the holder of a mineral concession either reaches an agreement with the landowner or fulfills an easement procedure before starting any mining activities.

In Serra Sul, the land usage for mining purposes is granted through three mining easements and 77 of VALE's real properties, or "real estate", as shown in Figure 3-3.

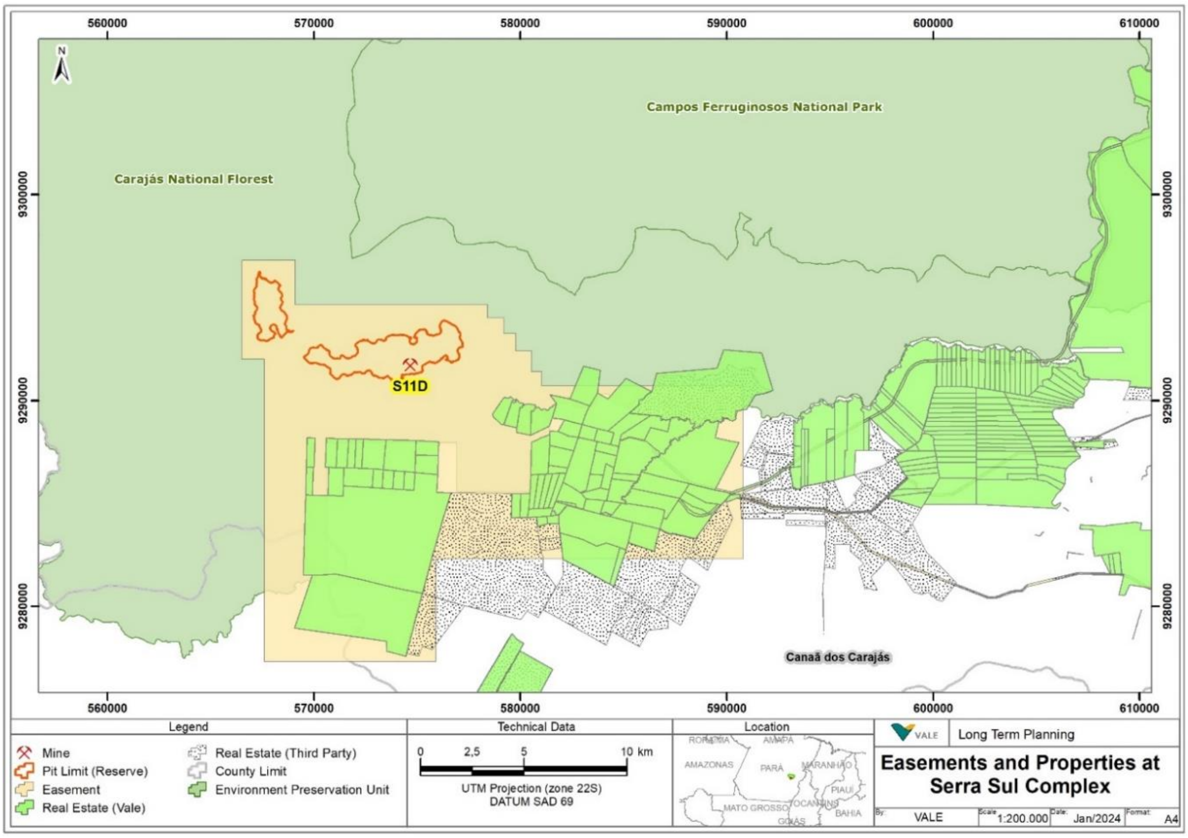

Figure 3-3 – Serra Sul - VALE Properties and Easements

There are currently three mining easements at the Serra Sul complex:

- Easement 1, with an area of 966.77 ha, for which the technical report was approved on October 21, 2010.
- Easement 2, with an area of 29,315.45 ha, for which the technical report was approved on January 25, 2013.
- Easement 3, with an area of 17,914.58 ha, for which the technical report was approved on January 25, 2013.

The three easements are contiguous and encompass all current and future industrial installations necessary for the Life of Mine plan based on the Mineral Reserves disclosed in this TRS.

3.3. 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 4.3734 per metric ton of ore produced in or shipped out of the state.

3.4. Material Government Consents

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 3-2 and 3-3.

Table 3-2 – Serra Sul operating licenses

License	Government Department	Description	Expiry date	Status
LO nº 043/2023	SEMAS-PA	Fuel station	Aug 31,2026	Valid license
LO_1361/2016 02001.000711/2009-46	IBAMA	Mining for S11D, expansions, plant and infrastructures	Sep 12, 2026	Valid license

(1) Brazilian law allows VALE to continue operations during the renewal process.

Table 3-3 – Serra Sul water usage licenses

License	Government Department	Description	Expiring date
Water usage license nº 2791/2017 - Process 2016/0000030550	SEMAS/PA	Process	Mar 20, 2022
Water usage license nº 3590/2019 – Process 2018/0000047840	SEMAS/PA	Process	Feb 13, 2024
Water usage license nº 4082/2019 – Process 2018/0000043086	SEMAS/PA	Human consumption	Dec 28, 2024
Water usage license nº 3918/2019 - Process 2018/0000027122	SEMAS/PA	Human consumption	Dec 17, 2029
Water usage license nº 4219/2020 – Process 2018/0000043090	SEMAS/PA	Process	Mar 03, 2025
Water usage license nº 4424/2020 - Process 2019/0000052144	SEMAS/PA	Human consumption	Jun 18, 2025
Water usage license nº 4746/2020 - Process 2020/0000008735	SEMAS/PA	Human consumption	Aug 29, 2030
Water usage license nº 4520/2020 - Process 2019/0000004930	SEMAS/PA	Lowering water table	Sep 16, 2030
Water usage license nº 1164/2016 - Process 02501.000073/2013	ANA	Process	Sep 29, 2026

4. Physiography, Accessibility, Climate, Local Resources, and Infrastructure.

4.1. Physiography

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

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 Sul has been modified by large-scale agricultural and livestock activities, resulting in a mix of pasture and forest remnants.

These are the national protected areas around Serra Sul:

- 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.

4.2. Accessibility

Serra Sul is connected by paved highways (PA-275 and PA-160) to nearby towns, including Canaã dos Carajás, which is 66 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, which connects the mine to the Ponta da Madeira port in the city of São Luis, Maranhão.

4.3. Climate

The mine is in a humid tropical monsoon region with dry springs, hot weather, and high average temperatures. The coldest months are January through March (20.5°C average), which coincides with part of the rain season. The highest temperatures are recorded from June to August (35°C average).

The rain season lasts from November to April, with 400mm average monthly precipitations, 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 never lower than 18°C.

Air moisture levels average from 70 to 85%. From June to August, the driest months, it reaches a minimum of about 50%. During the rainy months, October to May, it can exceed 95%.

4.4. Local Resources

The S11D Mine is located in the Carajás Mining Province in the State of Pará, Brazil. The nearest town is Canaã dos Carajás (population 77.079, 2022 census), 66 km east of the mine.

A greater range of general services, including hospital, accommodations, food, etc. is available in the city of Parauapebas (population 266.424, 2022 census), which is 70 kilometers north of Canaã dos Carajás.

4.5. Infrastructure

The Serra Sul operations include the following main infrastructure:

- Water catchment points, pipelines, and a treatment plant.
- Power line and substations.
- Maintenance workshops.
- Administrative buildings.
- Medical clinic.
- Offices and warehouses.
- Long-distance conveyor systems.
- In-pit crushing systems.
- Processing plant.
- Railway terminal.
- Ore stockpiles.
- Fuel stations.

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

Additional information on infrastructure is provided in Sections 16 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 mentions of 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 region’s phyto-physiognomy, when he observed non-forest formations with large clearings and lakes.

The first publication on Carajás can be found in the aerial photograph of Serra Sul bodies C and D in *Carta do Brasil ao Milionésimo*, published by IBGE in 1960, seven years before the deposits were discovered (Magalhães, 1960). The elevated fields of the area were inaccurately classified by the author as 'limestone plateaus with elevated lakes in the south of Pará'. It was later clarified that they correspond to iron plateaus and that the lagoons are water-filled sinkholes in the canga.

In 1967, the pioneering mapping work 'Stratigraphic, Structural and Economic Geology of the Araguaia Project Area' – DNPM/PROSPEC (1954 to 1966) was released. It includes a comprehensive aerial photogrammetric survey, but due to a lack of fieldwork the occurrence of iron ore was not identified. Because of the lakes in the region, forest clearings were interpreted as karstic landforms. In the same year, the United States Steel (USS) created the Brazilian Exploration Program–BEP to explore manganese, a strategic supply for the steel industry and for the American economy during the cold war. By the end of the May 1967, reconnaissance flights were made between the Tocantins and Tapajós rivers.

In July 1967, the Brazilian Exploration Program team received the Araguaia Project aerial photos and noticed several large 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. During a flyover in August at low altitude with a single-engine aircraft, the similarity between the clearings of Serra Norte and the canga cover of Serra Arqueada was noticed and an aeromagnetic survey was carried out in Sereno, Serra Leste, Serra Norte, and Serra Sul. Preliminary field surveys of the Serra Norte (N1, N2, N3, N4, N5) and Serra Sul were also conducted. In September 1967, the potential of 2 to 35 billion tons of iron ore was communicated to United States Steel in Pittsburgh.

Between September and October 1967, exploration requests were prepared and filed with the Departamento Nacional de Produção Mineral (DNPM) for 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, with 51% VALE (at the time Companhia Vale do Rio Doce – CVRD) and 49% United States Steel shares. The evaluation of Carajás iron deposits began in 1970. There were no access roads then and the work was conducted by air. Between 1970 and 1972, intensive exploration was performed 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 66% Fe iron ore were found concentrated in four main deposits: N4, N5, N1 (Serra Norte), and S11 (Serra Sul).

In 1977, VALE (CVRD) acquired the United States Steel shares and became the sole project owner. Construction of the Carajás Iron Project complex started in 1979, including 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, while the N4W deposit came into operation in 1994. Serra Sul operations started in 2016.

5.2. Past Production

Table 5-1 shows a summary of the Serra Sul complex production history.

Table 5-1 – Past production of Serra Sul complex

Year	Ore (t)	Waste (t)	Total Movement (t)	Product (t)	Stripping Ratio	Source
2016	380,138	0	380,138	380,138	0	Annual Mining Report
2017	22,183,561	11,055	22,194,616	22,183,561	0.00	Annual Mining Report
2018	58,025,579	362,718	58,388,297	58,025,579	0.01	Annual Mining Report
2019	73,368,966	905,528	74,274,494	73,368,966	0.01	Annual Mining Report
2020	82,846,725	1,632,140	84,478,866	82,846,725	0.02	Annual Mining Report
2021	73,698,914	4,781,969	78,480,883	73,698,914	0.06	Annual Mining Report
2022	69,256,883	8,293,229	77,550,112	69,256,883	0.12	Annual Mining Report
2023	74.981.741	9,150,041	84,131,782	74,981,741	0,12	Annual Mining Report

6. Geological Setting and Mineralization

6.1. Regional Geology

The Carajás Mineral Province (CKS) comprises an area of approximately 30,000 km^2 in the southeast of the state of Pará 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 6-3) and corresponds to its oldest core, of Archean age, limited by the Central Amazon Geochronological Province (1.9-1.7 Ga) to the west and the Paraguay-Araguaia mobile belt to the east (700-450 Ma) (Santos, 2000 and Santos, 2003). Although 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 by both its geochronology and the orientation of its main structures. We can thus recognize the domains of Rio Maria, of Mesoarchean age, with preferential N-S orientation, Carajás (Neoarquean), with WNW-ESE orientation, and Bacajá (Paleoproterozoic), with NW-SE orientation. Tectonic evolution is not clear for this portion of the craton, and the boundaries between domains are fuzzy and usually transitional.

The geological framework of the southeastern portion of the Amazon Craton is widely discussed in scientific literature and different explanations have been posed for its evolution, subdivision, and nomenclature. According to Tassinari and Macambira (2004), the definition adopted herein, the Carajás Mineral Province fits into the Maroni-Itacaiúnas Geochronological Province, limited the Central Amazon Province to the west, the Bacajá domain to the north, and the Araguaia Belt to the east. This geochronological province is split 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).

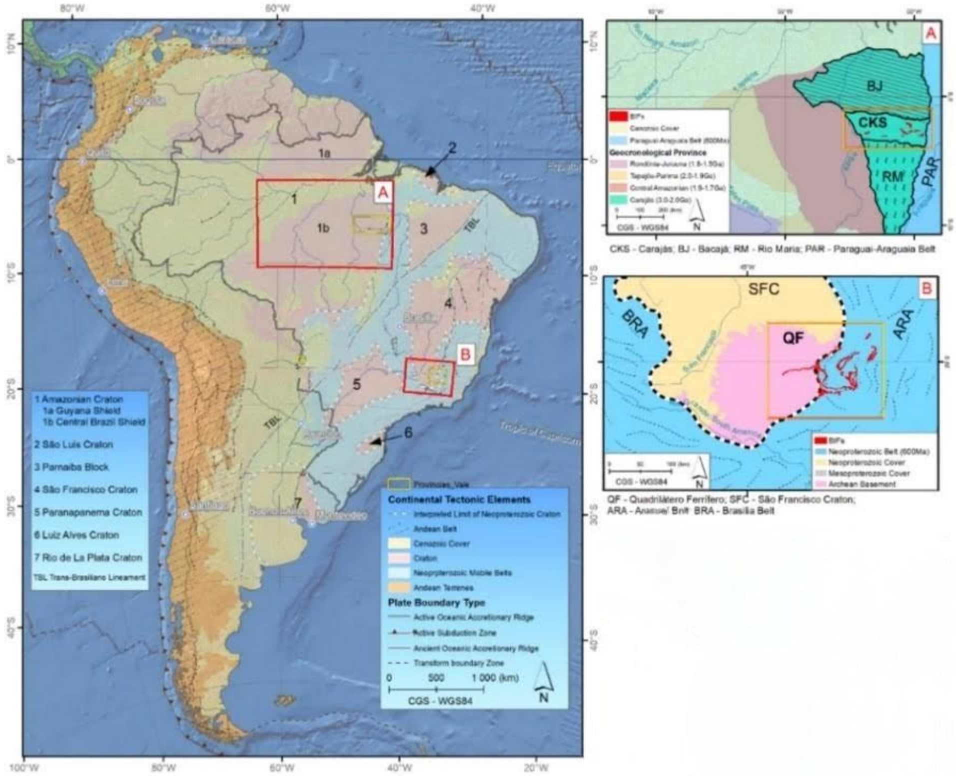

Figure 6-1- Tectonic map of South America (Cordani et al. 2016; Gómez et al. 2019) and locations of the Brazilian mining provinces operated by VALE.

6.1.1. Stratigraphy

In general, the Carajás Mineral Province comprises three main litho-structural domains intercalated over elongated ranges in the WNW-ESE orientation. 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 to the north and south by a granite-gneissic basement and to the east by a Mesoarchean granite-greenstone belt sequence, correlated to the Andorinhas Supergroup (Figure 6-2 and Figure 6-3).

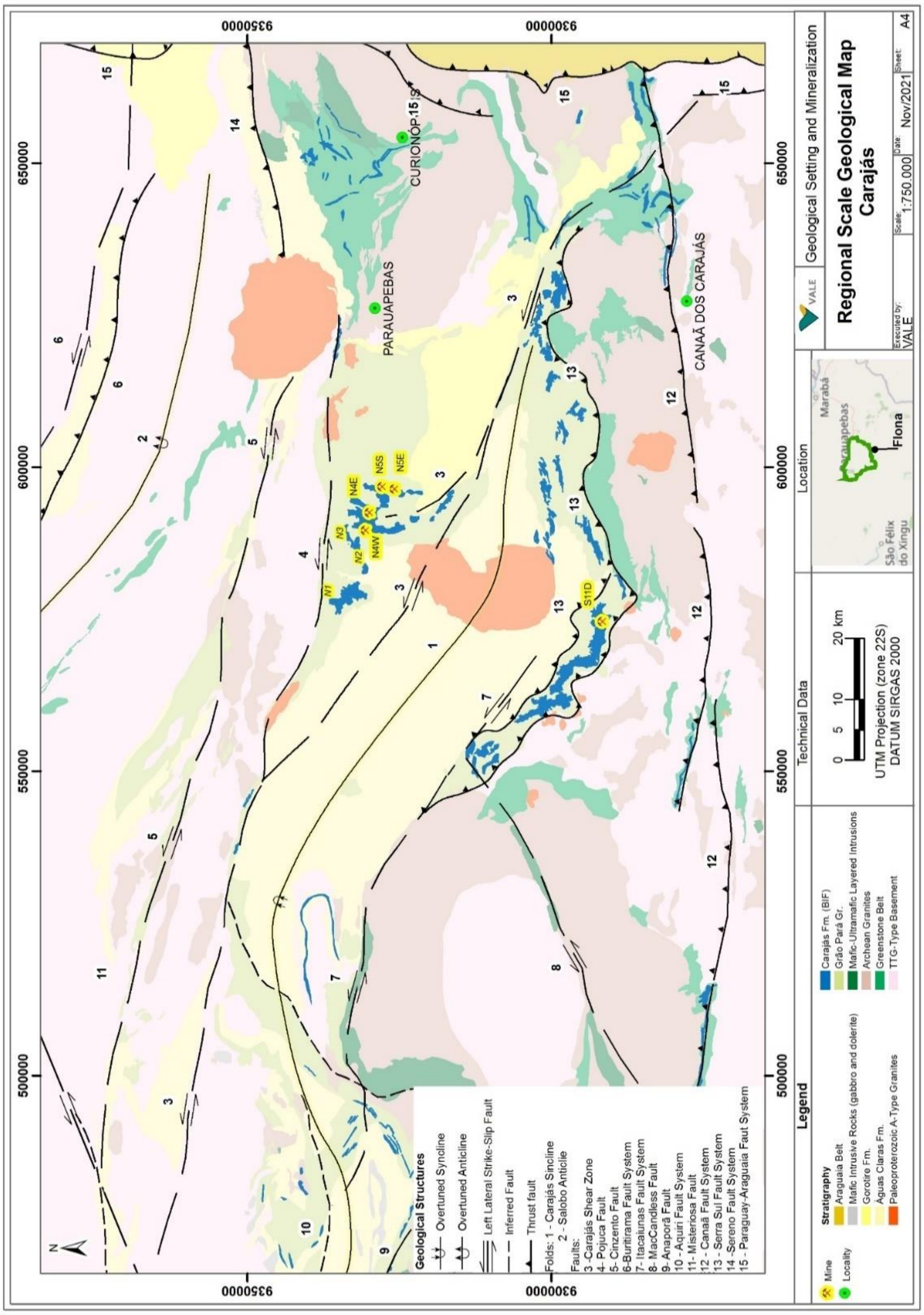

Figure 6-2 - Geological Map the Carajás Mineral Province (Costa et al., 2017).

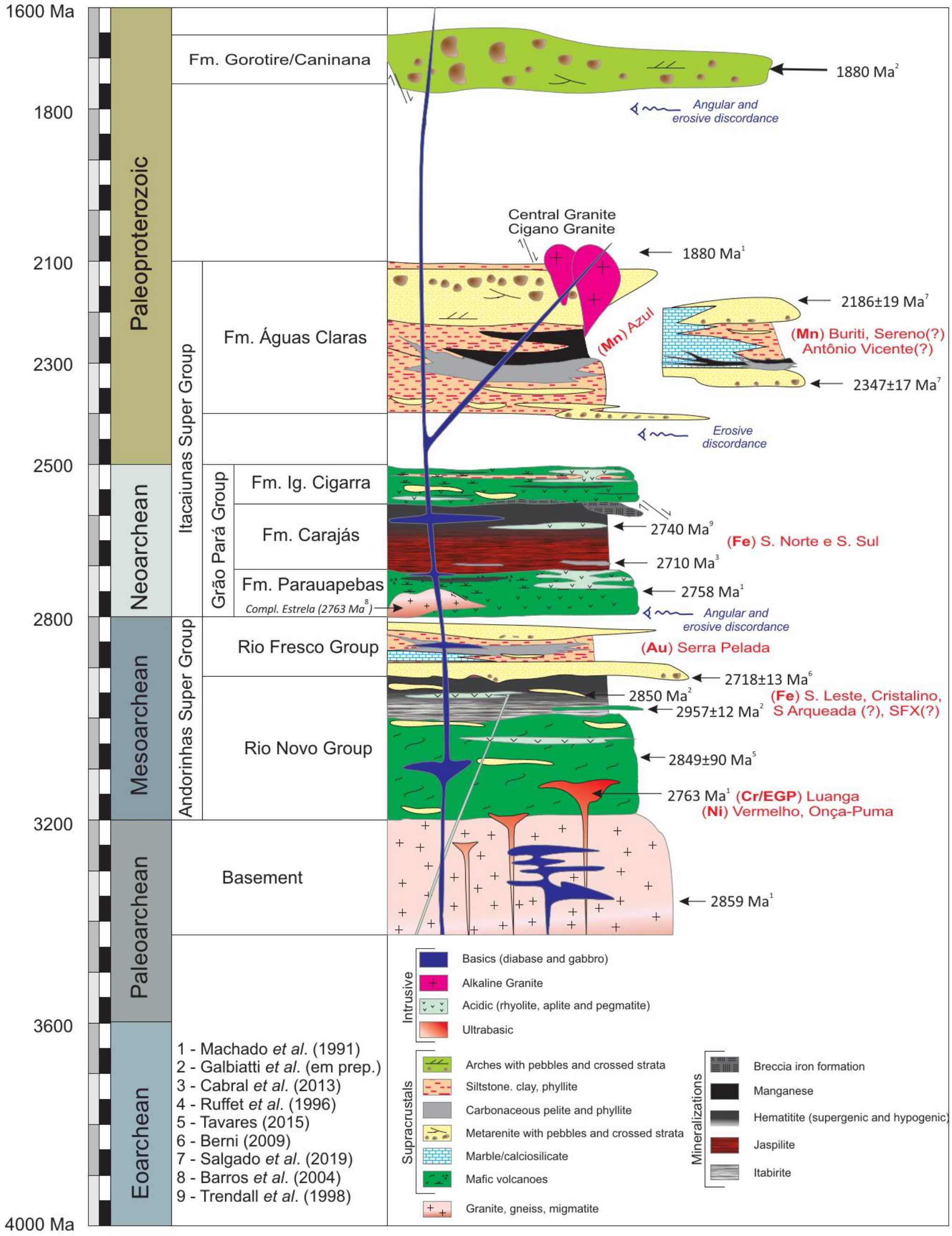

Figure 6-3 – Stratigraphic column of the Carajás Mineral Province.

6.1.2. Granite-gneiss terrains

The granite-gneiss terrains are comprised of 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). More recent research has reviewed and subdivided this classification, 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 syncollisional granitic to granodioritic composition of 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 split 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 interbedded with metasediments lenses, including amphibolite itabirite that grades into 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 Rio Novo Group rocks in the Serra Leste and Serra Pelada regions. This unit is composed of a succession of meta-sandstones and metapelites (locally carbonaceous), with discontinuous levels of dolomitic marble (Figure 6-1and Figure 6-2).

6.1.4. Mafic-ultramafic complexes

Complexes such as Luanga (Medeiros Filho & Meireles, 1985; Suita et al., 1988; Ferreira Filho et al., 2007) and related ones (Onça-Puma, Vermelho, and Madeira) are dated 2,763 Ma (Machado et al., 1991) and occur as intrusions in the basement and the basal portion of rocks attributed to the Rio Novo Group (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 metamorphisms of the Gabro Santa Inês (DOCEGEO, 1988), which occurs as an intrusive anorthosite 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 6-3) 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).

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

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 concordant 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 that inhibit the growth of the typical tropical forest of the surrounding region (Figure 6-4).

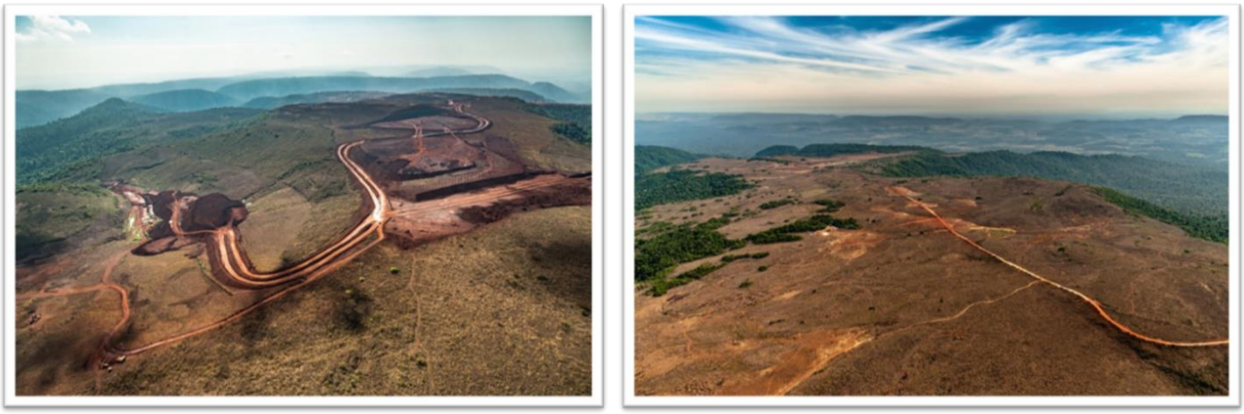

Figure 6-4 –S11D (left) and N1 (right) plateaus of Carajás Mineral Province.

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

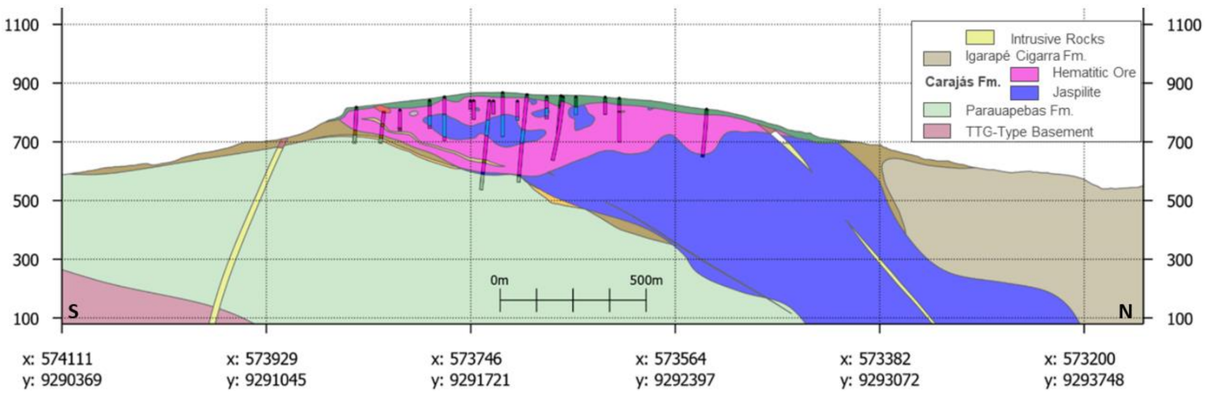

Figure 6-5 - Geological section at the S11D mine, Carajás Mineral Province.

The Igarapé Cigarra Formation was originally defined by the CVRD/AMZA team (1972) as the Upper Paleovolcanic Sequence and later renamed due to the identification of sedimentary levels (Macambira, 2003). It occurs in a stratiform body following the banding of iron formations 300 to 400 m thick (CVRD/AMZA, 1972). It is formed mainly by basalts with tufts and clastic sediment intercalations 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 unit's sedimentation environment. It constitutes a package of pelites and sandstones about 1,500 m thick, respectively subdivided into the Lower and Upper members superimposed to the rocks of the Grão Pará Group by erosive non-conformity (Figure 6-3). The age of this unit is not yet well-defined, but recent studies indicate that its deposition is younger than 2.45 Ga (Cabral et al., 2017), which is in line with the age range defined for Buritirama Formation quartzites (2,186-2,347 Ma, Salgado, et al., 2019). The Azul mine manganese ore is associated with 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: 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 from 1,800 to 1,900 Ma (Gibbs et al., 1986; Machado et al., 1991), which puts them in the same chronological range as the Uatumã Magmatism.

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

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

6.1.7. Cenozoic units and recent coverage

Cangas are commonly formed from the weathering of iron formations or the residual concentration of iron and aluminum oxides from the host rocks. They are divided into structured (rich or ore), detrital, and chemical (or laterite) types depending on their structure, composition, and iron content. There are usually high concentrations of aluminum, phosphorus, and manganese, which often prevent it from being used as ore. Nevertheless, they can be diluted to make up a fraction of ROM, so economic use is possible. Many of the iron ore pits recorded in Carajás are associated with canga domains, mainly on the edge of the plateaus.

Eluvium-colluvial deposits: small discontinuous deposits of little economic interest at the base and 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 a highly complex structural arrangement (Figure 6-2 and Figure 6-3).

The compilation of structures and geochronological data supports the interpretation of three major deformation moments (or tectonic cycles) that created the architecture of the Carajás Mineral Province:

The Archean Cycle comprises the main period of crustal growth in the Carajás Mineral Province, which led to the formation and deformation of the TTG basement (Xingu Complex and related), the deposition and deformation with low-grade metamorphism of the Andorinhas Supergroup rocks, 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 are 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 an axis around E-W 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 without 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 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 Braziliano 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 folds and faults in the N-S direction. 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 dikes with orientations similar to these fold axes.

The structures of this cycle interfere in the deposits, with variation in the thickness and geometry of iron formations (either by duplicating layers in 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 Sul Complex are generally constituted by elevated areas from 650 to 800 meters, limited to the south by the domain of volcanic rocks of the Parauapebas Formation and gneissic granite basement, which configure an extensive plain at 200-400 meters elevation. To the north, it is limited by the Águas Claras Formation terrigenous sediments domain, which an intercalated crest and valley morphology aligned in the NW-SE direction, with elevations ranging from 500 to 700 m (Figure 6-6).

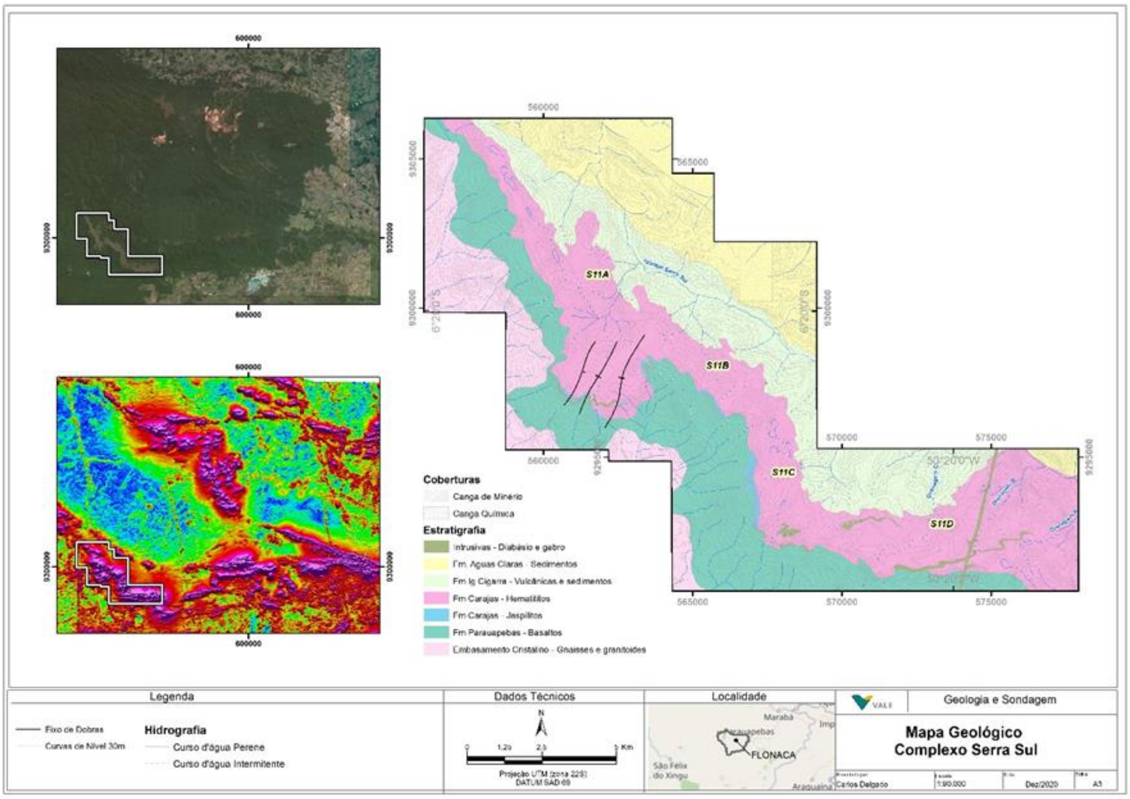

Figure 6-6 – Geology of the Serra Sul Complex (right) and satellite and airborne geophysics (MAG) images.

6.2.2. Stratigraphy

The Serra Sul 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 the Carajás Formation, which is part of the Neo-Archaean metavolcano-sedimentary sequence of the Grão Pará Group (Itacaiunas Supergroup). The Grão Pará Group superimposes the crystalline basement and the Mesoarchean greenstone belt sequence of the Andorinhas Supergroup and is covered by the terrigenous sediments of the Águas Claras and Gorotire formations and cut by acidic and basic intrusive rocks.

Mafic rocks are the iron formation host rocks, 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 stratigraphic units mentioned here and were considered only as mafic rocks, discriminated into decomposed mafic (MD), semi-decomposed mafic (MSD), and fresh mafic (MS). In addition to their role as host rocks (top and base of the iron formation), they also occur as sills and mafic dikes in iron formations.

Decomposed mafic rock (MD) is highly weathered, poorly structured, with color ranging from reddish to yellowish, clayey, with a predominantly soft consistency.

Semi-decomposed mafic rock (MSD) is an intermediate between MS and MD, sometimes still showing relicts of the original rock texture but with deep mineralogical and consequent color transformations.

Fresh mafic rock (MS) is not affected by weathering, is systematically chloritized, and corresponds to the product of basalt and diabase hydration. These are dark green rocks 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 geological interpretation.

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 that developed on sedimentary and magmatic rocks of the Amazonian Craton Archean core.

Mineralization occurs mainly as a product of supergenic enrichment 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 the discontinuity of the deposits along this mineral province demonstrate the existence of structures inherited from deformational events that favored the thickening of 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 Sul district are described below. The mentioned mean grades are average grades of samples (weighted by length) of each lithotype modeled in this review, considering the interpreted classification (CLI).

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

Chemical canga (CQ) are the iron-aluminous crusts that usually cover the decomposed mafic rocks. With a colloform texture and highly porous, it often presents considerable levels of Al_2O_3GL, evidenced by the light coloring of gibbsite and clay minerals. Hematite fragments are scarce or absent. Iron content is usually under 55%, with high phosphorus and Al_2O_3GL.

Structural canga (CE) is a 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 distances from the source area, and it is a good indicator of ore bodies locations. Thickness is variable but can reach more than 20 meters. Iron content is above 55%, with relatively low Al_2O_3GL and phosphorus grades, which makes structural canga a potential iron ore.

Jaspilite (JP) is a banded iron formation, usually of the oxide facies composed of alternating bands of opaque minerals, such as hematites (predominantly), magnetite or martite, and reddish or white bands 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-grey 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. Lenses are usually not too thick (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 in-depth continuity in some regions of the mine is unknown. In the large mass of jaspilite which constitutes the base of the iron formation, hematite lenses, mostly friable hematite, are observed in regions close to the jaspilite/hematite top contact.

Friable hematite (HF) is the predominant ore type, occurring throughout the Serra Sul mine. It is commonly banded, showing localized primary lamination planes. It consists of a grey friable hematite material of high porosity and with a metallic luster. It can be powdery or can 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). The enrichments profile presents variable thickness reaching up to 350 m, with great continuity throughout the dip.

Compact hematite (HC) is an iron-rich material and, like HFs, generated from jaspilite weathering. Its color varies from black to reddish-brown; the latter is typical of goethite/limonite cementation, which is considered the reason for the compactness of this lithotype. HC occurs subordinately throughout the deposit in the form of lenses within 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. HC is bluish grey with metallic luster. It is dense, with low porosity, and it can be banded, following the original banding of the preserved jaspilite in compact layers alternating with porous or brecciated layers. This lithotype can also be massive, aggregating hematite crystals with none of the original texture. Fe contents are between 59% and 69%. Al_2O_3GL is an important contaminant in this lithology.

Manganiferous hematite (HMN) is dull dark grey, and it occurs in lenses ranging from 5 to 10 m thick, reaching thicknesses of 60 m in spots without much lateral continuity, dispersed within the mass of friable hematite. HMN is rich in Fe, with Mn contents greater than 2% (global). It is usually at the base of hematite bodies, probably due to the accumulation of Mn leached from the weathered horizons.

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

6.2.4. Structural

The main Carajás iron ore deposits are associated with flat-topped elevated plateaus, defined along two main morphological lineaments corresponding to Serra Norte and Serra Sul. These lineaments form the limbs of the structure called the Carajás Syncline, which reaches about 150 km length and 100 km width (CVRD/AMZA, 1972; Beisegel et al., 1973). The Serra da Bocaina region, also known as the Água Boa plateau, corresponds to the endzone of this syncline and has large concentrations of jaspilite-type ore protolith. This region must not have experienced the ideal conditions for significant iron ore deposits formation or even for preserving potential previously formed deposits.

The Serra Sul Complex corresponds to the normal limb domain of the Carajás Syncline, characterized by a lower degree of deformation when compared to the inverse limb, which is reflected in the greater continuity of its iron formations (Figure 6-6).

6.3. Property geology

6.3.1. S11CD Plateau

6.3.1.1. Deposit dimensions

The SS11 deposit corresponds to the largest plateau and the main mineralized body of Serra Sul (Figure 6-5). This plateau extends for 28 km in the NW-SE direction, with elevations ranging from 650 to 850 m. Its segmented shape, with directions that vary sharply between N-S and E-W, configures a kink-type pattern. The deposit includes bodies A, B, C, and D, the latter of which presents the most economic interest. The plateau is predominantly composed of rocks from the Carajás and Igarapé Cigarra formations of the Grão Pará Group, which is in contact with the Parauapebas Formation to the south and the Águas Claras Formation to the north. In general, the layers present dips and azimuths that vary between the north and east directions, configuring a normal stratigraphic stacking.

Rocky outcrops are scarce due to the absence of cuts and excavations, except for the eastern portion of the plateau, which comprises the active part of the SSD mine and was mapped on a 1:2,000 scale for geological information. Therefore, most geological information on this plateau comes from diamond drill cores and the mapping of surface alteration materials developed over the iron formations—such as cangas—and laterite (or "chemical canga"), developed over the mafic rocks, whether they are enclosing or intrusive in the iron formations.

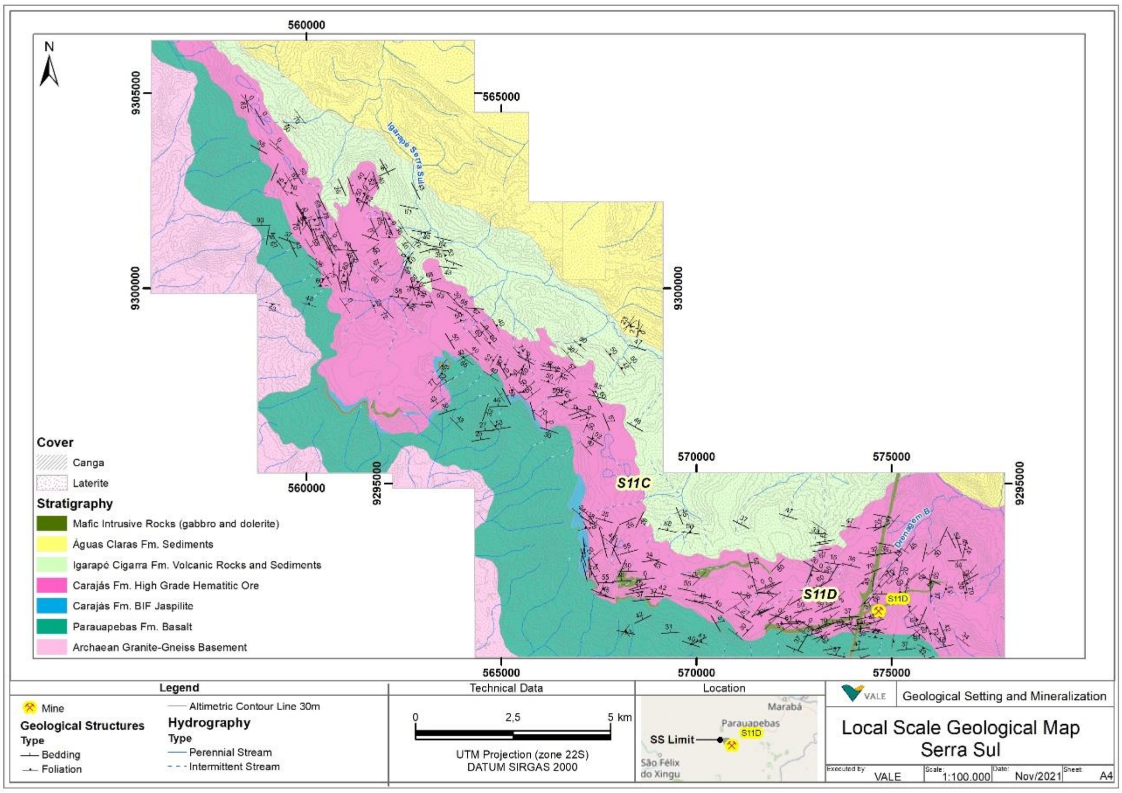

Figure 6-7 – Geological map of SSCD.

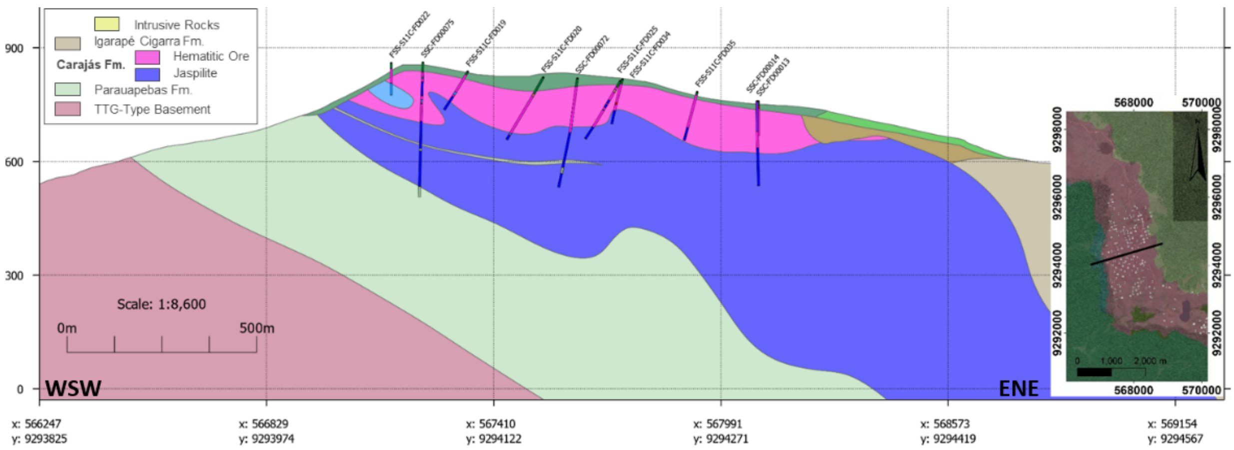

Figure 6-8 – Geological section of SSC.

6.3.1.2. Lithologies

The Parauapebas Formation is found on the southern and western edges of the SS11 plateau and is formed by a thick package of basalts and basalt andesites, locally amygdaloid and vesicular. It is usually affected by hydrothermal weathering and underlays Carajás Formation rocks in a conformable transitional contact, locally marked by breccias in the iron formation.

The Carajás Formation comprises about 50% of the plateau area and is the thickest domain of the iron formations. It coincides with the highest elevations and occurs continuously throughout the central portion of the plateau, from around the contact with the Parauapebas Formation to the vicinity of the opposite margin, where it is in contact with the rocks of the Igarapé Cigarra Formation (Figure 6-7).

The iron formations of the Carajás Formation domain occur in a tabular layer with medium to low-dip angle to the north and in the EW-oriented bodies, such as orebody D of S11, and medium to high-dip angle to the east and northeast in the NS oriented bodies, such as orebody C of S11. Its actual thickness has not been determined; however, it can exceed 450 m depth and from 200 m to 1,200 m in plan.

The Igarapé Cigarra Formation consists of large volumes of volcanic rock, mainly flows and tuffs of a bimodal nature interlayered with lenses of chemical and subordinate terrigenous sediments.

The Águas Claras Formation terrigenous sediments overlap the Igarapé Cigarra Formation domain to the north and east of the plateau margins. This unit fills the Carajás Syncline trough, occurring continuously from the northern portion of Serra Sul to the southern portion of Serra Norte.

It has also been noted, in both drill cores and in outcrops, that the entire package of the Grão Pará Group and the Águas Claras Formation is cut by mafic rock, with variable orientation and generally of small thickness. The composition of these bodies is basic/intermediate, and they make contacts that are conformable or non-conformable with the compositional banding of the iron formations, configuring sills and dikes (Figure 6-8).

6.3.1.3. Structures

The plan and section layout of the SS11 iron formations express strong structural control. Faults and folds condition the thickness and continuity of iron formations. The main structures controlling mineralization have been recognized since the 1970s (CVRD/AMZA, 1972; Beisegel et al., 1973).

These will be presented below in chronological order, from the oldest to the youngest structure, indicating the tectonic events that were likely responsible for their generation:

Structures correlated to Transamazonian tectonics:

• Nucleation of the Carajás Syncline, reflected by the tilting of the entire metavolcano-sedimentary package which, in the Serra Sul region, tends to dip northward with a medium angle.

• Folding with sub-horizontal axes of NW-SE direction, verging towards SW. These structures can be rotated, due to the superposition of tectonic events, as is the case of body D, where the axes assume an E-W orientation and the folds present a southward verge (Figure 6-8).

Structures correlated to Brazilian tectonics:

• Development of faults that cause the SS11 plateau segmentation and the formation of kink-style geometry (Figure 6-7).

• Formation of discontinuities filled by mafic dikes in the NW-SE direction.

• Implantation of normal faults that create a horsts and grabens system responsible for the localized lifting of jaspilite bodies (Figure 6-9).

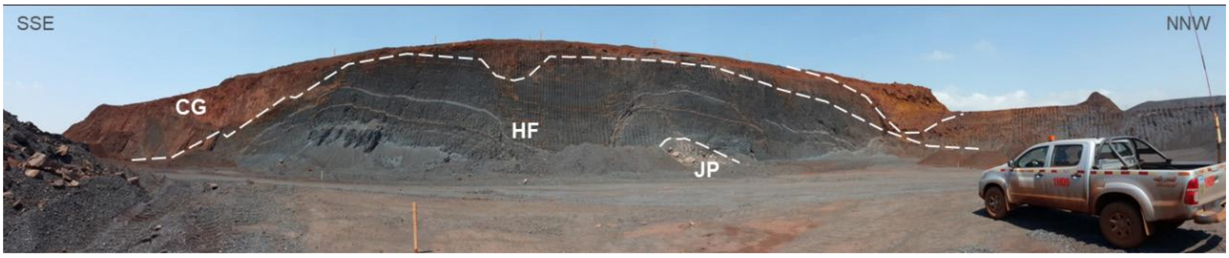

Figure 6-9 – SSD outcrop. CG – Canga; HF – friable hematite; JP – Jaspilite.

6.3.1.4. Mineralization

The mineralization at Serra Sul depends mainly on the weathering of jaspilites, 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 that tends to follow the topographical surface. This is usually covered by a layer of canga that is also considered a mineralized lithotype.

Friable hematite (HF) accounts for about 85% of the mineralization. It is essentially composed of hematite, with irregular masses of magnetite, goethite, and limonite inherited from the jaspilite ore protolith, in addition to local points of kaolin and clay minerals originating from volcanic rock weathering. HF occurs from near the surface to depths greater than 450 m, with average Fe grades around 68.8% and relatively low levels of phosphorus, silica, alumina, and loss on ignition. Loss on ignition and phosphorus are generally found near canga contacts, where a transition zone measuring from centimeters to meters can be identified; alumina is most commonly associated with centimetric to metric intercalations of mafic rocks. At the jaspilite contact points, there is a sharp drop in iron content, and gradational contacts are rarely observed; when found, these do not exceed the metric scale.

Compact hematite (HC) corresponds to 1% of the mineralization and is restricted to some regions of bodies C and D, mostly as lenses below the canga and, more rarely, in deeper layers within the jaspilites, suggesting a hypogenic origin. Its structure is massive or foliated, with up to 30 m thickness, and an average Fe content of around 66%, with slightly higher levels of contaminants than HF.

Manganese hematite (HMN) is subordinate and has no representation in the deposit. It occurs under low continuity lenses, up to 50 m thick, usually close to contacts with jaspilites and mafic rocks, suggesting a hypogenic origin. In chemical and granulometric terms, it preserves characteristics similar to those of friable hematites, differentiating mainly by higher Mn contents, around 2.4% on average, and average Fe contents around 63%.

Although jaspilite (JP) is not a mineralized type in Carajás, it will be described here, as it is genetically related to mineralization. These are iron formations characterized by the alternation of hematite bands and jasper/silica, subordinately, chlorite and carbonates bands. They can be grouped, according to mineralogy and texture, into carbonate, siliceous, chlorite, and breccia types. The SS11 jaspilites are greyish and may resemble itabirites, but present geomechanical characteristics similar to those of Serra Norte jaspilites, constituting an extremely compact, hard to sample lithotype. Fe average content is 45.6% and contaminant levels are lower than in HF, with alumina as the main contaminant at around 0.6% or higher in the vicinity of mafic rock contacts. They occur at the base of the iron formations package, with unknown thickness in contact with mafic rocks, but also as centimeter-thick lenses and up to 200 m, immersed in the large mass of friable hematites.

The cangas occur widely on the surface of Plateau SS11 as the product of weathering of different rocks in the region. They differ according to the substrate and can be classified as chemical canga (CQ), which covers mafic rocks, enclosing or intrusive in the iron formation, and structured canga (CE), developed directly over the iron formations and economically usable, therefore classified as ore. CE represents 14% of the mineralization and its thickness can range from a few meters to 60 m, averaging at around 15 m. It can be observed locally on hillsides, indicating a low transport rate. CE is predominantly compact and may preserve the banded texture. It is a very hydrated lithotype; its mineralogy is hard to define by the naked eye. Its average Fe content is 64.2% and the main contaminants are alumina and phosphorus, in addition to high amounts of loss on ignition.

7. Exploration

7.1. Exploration

7.1.1. Introduction

The mineral exploration started in the ‘70s and is still in progress. Currently, most of the areas comprise a drilling grid of 100x100m or 50x50m within the mining areas of S11D, focused on detailing the ore bodies and investigation of new potential areas for reclassification of resources to measured and indicated. In S11C, 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 teams prioritize the use of information to cover all operational areas, with aerolaser being used to complement the polygonal area of interest. The topographies are available about to the Horizontal Datum SAD69 and the Vertical Datum Imbituba, 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 treated and selected as targets of geological mapping and drilling. In addition, part of the most recent holes has been profiled by gamma-gamma method.

7.1.4. Qualified person’s interpretation of the exploration information

The Serra Sul Complex has been extensively explored since ‘70s, and a large database has been developed as a result of both exploration and mining activities. The primary exploration method is core drilling and assay collection. However, advancements in geophysics, have improved the amount and 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 exploratory potential of this area.

7.2. Drilling

7.2.1. Overview

The exploration of Serra Sul began in the late 60's and continued into 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 the Ferrous Geology and Drilling Management and recent works developed in Serra Sul were responsible for the incorporation of approximately 82,000 meters of drilling in 2017 and 79,000 meters in 2020.

7.2.2. Drilling on property

The purpose of the most recent drilling campaigns was to densify the resources definition grid in 100x100m and ore control grid in 50x50m in the pit area of S11D. In the region to the west, called S11C, the drilling grid is 200x200m (optimal drilling grid for resource definition). In addition, short-term drilling information was used to reduce grade control uncertainty in mining area.

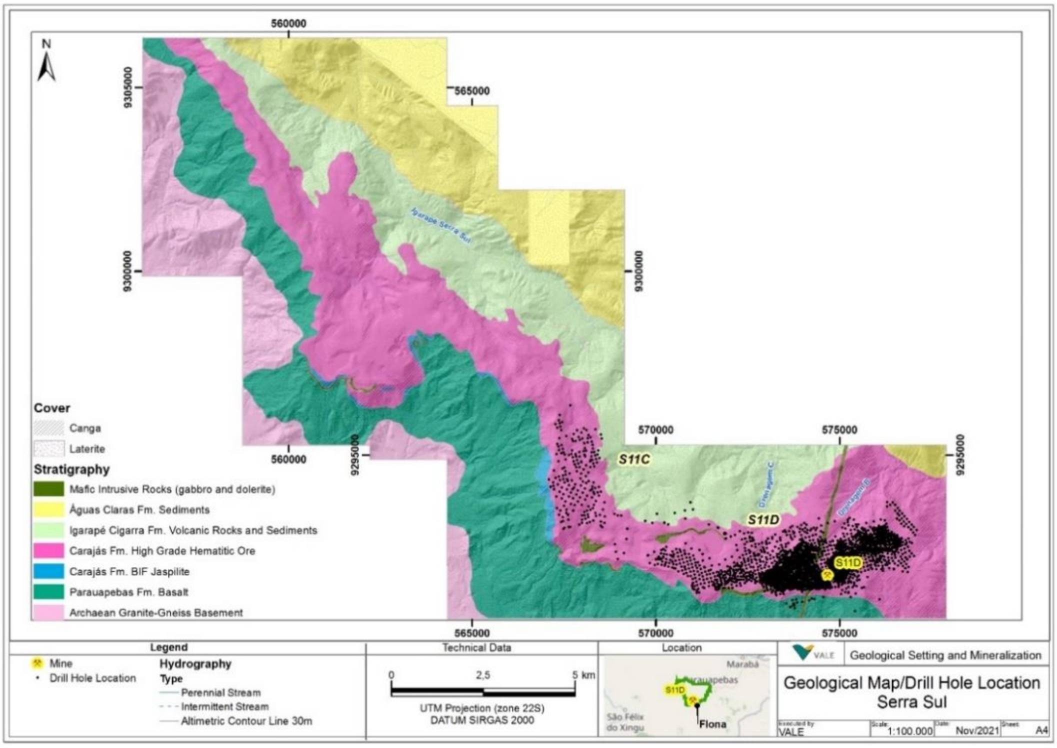

Figure 7-1– Geological map with drilling distribution in SSCD.

A brief drilling history of the latest models is presented in the table below:

Table 7-1– Serra Sul drilling campaigns.

Year	Area	Nb of drill holes	Total Meters (m)	Depth (m)		
				Min	Max	Average
1971	SSC	7	1,233.46	138.99	267.15	176.21
	SSD	22	4,316.08	52.15	403.94	196.19
Subtotal		**29**	**5,549.54**	**52.15**	**403.94**	**191.36**
2003	SSD	25	4,871.25	58.00	284.15	194.85
2004	SSD	127	31,642.15	82.55	489.15	249.15
2005	SSC	51	7,659.15	56.70	261.45	150.18
	SSD	116	23,591.90	26.45	500.90	203.38
Subtotal		**319**	**67,764.45**	**26.45**	**500.90**	**212.43**
2010	SSD	19	4,738.30	127.80	422.00	249.38
2011	SSD	19	3,057.05	40.00	305.15	160.90
2012	SSD	129	26,363.30	89.25	483.20	204.37
2013	SSD	50	12,540.70	30.00	556.95	250.81
2014	SSD	149	25,998.20	88.20	614.55	174.48
2015	SSC	14	2,953.50	90.95	380.90	210.96
	SSD	62	13,786.50	54.45	525.10	222.36
Subtotal		**442**	**89,437.55**	**30.00**	**614.55**	**202.35**
2016	SSD	376	58,466.65	23.40	580.00	155.50
2017	SSD	208	37,382.75	30.00	697.75	179.72
2018	SSC	53	11,871.70	60.60	443.20	223.99
	SSD	191	28,824.45	30.00	654.35	150.91
2019	SSC	17	5,244.25	199.85	450.00	308.49
	SSD	198	31,533.90	8.35	605.20	159.26
2020	SSC	46	11,412.95	71.60	500.15	248.11
	SSD	210	19,200.65	15.70	450.60	91.43
Subtotal		**1299**	**203,937.30**	**8.35**	**697.75**	**157.00**
TOTAL	**SSC**	**188**	**40,375.01**	**56.70**	**500.15**	**214.76**
	SSD	**1901**	**326,313.83**	**8.35**	**697.75**	**171.65**
	SSCD	**2089**	**366,688.84**	**8.35**	**697.75**	**175.53**

7.2.3. Drilling excluded for estimation purposes

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

7.2.4. Drilling methods

The main drilling type is conventional rotary diamond drill and most drillholes are vertical to sub-vertical. In the different campaigns at Serra Sul, the drilling was performed predominantly in HW (76.2mm) or HQ (63.5 mm) diameter, which can be reduced to NX (55mm), NW (54.7mm) or NQ (47.3mm), and in some cases, to BQ (36.4mm) due to operational issues. Some rotary percussive holes were drilled with 5'' diameter.

7.2.5. Logging

The Serra Sul drillholes of 1971 campaign were stored in the project core shed located on the S11 plateau, where they were catalogued, logged and sampled. For the iron formation, the intervals were logged in the sample length of 3m respecting the lithological contacts. For mafic rocks, the intervals were described considering the textural variations observed in the drill cores. Sampling was carried out taking half of the core, in the longitudinal direction, at intervals generally of 3m within each type of material.

The drilling campaign carried out between 2003 and 2005 was logged during the period 2004-2007 according to the new standard of geological and geotechnical description for iron ore used by the Serra Norte and the Department of Mineral Exploration (DIPM) teams. During this period, the drillholes from the 1970s campaign were resampled to make granulochemical analyses. The samples were collected continuously and in half of the core, with 7.5m sample length and tolerance of 2.5m, respecting the geological contact.

From 2012 onwards, the descriptions standards were reviewed. The criteria used for the geological logging of drilling cores for the Carajás Complex consider the individualization of minimum intervals of iron formation 7.5m length in the mine areas and 5m in the exploration areas, respecting the lithological contacts. For waste lithotypes, a minimum interval of 1.5m is considered and for covers, it is individualized regardless of the core length. In the rotary drilling sampling, 50% of the core is collected along the length, from the left side of the box channel, keeping the remaining 50% of the material in the core box. Compact materials, such as jaspilite are cut longitudinally using a circular saw. These samples are then sent to the physical laboratories for the subsequent steps carried out according to the criteria defined in the corresponding analytical flows. For reverse circulation drilling, the same procedure was followed, except that the sampling, which ranged from 1m to 5m, respected lithological contacts as defined by the geologist in the description of the cutting chips.

7.2.6. Recovery

Core recovery is good at Serra Sul. 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 stored in Geological Database Management System. Currently, these data is collected about the Horizontal Datum SAD69 and the 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, Deviflex and Reflex gyroscopes. Surveying was also carried out using Tropari equipment; however, the data was not used in geological modeling due to interference from the magnetism of the iron formation.

7.2.9. Comments on material results and interpretation

Drilling and surveying were conducted in accordance with standard practices in the industry at the time the drilling as performed and provide suitable coverage of the zones of iron ore mineralization. Collar and down hole survey methods used generally provide reliable sample locations. Drilling methods provide good core recovery. Logging procedures provide consistency in descriptions.

This data is suitable for mineral resource and mineral reserve estimation. There are no drilling or core recovery factors in the drilling that supports 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

A hydrogeological model for the Serra Sul region has been developed in the MODFLOW (MDGEO, 2020) and revised by the Vale’s technical team in 2022 was used for the dewatering simulation. The construction and update of the hydrogeological model are entrusted to a third-party company, with VALE's technical team overseeing data analysis. Currently, a Quality Assurance/Quality Control (QA/QC) program for the hydrogeology database is in the developmental stage.

The Serra Sul raw water demand is supplied by wells, which are licensed to operate.

Table 7-2 - Summary of the main information and the results of the hydrogeological model numerical simulations

Contracted Company	Pit	Calibrated model year	Software	nRMS (%)	Drainage flow rate (m^3/h)	Number of instruments considered in the calibration
MDGEO	S11C&D	2020	FEFLOW	4.40	1,0223	92

Mine dewatering at S11D is carried out by pumping systems. Horizontal drain holes are also used for slope depressurization.

The hydrogeological data is deemed sufficient to fulfill the primary objective, which is to construct, calibrate, and simulate prospective mining scenarios within a numerical groundwater model. As the groundwater monitoring network expands, ongoing enhancements to operational processes and protocols are underway. The implementation of a QA/QC program is in progress, both of which are anticipated to bolster confidence in the acquired data and the numerical models.

7.3.2. Comment on Results

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7.4. Geotechnical

7.4.1. Sampling Methods and Laboratory Determinations

VALE's geotechnical procedures encompass a comprehensive approach that involves geotechnical mapping, core logging, and laboratory tests. The delineation of geotechnical domains is founded on both regional and local surface geological mapping, coupled with information from drill holes.

Regularly, several geotechnical parameters are recorded, encompassing compressive strength, weathering, degree of fracturing, Rock Quality Designation (RQD), types of discontinuity, alpha angle of the principal discontinuity, and conditions of the main discontinuity (including parameters such as opening, roughness, spacing, wall alteration, wall-filling, type, and thickness). These parameters contribute to the definition of rock mass classification systems consistently applied across all of VALE's mining operations.

Within the Serra Sul context, rocks with compressive strength less than 5 MPa are categorized using Weak Rock Classification, while those with compressive strength equal to or greater than R2+ are classified according to Rock Mass Rating (RMR). The Geological Strength Index (GSI) classification is also employed, derived through empirical correlation with the proposed RMR value, where GSI = RMR - 5.

As of December 31, 2023, a total of 319,910 meters of geotechnical drill holes and 414 geotechnical mapping points were used to prepare the Serra Sul geomechanical model.

7.4.2. Quality Assurance and Quality Control

A complete QA/QC program for geotechnical core logging description is under development. Currently, the cross-validation techniques used are based 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 the degree of fracturing, RQD, and joint spacing.

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

7.4.3. Comment on Results

A combination of historical and current geotechnical data, together with mining experience, are used to engineer ground support guidelines and procedures that all ground support designs must follow. These data and mining experience support the geotechnical operating considerations used in the mine plans is in Chapter 14 of this Report.

8. Sample preparation, analyses, and security

8.1. Overview

VALE's 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. Protocol documentation is kept updated and personnel receive adequate training to apply them. All data is properly identified by unique reference numbers so that drillhole information on specific collars, surveys, geology, physical properties, and assay tables can be reliably retrieved. All data is verified and checked prior to being populated into the database. Sampling practices and assaying methodologies are clearly described and supported. Proficiency and technical capabilities of sample preparation and assaying facilities are confirmed by means of periodic reviews and - or audits. The database contains all relevant information pertaining to Mineral Resource and Mineral Reserve estimation. The database used in estimations contains unbiased and representative data, and, besides that, appropriate corrective actions are taken and disclosed for any major issues identified by QA/QC programs.

8.2. Sampling methods

Drill core samples were taken from VALE core shed facilities in accordance with the standard adopted for Serra Norte deposits. 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. A laboratory was implemented in N4E, where physical preparation activities and chemical analyses of exploration and production samples of iron and manganese ores were performed. As of August 2008, geological exploration samples were prepared in Parauapebas, in state of Pará, at an outsourced laboratory owned by SGS Geosol Laboratório Ltda located. Between August 2009 and April 2013, samples were prepared by Intertek do Brasil Inspeções Ltda. Physical preparation was outsourced to SGS Geosol and Intertek and overseen by VALE's team. As of April 2013, VALE's laboratory located at the N4 mine took over sample preparation and chemical assay execution.

Only global assays were performed for Fe, SiO_2, P, Al_2O_3, Mn, FeO and LOI (Loss on Ignition) in the 70's program drillholes. Measurements of magnetite content in the ore were also taken using Satmagan equipment. For hematite samples, assays of SiO_2, P, and Al_2O_3 were done using X-ray fluorescence and other constituents (Fe, Mn, and FeO) were tested using the wet method. For jaspilites, the wet method was used to test all analytes. For mafic rocks and cangas, only P was tested using X-ray fluorescence, and the other analytes were tested via wet method. Part of the results represent the sum of SiO_2 and Al_2O_3, was data recording was not broken down into individual parts.

The rotary drill cores from the 2003 to 2005 program were analyzed by GADIN Chemical Analysis Laboratory at Carajás Iron Mine, Brazil. In 2005 and 2006, to assess the performance of GADIN Chemical Laboratory, VALE retained ALS Chemex Laboratory in Vancouver, Canada, exclusively to perform 5% checks on pulverized material duplicates. The following analytes were assayed:

- Fe%: GADIN routine, Fe% determined by difference, for verification, it was performed via wet analysis and X-Ray fluorescence (FRX).
- SiO_2%, Al_2O_3%, P%, Mn%, MgO%, TiO_2%, CaO%, Cu ppm: pressed pellets and X-Ray fluorescence, and ,occasionally, fused pellets and reading using X-Ray fluorescence.
- LOI (Loss on ignition): via gravimetry.

Fe was tested via wet method as of November 2008. Fe calculation verification compared the Fe of the most representative fraction analyzed via wet method with the value calculated. If the difference was lower than 0.70%, calculated contents were validated. Otherwise, Fe was assayed on wet basis in all fractions. Sieving was performed on dry basis using four sieves (19mm, 8mm, 1mm, 0.5mm, and 0.15mm), generating five granulometric fractions. From these, each fraction's mass and chemical recoveries were determined. As of June 2013, Fe started to be assayed via wet method in all fractions. The other analytes were determined via X-Ray fluorescence, and LOI was tested via gravimetry.

As for chemical closure, results within the 98%-101% range were considered acceptable up to 2006. However, as of 2007, acceptance thresholds were those in the 99%-101% range.

8.3. Sample security methods

8.3.1. Quality Assurance and Quality Control (QA/QC)

The historical QA/QC data acquired prior to 2012 and pertaining to control samples, twin samples, field duplicates, crushed material duplicates, pulverized material duplicates, external duplicates and standards did not reveal any 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, or resources and reserves classification of areas and mines in the Serra Norte and Serra Sul Complexes at the Carajás Mineral Province.

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

Al_2O_3, Fe, Mn, P, LOI, and SiO_2 tests followed 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 inter-laboratories were assessed: 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 2019 by VALE personnel. In general, laboratory performance was deemed to be satisfactory (compliant results ≥ 90% or very close to 90%) and/or acceptable (compliant + acceptable results ≥ 90% or very close to 90%). In most cases, sampling/chemical assay accuracies are good and analytical biases/flaws are minor or insignificant compared to the grade ranges in question.

Laboratory technical performance for Fe was considered to be satisfactory and acceptable. Technical performance for contaminants varied between satisfactory and unsatisfactory (some points of attention were identified at lower grades). Crushed material duplicates and pulp duplicates DP show more non-conforming results and higher mean relative inaccuracies (yet, 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 at the Intertek laboratory indicate a slight overestimation trend at lower grades (still acceptable and conservative bias) for analyte P. External duplicates assayed at the SGS Geosol laboratory indicate a slight overestimation and underestimation trend at lower levels (bias still acceptable) for P (conservative bias) and LOI (non-conservative bias), respectively.

Standard control samples indicated a minor overestimation trend at very low grades for Al_2O_3, Mn and P. Geology and laboratory teams are currently investigating the most important points of attention identified.

Routine laboratory inspections are performed to check organization and storage, equipment (scales, ovens, sieves, crushers, mills/pulverizers, splitters), operating procedures, and records related to the internal QA/QC program. QA/QC data revealed non-compliance, precision and accuracy general indicators to be satisfactory, not compromising the database associated with such data.

8.3.1.1. Database management system

The main information available in the short-term, long-term drillholes, and geotechnical drillhole database is organized in three tables: header, survey, and assay.

The basic data presented in the Header table consist of drillhole identification, east and north coordinates, elevation, depth, percentage recovery, drillhole completion date, DATUM and whether or not the drillhole had been profiled.

The Survey table presents drillhole identification, Azimuth information, as well as drillhole dip and depth.

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

8.3.1.2. Header table validations

The items below describe the checks pertaining to the Header table pertaining to short-term, long-term, and geotechnical drillholes in the Serra Sul database.

Validation of drillholes with surveying

Drillhole position validation, checking for positioning discrepancies between original and current topographies. Drillholes presenting relevant discrepancies were excluded from the database.

Validation of drillholes recently added to the database

This check consists of comparing the previous model's database with the current one. Thus, the difference in the total depth of both databases can be checked and new drillholes can be identified.

Drillhole recovery validation

This check considered the recovery column, and a formula was used to indicate drillholes with recovery below 50%.

Duplicate coordinate validation

This check is intended to identify drillholes with coinciding east and/or north coordinates.

DATUM validation

This check intended to ensure that all drillhole coordinate data would be in the same Coordinate System and Datum. For Serra Sul, VALE used Horizontal Datum SAD69 and Vertical Datum Imbituba, projected at UTM-22S. Drillhole coordinate data in Vertical Datum PD04 was re-surveyed and the database was duly updated.

Coordinate validation

This check compared original file coordinates sourced from the Survey Monitoring spreadsheet to coordinates sourced from the Geological Database Management System.

8.3.1.3. Survey table validations

The items below describe checks pertaining to the Survey table in the Serra Sul model database. The pieces of equipment were used to acquire the original logging data were: Deviflex, Maxibor I, Maxibor II, Reflex Gyro, and surveying Azimuth.

General profile validation

Profiling general check is performed once the Survey spreadsheet is developed, bearing all the data required, namely: drillhole, depth (prof.), Azimuth (Azim) and Dip (Dip). Trajectory deviation data is typically required to cover at least 85% of the total drillhole length. The checks included Azimuth differences, dip differences, whether or not the drillhole had been profiled, type of range, and overall check of the difference between subsequent readings. The latter consists of checking for intervals in which dip or Azimuth difference is greater than or equal to 1.4°/m.

Header x Survey depth validation

This check validates the final depth shown in the Header table against the final depth in the Survey table.

Dip and Azimuth validation x drilling follow-up worksheet

This check compares the Dip and Azimuth values used in the modelling against the original values in Survey Monitoring spreadsheets (deemed to be official).

Dip and Azimuth consistency validation

This check is intended to validate whether Azimuth drillholes equal to 0 are vertical and vice versa. Non-vertical drillholes must have Azimuth information. We can also check dip and Azimuth minimum and maximum values. It is key that the dip always be negative.

8.3.1.4. Assay table validations

The items below describe checks pertaining to the Assay table for long-term, short-term and geotechnical drillhole database for Serra Sul geological model. As for the items regularly checked during database preparation modeling, all inconsistencies have been addressed and, in some cases, analytical results have been discarded.

Duplicate sample validation

This check is intended to identify the presence of duplicate samples in the database.

Gap and overlap validation

This is one of the main checks in the database. It is intended to identify the proper interval array, considering the "From" and "To" interval, as well as to highlight Gap errors (intervals with missing length) or Overlap (intervals with overlapping length). This check consists of a direct cross-check of information in the "From" and "To" columns.

Validation of calculated global content

This check is intended to validate global chemical values of all analytes calculated in the samples with particle size and range analyses. A weighted average of the content by mass in the particle size ranges is calculated using the following formula:

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

Validation of anomalous values

The anomalous value check consists of verifying whether the maximum and minimum values are consistent with each element analyzed. It is possible, for example, to highlight column changes (P and Al_2O_3, for instance). No chemistry value can equal 0 in the database, as the minimum value must always be the limit of detection. Negative values can also be identified in this check.

Particle size vs. chemical validation by range

This check is solely intended to ensure chemistry per range is necessarily available for any ranges with particle size.

Validation of equal analytical results in different samples

This is a simple, yet important, check that considers the existence of equal results for some analytes. The check verifies each element of the Assay table, sorting and checking for discrepancies or equal results. All analytes must undergo this check, and equal results for two different samples it is considered an error.

Sample recovery validation

This check must use a filter considering a minimum 60% recovery, as per the “Resource Estimation Management’s Manual of Good Practices”. There may also be intervals with recovery lower than 60%, but those are intervals with NR-NS identification (not recovered - not sampled).

Particle size closing validation

The sum of particle size values must be considered to check particle size closing, and subsequently compared with the value sourced from the Assay Table. The acceptable limit for particle size closing ranges between 99% and 101%.

Chemical closing validation

It verifies chemical results’ stoichiometry and the sum of granulometric fractions. This validation step checks whether closure was adequately calculated and whether closure limits are acceptable. The following equation was used for this calculation:

$$(Fe*1.4297)+SiO_2+(P*2.2913)+Al_2O_3+(Mn*1.2912)+CaO+MgO+TiO_2+K2O+(Cu*1.2518)+LOI$$

Although this check shows chemical closures below or above an accepted range, this is not a reason to invalidate samples. Therefore, all these samples remained in the database and were used in the geological modeling and will, or will not, be used in estimates depending on geostatistical assessment results.

Depth validation between the Assay, Header and Survey tables

This is one of the main database checks. Basically, it consists of comparing drillhole depth in the three tables. Each drillhole’s total depth must be the same in all tables.

8.4. Density determination

Density is an attribute that direct impacts quantification of any mineral deposit mass, and this is the very reason why it is deemed to be a highly relevant item in VALE's iron ore geological models. Several studies have been developed by VALE professionals 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). Density values currently attributed to blocks result from a combination of the three methods, and the results are presented in Chapter 11.

Each method adopted and the final value were validated by descriptive statistics' analyses, vertical section visual inspection, and chemical analysis review of each material. The purpose of validation was to observe consistency between 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 for compacted materials. Each methodology is briefly described below:

- **Volume Fill Method**: it consists of digging a hole with regular walls and removing the material, which is then weighed. The hole is then lined with thin plastic and filled it with a known volume of water.
- **Sand Flask Method**: it consists of digging an opening with regular walls in the ground, then removing and weighing the material extracted. This hole is then filled with selected sand of known density. Material density is then determined from the selected sand volume and mass data.
- **Volume Displacement Method**: density is calculated from the relationship between sample weight and water displacement stemming from sample immersion in a graduated container.
- **Hydrostatic Weighing Method**: density is derived from the ratio between sample weight divided by weight loss when the same sample is immersed in water, using the Jolly scale.

Moisture is obtained by drying a sample aliquot and comparing the sample's dry (M) and wet masses ($M+MH_2O$). This is key, as tonnage calculations in VALE's iron ore mine evaluations consider density on wet basis (ρu), considering the free water mass (MH_2O) obtained from moisture measurements (u). All conventional density determination methodologies determine wet density and moisture values and calculate dry density.

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 is equipped with a radioactive source and a scintillation meter. This probe emits gamma radiation, and depending on the present electron density, it is deflected. The scintillation meter measures the amount of radiation scattered through the medium, thus, the denser the rock, the less radiation is scattered. The technique continuously records variations in the specific weight of rocks traversed by a drillhole. Total rock density measurements, with density profile, is made by means of a monoenergetic gamma-ray beam fired onto drillhole walls.

8.4.3. Mineralogical normative calculation (CNM)

The normative calculation studies were developed by Ribeiro (2003) for lithotypes present in Banded Iron Formations in the Iron Quadrangle region and complemented by observations made by Voicu et al. (1997) regarding paragenesis calculation of rocks with relevant weathering profile. The first studies coordinated by Ribeiro for an internal project at VALE were carried out in 2010 and focused solely on siliceous compact itabirites, whose the paragenesis is basically composed of quartz and iron oxides. The total density of each sample was calculated considering the proportions of each mineral - obtained based on global chemistry – as well as their respective theoretical densities. The correlations obtained by comparing these results with data collected via direct methods were very good, and, therefore, VALE decided to also apply this technique to the other iron-enriched lithotypes in its deposits.

Case studies carried out later by Motta et al. (2016) considered particle size partitions to obtain paragenesis and density calculation, and also showed good correlations (Figure 8-1). This study represents progress in the methodology itself, as it addresses the difference between density of the finest and coarsest part of the material because, implicitly, it considers each particle size fraction's porosity.

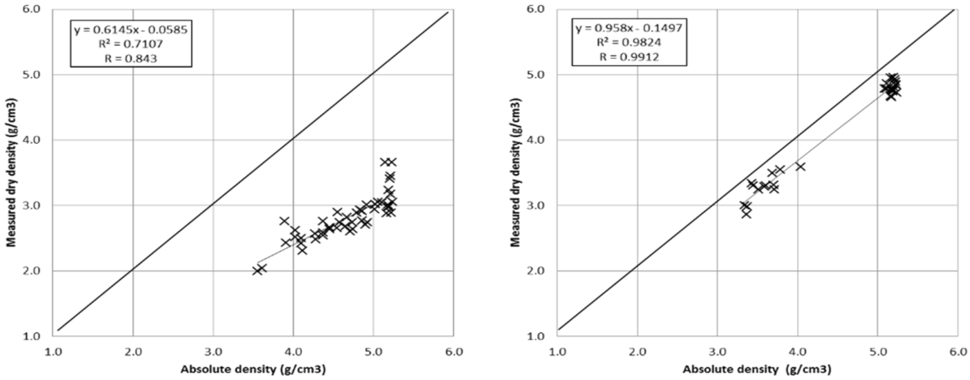


Figure 8-1 - Linear regression between the mineralogical density and the measured dry base density for friable (left) and compact (right) samples, according to Motta et al. (2016).

Recent studies based on pycnometer tests carried out at the Mineral Development Center (CDM) and VALE Technological Research Center (CPT) laboratories confirm the mineral density values calculated using this methodology. The database contains 267 pulverized material samples from chemical analysis of density samples by direct acquisition.

8.5. Qualified Person's opinion on sample preparation, security and analytical procedures

Sample preparation, analysis, quality control, and security procedures applied at the Serra Sul Complex have changed over time to meet industry practices, and often consist of industry-leading practices.

The Qualified Person's opinion is that sample preparation, analysis, quality control, and security procedures are sufficient to provide reliable data to support mineral resource and subsequent mineral reserve estimation.

9. Data Verification

9.1. Internal data verification

9.1.1. Data collection and storage

VALE's Mineral Exploration Management in charge of geological description, data collection, and QA/QC checks procedures daily, from drilling to laboratory analysis chemical results received.

During the drilling process, several processes are checked by drilling inspectors, from the drillhole depth, recovery in each maneuver, to haulage of core boxes to the core shed. After the hole is drilled, the spatial trajectory deviation is logged, follow-up by the drilling inspector and validation of the data obtained.

A quality management protocol is in place for box receiving, checkout, and arrangement in the core shed. The protocol focuses on boxes' physical integrity and identification, as well as on their arrangement on pallets (lined up for plastic boxes, or stacked for wooden boxes), strapped boxes, unlocked pallets, head sign checkout, correct numerical sequences, depth, progress and maneuver recovery.

The core is exposed in numerical sequence for each box, and then photographed. This is followed by geotechnical description, geological description, chemical analysis sampling plan development, density sampling plan development, and sample collection. Core samples collected for physical and chemical analysis are placed in plastic bags, which are duly identified with barcode labels.

Boxes with half-core or non-sampled intervals are archived, as per the core disposal procedure.

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

Processes intended to address quality control, quality assurance, and data integrity are under development, being 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 checks, as well as error and mitigation reports.

All technical records pertaining to a given drillhole, spatial and geophysical trajectory logs, core box photographs, description, density tests, samples, petrography, physical and chemical results, etc. constitute a source of data and information and are kept in the adequate repository(ies) and/or information technology system(s), being accessible at all times for checking and/or investigation purposes. There are operating procedures for all these processes, which are under the responsibility of the data acquisition team in the Iron Ore Mineral Exploration Management. VALE staff also conducted regular laboratory reviews and audits.

9.1.2. Mineral resource and mineral reserve estimates

A Mineral Resource and Reserve Committee was established within VALE's Iron Ore Division to document and ensure the reliability of information supporting mineral resource and mineral reserve estimates, including all technical and economic premises. The Committee is made up of qualified persons/competent persons from different areas, and departments (resources, reserves, mineral processing, geotechnics (pit, project and dams), hydrogeology, production, strategy, environmental, speleology, finance, mining rights, future use, engineering), who sign off or certify the assumptions required to develop mineral resource and mineral reserve estimates.

Mineral reserves and mineral resources are estimated in accordance with VALE's Global and Iron Ore Guidelines and Standards for Mineral Resource and Mineral Reserve Reporting protocols. The guidelines may be subject to reviews throughout the year, based on certain circumstances, such as external opinions or amendments to external regulations.

The responsible persons nominated in each operation must ensure that mineral reserve and mineral resource estimates, technical documents, and other scientific and technical information for their operation are consistent with VALE´s Global and Iron Ore Guidelines. Other experts include professionals in marketing, legal, corporate affairs, finance (tax), strategic and business planning and sustainability (environment, social, governance). These experts must provide information, as it may be required by the Iron Ore Committee of qualified persons, to ensure that all pertinent information is included in the reports supporting mineral resource and mineral reserve disclosure.

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

Mineral resource and reserve qualified persons must develop and maintain mineral resource and mineral reserve estimation and reporting standards, ensuring that such standards and guidelines follow the best practices in the industry, and meet VALE's corporate requirements, as well as legal requirements.

Technical reviews of mineral reserve and mineral resource estimates are made annually (or as needed) by the Resource Management Group for each operation and mine. The Iron Ore Mineral Resource and Reserve Committee prepares and issues a technical review report for each mine and operation, presenting the risks identified. All risks identified must be mitigated and addressed according to the risk rating assigned thereto, and as per SK1300 disclosure requirements, and VALE Global Guidelines for Mineral Resource and Mineral Reserve Management.

9.1.3. Studies

VALE staff performs several internal studies and reports to support Serra Sul Mineral Resource and Mineral Reserve estimation, including reconciliation studies, mineability, and dilution evaluations, investigations on grade discrepancies between model assumptions and drilling data, drillhole density evaluations, long-term plan reviews, and mining studies to meet project advancement internal financing criteria.

9.1.4. Reconciliation

Serra Sul short-term team performs monthly, quarterly, and yearly reconciliation assessments. The long-term mineral resource team performs monthly, quarterly and annual assessments, the long-term mine planning/reserves team also performs monthly, quarterly, and annual reconciliation. An annual report on the consolidated results compares the short-term model, mineral resource, and reserve model. Moreover, production grades and tons are discussed during an annual technical meeting to foster continuous improvement in all areas involved. The results indicate that ore tonnages and grades in the long-term model are controlled within acceptable limits.

9.2. External data verification

In 2023, mineral resource and mineral reserves were reviewed by an external audit company. The work reviewed the geology, mineral resources and reserves, metallurgy, processing plants, and environmental management, concluding that they comply with the industry standards for iron deposits.

9.3. Qualified Person's opinion on data adequacy

The data that has been verified, uploaded to the database, and checked based on layered responsibility protocols, is acceptable and fit-for-use in mineral resource and mineral reserve estimation.

10. Mineral Processing and Metallurgical Testing

The iron content in Serra Sul homogeneous deposit is high, thus requiring little metallurgical test work to determine process routing and operation monitoring. There is no ore concentration in place, and the entire process is carried out at natural moisture. Serra Sul processing plant consists of comminution and screening stages intended to adjust product grain size prior to shipping.

Most of the tests are carried out at VALE's laboratory, yet it is possible to perform specific tests in external laboratories.

10.1. Metallurgical test work

Due to a recent increase in jaspilite content in the process, additional compressive strength tests had to be conducted to determine the existing roll crusher's capacity and potential need for replacement.

A total of 117 samples were sent to the internal laboratory for compressive strength testing, and the results are shown in histogram format in Figure 10-1. The results confirmed that the roll crushers need to be replaced. A 500 MPa compressive strength was considered as design basis.

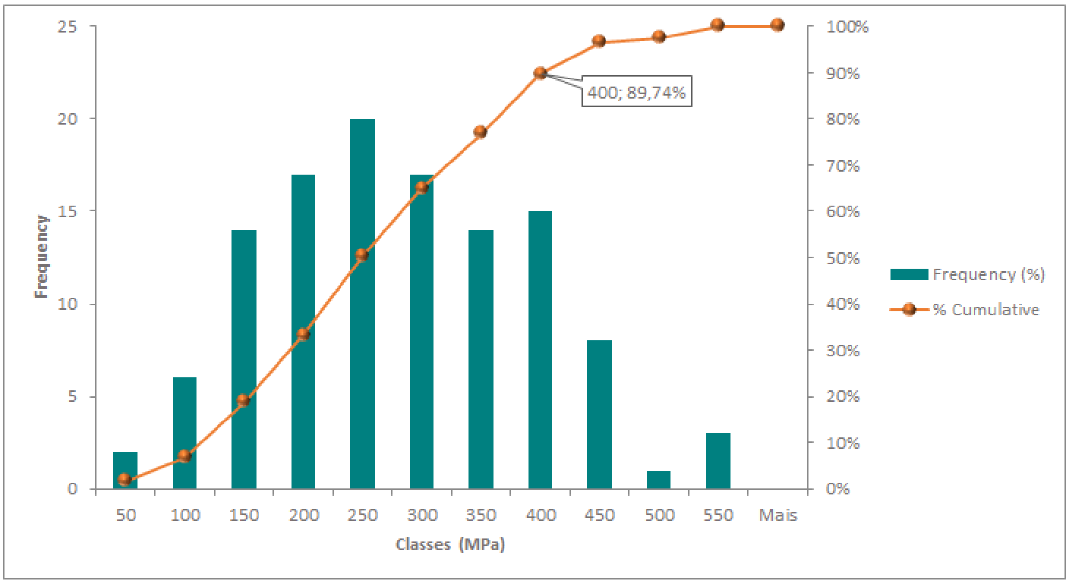


Figure 10-1 – Jaspilite compression strength histogram.

10.2. Recovery estimates

Serra Sul operates on wet basis (natural moisture) and 100% metallurgical recovery, given that process routing consists of natural moisture processing and there is no process loss.

10.3. Current performance

Table 10-3 summarizes the historical performance at Serra Sul.

Table 10-1 Production, recovery, and quality

Year	Production (Mt)	Fe (%)	SiO_2 (%)	Al_2O_3 (%)	P (%)	Mn (%)	PF (%)	Mass Recovery (%)
2018	58.0	65.20	0.96	0.92	0.100	0.045	4.30	100
2019	73.4	65.06	1.31	1.14	0.111	0.052	3.90	100
2020	82.9	64.64	1.58	1.41	0.118	0.055	3.98	100
2021	73.7	64.49	2.02	1.33	0.103	0.052	3.80	100
2022	69.3	64.28	1.95	1.32	0.098	0.480	3.90	100
2023	75.0	65.05	1.80	1.18	0.100	0.050	3.42	100

As there is no concentration operation in place, Serra Sul recovers 100% of the plant throughput.

10.4. Deleterious elements

Table 10-1 shows the main chemical contents in Serra Sul products.

The key deleterious elements for iron ore products are silicon, alumina, phosphorus, and manganese.

Serra Sul mine is characterized as a high-purity iron ore producer, with low contaminant levels, and its product is used to adjust other VALE products. Given its high quality, no commercial penalties are applicable to this type of ore.

10.5. Qualified Person's opinion on data adequacy

Ore body performance in beneficiation plants is well known. Production experience provides a solid basis to forecast production.

As geological knowledge advances, from time to time, requirements to adjust cut-off grades, modify the process flowchart or change plant parameters to meet quality, production, and economic targets may be provided.

11. Mineral Resources Estimate

11.1. Summary

Resource estimation steps include geological modeling, grade estimation, and mineral inventory classification. This item will detail the nature of the deposit, as well as geological information reliability with which the lithological, structural, mineralogical, weathering or other geological, geotechnical, and geo-metallurgical characteristics used in the typological domains have been recorded.

Once the deposit geological modeling step is completed, using explicit modeling, implicit modeling, or a combination thereof, the 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). In both cases, the majority lithology is assumed. Lithology is always used to interpolate grades in mineral inventory classification.

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

Block model mineral inventories are classified based on the “Risk Index” (RI) calculation, 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 pertaining to the database, geological modeling, grade estimation of VALE iron ore deposits’ mineral inventory classification (Figure 11-1).

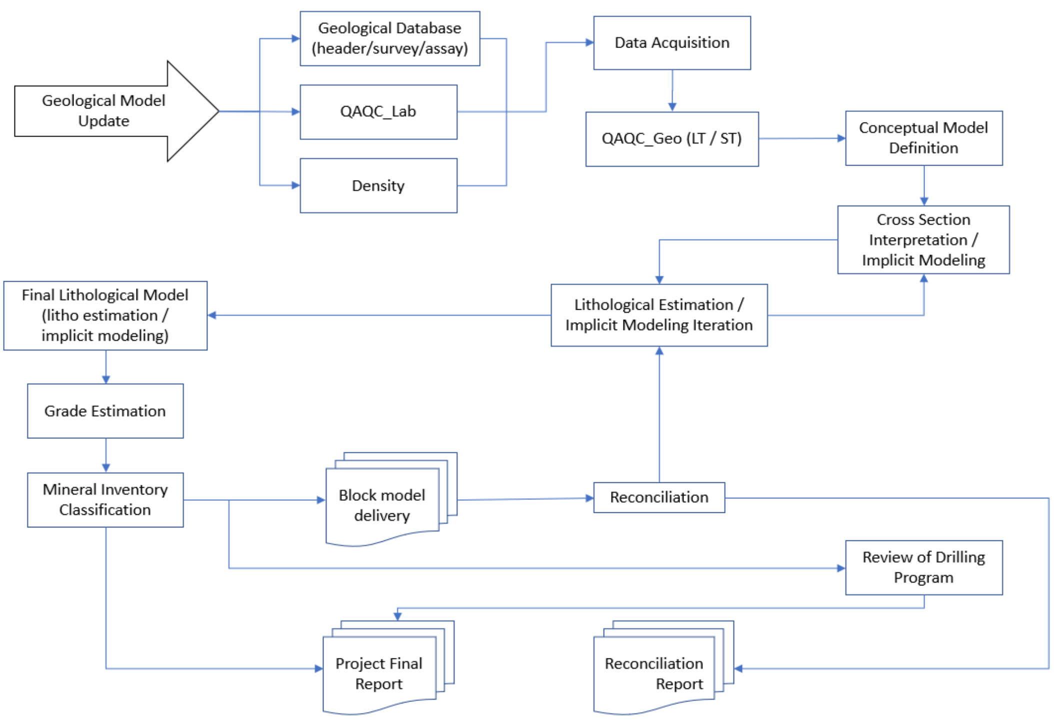


Figure 11-1 – Macro processes’ flowchart for modeling, grade estimation, and mineral inventory classification of iron deposits.

11.2. Resource database

The database used to estimate Serra Sul deposits' grade is made up of the following chemical assays: Fe, SiO_2, P, Al_2O_3, Mn, LOI, TiO_2, MgO, and CaO. These elements were assayed in different grain 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). Serra Sul deposits' geological models were only updated once the entire database had been thoroughly revised.

11.2.1. Database verification

Isotopy comprised the following steps:

- Removal of untested sample intervals.
- Removal of samples from the RSUL_SILAB analytical flux, as there were issues in the sampling procedure and the remaining mass available is not sufficient for a second sampling check. This information was used with prudence in the geological modeling, but not in the grade estimation step.
- Removal of samples for isotopy of global Fe, SiO_2, P, Al_2O_3, Mn and PF grades.
- Removal of samples with chemical closure outside the 95% and 102% limits established.
- Chemistry and grain size fraction consistency check. The database is isotopic in all analytes, except for <5% of the samples that did not present global values of Ca, Ti and Mg. This heterotopy was addressed in the post-estimation process.
- Removal of samples with recovery lower than 60%.

11.3. Geological interpretation and modelling

11.3.1. Implicit modeling with percentile model

The drilling information currently available is sufficient to satisfactorily define ore mass and quality only for bodies C and D. The SSCD geological model has EW orientation, and approximate dimension of 12 x 7 x 1 km. The model was developed based on the implicit modeling technique, incorporating direct (drilling) and indirect (geophysics and mapping) data, and it was built from the conceptual framework, with further detailing of the iron formation internal structure. This model was audited in 2016 by RPM Global and deemed to satisfactorily reproduce mineralized body continuity, as well as host rocks, coverings, and intrusive rocks in such bodies.

The geological interpretation is supported by a survey carried out over several years by different companies, starting in the late 1960s.

Currently, the implicit modeling is built using Leapfrog Geo. With Leapfrog, it is possible to create implicit models directly from the data, reducing, or even eliminating, the need for explicit modeling by manual interpretation of vertical sections.

The main steps of the work are:

- Geological database.
- Conceptual model.
- Individualization of the events that drive the mineralized body shape.
- Data Input into the software.
- Interpolation parameters.
- Resulting model validation.

The major advantages of this method are how dynamic information updating is and how easy it is to view the deposit in 3D at all interpretation stages. As a result, two basic models that drive the mineralized bodies were interpreted, namely: litho-stratigraphic units and weathering domains. Proper fine-tuning the lithotypes within the main body were made based on the combination of these macro domains (Figure 11-2).

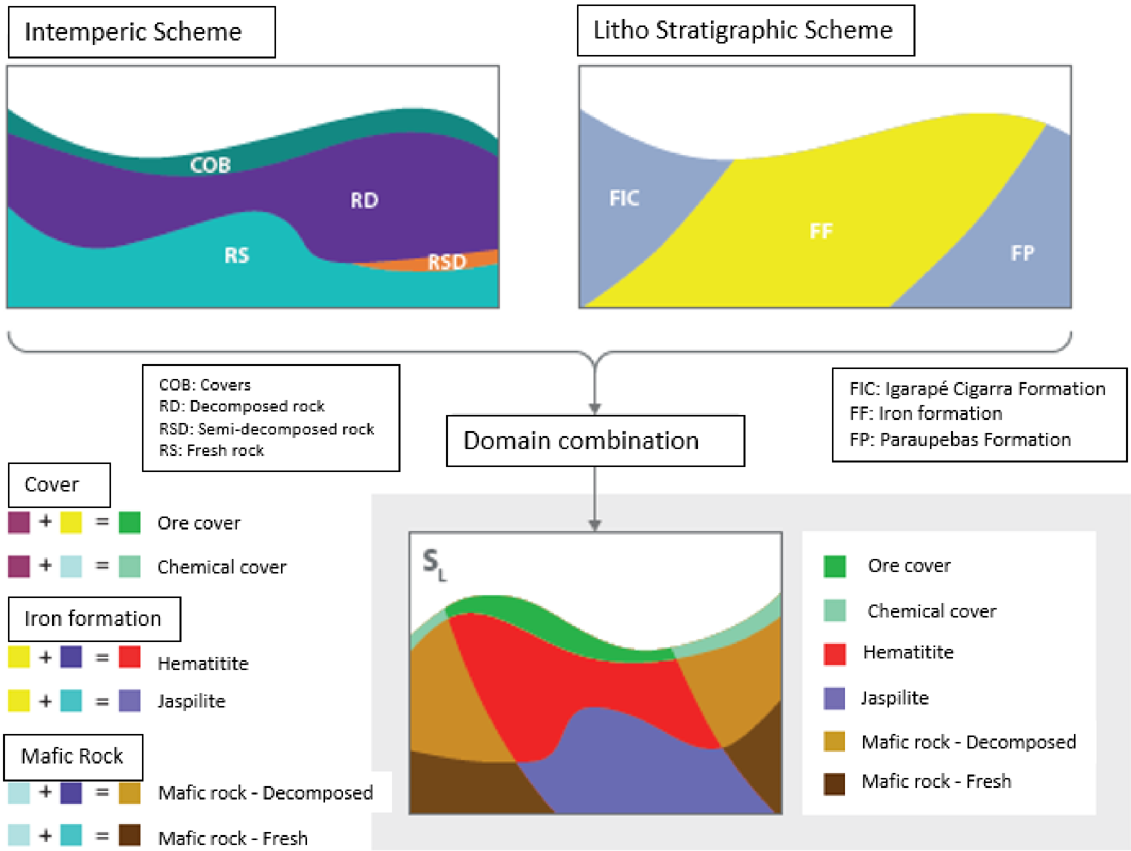


Figure 11-2 – Leapfrog simplified interpretation model of Carajás-type iron ore deposits.

The interpretation stage's final products are 3D solids which are saved and imported into Vulcan, where the mass model is generated. Lithology variable is attributed in the block model with the majority lithology and its indicators, in percentile, as shown in the flowchart below (Figure 11-3).

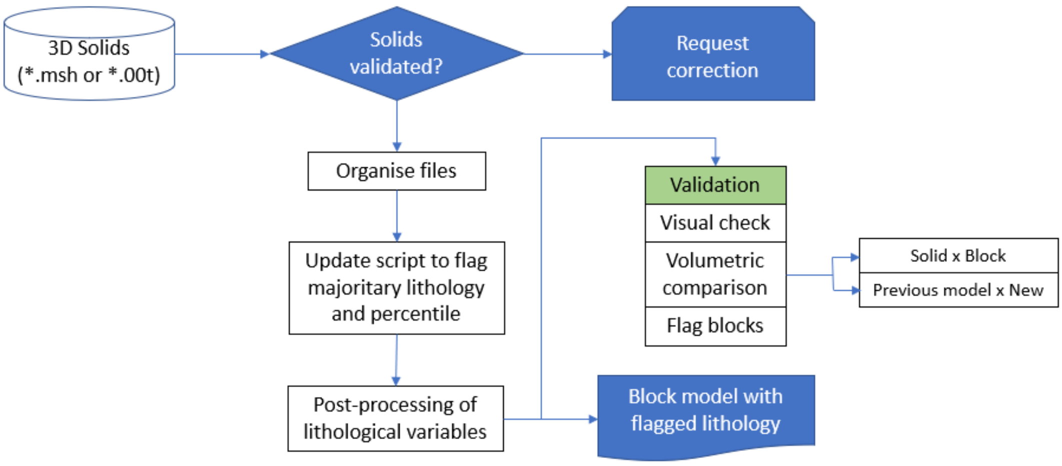


Figure 11-3 – Flowchart of the lithological estimate for VALE iron ore deposits (percentile models).

The information generated must be analyzed and interpreted to allow for mathematical checks for percentile models (mostly automated). All deviations must be recorded, justified, and saved in project folders.

11.3.2. Serra Sul geological model

The Serra Sul geological model was completed entirely with implicit modeling in Leapfrog Geo. The mass model with lithological assignment was made in Vulcan, which allows indicators to be calculated by the percentage of each lithotype in the block from Leapfrog solids . Table 11-1 show the amount of drilling data used in the interpretation.

Table 11-1 – Database used in the Serra Sul model

Drilling Campaigns – Serra Sul		2008 Model		2013 Model		2016 Model		2017 Model		2021 Model		
		N ° Drill holes	Meters (m)	N ° Drill holes	Meters (m)	N ° Drill holes	Meters (m)	N ° Drill holes	Meters (m)	N ° Drill holes	Meters (m)	*Diff. 2021 vs. 2017*
Orebody D	Short-term	-	-	-	-	111	11,008	374	33,541	933	76,911	*43,370*
	Long-term	290	64,421	466	99,448	595	136,338	818	195,345	968	249,403	*54,058*
	Subtotal	290	64,421	466	99,448	706	147,346	1,192	228,886	1,901	326,314	*97,428*
Orebody C		58	8,893	58	8,893	71	11,609	72	11,846	188	40,375	*28,529*
TOTAL		**348**	**73,314**	**524**	**108,341**	**777**	**158,955**	**1,264**	**240,732**	**2,089**	**366,689**	***125,957***

This list does not include the FP drillholes incorporated into the SSCD model, which total 134,751 meters of mine production drilling.

S11 C and D geological model was completed in two different stages. The first stage addressed implicit modeling of major events driving mineralization (weathering and tectonostratigraphic contacts), resulting in the large contact model as a product of the combination of these events. The second stage delt with the internal detailing of the iron formation's lenticular bodies in vertical sections, in which external contacts and covering are consistent with implicit modeling. Leapfrog® was used for implicit modeling, and vertical sections were interpreted in Vulcan®.

Application of 3D seismic survey in geological interpretation

In 2015, a 3D seismic survey was carried out on S11D plateau. The area surveyed concentrated in the active mine operation region.

The end product was a 3D cube with wave amplitude values, previously processed by the exploration team (Figure 11-4).

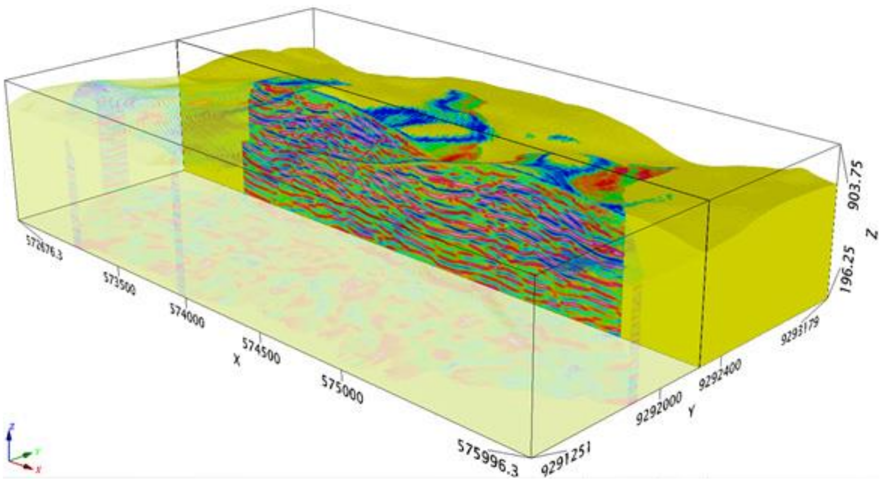


Figure 11-4 – Representation of the seismic cube.

Amplitude signals associated with the drilling information were used as input to simulate the probability of the block being jaspilite, considering geological continuity (which drives mineralization) through dynamic anisotropy. This probability simulation was then populated into the implicit modeling software and used to interpret jaspilite bodies (Figure 11-5).

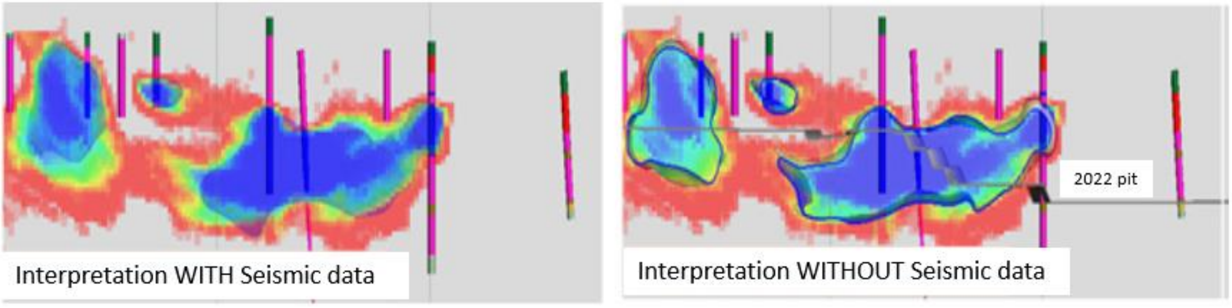


Figure 11-5 – Modeling of S11D sections using seismic information.

Figure 11-6 represents the geological model interpreted in Leapfrog Geo.

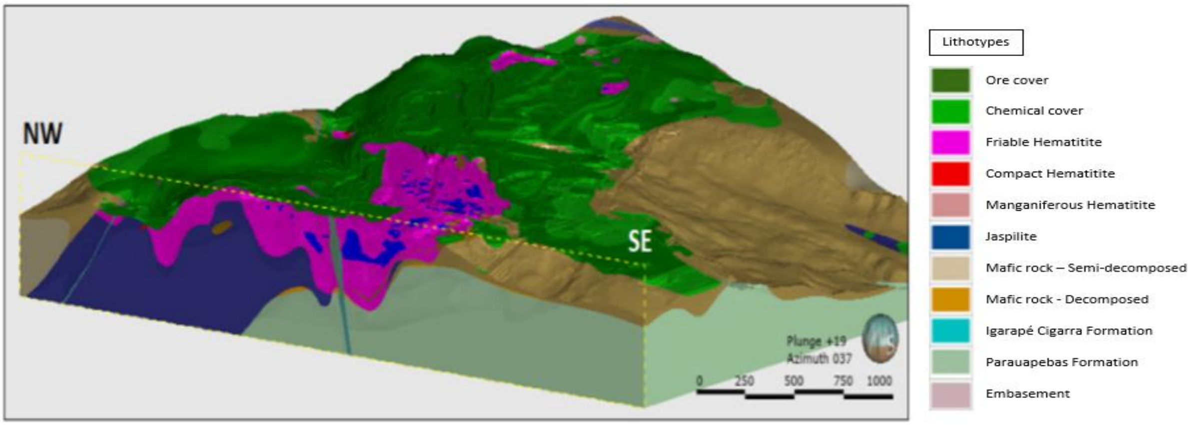


Figure 11-6 – Serra Sul geological model interpreted (detail: ore body D).

11.3.3. Serra Sul lithotype estimation

The model box includes Serra Sul deposit, S11 target, bodies C and D, adopting regular 25 x 25 x 15 m blocks. Block model dimensions are: 12,100 m X axis; 6,800 m in the Y axis, and 975 m Z axis (Figure 11-7).

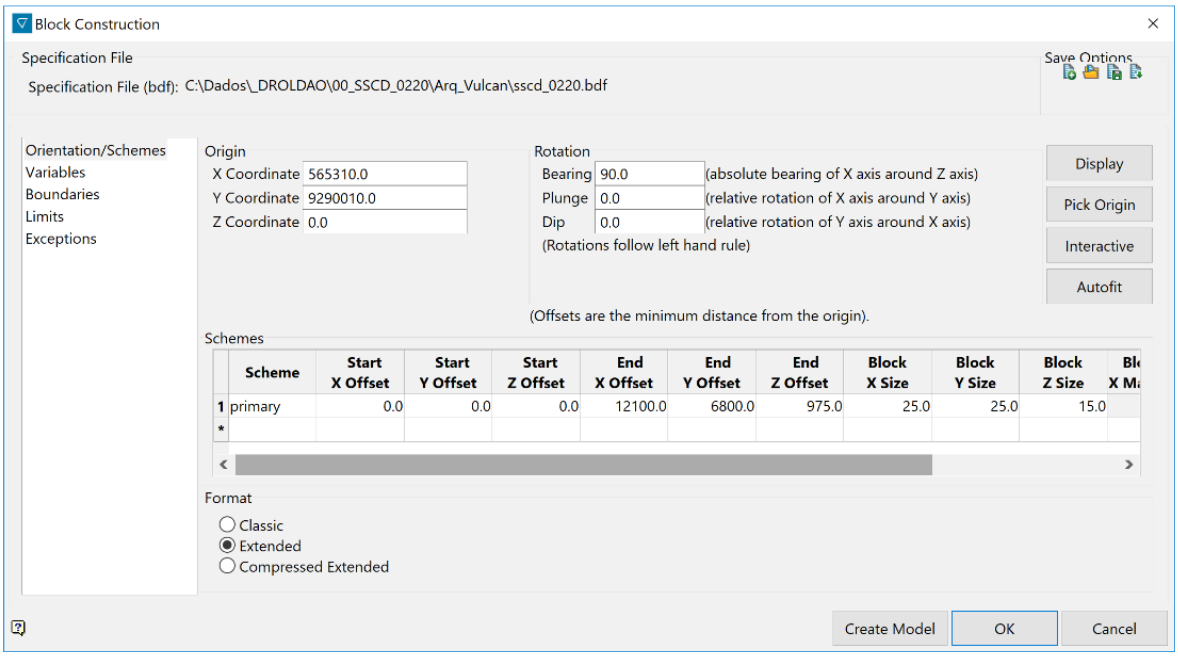


Figure 11-7 – Parameters adopted to define Serra Sul block model box.

The lithological fields are made up of the majority lithotype and indicators of each lithotype, calculated by the 3D solid percentile contained in the block (Figure 11-8).

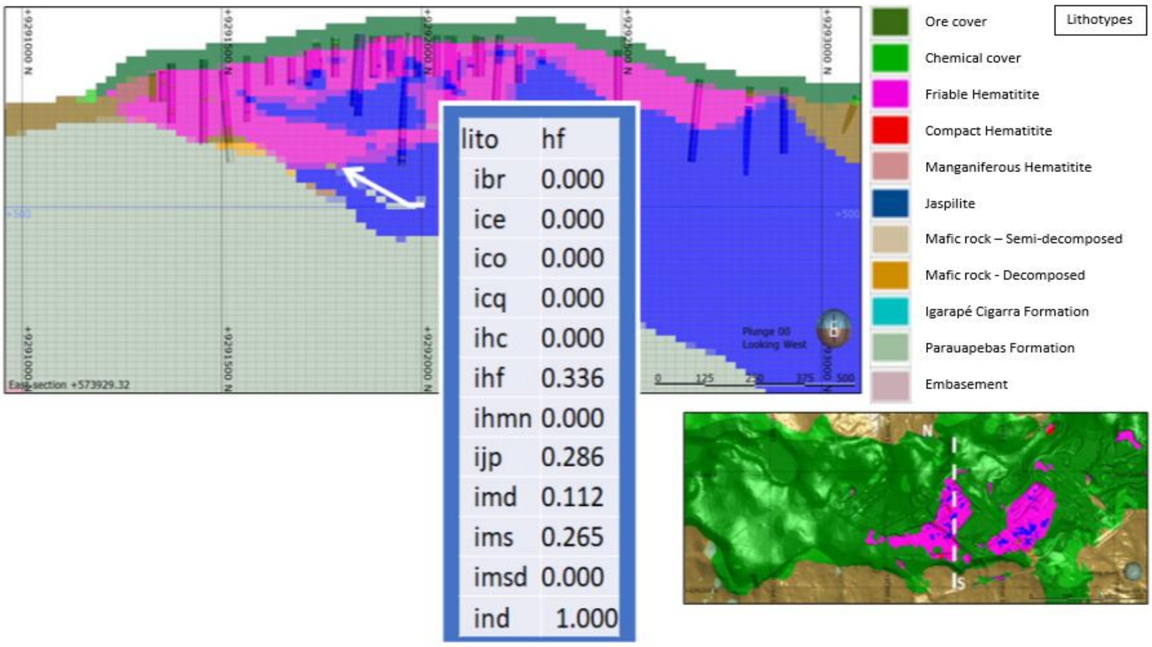


Figure 11-8 – Block model with lithological indicators and majority lithology, interpreted using exploration and ore control drilling.

Validation

Once block modeling is finished, interpretation and block model visual validation is conducted.

11.4. Domain modelling

The geological model was built based on the categorical field referred to as CLI (interpreted geological classification). This field is generated by consolidating CLV (Visual Lithological Classification), global chemistry results, classification key, and spatial continuity of geological bodies.

Figure 11-9 shows the relationship between the interpreted lithotypes (left columns) and the final block model classification (right columns).

Lithotype separation into sill (*SL), dyke (*DK), and lenticular bodies (*_L) is merely interpretative, considering that these units have specific geological drivers. These units are grouped in the subsequent grade estimation step, as shown in the table.

The proposal adopted in the 2016 model in the classification key was maintained (Figure 11-10).

Interpreted Lithotypes		Lithotypes in the Block Model	
AT	Dump	AT	Dump
CE	Ore Duricrust Cover	CE	Ore Duricrust Cover
CQ	Chemical Duricrust Cover	CQ	Chemical Duricrust Cover
HF	Friable Hematitite	HF	Friable Hematitite
		HGO	Goethitic Hematitite
HC	Compact Hematitite	HC	Compact Hematitite
HMN	Manganiferous Hematitite	HMN	Manganiferous Hematitite
JP	Jaspilite	JP	Jaspilite
JP_L	Jaspilite Lenses		Jaspilite Lenses
MD	Mafic Rock - Decomposed	MD	Mafic Rock - Decomposed
MD_SL	Mafic Rock - Decomposed - Sill		
MD_DK	Mafic Rock - Decomposed - Dike		
MSD	Mafic Rock - Semi-Decomposed	MSD	Mafic Rock - Semi-Decomposed
MSD_SL	Mafic Rock - Semi-Decomposed - Sill		
MSD_DK	Mafic Rock - Semi-Decomposed - Dike		
MS	Mafic Rock - Fresh	MS	Mafic Rock - Fresh
MS_SL	Mafic Rock - Fresh - Sill		
MS_DK	Mafic Rock - Fresh - Dike		
FAC	Aguas Claras Formation	FAC	Aguas Claras Formation
FIC	Igarapé Cigarra Formation	FIC	Igarapé Cigarra Formation
FP	Paraupaebas Formation	FP	Paraupaebas Formation
EC	Embasement	EC	Embasement

Figure 11-9 – Serra Sul model for lithotypes interpreted.

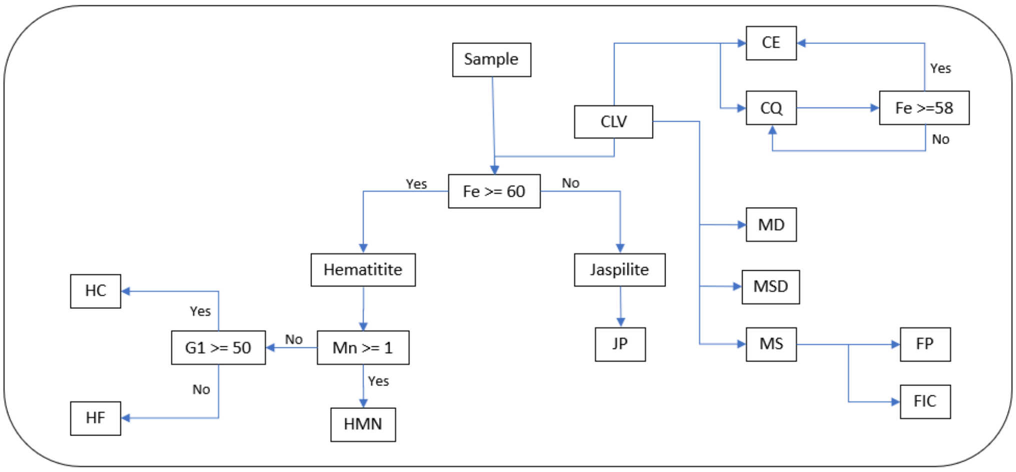


Figure 11-10 – Classification key used in the Serra Sul model.

Lithotypes modeled

The lithotypes modeled resulting from the process are: cangas (structural canga – CE and chemical canga – CQ), hematites (friable hematite – HF, compact hematites – HC, and manganese hematites – HMN), jaspilites (JP), breccias (BR), and mafic rocks.

11.5. Resource assays

11.5.1. Exploratory data analysis

VALE made exploratory data analysis (EDA) for each estimation domain, including univariate statistics, histograms, cumulative probability plots, and box plots to compare geology domain statistics and contact plots in order to investigate grade profiles between estimation domains. Figure 11-11 show the global iron distribution (FEGL).

Hematites have normal distribution with low dispersion, being extremely rich bodies, with average iron grade close to 66%. This is true except for manganese hematite, which presents lower grades given the high levels (> 2%) of manganese.

Mafic rocks in the inner portion of Carajás Formation sequentially present high iron grades. This is due to ore-mafic rock interdigitation, which is very common in this deposit. Sills and dykes in Serra Sul are not very relevant, rarely exceeding 10 m.

Low iron grade jaspilite (<20%) indicates thicker chert levels. Average jaspilite grades are not considered to be representative of the entire package interpreted, as only lenticular bodies (immersed in the hematite package) and a 30-meter horizon of the base jaspilite have been sampled. This effect reveals a positive bias in this unit's grades, as jaspilites tend to be poorer in depth.

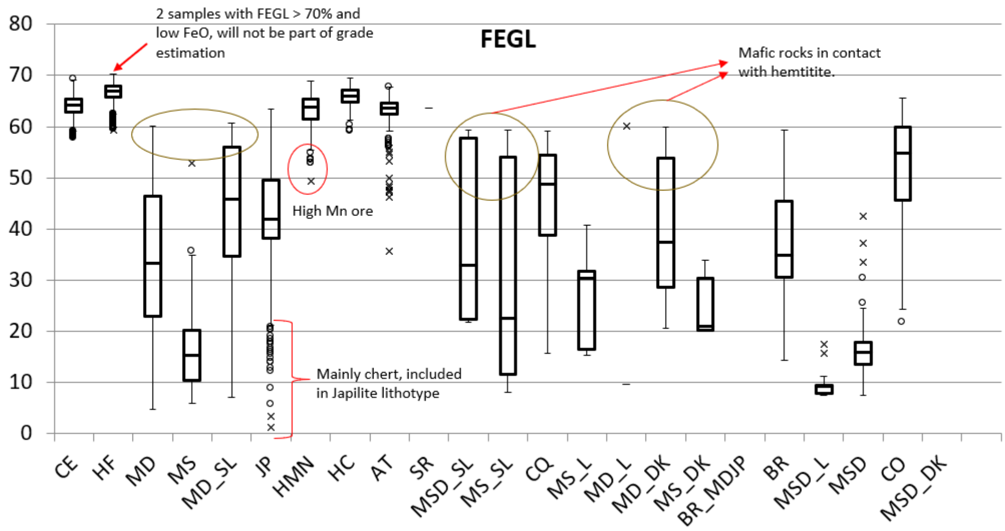


Figure 11-11 – Global iron distribution for the lithotypes interpreted.

Higher phosphorus values may occur in hematites, a pattern not identified in jaspilites, indicating that phosphorus is strongly driven by weathering.

The high loss on ignition values in hematites and phosphorus are strongly related to weathering, or locally, to incipient hydrothermalism in compact hematites. The jaspilite also shows high loss on ignition levels, which may be related to secondary carbonation that can be associated with hydrothermalism.

Negative loss on ignition values (anomalous) were addressed in the grade estimation step.

11.6. Treatment of high-grade assays

Anomalous higher-grade values were evaluated by means of grade distribution statistical analyses (histograms, cumulative frequency plots). The blocks estimated to be outliers were those located within the ellipsoid sized 150 x 75 x 15 meters for HC and 200 x 100 x 15 meters for HF. Ellipsoid orientation was consistent to the orientation defined for the domain containing the block. For blocks attributed as outliers, the estimation process used the entire database (no database restriction) including outliers samples. For the blocks not defined as outliers the estimation was performed using only samples flagged as "not outliers", to prevent grade estimation to be biased with outlier's samples.

11.7. Compositing

For variography and grade estimation, the database was submitted to an isotopy process and subsequent regularization in 15-meter composites. Drilling intervals were regularized according to mine bench and lithological contact heights. Vulcan standard was the method adopted in regularization (composites), this method considers the pre-established constant length and lithological contacts. The broken interval (residual) acceptance limit during regularization in the grade estimation step was 30% of the bench height. The sum of all these broken intervals was less than 2% of the total meters in the database.

11.8. Trend analysis

Grade variographic analysis

The variographic analysis made prior to grade estimation of S11 bodies C and D included experimental variography. This was done considering two different groups: the first one consisted of structural canga and hematites; and the second one consisted of the jaspilite domain. The analysis was initially based on the FEGL variable and then validated in the simple and cross-variogram matrix with six global variables and 40 size fractions and chemistry by fraction variables (four physical variables and 36 chemistries by particle size fraction variables).

The experimental variogram process performed in ISATIS® used the following parameters:

- Accumulated grade database with sample length >= 4.5 m.
- Selections considered by GEOCOD: hematites and canga {hemat + ce} and jaspilites {jasp};
- Direction: 90° (Azimuth), 0° (Dip), and 0° (Plunge).
- Angular tolerance: 22.5°.
- Lags:
    - HEMAT + CE group: 100 m (X and Y) and 15 m (Z).
    - JASP group: 150 m (X and Y) and 30 m (Z).
- Number of lags:
    - HEMAT group: 15 (X, Y and Z).
    - JASP group: 10 (X, Y and Z).

Table 11-2 shows the search parameters considered for both groups:

Table 11-2 - Search parameters applied to S11CD model estimation.

Search parameter	X	Y	Z
Hematite	450	250	60
Hematite with outliers	200	100	15
Jaspilite	450	250	60

11.9. Search strategy and grade interpolation analysis

VALE's iron ore deposits are the most complex cases in the multivariate domain. Carajás Iron deposits typically have nine global variables, four particle size fractions and nine more chemical variables retained in each fraction, totaling 49 variables that must be estimated as per their stoichiometric ratios and particle size closure. Estimating these variables targeting stoichiometry compliance is only possible by using (co)kriging.

In 2008, a study intended to standardize the estimation method to be used in VALE iron ore deposits. Said study compared the main multivariate methods adopted in the industry: Correlogram, Linear Coregionalization Model (MLC), and Intrinsic Correlation Model (MCI). MCI was considered to be the most suitable method for VALE deposits.

The MCI method can be considered a simplification of the MLC, but its theoretical grounds are as robust. The method's easiness is that, as it works with proportional variograms, crossed variograms act as residue and become null during the kriging process. Its main advantage is that estimation can be made in software that works with both multivariate and univariate data, facilitating estimation process implementation in operational areas (short-term geology). The method's main advantage is that, like the correlogram, it virtually overthrows data post-processing, as it gives recognition to stoichiometry and sampling range for isotopic cases.

Figure 11-12 shows the cross-validation of variables estimated either via ordinary kriging (A) or ordinary (co)kriging (B), the latter being estimated by both MCL and MCI.

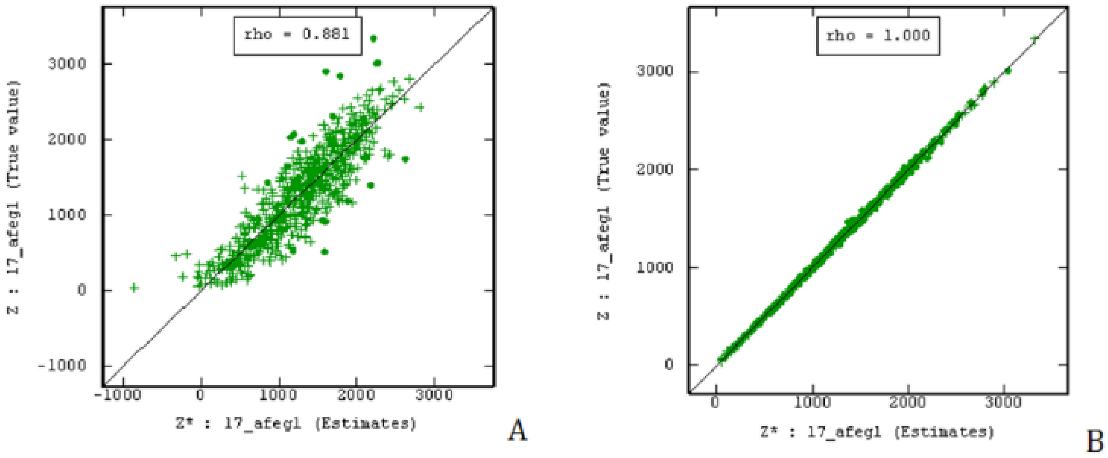


Figure 11-12 – Cross-validation of FEGL estimated via kriging (A) and (co)kriging (MCI, B).

As previously presented, the MCI is a method that guarantees proportionality between simple and crossed variograms. Thus, (co)kriging and kriging yield the same results. Intrinsic correlation variographic models for stationary cases can be written as:

$$\gamma(h) = b^k \gamma^k(h)$$

Where simple and crossed variograms can be written as linear combinations, and consequently, variable Z(x) can be broken down into k variables Y(x) from a linear combination not correlated at the same point (Rivoirard, 2003).

$$Z(x) = \sum_k a^k Y^k(h) \text{ , where } b^k = (a^k)^2$$

The method used to interpolate global standard grades and particle size fraction variable grades for iron deposits is ordinary (co)kriging with intrinsic correlation variographic models (MCI). Geostatistical domains coincide with geological domains because contacts between lithotypes represent chemical/mineralogical and particle size discontinuities that must be considered in the estimation. Thus, only regularized samples of a certain lithotype are used to estimate that same lithotype's block (for example, only regularized HF samples were used to estimate HF blocks).

Another standard established regards drill cores, which are regularized considering the lithological contacts and bench height. The Vulcan standard method was adopted in regularization (composites), and it considers the pre-established constant length and lithological contacts. The grade estimation step considers the broken interval (residual) acceptance limit during regularization to be 30% of bench height.

The main stages of grade estimation can be grouped into four steps: 1) database preparation; 2) multivariate variography; 3) grade estimation; and 4) validation and post-processing of interpolated grades. Variography is performed using ISATIS®. Vulcan® is used in all database preparation, grade estimation, post-processing, and validation steps. Figure 11-13 details each grade estimation step.

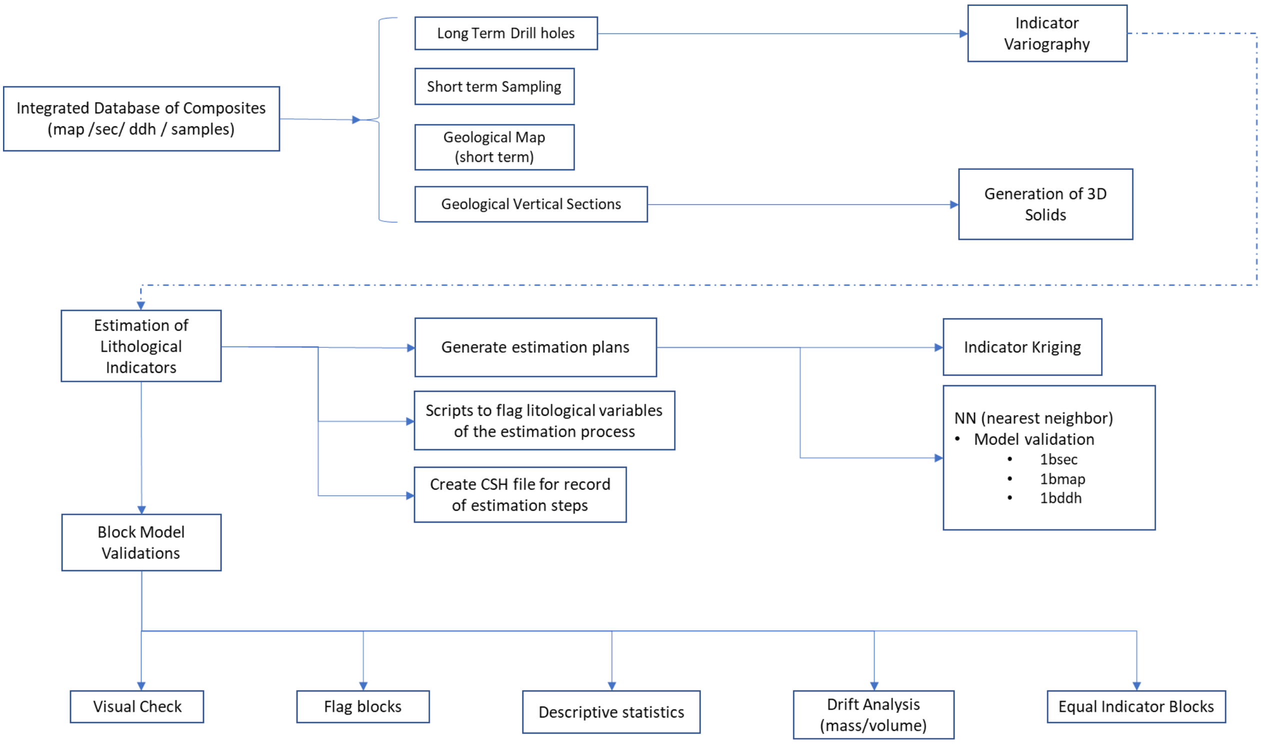


Figure 11-13 – Grade estimation process flowchart for VALE iron ore deposits.

Serra Sul grade estimation parameters

Grades were estimated based on the ordinary (co)kriging principle using intrinsic correlation (MCI) variographic models. As explained above, based on this method, both variable-independent kriging and (co)kriging yield the same results, given that variograms are proportional. The estimation used normalized variance levels. Such value normalization consists of a simplification of the method which allows the estimation process to be run in software with basic geostatistics modules. The S11CD model was estimated using the Geostats module (GSLIB algorithms) within Vulcan®.

Seven distinct domains were estimated (CE, CG, HC, HF, HMN, JP, and MD). The estimated variables were:

- Nine global grades: Fe, SiO_2, P, Al_2O_3, Mn, LOI, Ti, Mg, and Ca.
- Four physical fractions: G1A (+ 19 mm), G1B (-19 + 8 mm), G2 (-8 + 0.15 mm), and G3 (-0.15 mm).
- Nine grades for each physical fraction.

In summary, estimated variables pertaining to grades and physical fractions totaled 49.

Although more comprehensive lithological grouping approaches were used to adjust the variographic model, lithological units were taken into account in the kriging process, that is, composites of a certain lithotype only estimate blocks of the same lithotype. Table 11-3 shows the estimation parameters.

Table 11-3 - Summary of parameters considered in the S11 C and D model grade estimation process.

Samples	Database	s11cdflp.cac.isis	
	Group	15MFLP	
	Min. samples	1	1
	Max. samples	16	1
	Octant	Yes	No
Blocks	Discretization	5 x 5 x 2	-
	Search range	450 x 250 x 85	
	Block size	25 x 25 x 15	
	No. of structural sectors	5	

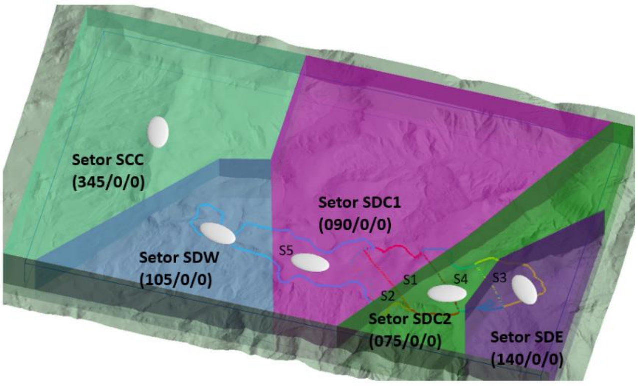


Figure 11-14 – Representation of the five sectors considered in grade estimation and their respective ellipsoids.

11.9.1. Grade estimation post-processing

Figure 11-15 below shows the post-processing workflow adopted for Serra Sul.

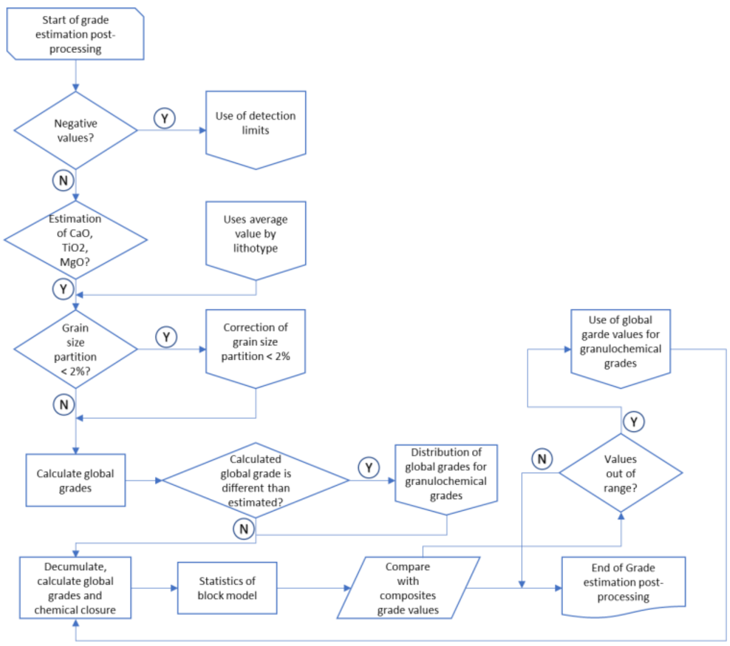


Figure 11-15 – Flowchart of the post-processing adopted in grade estimation in the Serra Sul model.

Once estimation was finalized, post-processing started with the following checks:

- Presence of blocks with negative grades.
- Treatment of blocks with no CaO, MgO, and TiO_2.
- Identification and correction of very low particle size fraction values.
- Compatibility of fraction chemistry with estimated global grades.
- Marking and correction of anomalous stoichiometric closing values.

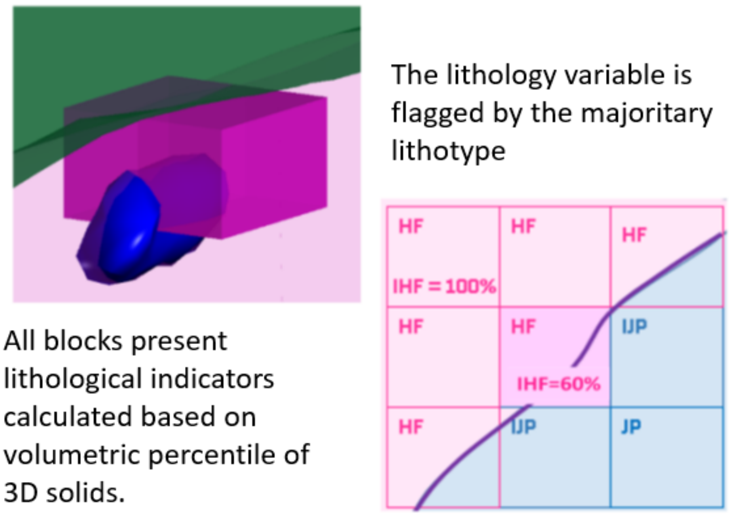
11.9.2. Density and grade dilution

All Carajás iron ore deposits have both diluted (mass and grade) and undiluted variables. It is up to short and long-term planning to use these variables as a function of the production scale (low operational selectivity). Dilution is calculated by weighing blocks' grade variables, as well as those in the vicinity, considering pre-established lithological indicators (Figure 11-16), in addition to the following indicators:

• 0.8 limit for ore indicators: this value informs that if any ore indicator reported (ice, ihc, ihmn, ihf, and ijp) equals or is greater than 0.8, the block's grades will not be diluted. This case implies that most of the block is ore, thus eliminating the need for dilution. This case occurs in blocks located in central portions of ore bodies and away from contact zones between ore and waste rock. Dilution is applied if any given indicator is lower than 0.8.

• 0.4 limit for waste rock indicators: this case considers the sum of waste rock indicator values (icg, imd, imsd and ms). Dilution is applied if the sum of the values equals or is lower than 0.4.

These tolerance values may vary depending on the operational flexibility and lithological indicators' calculation method. Adoption of these values should happen in collaboration between short and long term mine planning and geology teams.



Dilution Calculation	Friable Hematite	Jaspilite	Ore cover
% Litho in the block	60	30	10
Iron grade (%)	68.34	55.57	62.35
Diluted Iron grade (%)	$Fegli = \frac{(68.34 * 60 + 55.57 * 30 + 62.35 * 10 + 0)}{100}$	=	63.91

Figure 11-16 – Schematic representation of the dilution process applied in Serra Sul.

Upon grade estimation completion, grade dilution is applied (Figure 11-17) and density is adjusted. Indicators' threshold values considered for grade dilution applied in the Serra Sul model were:

• 95% for ore lithologies (CE, HF, HMN and HC) and JP, meaning that blocks with ore indicator above 95% would not be diluted.

• 40% for waste lithologies (CQ, CO, MD, MSD, MS FP, FIC, and BR), meaning that the sum of waste rock indicators above 40% would not trigger the dilution process.

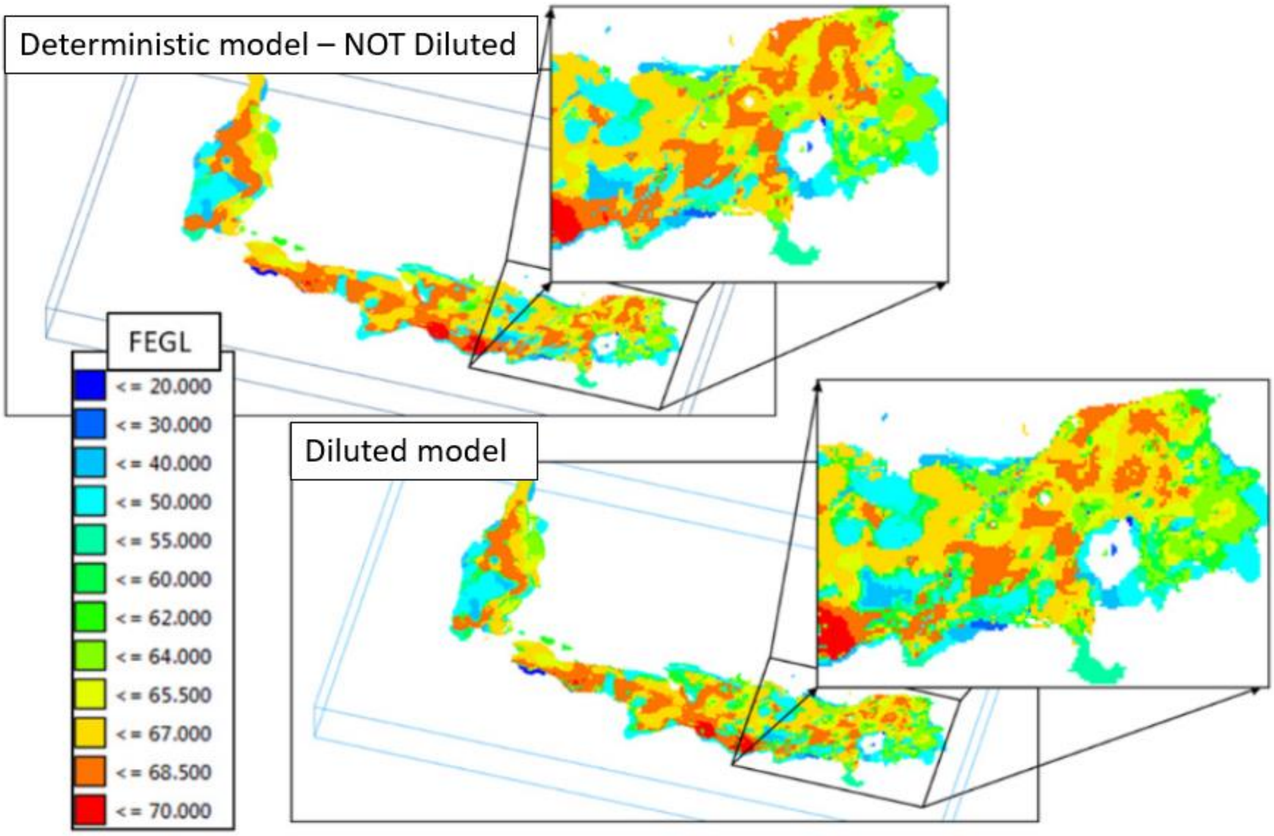


Figure 11-17 – Comparison between deterministic and diluted models for Serra Sul.

11.10. Bulk density

The methodology adopted to estimate density was the same one used in the 2016 geological model, and the geophysical information validation stage (gamma-gamma) was the key difference. The gamma-gamma data validation procedure review used normative calculation, which allowed 50% gain in the information validated.

Assignment of density values depends on the lithotype. For hematites, a combination was made between estimating geophysical parameters (density via gamma-gamma survey, variogram analysis, mineralogical calculation and variable density with depth). As for JP (jaspilite), MD (decomposed mafic), MSD (semi-decomposed mafic), and MS (fresh mafic) lithotypes, densities were estimated via geophysical survey and density variable with depth. Structural canga (CE) considered the mean of valid geophysical density values. Finally, conventional density tests (single value) were adopted for other waste and chemical canga.

In Serra Sul, four different methods were combined:

- Density estimate, with values obtained via gamma-gamma survey.
- Density derived from mineralogical density with variable porosity.
- Variable density based on the distance between the block and the topographic surface.
- Mean density value.

Table 11-4 summarizes density values applied to block models, as well as the methodology adopted for each lithotype.

Table 11-4 - Density values applied to blocks and methodology adopted for each lithotype.

Lithology	Density			Method			
	Minimum	Average	Maximum	Gamma-Gamma	CNM	Drift	Conventional
Structural Canga - CE		3.14					X
Chemical Canga - CQ		2.96					X
Compact Hematite - HC	2.95	3.37	3.68	X	X	X	
Friable Hematite - HF	2.62	3.22	3.86	X	X	X	
Mn Hematite – HMN	2.60	3.15	3.68	X	X	X	
Weathered Mafic – MD*1	1.83	2.15	2.35	X		X	
Semi-weathered Mafic – MSD*2	2.26	2.49	2.59	X		X	
Mafic - MS	2.79	2.81	2.82	X			
Parauapebas Formation- FC*3		2.79					X
Igarapé Formation- FIC*3		2.85					X
Águas Claras Formation- FAC*3		2.30					X
Crystalline Base - (EC)*3		2.30					X
Jaspilite – JP*4	2.26	3.23	3.65	X		X	
Colluvium - CO*1		2.96					X
Breccia - BR*5		2.81					X

**1 - CQ moisture values adopted / *2 - MD and MS average moisture / *3 - Historical values / *4 - Average moisture values from conventional tests of Carajás iron ore deposits / *5 - values adopted from MS.*

The moisture data used in the model was calculated from reverse circulation drilling results (RC). RC samples were sealed in the field so that correct moisture values could be obtained. This information was consolidated using the conventional density acquisition methodology.

Mean distribution values were considered for the Serra Sul model. The average moisture content of Carajás iron ore deposits was adopted for basement and lenticular jaspilite. RC density values for these lithotypes were disregarded as they presented a very high positive bias, probably due to hematite moisture contamination.

Conclusions and Recommendations

Density values for Serra Sul deposit were reviewed, and, considering the results of gamma-gamma survey, conventional data (traditional methods) and mineral normative calculation (CNM), it was assumed that the average values weighed considering the number of samples were representative of each lithotype's density.

Weighing considered samples from gamma-gamma logging and conventional tests.

Tests using traditional methods and gamma-gamma geophysical survey are ongoing at all Serra Norte, Leste, and Sul mines to improve sampling representativity, mainly in the southern portion of N4W and northern N4E. Continuous wet density programs are required mainly for ore, waste, and stockpiles to populate the database and to perform checks with other indirect methods. There are also plans to carry out tests to determine clay lithotype (AG) density, which, due to the lack of data, was assigned with the decomposed mafic density (MD).

11.11. Block models

Serra Sul wireframes were filled with blocks in Vulcan®. The block model was not sub-celled at wireframe boundaries in a single scheme with parent cells measuring 25 m by 25 m by 15 m. Table 11-5 shows the block model setup.

Table 11-5 - SSCD Block model setup.

Parameter	X	Y	Z
Origin (m)	565,310	9,290,010	0
Bearing/Dip/Plunge	90	0	0
Block size (m)	25	25	15
Number of blocks	484	272	65

RPM Qualified Person's opinion (2016 audit) was that block size is appropriate, based on drilling spacing and the mining method proposed, thus being adequate to support mineral resource and mineral reserve estimation.

11.12. Net value return and cut-off value

Economic cut-off grade calculation considers the metal's sale price, as well as mineral processing, commercial, mining, processing, haulage and marketing costs, grade, and process plant recovery. The cut-off grade is not defined as a matter of iron grade itself, but rather as a technological approach at each processing plant recovery and productivity stage used to estimate mineral resources and mineral reserves. Decision to mine a specific block will be made in final pit generation as a function of product price and all associated costs.

Ore lithology destination and recovery are defined by means of processing equations that will seek lithotypes totally or partially routed to VALE's site operational processing route or whose processing route has been successfully tested at design/study level.

11.13. Classification

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

11.13.1. Risk index methodology

The Risk Index method uses a single index that combines geological continuity - measured by the "ore" kriging indicator (IK) - and estimation error - measured by kriging (σ2IK) indicator variance - to classify blocks into measured, indicated, and inferred. The Risk Index is calculated based on the following equation, which consists of a simplification of the original 1996 equation:

$$IR(u)_{simplificado} = \sqrt{[1 - I^{*}_{K}(u)]^2 + [\sigma^{2}_{IK}(u)]^2}$$

where:

$I^{*}_{K}(u)$ - is the indicator estimated by kriging, associated with the support of a given block, located at position u;

$\sigma^{2}_{IK}(u)$ is the kriging indicator variance of the block at position u, using a normalized semivariogram model, with unit sill.

Graphic representation of the equation presented can be seen in Figure 11-18. This figure shows the geological continuity horizontal axis, $(1 - I_K(u))$, the estimation error vertical axis, $(\sigma^2_{IK}(u))$, RI vector, and the limits used to classify blocks as measured, indicated, and inferred.

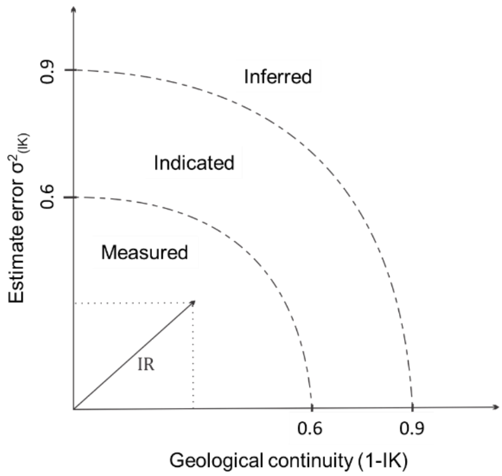


Figure 11-18 - Graphic representation of IR calculation and class limits.

RI method validation, including the chosen Risk Indices, is carried out by comparison with another classification method, namely, the dilation and erosion method. Dilation and erosion are geometric methods which typically consider blocks belonging to a 100 x 100 m mesh to be measured, those within a 200 x 200 m mesh are considered to be indicated, and other blocks with estimated grades are considered to be inferred.

11.13.2. Serra Sul mineral inventory classification

The indicative variable for this deposit was created with a unit value (one) for regularized drilling intervals considered to be "ore" (structural canga and hematites) and zero for lithotypes considered to be "waste" (chemical canga, jaspilites and mafic rocks). Figure 11-19 shows the variographic parameters applied to estimate the indicator used to calculate this deposit's Risk Index.

```
Isatis
Banco_de_Dados/s11cd_ind(SEM_FUROS_RASOS{SEM_FUROS_RASOS})
- Variable #1 : v_ind
Variogram : in 3 direction(s)
D1   : N90
       Angular tolerance =  22.50
       Lag =  100.000000m, Count = 15 lags, Tolerance = 50.00%
       Vertical Slicing =  7.500000m
D2   : N180
       Angular tolerance =  22.50
       Lag =  100.000000m, Count = 15 lags, Tolerance = 50.00%
       Vertical Slicing =  7.500000m
D3   : D-90
       Angular tolerance =  22.50
       Lag =  15.000000m, Count = 18 lags, Tolerance = 50.00%
Model : 2 basic structure(s)
Global rotation = No rotation
S1   - Nugget effect, Sill =       0.018
S2   - Exponential - Scale = 90.000000m, Sill =       0.175
       Directional Scales = (     350.000000m,      310.000000m,       90.000000m)
```

Figure 11-19 – Variographic parameters applied to estimate the indicator used to calculate the Risk Index.

Block kriging and index classification were performed using Vulcan®. The sample search ellipsoid radii used to develop the kriging matrix was 450 x 250 x 60 m. These distances correspond to a maximum acceptable grid for iron ore resource exploration in the horizontal plane and four extrapolation benches in the vertical direction. The estimates considered the same sectorization applied to grade estimation.

Long and short-term sample composites were used to estimate the Risk Index. Indicator distribution for the estimate was: indicator 1 for CE, HC, HF, and HMN lithotypes, and indicator 0 for CQ, JP, MD, MSD, and MS.

The minimum and maximum samples were 1 and 16, respectively, considering two samples per octant to be optimal, and block discretization was 5 x 5 x 1. In this step, variable IK (Risk Index indicator) and kriged block IK variance were obtained during the process. The Risk Index was calculated using a script from these variables, as follows: up to 0.6 for measured, between 0.6 and 0.9 for indicated, and above 0.9 for inferred. The indices were defined from block model textural analysis (visual) and comparison with an auxiliary method (dilation and erosion method).

Final block classification into measured, indicated, and inferred was further conditioned to the presence of valid grade values; otherwise, the block was assigned as “n” (potential). Blocks classified as measured but estimated with samples from a single drillhole were downgraded to indicated.

11.13.3. Validation of Serra Sul mineral inventory classification

Mineral inventory classification validation was carried out by means of visual inspection, in vertical and plan sections, so as to allow identification of inconsistencies and distortions of the method. A comparison between Risk Index method classification and dilation/erosion traditional classification from the drilling grid was also conducted (Figure 11-20).

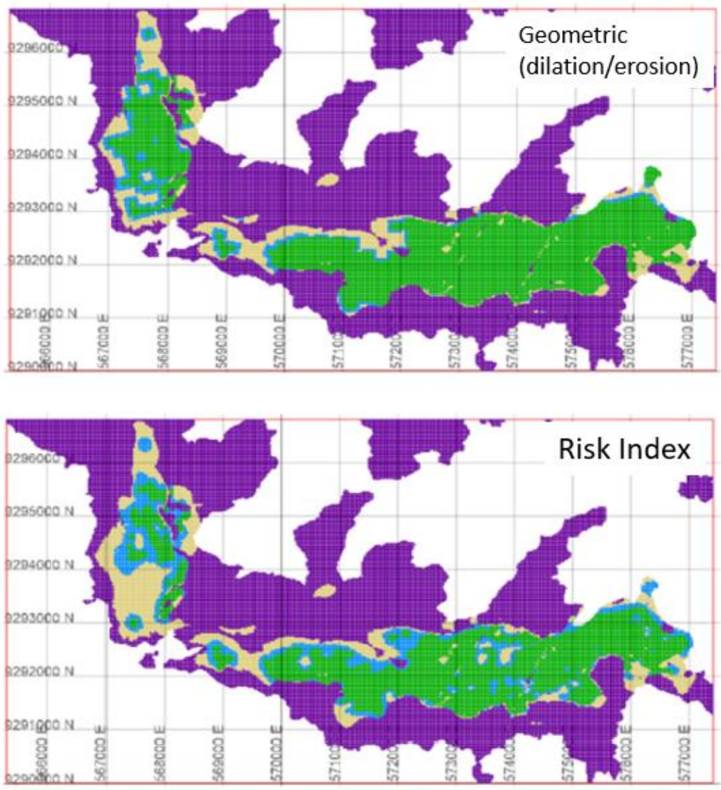


Figure 11-20 – Visual comparison between the two types of mineral inventory classification, by Risk Index and dilation/erosion, for level 700.

11.13.4. Serra Sul mineral inventory

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

11.14. Block model validation

The mathematical checks made during grade estimation (mostly automated), as well as lithological estimation, require that the information generated be analyzed and interpreted. All deviations must be recorded, justified, and stored in the database in each project folder.

The primary validation steps are described below.

- **Summary of estimation plans**: check whether the same block numbers have been estimated for the same process.
- **Block length**: checks whether all blocks in the model have the same dimensions, proving the model had not been compromised during the process.
- **Sampling range**: this check is made by performing a statistical analysis of kriged values compared with composite sample values.
- **Drift analysis**: this check is intended to validate whether or not bias has been identified in the estimates. A parallel estimation process was performed for global grades and physical fractions using the nearest neighbor method during grade kriging process.
- **Visual check**: it consists of the visual inspection of the grade distribution estimated.

All validations are recorded and organized in project folders. Figure 11-21 exemplifies some of these validations.

	Lito	N Composite	mean	min	max	N Block	mean	min	max	Dif mean	Dif min	Dif max
FEGL	CE	7100	63.840	54.700	68.939	85671	63.999	58.547	68.151	-0.159	-3.847	0.788
	CQ	318	48.760	19.210	57.950	12809	45.654	19.210	57.409	3.105	0.000	0.541
	HC	655	65.748	55.900	69.354	1276	65.993	58.493	69.001	-0.244	-2.593	0.353
	HF	17961	66.521	58.279	69.739	203622	66.568	59.370	69.386	-0.046	-1.092	0.353
	HMN	332	63.152	49.290	68.847	444	62.763	54.914	67.984	0.390	-5.624	0.864
	JP	4036	44.945	8.820	61.722	234896	43.499	12.200	61.722	1.445	-3.380	0.000
	MD	622	44.180	6.570	61.980	8252	40.444	7.780	59.510	3.736	-1.210	2.470

Figure 11-21 – Examples of validations applied during the grade estimation process.

11.15. Mineral resource reporting

11.15.1. Assessment of the reasonable for potential mineral extraction for Serra Sul mineral resources

The Mineral Resource does not consist of an 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, which, depending on assumed and justified technical and economic conditions, could become economically mineable in whole or in part.

For this evaluation, some technical parameters (mining method, geotechnical, process engineering, restrictions of protected areas, hydrogeological, speleological and surface restrictions, mining rights, among others) were applied to the Classified Mineral Inventory, as well as economic parameters (cost and price), to establish the mass to be declared as a mineral resource.

Software NPV Scheduler (CAE®) was utilized to optimize open-pit usage of the Lerch-Grossman algorithm. Before, during, and after all these optimization steps, statistical validations of the lithotypes, mineral processing disposal, geotechnical parameters, costs, prices, recovery equations, and product quality were carried out, in addition to 2D and 3D visual validations.

11.15.2. 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 company's long-term pricing policy. This price analysis considered the average moisture for the product to be 8.17%.

Prices of products from these deposits were adjusted solely with Fe grade curves above 60%, considering that VALE uses blending centers in Asia to sell its products (BRBF – Brazilian Blend Fines).

Mining costs were defined as the average cost per mined ton (ore + waste) calculated from assumptions pertaining to mining costs and mining movements used in Strategic Planning Cycle.

Mineral processing costs were defined by the average cost per ton of ROM fed into the deposit's long-term mine planning, recorded in the Strategic Planning Cycle.

Commercial costs, including logistics, administration, etc., were calculated considering the average current costs and investments per ton of product from stockpiles in mineral processing plants up to the port in China, and were properly used to build the final pit to define Serra Sul Complex mineral resources.

11.15.3. Mineral process parameters

Recovery and product grades consider the use of the following materials in the existing mineral processing plant:

- ce: structural canga.
- hc: compact hematite.
- hf: friable hematite.
- hmn: manganese hematite.

  Such lithotypes are grouped as follows:
- Hematites (HEM): hc, hf, hgo, and hmn
- Rolled (ROL): ce

From these evaluations, block-by-block qualities and respective mass recoveries were obtained based on equations provided by VALE process engineering team.

Given the quality of the material, and because processing will be based on wet basis, mass recovery was 100%.

11.15.4. Mining method parameters

The open-pit mining method was chosen considering the characteristics of the deposit, which presents superficial to subsurface iron mineralization, as well as its low waste-ore ratio and similarity to deposits previously mined at the Carajás Mineral Complex.

Conveyor belts are currently used to transport ore and waste rock. However, as the current operation uses trucks for locations where geometry is considered to be a constraint, it was conceptually considered that all ore could be mined by trucks. Conveyor belt and truck mining studies will be detailed in further engineering studies.

11.15.5. Geotechnical/hydrogeological parameters

The geomechanical model based on the geological and structural database considered for the mine's rock mass was the starting point of slope stability assessments. This information is mainly collected in drill core geological-geotechnical description, as well as on surface mapping. Detailed information regarding to geotechnical procedures is presented in Section 7.4.

Software NPV Scheduler requires geotechnical inputs from individual "slope regions", which define geotechnical parameters for each lithology. The inter-ramp slope angles (grouping by lithologies) applied to each block were assigned as shown in Table 11-6.

Table 11-6 - Geotechnical parameters used to generate the resource pit.

Lithologies	Angle
AT	22
MD	26
CO	28
BR-CQ-CE	30
MSD	32
HF-HMN	34
JP-MS-EC-FIC-FP-HC-FAC	40

Locally, the operational reserve pit may cross the resource pit, which is perfectly acceptable given the mines' definitive geotechnical sectors, geomechanical and structural characteristics of the materials, and the final design of ramps and accesses to this pit.

In this mining complex, water is supplied by underground sources.

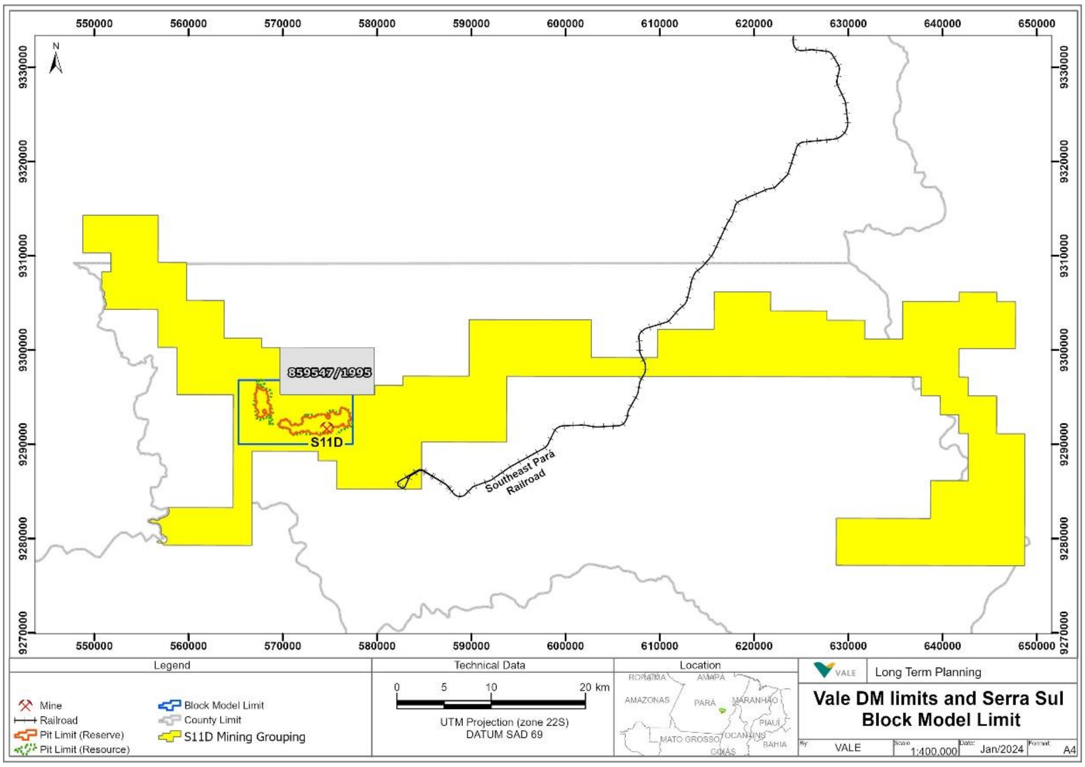
11.15.6. Waste/tailings disposal parameters

The waste material generated by the resource pit is included in the Northern Corridor Waste and Tailings Master Plan, whose design is currently at conceptual development level, requiring additional studies to define its technical, economic and environmental feasibility to implement, as required in the Iron Ore Master Plan and LOM for that deposit.

11.15.7. Mining/surficial rights parameters

VALE mineral rights (DM) cover the entire model box area; therefore, it does not limit mineral resource pit development. (Figure 11-22).

Figure 11-22 – Vale mineral rights limits and S11 model box limits (blue polygon).



11.15.8. Environmental / sustainability / speleological parameters

The deposits covered in this Report are located in the Carajás National Forest (FLONACA). This protected area was approved by Ordinance No. 45 on Apr. 28,2004 and amended on May 9, 2016.

Licenses for any expansion of this pit or for new mine fronts encompassing resource pit/reserve areas will be timely requested so that these respective areas can be mined, as per the Iron Ore Master Plan. Body "C" is located in the sustainable management zone, where geological exploration is allowed. Body "D" is located in the mining zone. There are reasonable prospects for review of FLONACA Carajás management plan in the next 10 years, expanding the mining zone and encompassing Body C, allowing mining of this body.

The 150-meter-radius buffer around the most relevant iron ore caves categorized as maximum relevance with low probability of change, as well as the buffer around two lakes and water catchment area were considered to be environmental constraints.

11.15.9. Physical structure constraint parameters

Crushing structures close to the current pit mine were not considered permanent restrictions, as they can be relocated depending on production needs.

11.15.10. Mineral resource

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

Due to the limitations imposed by the environmental constraints described and economic reasonability, not all mineral inventory was converted into mineral resources. Resource/inventory conversion rate for Serra Sul models was greater than 83%.

For Serra Sul deposits, NPV Scheduler® mathematical pit with 110% price factor was used for each deposit, consisting of a more flexible approach when compared to that adopted for mineral reserves.

Table 11-7 shows the total mineral resource tonnages and grades exclusive of mineral reserves considering the optimized pit.

Table 11-7 - Mineral resources (exclusive of mineral reserves).

Mineral Resources (exclusive of Mineral Reserves)								
Lithology	Measured		Indicated		Inferred		TOTAL	
	Tonnage (Mt)	FeGL (%)	Tonnage (Mt)	FeGL (%)	Tonnage (Mt)	FeGL (%)	Tonnage (Mt)	FeGL (%)
CE	29.2	63.1	37.7	63.3	13.8	62.2	80.6	63.1
HC	2.3	64.4	1.5	62.9	0.0	59.5	3.8	63.7
HF	489.1	66.3	351.5	65.0	106.0	65.0	946.5	65.7
HGO	20.8	64.6	15.8	63.8	3.8	62.9	40.4	64.1
HMN	1.2	60.5	0.6	60.0	0.1	57.1	1.9	60.2
TOTAL	**542.5**	**66.1**	**407.0**	**64.8**	**123.7**	**64.6**	**1073.3**	**65.4**

The mineral resource estimate has changed since the previous Serra Sul Complex Technical Report Summary was filed, having increased by 82 million tons (corresponding 8% of the exclusive mineral resource) due to partial incorporation of downgraded material in mineral reserve mine design review.

The mineral resource estimate (exclusive of mineral reserves) is to be effective as of December 31, 2023, for *in situ* material. The mineral resource estimate (exclusive of mineral reserves) is between the minimum topographic base between October 2018 and September 2023, defined by the economic reasonableness resource pit. The iron grade is expressed on dry basis, and, the mass, on wet basis.

The resource pit was generated by considering economic, legal, geotechnical, environmental, and other modifying factors.

The total values shown in the table have been rounded to reflect estimate uncertainties; thus, total ton and grade values may differ.

Mineral resources comply with the United States Securities and Exchange Commission's (SEC) Modernization of Property Disclosures 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.

11.15.11. Conclusions and recommendations

Resource pit geometry assessment shows that the structure fully complies with resource classification and is limited by environmental constraints (lakes and iron ore caves). Despite these restrictions, inferred resources can potentially be converted into measured + indicated resources, leading to increased mineral resources, especially around the lakes and in the body referred to as Body C.

Condemnation drilling must be carried out in the vicinity of mineralized bodies to characterize potential areas for possible siting of waste dumps, crushing, and overland conveyor (TCLD) so as to allow for expansion of the current operations.

The current mineral resources exclusively pertaining to mineral reserves represent a resource pit update due to a change in the hydrological recharge area of S11 deposit lakes.

11.15.12. Uncertainties that may affect mineral resource estimates

Uncertainties that may objectively impact all mineral resource estimates include:

- Changes in long-term metal price and exchange rate assumptions.
- Changes in local interpretations of mineralization geometry stemming from additional drillings programs; faults, dykes and other structures; and ore body continuity.
- Changes in geological and grade shape, and geological and grade continuity assumptions.
- Changes in variographic interpretations and search ellipse ranges which have been interpreted based on limited drilling data; such changes may occur when closer-spaced drilling becomes available.
- Changes in metallurgical recovery assumptions.

12. Mineral Reserves Estimates

12.1. Introduction

The Serra Sul complex is divided into four bodies: A, B, C and D. Only orebodies C and D have estimated mineral reserves, with only orebody D currently in operation. The measured and indicated mineral resources of these orebodies (C and D) 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-K1300.

The mineral reserve estimate has changed, in comparison to the previous Serra Sul Complex Technical Report Summary filed, due to a review study on the environmental protection buffer. This review aimed at safeguarding some maximum relevance caves, Violão and Amendoim lakes and their respective hydrological contribution area. Therefore, we expanded our environmental constraints for pit generation, increasing the protection buffer, which resulted in a decrease in mineral reserves at Serra Sul by 418 million tons (-10%). We have reasonable expectation of the permit being granted however, the final impact on the mineral reserve and mineral resource will depend on the size of buffer area approved by Brazilian federal environmental agencies.

The mineral reserve at Serra Sul was further reduced by 75 million tons (-2%) due to mine depletion and by 269 million tons (-6%) due to the application of a mining recovery of 96% in our assumptions. This adjustment is related to contact between ore lithologies and jaspilites, and mine design reviews to adjust the mine operations to the two mining methods applied in the complex.

The expected exhaustion date for the Serra Sul Complex has not significantly changed after adjusting the production plan, with the impact deferred to the final years of production.

Table 12-1 shows the mineral reserve estimate for Serra Sul operation as of Dec. 31, 2023.

Table 12-1: Mineral reserve estimate.

Pit/Operation	Classification	Tonnage (Mt)	Fe (%)
S11C	Proven		
	Probable	705.7	65.4
	Total Proven + Probable	705.7	65.4
S11D	Proven	1,506.6	65.7
	Probable	1,218.6	65.1
	Total Proven + Probable	2,746.8	65.5
S11CD	Proven	1,506.6	65.7
	Probable	1,924.3	65.2
	Total Proven + Probable	**3,430.8**	**65.4**

Notes on mineral reserve tables:

1. The estimate's effective date is Dec. 31, 2023.

2. Tonnage stated as metric million tons inclusive of 6.79% of moisture content and dry %Fe grade. The reference point used is in situ metric tons.

3. The mineral reserve economic viability was determined based price curve with the long-term price being USD79.62/dmt for 62% iron grade.

4. The estimate assumes open-pit mining methods and uses the following key input parameters: average mining recovery of 95.5% and Fe average dilution of 0.596%, 100% mass recoveries, mining at 2.75 USD/t mined, mineral processing at 1.13 USD/t processed, and other costs including selling costs at 32.70 USD/t of product.

5. Numbers may not add up due to rounding.

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.

The optimization software used to generate the pit shell was NPV Scheduler®. No economic cut-off grade was applied to the mineral reserve as the average grade of the resource is 60% Fe. Metallurgical recovery was set at 100% as there is no concentration process in place at Serra Sul Mine, thus all materials are treated as ore. Environmental constraints, the presence of iron ore caves, and mining concession limits were also uploaded to NPV Scheduler® prior to pit optimization.

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

The final pit is returned to NPV Scheduler® and the pit optimization is re-run. Economic phases are generated, followed by a production schedule. Mineral reserves are reported as diluted, and VALE QP certifies that these have been fully scheduled in a proper LOM plan and applied to a discounted cash flow model. The mineral reserve estimate has shown economic viability.

VALE QP is not aware of any changes or risk factors associated with any aspect pertaining to the identified modifying factors, such as mining, metallurgical, infrastructure, permitting, or other relevant factors that could objectively affect the mineral reserve estimate.

12.2. Methodology

12.2.1. Dilution

Dilution is calculated by reconciling planned production with the feed received at the plant over a one-year period. Crusher feed is sampled every two hours and consolidated for the entire current year to date, compared with the grade estimate in the short-term mining plan. The pit optimization dilution factor is then defined based on this comparison.

12.2.2. Mining losses

Mining losses are obtained by comparing planned with actual plant feed each year. The crushed mass is obtained from plant scale records and compiled each month. The annual production is compared with the short-term plan and the mining recovery factor is determined by comparing the production plan to the actual recovery achieved.

12.2.3. Net value return and cut-off value

NSR cut-off value is determined using metal prices considered in the mineral reserves, metal recoveries, transport, process, and mine operating costs. The metal prices used for the mineral reserves are based on a market price model and consider client preferences, supply and demand for iron ore exports, bonuses, and penalties based on product quality.

Costs and other parameters used to calculate the cut-off grade are shown in Table 12-2. The cut-off grade is estimated at 10%, considering actual parameters. No economic cut-off grade is applied to the mineral reserve due to the high iron content of mineral resources (average of 60% Fe), which is above the estimated cut-off grade. The cut-off is not material to mineral reserve estimate. Nevertheless, a check is made as good practice.

Table 12-2: Modifying factors for cut-off grade

Item	Units	Parameters
Metallurgical recovery	%	100
Fe product payable	%	65.5
Price	USD/t product	79.6
Mining cost	USD/t rock.	2.75
Processing cost	USD/t fed	1.13
Selling cost	USD/t product	32.7

12.2.4. Modifying factors for pit optimization

The modifying factors used for pit optimization are shown in Table 12-3.

Operating costs are based on actual costs adjusted for future conditions. They include mine, plant, infrastructure, environmental, and other costs, and are representative for the life of mine.

Table 12-3 - Modifying factors for pit optimization.

Item	Unit	Costs
Mining cost - ore	USD/t ore	2.11 to 2.61
Mining cost - waste	USD/t waste	2.26 to 2.75
Processing plant	USD/t crusher feed	1.13
Other costs	USD/t product	32.7
Vertical rate cost	USD/m	0.0045
Mining recovery	%	95.5
Mining dilution	%	0.596

12.2.5. Commodity price

Price curves were provided by the VALE Marketing Department, and were developed based on a market price model, also considering client preferences, supply and demand of transoceanic iron ore, bonuses, and penalties for deleterious components according to the quality of the product shipped. USD 79.62/dmt (62% Fe) was used as a reference price and may vary depending on iron grade.

12.2.6. Iron ore caves

Iron ore cave limits are classified and updated in a special database as required by Brazilian federal legislation. A stand-off distance of 150m is required as an exclusion zone for maximum relevance caves.

12.2.7. Mass recovery

An overall mass recovery factor of 100% was used as there is no concentration in the process.

12.2.8. Wall slope angles

The pits are generated using slope angles for each lithology. These slope angles are used except where company policies require smoother slopes, as in regions where there are structures, such as piles, industrial facilities, railways, highways, etc.

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

12.3. Uncertainties (factors) that may affect mineral reserve estimate

The following factors may affect mineral reserve results obtained:

- Prices of iron commodities.
- US dollar exchange rate.
- Brazilian inflation rate.
- Geotechnical assumptions (including seismicity) and hydrogeological conditions.
- Changes in capital and operating cost estimates.
- Stockpile estimates.
- Mining operation capacity to fulfill the annual production rate.
- Process plant recovery rates and the capacity to control levels of deleterious elements within the expectations set forth in the LOM plan.
- Capacity to comply with and keep environmental licenses and permits, and capacity to maintain a social license to operate.

The Qualified Person's opinion is that there are no other environmental, licensing, legal, title, tax, social-political, or marketing issues that could objectively affect the mineral reserve estimate which have not been discussed in this Report.

13. Mining Methods

13.1. Introduction

Serra Sul's operation began in 2016, and output has been approximately 80 Mtpa in recent years. It is mined by open-pit method with berms and benches, using In-Pit Crusher Conveyer (IPCC) besides large trucks and shovels.

13.2. Mine design

Mine design includes 15-meter high benches, 15-meter-wide berms, bench face angles between 50 and 85 degrees, depending on mine lithology. Ramp access is 42.3m wide with 10% gradient. The open-pit design is shown in Figure 13-1: Open-pit design..

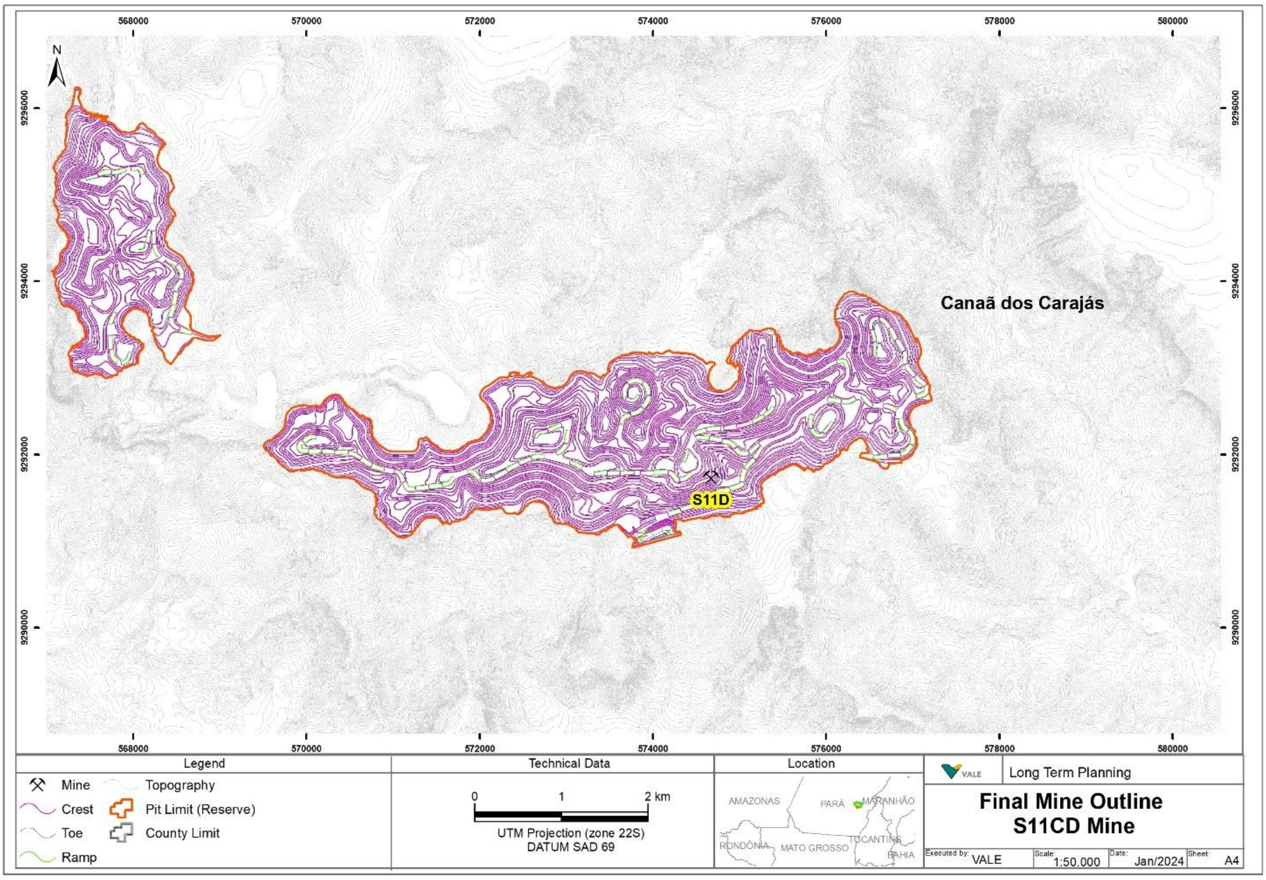


Figure 13-1: Open-pit design.

13.3. Mining method

The mining method at Serra Sul is open pit. Materials requiring drilling and blasting in areas where geometry does not favor the use of IPCC are mined by conventional truck and shovel method; otherwise, IPCC is used.

Materials are moved by an electric and/or hydraulic shovels into mobile crushers. The mobile crushing plants are equipped with a "sizer" (friable materials) or jaw crushers (compact material). Once particle size is reduced to a size suitable for the conveyor belt, both ore and waste are sent to a transfer tower where conveyors are equipped with a mobile head and adjusted to transfer the ore onto a belt that, then, conveys it up to a stockpile. The waste, on the other hand, is sent to another belt that conveys it up to spreaders used to build the waste dumps.

13.4. Geotechnics

13.4.1. Introduction

The geotechnical assessment for the ultimate pit shell's final assessments was developed in collaboration by a multidisciplinary team that included geotechnics, hydrogeology, geology, and long-term teams. This activity relied on teamwork from mathematical pit surface definition to the ultimate pit final geometry operationalization. As shown in Figure 13-2, this assignment has been divided into four phases (rows) and accountabilities (columns).

• Phase 1 – Definition of lithogeometric parameters and initial mathematical pit.

• Phase 2 – Geotechnical model development.

• Phase 3 – Operational pit assessment.

• Phase 4 – Final approval and check of closing conditions.

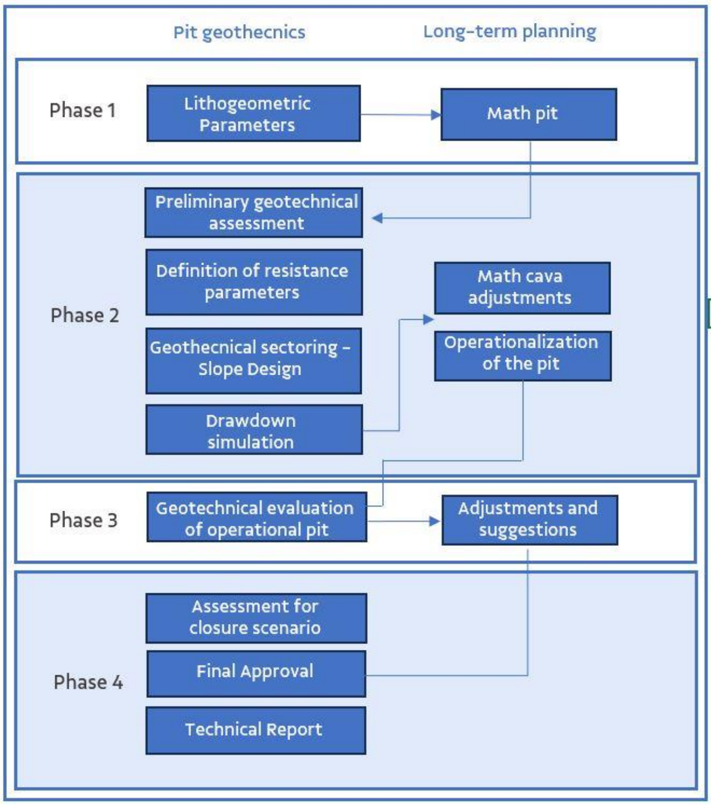


Figure 13-2 - Geotechnical assessment process for the final pits.

13.4.2. Geotechnical assessment

The criteria used for slope design approval comply with international standards and best practices proposed by Read & Stacey (2009). The acceptance criteria established were based on slope stability analyses that used a deterministic Factor of Safety (FoS) approach and should be in line with the indicative minimum values outlined in Table 13-1.

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

Slope scale	Consequence 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
Global	Low	1.2–1.3	1.0
	Moderate	1.3	1.05
	High	1.3–1.5	1.1

[a] Must meet all acceptance criteria.
[b] Semi-quantitatively evaluated.

Limit equilibrium analyses were made to assess potential non-circular and circular failures, including considerations of geotechnical models, suitable failure mechanisms, and shear strength parameters. These analyses were systematically conducted across the entire pit, focusing on critical sections and assessment of inter-ramp and global failure mechanism scales.

Identification of critical analysis sections was guided by the following criteria:

- Areas where the highest slopes were located.
- Maximum bench stack height without ramps or geotechnical ramps.
- Variations in inter-ramp angles of notable weak materials.
- Areas where the lowest shear strength materials were observed.
- Slope sectors with the steepest overall angles.
- Lithotype interfaces marked by significant strength variations.
- Industrial facilities or other geotechnical structures near pit crest areas.
- At least one section representative of each geotechnical sector deemed relevant.
- Underlying factors contributing to instability, such as shear zones, discontinuities, or discontinuity directional anisotropy.
- High pore pressure areas.

Slope assessment and FoS definition were based on the following assumptions:

- Stability analysis was conducted using the Limit Equilibrium Method (LEM) for each most likely failure mechanism outlined in the geotechnical model, under static conditions.
- Water and piezometric levels used in the stability analyses stemmed from hydrogeological models specifically developed for the final pit scenario, as well as from local hydrogeological instrumentation.
- High-consequence slope identification was assessed for the infrastructure surrounding the pit rim. For these critical slopes, the acceptance criteria required a Factor of Safety (FoS) of 1.5 for global failures.

Stability analyses were conducted using SLIDE2 (Rocscience Inc.®). LEM analyses were based on the GLE/Morgenstern-Price method, considering search methods such as Cuckoo Search, Auto Refine Search, and Path Search. Results were selected based on their consistency with geological-geomechanical conditions of the section in question.

Pit geometry approval was based on acceptance criteria fulfillment, as determined by the FoS calculated for the respective sections. Detailed assessment outcomes for each operational pit will be presented in Section 13.4.1.

13.4.3. Geotechnical overview

Final slope design geotechnical assessment was conducted by VALE's geomechanical and hydrogeological team, as per procedures set forth Section 13.4.1. Geotechnical assessments for the Serra Sul project were grounded in a number of previous studies, including those conducted by Vale in 2022, VOGBR in 2008, Golder in 2012 and 2013, Geominas in 2017, SRK in 2020, MDGEO in 2020, and TEC3 in 2020.

Lithologies have been described and modeled to provide adequate support for geotechnical characterization and geohazard assessment associated with mining activities. As for the open-pit mining method, rock mass conditions are well-understood and suitable for current mining depths, local rock reinforcement techniques, and geotechnical considerations in mine processes.

Geotechnical mapping and data analysis protocols include standard practices used in the industry, such as detailed mapping of the different structural domains and their characteristics based on field mapping, geological modeling, and geotechnical core drilling.

13.4.4. Geotechnical and rock mass models

The geomechanical model used for the Serra Sul Mine Complex includes Rock Mass Rating (RMR) and Weak Rock classifications. The rock mass is systematically categorized into distinct classes, namely, I, II, III, IV, Weak, Very Weak, and Extremely Weak. Table 13-2 summarizes the geotechnical data gathered for Serra Sul mine sites.

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

Mine	Consultants responsible for structural mapping and geomechanical model	Year of structural mapping / geomechanical model	Drill holes with geotechnical assay		Surface-mapped points
			Number of drillholes	Total drilled (m)	
S11C	Vale	2022	199	28,136	None
S11D	SRK & Geoestrutural / VALE	2020 / 2022	2,053	291,774	414

Geotechnical parameters were determined based on lithotypes and weathering degrees sourced from the geological model, geomechanical model, and structural features, including anisotropies and discontinuities acquired via structural mapping and geological sections. Table 13-3 briefly describes the strength tests used to define the geotechnical parameters used in Serra Sul's slope stability analyses. In cases in which corresponding tests were not available for certain lithotypes, parameters from nearby mines with similar lithostratigraphic, tectonics, and geomechanical characteristics were adopted.

Table 13-3: Geotechnical laboratory test reports – Serra Sul Mine Complex.

Laboratory test	Company	Year	Number of tests
Consolidated drained triaxial shear test (CD)	Pattrol	2017	2
Consolidated undrained triaxial shear test (CU)	Pattrol	2017	4
Direct shear	Pattrol	2017	2
	Furnas	2017	1
Unconfined Compressive Strength (UCS)	VALE	2017	92
PLT (Point Load Strength Index)	VALE	2017	92

13.4.5. Slope stability analysis

Multiple geotechnical sections were compiled and systematically assessed across Serra Sul mines. Using the final pit design and geomechanical model, VALE conducted comprehensive studies to establish potential failure mechanisms considering the geotechnical parameters adopted. This investigation was performed selectively in specific sections along the final pit to examine the stability analysis factor of safety for each mine.

Deterministic limit equilibrium analyses were used to evaluate potential failures, including circular and non-circular ones. This assessment was based on the geotechnical model and considered hydrogeological factors detailed in Section 13.5. The analyses covered the entire pit and were carried out using representative sections, as shown in Figure 13-3 and Figure 13-4.

A summary of the slope stability analysis results considering the FoS, near-mine-border interferences in each section, and other relevant information is shown in Table 13-4 and Table 13-5

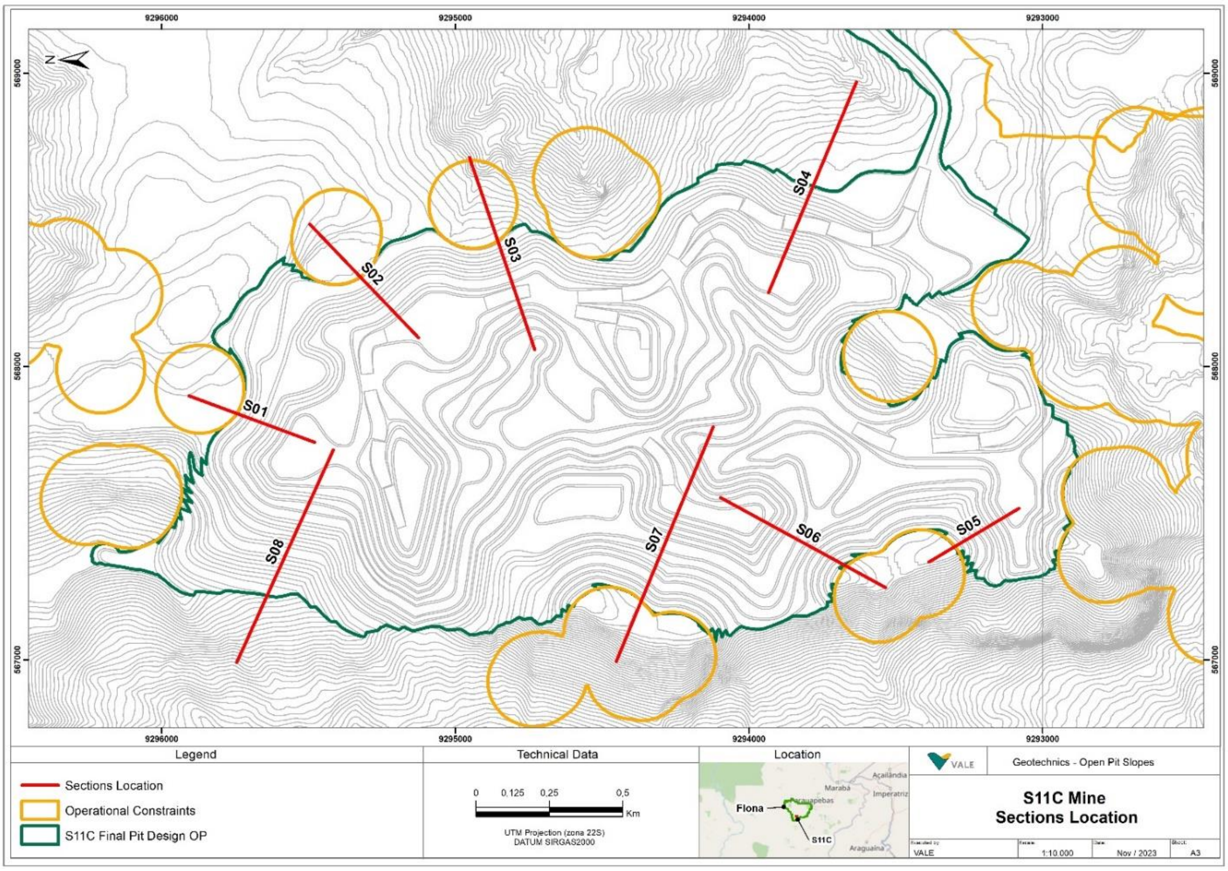


Figure 13-3 - Slope stability analysis cross-section location – S11C mine.

Table 13-4 –Factor of Safety (FoS) and other information from S11C final pit slope design.

Pit	Section	Acceptable criteria		Results		
		FoS (required)	Near-mine-border interference	FoS	Failure scale	Failure trigger
S11C	S01	1.30	-	1.61	inter-ramp	anisotropic rock mass
	S02	1.30	-	1.76	inter-ramp	material shear strength
	S03	1.30	-	1.80	inter-ramp	material shear strength
	S04	1.30	-	1.72	global	material shear strength
	S05	1.30	-	1.49	inter-ramp	material shear strength
	S06	1.30	-	1.54	inter-ramp	anisotropic rock mass
	S07	1.30	-	1.53	inter-ramp	material shear strength
	S08	1.30	-	1.73	global	material shear strength

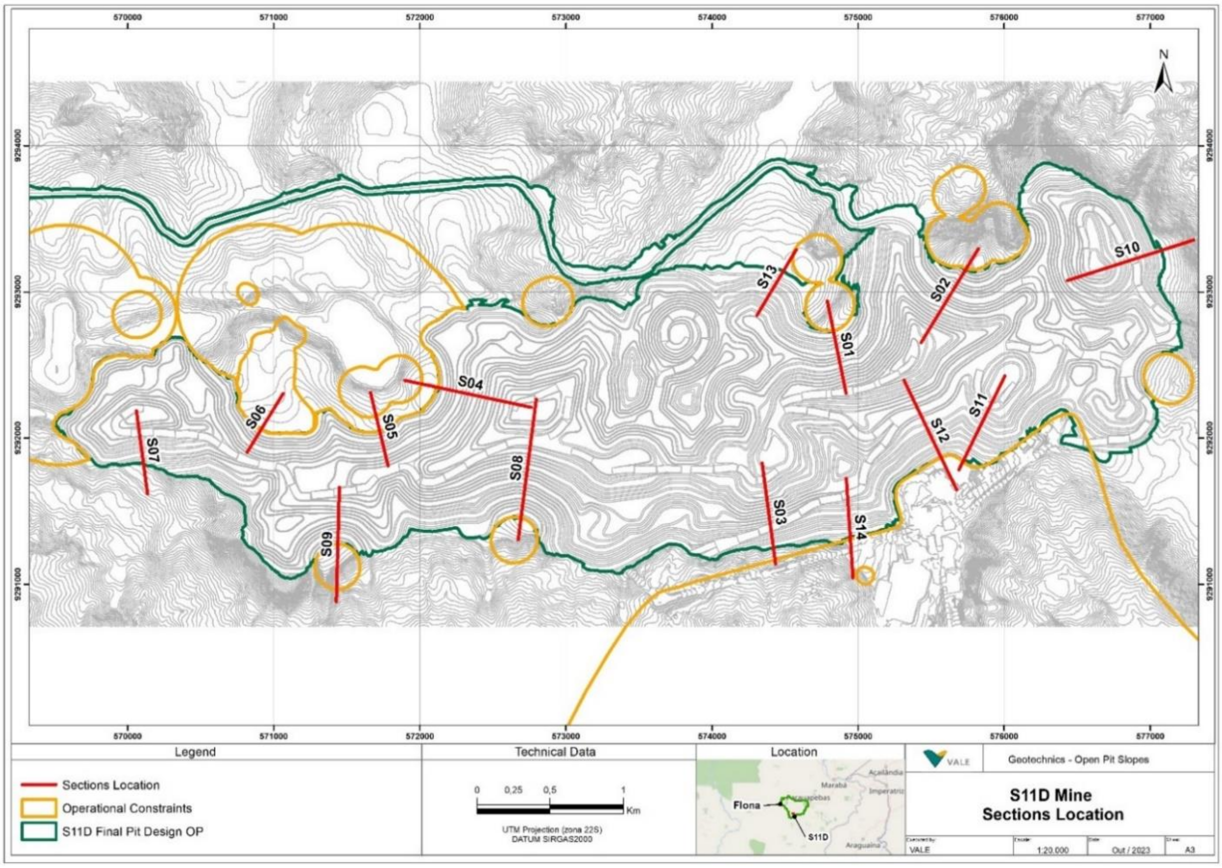


Figure 13-4 - Slope stability analysis cross-section location – S11D mine

Table 13-5 –Factor of Safety (FoS) and other information pertaining to S11D final pit slope design.

Pit	Section	Acceptable criteria		Results		
		FoS (required)	Near-mine-border interference	FoS	Failure scale	Failure trigger
S11D	S01	1.30	-	1.52	global	material shear strength
	S02	1.30	-	1.50	global	material shear strength
	S03	1.50	industrial facilities	1.85	global	material shear strength
	S04	1.30	-	1.55	global	material shear strength
	S05	1.30	-	1.50	global	material shear strength
	S06	1.30	-	1.60	global	material shear strength
	S07	1.30	-	2.15	bench scale	material shear strength
	S08	1.30	-	1.42	inter-ramp	geological contact
	S09	1.30	-	1.57	inter-ramp	anisotropic rock mass
	S10	1.30	-	1.76	bench scale	material shear strength
	S11	1.50	industrial facilities	1.73	global	material shear strength
	S12	1.50	industrial facilities	1.71	inter-ramp	material shear strength
	S13	1.30	-	1.85	global	material shear strength
	S14	1.50	industrial facilities	1.74	global	material shear strength

13.5. Hydrogeological considerations

13.5.1. S11C and S11D hydrogeological model

Drawdown simulation was based on the numerical model developed using MODFLOW (MDGEO, 2020) and revised by VALE's team in 2022. The simulated outflow was estimated at 1,032 m^3/h, 215 m^3/h of which were from body C pit and the remaining 817 m^3/h were from body D pit. Ninety-two instruments were used to calibrate the model, and the resulting normalized root mean squared (nRMS) was 4.4%.

Figure 13-5 shows the equipotential lines (20 in 20 m) generated in the simulation of maximum dewatering conditions and groundwater flow direction. Those surfaces were used as input for the stability analysis described in Section 13.4.1.

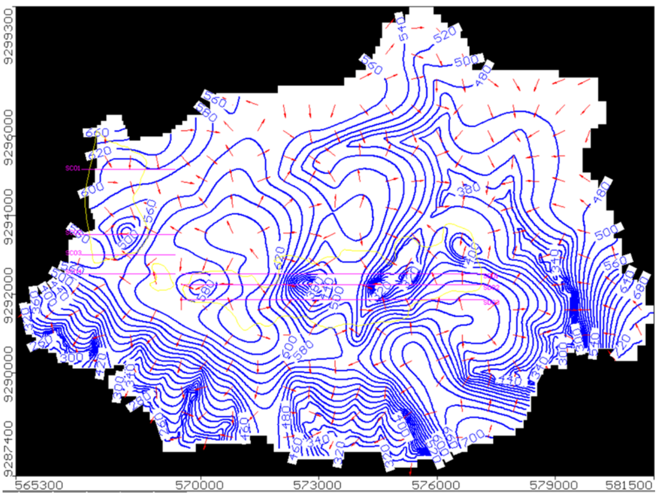


Figure 13-5 Equipotential lines for the water level resulting from the long-term maximum drawdown simulation (final pit) — layer 20, referring to elevation 270 m — S11.

Figure 13-6 shows the water table (equipotential lines) below the final pit.

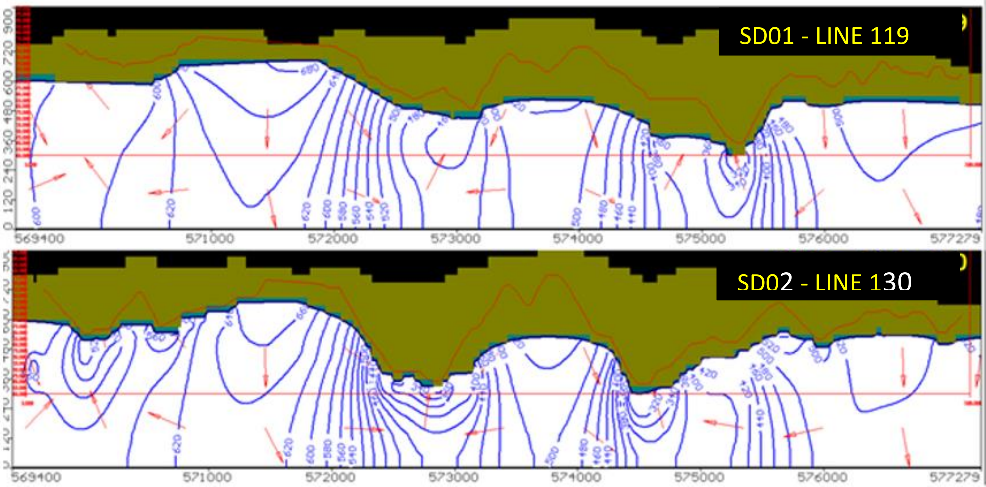


Figure 13-6 Maximum drawdown cross sections

13.6. Production schedule

The Life of Mine production plan is shown in Figure 13-7. The production from 2024 through 2060 will include approximately 3,4Bt with average grades of 65.4% FeGL, 2.24% SiO2GL, 1.12%Al2O3GL, 0.057%PGL, 2.6% LOI. Stripping ratio for the LOM is 0.3.

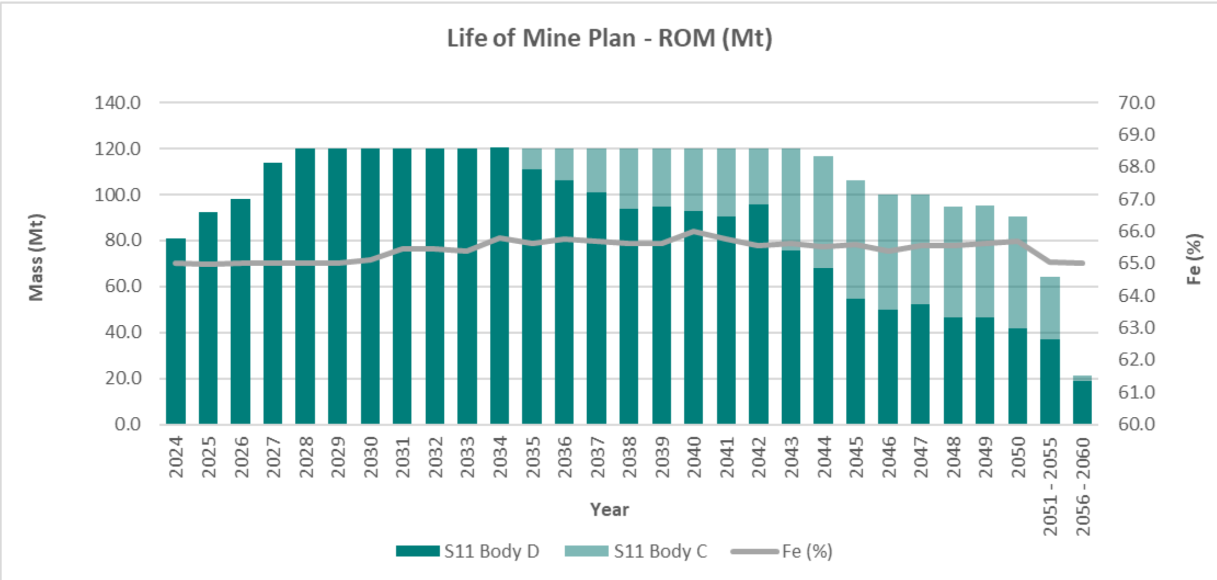


Figure 13-7: Life of Mine vs Fe grades.

13.7. Mine equipment

Erro! Fonte de referência não encontrada. shows the current requirements for primary and ancillary mining equipment. Additional equipment will be required to cover the entire LoMP, in these cases we expect to obtain the necessary licenses in a timely manner.

Table 13-6: Mining equipment.

Equipment	Units currently available
Crusher	7
Hopper	4
Spreader	2
Connecting conveyor	4
Belt wagon	4
Mobile conveyor	11
Loading	12
Haulage	25
Drilling	11
Ancillary equipment	56

13.8. Infrastructure

13.8.1. Workshops

There is a fully-equipped maintenance workshop at Serra Sul. The workshop is built in steel structure and steel sheets and is equipped with bays to accommodate large mobile equipment, as well as workshops for machining, maintenance of diesel generators, electrical and electronic equipment, warehouse, and tooling.

13.8.2. Laboratory

Most ore quality control procedures are carried out at Serra Sul's own facilities, where physical tests and assays of the entire production chain are performed. Occasionally, some RC and short-term drilling samples are sent to an outsourced laboratory (SGS Geosol Laboratório Ltda located in the city of Parauapebas).

13.8.3. Offices

VALE and contractors' office buildings are located in the administrative areas. This is where offices used by senior management, management, coordinating, and technical teams are located, and also where the reception, archive rooms and restrooms used by the administrative personnel can be found.

13.8.4. Warehouses

The warehouse is partly built in masonry and partly in steel structure and steel sheets and is surrounded by a gated outdoor area. The indoor area includes workstations, offices, and restrooms, and the outdoor area includes storerooms and annexes used to store lubricants, fuels, and tires. The fuel storage facility is equipped with horizontal tanks for filtered diesel, with drainage basins and a water-oil separation system.

13.8.5. Cafeteria

There is a cafeteria that provides lunch, dinner, and snacks to both VALE and contractors' employees. As it happens in other VALE operating units, the cafeteria is operated by an outsourced company.

13.8.6. Clinic

The clinic is equipped to deal with first-aid cases. More serious cases are sent to the hospital located in the urban center, in which case an ambulance and driver are available at all times.

13.8.7. Fire suppression system

Firefighting water is stored in concrete tanks, which are divided into two different compartments that allow the tank to be cleaned and still ensure that half of the fire water supply is available for use if needed.

Fire hydrants are strategically sited, in addition to a fire truck parked 24 hours at the entrance.

13.9. Personnel

Serra Sul's workforce is made up of both VALE and contractor personnel. VALE's current headcount and the list of main contractors' headcounts are shown in Table 13-7 and Table 13-8, respectively. VALE headcount required in mining operations is not expected to significantly change in the foreseeable future. The number of contractors varies month to month depending on labor requirements at the mine site.

Mine production is carried out by VALE personnel, while ancillary services are provided by contractors. Administrative staff works 8-hour shifts on 5-on x 2-off schedule, whereas operation and maintenance staff work 12-hour shifts on a 3-on x3-off schedule.

Table 13-7: VALE's workforce

Serra Sul	Manager	Supervisor	Coordinator	Staff and technical specialist	Total
Mine	6	42	12	938	998
Plant	7	41	11	984	1,043
Other	6	22	6	709	743
Total	19	105	29	2,631	2,784

Table 13-8: Contractors' workforce.

Serra Sul (Contractors)	Full-time (Permanent)	Project	Part-time	Total
Mine	1,682	5	67	1,754
Plant	1,549	21	87	1,657
Other	2,622	113	153	2,887
Total	5,853	139	307	6,298

14. Processing and Recovery Methods

14.1. Processing Method Selection

Serra Sul deposit is characterized by its high iron content, which requires few metallurgical tests for process route definition and process monitoring. Process route is typically defined by assessing the chemical analysis of the deposit geological model. This analysis establishes whether the ROM of a given deposit should be concentrated or not.

If necessary for additional characterization, samples can be collected from the mine or directly from the plants in operation.

The iron content of some of Serra Sul deposits exceeds 64%, meaning that products can be obtained without concentration. Process route encompasses the processing of natural moisture material, with crushing and screening operations aimed to adjust product size.

14.2. Processing Flowsheets and Processing Facilities

Serra Sul ore processing starts with in-pit crushers. Electric shovels are used to feed a Mobile Sizing Rig (MSR) and Mobile crusher Rig (MCR). The MSR comprises roller crushers, with 4 units in operation. The MCR encompasses jaw crushers, with 3 units in operation, which is used for ore compaction.

Crushed ore is transferred to conveyors by a Mobile Belt Wagon (MBW). Crushed ore is stacked in two stockpiles, one of which with operational capacity of 50,000 t and another with operational capacity of 10,000 t. Ore is reclaimed from these stockpiles and conveyed to the processing plant via a 9.5-km long conveyor belt for subsequent crushing and screening.

Serra Sul plant is a conventional crushing and screening facility, with an installed capacity of 90 Mtpy, with all of its ROM processed at natural moisture. With no concentration operation in place, all plant throughput is recovered as final product. Primary unit operations include:

- Primary vibrating banana-type screen.
- Secondary cone crushing.
- Secondary vibrating screen.
- Tertiary cone crushing.

Serra Sul plant process begins with primary screening feeding, where the corresponding oversize (+90 mm) is directed to secondary crushing. The secondary crushing product, together with the material that passes through primary screening, is fed to blending stockpiles, which are used to homogenize the operating yields coming from the mine and the plant. The blending stockpile stage can be bypassed through direct secondary screening feeding. From the blending stockyard, ROM is directed to secondary screening. Material retained on the screens (+19 mm) is sent for tertiary crushing and the tertiary crusher product is returned as secondary screening feed, composing the circulating load. Tertiary screening undersize comprises Sinter Feed product (-19 mm) which is directed to product stockyards. Then, the product is conveyed to train loading silos. The final product is shipped by railway to the port of São Luiz, State of Maranhão. The following figure shows the simplified processing flowchart.

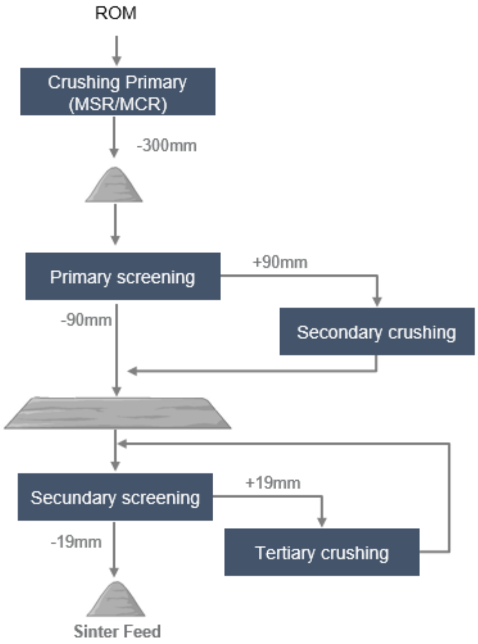


Figure 14-1: Simplified flowsheet.

Serra Sul processing plant annual capacity is 90 million tons of iron ore, with 3 lines producing 30 million tons each, every year.

In addition to the mine and processing plant, Serra Sul complex includes a 104-km railway. Processing is carried out at natural moisture.

Serra Sul recovery, utilization, and capacity rates are shown in **Erro! Fonte de referência não encontrada.**.

Table 14-1: Plant recovery, utilization and capacity.

Metallurgical Recovery (%)	Average Physical Utilization (%) (last 5 years)	Nominal Capacity (Mty)
100	83.6	90.0

With no concentration process in place, all plant throughput is recovered as product, resulting in 100% recovery.

The expansion of the S11 project to 120 Mtpy includes the implementation of new crushing and screening stages, as well as a new long distance conveyor belt for transporting ore from extraction points to processing.

14.3. Equipment Sizing

Table 14-2 summarizes the key equipment used in Serra Sul ore processing.

Table 14-2: Equipment list.

Unit operation	Quantity	Type of Equipment	Dimensions/Model
MSR	4	Roller crusher	Abon 16/400
MCR	3	Jaw crusher	EB2015
Primary Crushing	6	Vibrating screen	12' x 28'
Secondary Crushing	6	Cone crusher	CS660
Secondary Screening	30	Vibrating screen	8' x 32'
Tertiary Crushing	12	Cone crusher	CH860

14.4. Logistics

Serra Sul mine is integrated with a mine-railroad-port system.

The EFC (“Estrada de Ferro Carajás”) railroad connects the production complexes of Serra Norte (Carajás Mine), Serra Sul (S11D Mine) and Serra Leste, all located in the Brazilian state of Pará, to 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 Ponta da Madeira terminal.

Connected to the EFC, Ponta da Madeira Maritime Terminal (TMPM) is located near the city of São Luís, State of Maranhão. Port configuration allows for the operation of high-capacity vessels, such as Valemax.

14.5. Personnel

The processing plant personnel comprises management and supervisory staff, and operators, totaling 2,700, out of which 1,657 are contractors, as of December 2023.

15. Infrastructure

15.1. Introduction

Serra Sul in-situ and operational infrastructure includes the following:

- An open pit mine accessed by 3 main ramps.
- In-pit crushing and conveyor system.
- Surface ore stockpiles and waste rock dumps.
- A 90 Mtpy processing plant.
- Power supply facilities.
- Site access roads.
- Mine workshops, offices, warehouse facilities.
- Administrative buildings.
- 9.5 km long-distance conveyor belt system.

A surface plan showing the mine site infrastructure is provided in Figure 15-1.

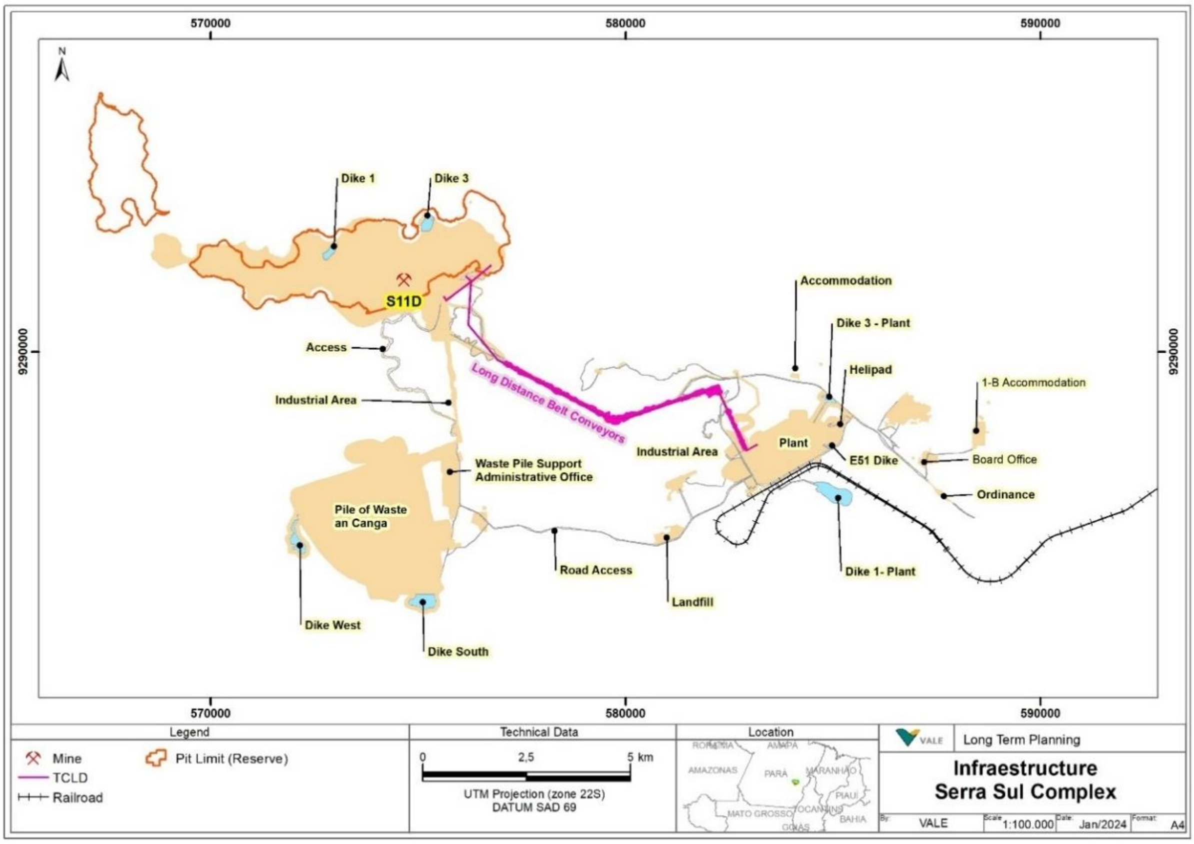


Figure 15-1: Mine site infrastructure map

15.2. Site Access

Provided in chapter 3.

15.3. Power Supply

Serra Sul operational complex is integrated into the National Interconnected System (SIN) and is connected via a 230 kV line to the Eletronorte (Eletrobrás) Substation.

The internal distribution system is carried out through VALE 34.5 KV networks. In 2023, Plant and Mine consumption was around 303,301 MWh, whereby 56% corresponded to the processing plant, 35.0% to the mine, and 8.0% to other supporting structures.

15.4. Water Supply

S11D has a permit for up to 21 boreholes for dewatering and water supply, and by December 2023, a total of eight deep tube wells were drilled into the S11D plateau.

These boreholes depths range from 210 to 330 m and their flow rates vary from 67 to 250 m^3/h. Average pumping flow rate is 800 m^3/h and is expected to reach 1000 m^3/h when all eight wells come into operation.

15.4.1. Raw Water Catchment, Industrial Water Collection and Supply

Water consumption is estimated to be around 0.0176 m^3/ton per crusher feed. Water catchment sites are connected to mine wells, small-diameter wells located in offices outside the mine and at Igarapé Sossego catchment.

15.4.2. Potable Water System

There are two wells at the mine site, close to industrial areas; they are pumped into a fire-fighting tank which flows, when full, to a raw water tank. From this raw water tank, water is conveyed to a water truck filling station. Another part of it is supplied to the mine water treatment plant, WTP, where it is stored in another treated water tank and distributed for use in offices, workshops, restaurant, and to be consumed as drinking water.

The other four wells in operation were drilled into the pit area, with the purpose of drawing down the aquifer, whereby 90 to 95% of it is directed to Igarapé Sossego, and the remaining 5 to 10% is used for road dust control.

15.5. Site Buildings

Site facilities are distributed around Serra Sul mines. The facilities include offices, warehousing and storage areas, maintenance shops, fuel station, processing plants, canteen and a locker room.

15.6. Mine Waste Management

15.6.1. Tailings Management

Serra Sul generates no tailings as ore is dry processed.

15.6.2. Tailings Storage Facility

As no wet processing is performed at Serra Sul, it comprises no Tailings storage facilities.

15.6.3. Waste Dumps

The open pit waste rock is dumped onto the surface shown in Figure 15-2. Serra Sul mid- to long-term waste rock disposal plan consists of a triangular-shaped waste dump with capacity of

627 Mm³ (Figure 15-2) located 4.7 km from the mine, between the transfer tower (CT1) and the belt pivot point.

Waste is hauled by two belts identified as TR-1083KS-02 and TR-1084KS-02, before being stacked by means of a Spreader equipment consisting of a rolling system and a stacking boom. Spreaders are connected along the belt via a bridge which directs material flow to the stacking system. The waste dump is built by lengthwise low dump and high-dump stacking, through a segment belt, as per Figure 15-2.

Figure 15-2: S11D waste dump location

S11D waste dump design was developed by Golder (2014) and later reviewed by Geoestável (2017); it included adjustment of the surface drainage design, which resulted in a final volume of 583 million cubic meters. Based on this study, waste disposal capacity was expanded, and VALE subsequently developed a complementary design with a final capacity of 627 million cubic meters.

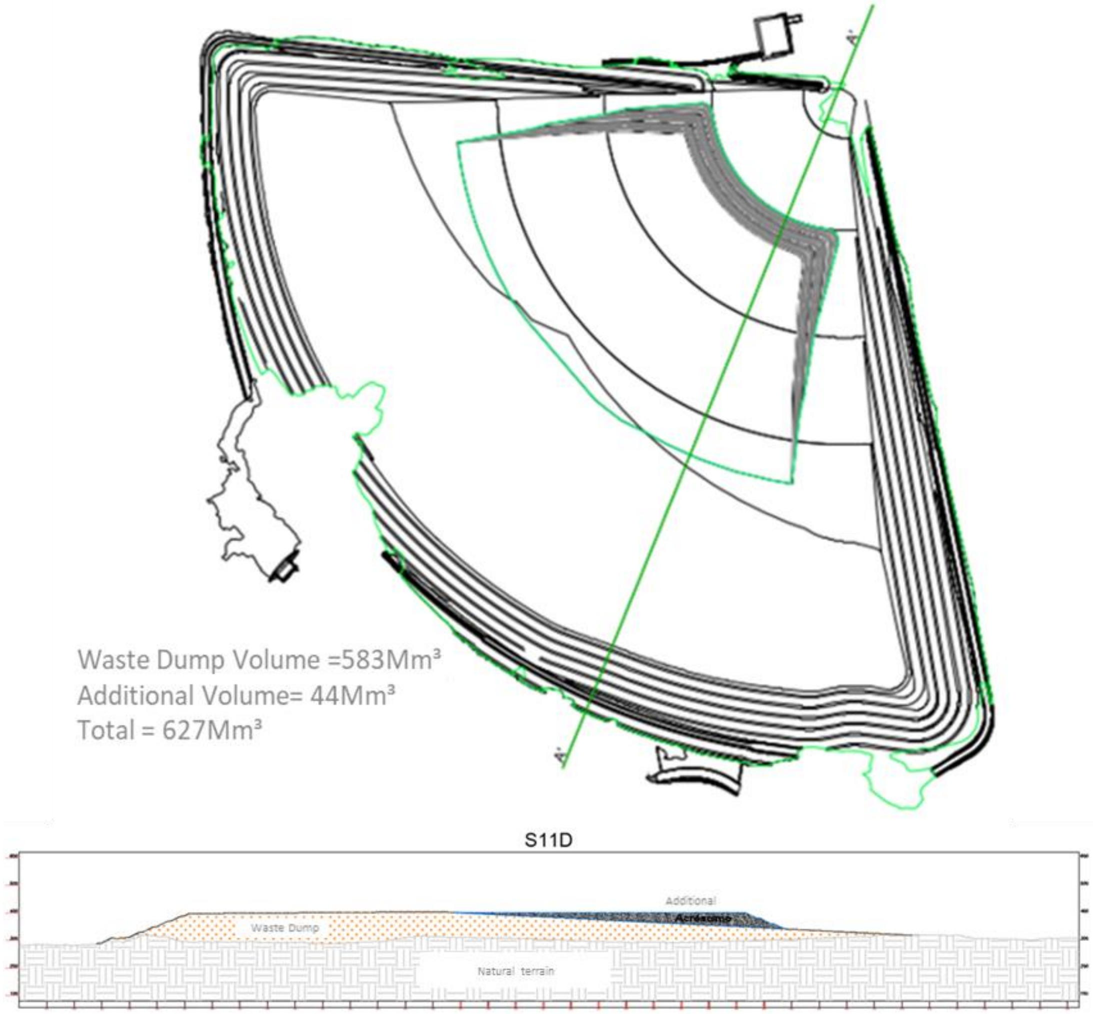


Figure 15-3: Final arrangement considering additional volume.

16. Market Studies

16.1. Markets

16.1.1. Introduction

Iron ore is one of the core products sold by VALE globally. Its price and premiums can fluctuate over the year based on supply and demand balance shifts and market sentiment short-term trends.

VALE operates three iron ore production and distribution systems in Brazil, which we refer to as Northern, Southeastern, and Southern Systems. The Northern and Southeastern Systems are fully integrated, encompassing mines, railroads, maritime terminals and a port. The Southern System consists of two mining complexes and two maritime terminals.

Iron ore prices were high throughout most of the year. In the first quarter, the reopening of China economy after COVID lockdown increased market demand, moving prices up. In the following quarters of the year high levels of steel and pig iron production in China, supported by steel exports, kept iron ore demand stable and iron ore stocks at low levels.

16.1.2. Demand

China has been the main driver of global demand for minerals and metals over recent decades. In 2022, Chinese demand represented 76% of global demand for seaborne iron ore. Therefore, any contraction in China economic growth, or changes in its economic profile, could result in lower demand for our products, leading to lower revenues, cash flow and profitability.

In 2022, China crude steel production was 1017.96 Mt, a decrease of -1.7% year-on-year. In the first 11 months of 2023, China crude steel production reached 952.14 Mt, a growth of 1.5% year-on-year. During the first 3 quarters of 2023, China GDP grew by 5.2% year-on-year, accelerating from the 3% year-on-year GDP growth registered in 2022, reflecting the recovery in activities after China lifted the lockdown and COVID control measures in 2023. During the first 11 months of 2023, China industrial production grew steadily by 4.3% year-on-year. Fixed asset investment (FAI) grew by 2.9% year-on-year in the first 11 months of 2023, out of which, the manufacturing FAI and infrastructure FAI outperformed in growth to offset the decline in property FAI and support the total investment demand in China. In the rest of the world, high inflationary pressures started in 2022 were caused by a confluence of factors such as supply disruptions, semiconductor shortage, energy crisis in Europe, and eruption of war in Ukraine. Those factors led major economies to start hiking policy rates to control inflation. Consequently, the EU, the USA, and Brazil have slowed down industrial production. On the upside, the services component of those economies helped to offset the economic contraction moving from 2022 into 2023. Nonetheless inflation has been redressed, energy costs have been redressed (although stabilizing on levels higher than those before eruption of the war in Ukraine) and central banks are now pointing to quantitative easing starting in 2024.

During the first 11 months of 2023, Global crude steel production, as published by World Steel Association, has grown timidly by 0.47% YoY, to 1715.1 Mt. For Ex-China, there is a small contraction of -0.65% YoY, to 762 Mt. At the individual markets level, there were mixed performances in terms of steel production. Brazil crude steel production was subdued by most of the year of 2023, -7.1% YoY in 11M23, showing a partial recovery in November due to a low-level comparison with November 2022. Similar behavior was observed for EU28 and SEAsia, with an accumulated loss of -7.7% YoY and -7.1% YoY, respectively in 11M23. The USA improved in the 2H23 offsetting the losses and production YoY should stay flattish. The sweet spot for Ex-China has been India, which has grown +12.1% YoY in 2023, with consistent higher production for the entire year.

The move towards a more efficient steel industry, with the enforcement of stricter environmental policies in China, should support the demand for high quality ores that enable productivity and lower emission levels like pellets and Carajás fines (IOCJ). For 2024, the World Steel Association

(WSA) forecast in October 2023 that steel demand should grow by 1.9% to 1,849.1 Mt. Demand is expected to mildly improve in 2024, as high interest rates are still weighing down on industrial production; however, this is less severe than initially thought in the beginning of 2023 where rumors of recession in the EU and the USA was a consensus.

In China, continued weakness in real estate sector and local government debt issue weighed on steel demand in 2023 and may continue doing so in 2024. The good news is China policymaker sent pro-growth policy tones for 2024 and may implement more concrete measures to support economic growth in 2024, which may lend support to domestic steel demand in China. While demand deceleration in China can present a downside risk, controlled inflationary pressures and easing on interest rates on major markets in Ex-China could lead to improved industrial production and sustain demand in good levels.

For the longer term, the slowdown in China economic growth and housing 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.

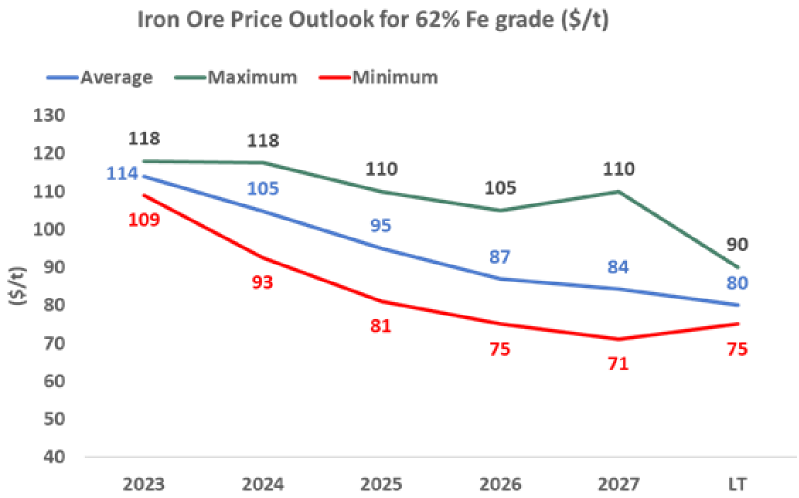
Our main competitors are in different locations than our sites and compete with VALE mainly on their regional markets. For the Asian market, the main competitors are in Australia and include subsidiaries and affiliates of BHP, Rio Tinto Ltd ("Rio Tinto") and Fortescue Metals Group Ltd. For the European 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. VALE also has competitors within the Brazilian market. Several small iron ore producers, 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 to the local steel production.

While for 2023 there is no relevant iron ore capacity addition from main competitors, only replacements of depleted mines, for the longer term the global supply might face reduction of supply due to the depletion of current operations, especially for the ores with lower cost and higher quality. Additionally, in terms of depletion, the main focus of miners is to supply high-grade ores given that the steel industry requirements for decarbonization will increase the demand for these types of ores. However, considering all the high-grade projects announced so far, there is still a surplus of demand from the steel industry for this material in the long term.

16.1.4. Price outlook

By the time that this report was prepared, during the last quarter of 2023 with lower iron ore and coal prices, steel margins improved, and no mandatory cut was implemented. On top of that, stimulus measures to support China economy and its real property sector were announced, further improving market sentiment and consequently iron ore prices. The third quarter closed with iron ore prices around $120/t and blast furnace capacity utilization above 90% as crude steel production was supported by strong export rates and good performance from other industrial sectors besides real property. For 2024, although iron ore supply is expected to slightly increase, lower stock levels and better economic performance from China than expected shall avoid significant price decreases. Seasonal trends shall provide higher support along the first quarter of the year. While for the rest of the year, global economic performance is expected to be similar to 2023, resulting also in a similar price behavior for iron ore.

By the time this report was prepared, the price consensus for iron ore prices at 62% Fe in 2023 of the analysts was $114/t (table below – prices in USD), with a downward trend going forward until prices reach the long-term level of around $80/t in the long term (beyond 2027). 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 iron ore price for 62% Fe.

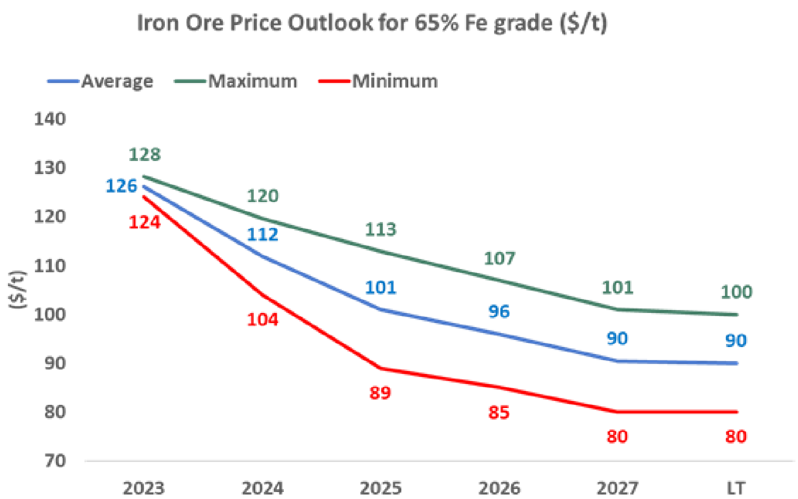


Source: Bank reports published between November and December 2023

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% depends on a few market-based fundamentals. Besides the environmental benefits of using high-grade ores to produce steel, a higher share of these ores in the blast furnace increases productivity as more Fe is added to the process and less fuel (coke) is required to reduce the ore into iron. So, during periods where mills are trying to get the most of their process (achieving high margins) or when coke costs increase, the demand and consequently the price differential of high-grade ores over medium grades will increase. For this year, a tailwind for a higher premium, the same as for the premium trend next year is a decrease on steel margins in China that could lead to necessary production cuts by mills. Also, lower steel prices outside China have decreased the price advantaged for Chinese exports and the domestic mills could not have the same demand from external markets along 2024 as they did in 2023. Anyhow the price spread shall move closer to market fundamentals improving from current levels.

By the time this report was prepared, the price consensus for iron ore prices at 65% Fe in 2023 of the analysts was $126/t (table below – prices in USD), with a downward trend going forward until prices reach the long-term level (beyond 2027) of around $90/t.



Source: Bank reports published between November and December 2023

Figure 16-2 - Iron ore price outlook for 65% Fe grade (US$/dry metric ton).

As the trend for 2023 for both steel margins and coal/coke prices remain recovering, most market analysts are forecasting that premiums for high-grade materials will remain well supported.

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)

	2023	2024	2025	2026	2027	LT
VIU per additional percentage point Fe	1.84	1.69	1.53	1.40	1.36	1.29

For comparison and information only, the table below shows iron ores prices realized over the last 5 years (2018-22) for Platts 62% Fe IODEX CFR China (Table 16-2).

Table 16-2: Platts iron ore for 62% Fe (US$/dry metric ton)

	2018	2019	2020	2021	2022	Average
Platts iron ore 62% Fe IODEX CFR China	69.46	93.40	108.9	159.5	120.2	110.3

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 renewed and will expire in 2057. The EFC railroad links our Northern System mines in the Carajás region in the Brazilian state of Pará 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 Carajás railroad (‘‘EFC’’). The EFC railroad links our Northern System mines in the Carajás region in the Brazilian state of Pará 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 renewed and will expire in 2057. EFC extends for 997 kilometers from our Carajás 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 2023, the EFC railroad transported 171,200 thousand metric tons of iron ore. In 2023, EFC had a fleet of 298 locomotives and 20,941 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 ship loaders, 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 ship loader. 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 and pellets. In 2023, 166.1 million metric tons of iron ore and pellets 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 Carajás, 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 Carajás 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 in the vicinity of Serra Sul complex, such as the National Forests of Tapirapé-Aquiri, Itacaiúnas and Carajás; the Campos Ferruginosos National Park; the Tapirapé Biological Reserve; the Xikrin do Cateté Indigenous Land; and Igarapé Gelado Protected Area. The total area comprises approximately 1.2 million hectares; it is relatively well preserved, in contrast with the anthropized surroundings.

17.2. Environmental Aspects

Serra Sul is located in Federal Areas, within the Carajás National Forest, established in 1998.

According to CONAMA Resolution No. 237/1997 rendered by the National Environmental Council and Federal Law LC No. 140/2011, environmental permitting for mining projects is undertaken by the corresponding State, except for specific conditions, such as when the location is bound to indigenous lands, two or more states, or federal lands.

Serra Sul (S11D) environmental permit is issued by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), which evaluates and approves mining activity projects.

In Brazil, the environmental permitting process allows a company to operate according to technical and legal aspects established by law. The process has three typical phases:

- Preliminary Permit (LP): This is requested even during the activity or project planning phase so as to approve the corresponding location and concept, attesting to environmental feasibility, and establishing the basic requirements to be fulfilled over the following phase.
- Installation Permit (LI): Authorizes installation of the project or activity as per specifications set forth in the approved plans, programs, and projects, including environmental restrictions and control measures.
- Operating Permit (LO): Authorizes project operation, after verification of effective compliance with the conditions established in the two previous permits, with environmental restraints and control, mitigative, and compensatory measures determined for the operation.
- The S11D mine was granted an operating permit in 2016. It was renewed on January 13, 2022, by IBAMA and is valid until 2026.

The ongoing implementation aimed to increase production by means of two projects, S11D +10 Mtpy and +20 Mtpy, mostly following the operating conditions and controls set forth in the initial permit, with parameters, monitoring points, and some programs being adjusted to ensure environmental assessment, control, and mitigation of environmental impacts arising from increased production rates. Table 17-1 shows the Environmental Permits in place for Serra Sul.

Table 17-1 - Environmental permits in place for Serra Sul.

Environmental Permit	Environmental Agency	Description	Expiry date	Status
LI no. 1329/2019 - 02001.000711/2009-46	IBAMA	Production increase by 10 Mtpy and mine fleet increase	12/15/2029	Valid permit: requested LO
LI no. 1437/2022 - 02001.000711/2009-46	IBAMA	Production increase by 20 Mtpy, mine fleet increase and additional infrastructure	07/21/2027	Valid permit
LO no. 043/2023	SEMAS-PA	Fuel Station (plant)	08/31/2025	Valid permit
LO_1361/2016 02001.000711/2009-46	IBAMA	Mine/Plant	12/08/2026	Valid permit
LP no. 671/2022	IBAMA	Production increase by 20 Mtpy, mine fleet increase and additional infrastructure	07/14/2026	Valid permit

The main environmental restrictions impacting Serra Sul operations are:

- Conservation units

Serra Sul is part of the Carajás National Forest, which is comprises a group of conservation units designed to protect biodiversity. Therefore, it is qualified as an extremely important area. These protected areas include forest reserves and other conservation units named special-use areas, and indigenous lands. The Carajás National Forest class pertains to “sustainable use” of protected areas which foresees multiple uses within its boundaries, including mining.

Discussions are being held with the conservation managing agency so as to change the zoning of Carajás National Forest Management Plan, which might reduce mining areas due to the occurrence of restricted endemic species or allow for the expansion of mining areas where there is no risk of endemic species extinction. Discussions on varied topics (fauna, flora and speleology) are starting but if restriction increases, the reserve might be affected.

- Natural Caves

The federal legislation and specific normative instructions establish that caves must be classified based on their relevance (Maximum, High, Medium and Low); they also define the necessary studies and compensation possibilities in case of impacts on High, Medium and Low relevance caves.

Maximum relevance caves cannot be subjected to irreversible negative impacts around their 250 m buffer zone until their respective areas of influence are validated by the Agency permitting bodies as regards the respective permitting processes.

Regarding studies and permits, VALE has been obtaining specific and individual authorizations for each cave for controlled mining in areas of influence that do not exceed 250 meters (average of 150 m), whereby projects are monitored by the environment agency through monitoring reports on the corresponding physical and biological conditions. VALE has also been successful in claims for relevance reclassification from maximum to non-maximum (High, Medium or Low), and consequently, it has become eligible for environmental compensation processes pursuant to the law, thus recovering embargoed reserves.

Also, in terms of cave compensation, aimed at itemizing caves which can be offered as compensation, VALE carries out programs to identify caves in areas without mining interests, seeking improved demand predictability and anticipation.

17.2.1. Climate

The region has two well defined seasons: the rainy season, from November to April, when 80% of total annual precipitation occurs, and the dry season, from May to October, including the three driest months (June, July, and August) and monthly average precipitation of 24 mm. The region annual average rainfall ranges from 1,500 to 1,900 mm, with average temperature ranging between 23.5 and 25.5°C; maximum temperature is 32.5ºC and minimum temperature never drops below 18°C.

Humidity in the region typically ranges from 70% to 85%. In the driest months, humidity can reach low rates of 50%, while in the rainy season it can exceed 95%.

Serra Sul historical precipitation is shown in Figure 17-1

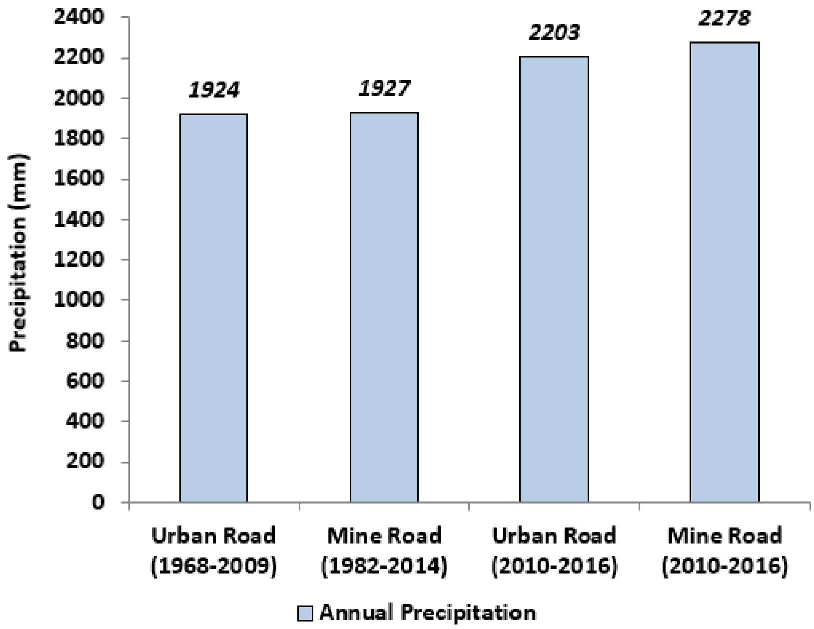


Figure 17-1: Serra Sul historical annual precipitation.

17.2.2. Hydrology

Serra Sul operations are bound to Parauapebas river watershed (eastern portion) and the Itacaiúnas portion (western portion). The Parauapebas River is an important tributary of Itacaiúnas, which is a tributary of Tocantins River at its left bank. Tocantins River flows into Pará River, which is bound to the Amazon River Basin.

Serra Sul mines are mostly developed in the sub-basins of Pacu and Sossego creeks.

17.2.3. Vegetation

The Serra Sul region encompasses the Amazon Biome, where the most common form of vegetation is the Ombrophiles Forests, which are adapted to the local humid climates. They are mainly located by mountains slopes and lower portions.

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 at small spots in the middle of Ombrophiles Forests on the slopes of mountain ranges.

Another type of vegetation is “rupestrian vegetation”, which grows on iron ore (“canga”). Despite being exposed to a lot of rain, canga remains dry for most of the year due to the rocky soil. As a result, plants that grow on 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 in place 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 S11D has been obtained by the end of 2022 and revalidated in 2023.

17.3.2. Topsoil Removal and Storage

The surface soil of cleared areas, formed by layers of higher organic matter content, is stored and used for landscaping. This material is nutrient-dense and comprises native vegetation propagules, which is important for the recovery of weathered or degraded areas.

17.3.3. Liquid Effluent Management

Effluents generated in workshops and fueling stations are treated with water-oil separators. 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 used to divert rainwater to watersheds and decantation ponds. Drainage systems are also important to convey water and prevent erosion. Those systems are constantly monitored and technically adjusted when necessary.

17.3.5. Solid Waste Management

Solid waste is properly segregated and packaged, according to its characteristics, until its destination.

17.3.6. Air Quality

Particulate matter is controlled with the use of water trucks on unpaved roads, fixed sprinklers, by setting vehicle speed limits, washing paved roads, carrying out maintenance on machinery and equipment, revegetation of waste dumps, stockpiles, and mining areas, and active monitoring.

The mine site air and meteorological quality are monitored by three automated stations that continuously generate data through specific analyzers and sensors.

17.3.7. Noise and Vibration Monitoring

This monitoring process aims to assess noise and vibration, through periodic seismographic monitoring, facilitating comparison with the standards set forth by the current legislation.

At S11D, such monitoring is performed periodically through a sampling network, from points distributed at the following locations: mine and plants, highway, natural forest and dams. The information obtained is stored in a database and submitted annually to IBAMA in a consolidated report.

17.3.8. Bioindicators

This monitoring process aims to assess how the project affects the fauna and flora dynamics.

17.3.9. Water Resources

The water quality management program is applied to monitor groundwater, potable water, and liquid effluents. The results are consolidated in annual reports and submitted to the environmental agencies.

17.3.10. Clearing and Grubbing

This program aims to apply forest management techniques focusing on workers´ safety, with minimal impact on the fauna and flora.

17.3.11. Bio Park VALE Amazônia

Located in the Carajás National Forest, in Pará, the Bio Park VALE Amazônia is a benchmark in terms of protecting species and promoting knowledge, by fostering VALE purpose pertaining to life improvement and future transformation.

Created in 1985 and maintained and administered by VALE, the Bio Park VALE Amazônia is the exclusive home to native species of fauna and Amazonian flora. Located in the National Forest of Carajás, in a Federal Conservation Unit, it takes up an area of 30 preserved hectares, which allows for free circulation of the local fauna. Approximately 100,000 people visit the area every 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.

17.3.13. Fire Prevention

VALE works jointly with IBAMA and ICMBio in terms of executing fire prevention and firefighting procedures to protect Carajás conservation units.

17.4. Social or Community Requirements

The nearest community to Serra Sul Operation is the municipality of Canaã dos Carajás, located approximately 50 km to the west, with a population of approximately 77,079 residents.

This section describes the operation main social initiatives and results.

17.4.1. Environmental Education Program

This program helps to increase critical awareness of the employees (VALE and third parties) and communities about environmental responsibility.

17.4.2. Recruitment Program and Workforce Training

This program is about hiring the greatest possible number of people who reside in the municipality where the project operates. Therefore, this program aims to qualify the local workforce through professional technical courses.

17.4.3. Health Program

Through partnerships with the government, VALE invests in infrastructure, education, and healthcare areas, including the construction and refurbishment of health centers and the donation of hospital equipment and ambulances.

17.4.4. Migrant Social Assistance and Protection Program

This program is based on the principles of the National Social Assistance Policy and aims to align the entrepreneur actions with the national policy guidelines so as to support the Social Development Secretariat of the municipality of Canaã dos Carajás.

17.5. Mine Closure

The mine closure plan includes the main infrastructure and natural sites, such as protected areas, waste dumps, containment dykes, basins and sumps, and industrial and administrative infrastructure.

The activities planned for the de-characterization and deactivation of S11D are described below, according to their specific characteristics, so as to adapt them to the safety standards required and to the closure scenario planned for the area.

17.5.1. Mine Pits

The S11D pit is undergoing its initial mining stages, so no slopes or sectors are being subjected to closure works. VALE intends to perform progressive closure as the mine nears completion or as soon as sectors are released. Some sectors in the upper portions of certain pits are already under closure conditions.

The activities designed for the closure of S11D pits are summarized in Table 17-2.

Table 17-2 - Closing activities - Pits

Typology	Structure	Activities
Pit	West East	- Topographic survey. - Localized slope adjustments. - Localized surface drainage adjustment. - Geotechnical monitoring system final adjustment. - Water level monitoring system final adjustment. - Localized slope revegetation. - Safety barrier implementation.

17.5.2. Waste Dumps

Activities planned for waste dump deactivation are summarized in Table 17-3.

Table 17-3 - Waste dump closure activities

Typology	Structure	Activities
Waste Dump	Waste and Canga Dump	- Topographic survey. - Geotechnical monitoring system final adjustment. - Localized slope adjustments. - Surface and perimeter channel final adjustment. - Slope and berm vegetation reinforcement.

17.5.3. Sediment Containment System

Activities planned for the closure of Serra Sul containment dykes are summarized in Table 17-4.

Table 17-4 - Closure activities - Sediment Containment System

Typology	Structure	Activities
Dams and Sumps	South Dam, West Dam, Dam 1 – Plant, Dam 3 – Plant, Maracanã, Mineirão.	- Topographic survey. - Geotechnical monitoring system final adjustment. - Slope and berm vegetation reinforcement. - Surface protection of embankment final adjustment. - Localized surface drainage adjustment. - Spillway final adjustment. - Revegetation. - Safety barrier implementation.

17.5.4. Industrial Facilities and Support Infrastructure

Activities designed for closure are briefly presented in Table 17-5.

Table 17-5 - Closing activities – industrial facilities and support infrastructure

Typology	Structure	Activities
Industrial Facilities and Structure	Office, storehouse, railway loop, 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 S11D closure plan, the need for geotechnical and environmental monitoring and maintenance of areas in the post-closure stage should be considered. Table 17-6 summarizes the main activities proposed to measure the efficiency of closure activities.

Table 17-6 - Post-closure monitoring and maintenance.

Activities	Attention points
Post-closure Monitoring and Maintenance	- Revegetation development. - Geotechnical stability. - Surface and groundwater quality.

17.5.6. Future Use Proposition

Part of Serra Sul Complex falls within the limits of the Carajás National Forest, a conservation unit aimed for sustainable use founded on 02/02/1998. Its specific objectives are bound to the purposes of its category and to those established in its creation decree; it is managed by the Chico Mendes Institute – ICMBio.

The Carajás National Forest Management Plan (STCP, 2016) is based on abiotic, biotic, and anthropogenic factor studies.

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.

17.5.7. 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 of creating a database on the flora, fauna, human occupation and natural resources within its boundaries.
- Training and Biodiversity Conservation: aiming at continued preservation of the Carajás National Forest and the development of activities that generate wealth for the region.
- Diversification of Plant Agro-Extractivism: to promote sustainable production and alignment between a community organization and technological development for the economic autonomy of Carajás National Forest.
- Ecological and Historical Tourism: following the example of other countries' mining industrial heritage conservation and similar initiatives in Brazil, and also because S11D mine is one of the largest in the world, associated with historical and touristic interest in terms of its remaining structures and facilities.
- Environmental Conservation Area: promotes the connection of preserved vegetation fragments and favors the construction of habitats for different faunal groups, allowing the occurrence of sufficient flora biodiversity to offer important sources of plant propagation, and subsequent efforts to recover disturbed ecosystems in the surroundings.

17.5.8. Financial provision

Closure of S11D Mine is scheduled for 2060, considering progressive closure, with decommissioning and deactivation efforts taking place during operations. Progressive closure is expected to take place according to the service life of the assets listed in Table 17-7. Closure efforts are described in Table 17-8, which refers to the provision of financial resources for asset demobilization as per the 2022 ARO model.

Table 17-7: Serra Sul assets in operation

Asset Name	Type	Useful Life
Pit S11D	Pit	2060
S11D Dump	Waste dump	2058
South Dump	Dam	2023
1 Mine	Dam	2023
3 Mine	Dam	2023
1 Plant	Dam	2023
S11D Industrial Facility	Industrial Installation	2060
S11D Overland Conveyor	Industrial Installation	2060
S11D Infrastructure	infrastructure	2060
Landfill and Wastewater Treatment Facility ETEQ	infrastructure	2060

Table 17-8 - Cash Provision for decommissioning (2022, ARO Model)

Assets	US$ M
Pit	14.65
Waste Dumps	5.93
Dams and Sumps	20.71
Industrial Infrastructure	96.58
Other structures	54.55
TOTAL	**192.42**

Note: numbers have been rounded

17.5.9. 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.

- Opinion 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.

There are areas for improvement to be applied, but these are related to new projects. These improvements have already been incorporated into the company regulations and aim to include elements (guidelines and concepts) that allow for resource optimization, focusing on a more sustainable approach even in the early stages of project development with an emphasis on closure.

18. Capital and Operating Costs

VALE QP reviewed capital and operating costs required for mining and processing of Mineral Reserves at Serra Sul. Serra Sul is an operating mine, and the capital and operating cost estimates were prepared based on recent operating performance and the current operating budget for 2023. All costs in this section are expressed in US dollars.

All capital and operating cost estimates 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 feasibility 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 Sul 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 consider capital projects that aim to maintain and/or increase productive capacity.

The overall capital cost estimate for LOM or evaluation period is US$ 15,573 million as shown in Table 18-1.

Table 18-1: LOM Capital Cost Estimate

Capital Cost Type	Unit	Value
Sustaining CAPEX	US$ M	***10,816***
Non-routine	US$ M	**940**
Mine and plant	US$ M	915
Waste and tailings dumps	US$ M	25
Routine	US$ M	**9,876**
Capital projects CAPEX	US$ M	**4,757**
Mine and plant	US$ M	903
Logistics and Other	US$ M	3,822
Waste and tailings dumps	US$ M	33
TOTAL	US$ M	**15,573**

Note: numbers have been rounded

18.2. Operating Costs

- LOM average unit operating cost and expenses:
  - Mine and plant: 6.7 US$/ton of product.
  - Logistics and Distribution: 17.3 US$/ton of product.
  - Royalties: 4.9 US$/ton of product.
  - Sales expenses, R&D, other: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 29.1 US$/ton of product.

The overall costs and expenses estimate for LOM or evaluation period is US$ 99,988 million as shown in Table 18-2.

Table 18-2: Operational Costs and Expenses

Type of costs and expenses	Unit	Value
Mine and plant	US$ M	23,006
Logistics and Distribution	US$ M	59,419
Royalties	US$ M	16,939
Sales expenses, R&D, other	US$ M	624
TOTAL	**US$ M**	**99,988**

Note: numbers have been rounded

The average operating cost is based on a 30-year life of mine from 2024 through 2053, and for the years after 2053, the unit costs of 2053 were replicated. The operating cost inputs including labor, consumables, supplies, selling costs, commercial offices, operational and maintenance research & development, were based on data from VALE 2023 budget.

18.2.1. Workforce

The workforce breakdown and main contractors list for the entire operation at Serra Sul are shown in Table 18-3 and Table 18-4, respectively.

Table 18-3: VALE site workforce

Serra Sul	Total
Mine	998
Plant	1,043
Other	743
TOTAL	**2,784**

Table 18-4: Contractors´ workforce

Serra Sul (Contractors)	Total
Mine	1,754
Plant	1,657
Other	2,887
TOTAL	**6,298**

The main contractor at Serra Sul is related to mining, plant maintenance and cleaning.

19. Economic Analysis

19.1. Forward-looking information caution

The aim of the economic evaluation presented in this chapter is to demonstrate the economic feasibility 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. Physical

- Open pit ore tonnes mined: 3,431 Mt.
- Total ore processed: 3,431 Mt.
- Life of Mine: 2024 to 2060.
- Ore grade: 65.4% Fe.
- Average LOM Recovery: 100%.
- Recovered Iron Ore: 3,431 Mt.

19.2.2. Revenue

Commodity prices were discussed in Chapter 16.

The average logistics costs considered for this model are: 17.3 US$/ton, around 80% of the total sells during Serra Sul mine life considered as foreign market and CFR (cost and freight) model.

The remaining 20% of the 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 iron-ore commercial strategy, the company operates two blending 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.

Serra Sul ore 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: 6.7 US$/ton of product.
  - Logistics and Distribution: 17.3 US$/ton of product.
  - Royalties: 4.9 US$/ton of product.
  - Sales expenses, R&D, other: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 29.1 US$/ton of product.
- Overall costs and expenses estimate for LOM or evaluation period: US$ 99,988 million.

Mine and plant costs include mining, processing, storage, and shipping of the ore to the loading points.

Logistics and distribution costs include railroad, ports, maritime freight, and distribution centers.

19.2.4. Capital Costs

- Overall capital cost estimate for LOM or evaluation period: US$ 15,573 million.
- Sustaining CAPEX: US$ 10,816 million.
- Capital projects CAPEX: US$ 4,757 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 2027);
- Income tax rate: 34% (from 2028 onwards).

19.3. Results of Economic Analysis

19.3.1. Introduction

VALE has prepared the Serra Sul 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 cashflow stemming exclusively from the mineral reserve for Serra Sul is used to confirm the economic feasibility. We present the forecasted average annual cash flows for grouped periods (first 2 years, followed by 3 years, and subsequently 5 years groups and after 30 years in a 7 year group) based on annual production quantities, revenues, and costs for the period. We believe presenting the average cash flows over these periods accounts for the uncertainty in the actual timing and amounts of the cash flows and better represent the material information about the economic viability of mining the reserves which has a long mine life. The cash flow summary is presented in Table 19-1 and Figure 19-1. 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

Cash Flow (Mineral Reserves only)	Unit	2024-25	2026-28	2029-33	2034-38	2039-43	2044-48	2049-53	2054-60
Iron Ore Recovered	Mt	87	111	120	120	120	104	83	27
Total Revenue	US$ million	7,965	8,642	9,000	9,040	9,008	7,853	6,307	2,084
Operating costs, expenses, royalties and closure costs	US$ million	-2,688	-3,173	-3,438	-3,371	-3,387	-2,983	-2,601	-901
Income Tax and working capital change	US$ million	-737	-1,079	-1,648	-1,627	-1,647	-1,458	-1,059	-194
Operational Cash Flow	US$ million	4,540	4,390	3,914	4,042	3,974	3,412	2,647	989
Total CAPEX	US$ million	-1,012	-461	-477	-984	-366	-265	-232	-78

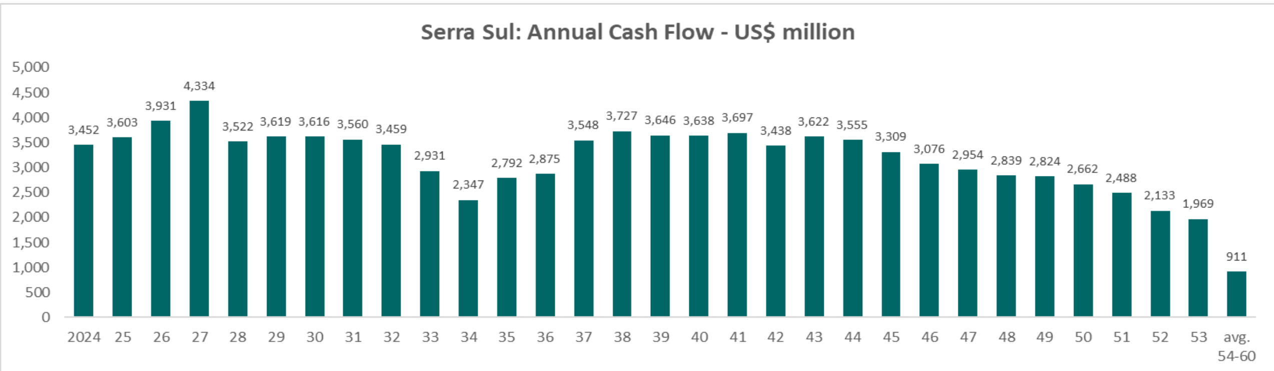


Figure 19-1: Annual cash flow

19.3.2. Cash flow analysis

The economic reserves valuation model 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 Sul is economically feasible. The after-tax NPV at a 7.0% discount rate and following a mid-year convention is US$ 44,505 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**	**111,117**
Total costs and expenses	US$ M	-41,402
Mine and plant	US$ M	-9,085
Logistics and Distribution	US$ M	-24,880
Royalties	US$ M	-7,159
Sales expenses, R&D, other	US$ M	-266
Closure costs	US$ M	-13
Income Tax and working capital change	US$ M	-17,509
Operational Cash Flow	**US$ M**	**52,205**
Total CAPEX	US$ M	-7,700
Free Cash Flow	**US$ M**	**44,505**

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 a 7.0% 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.

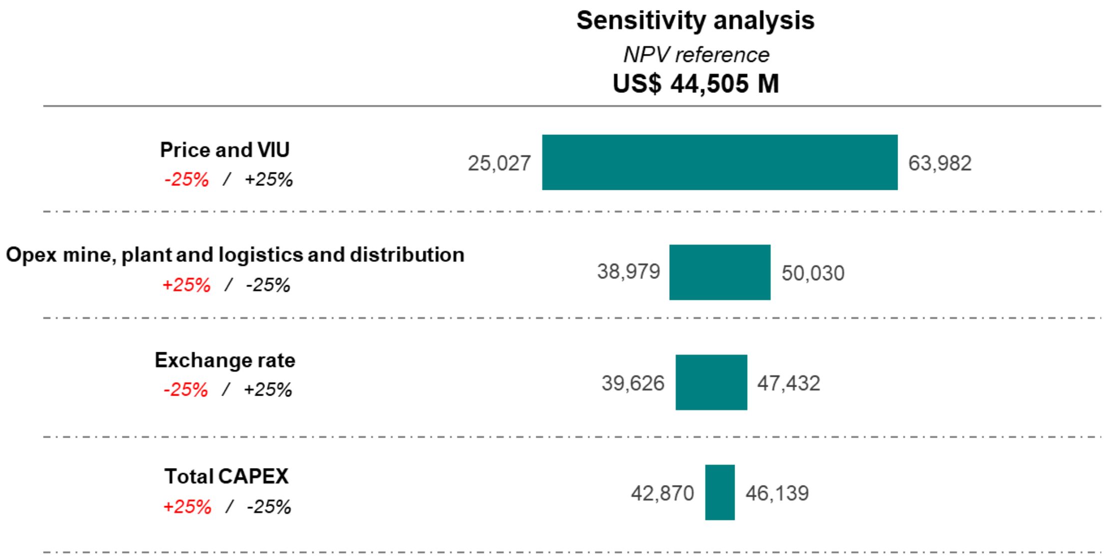


Figure 19-2- Sensitivity Analysis

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

20. Adjacent Properties

This chapter is not relevant to this Report.

21. Other Relevant Data and Information

No additional information or explanation is necessary to make this Technical Report Summary understandable and not misleading.

22. Interpretation and Conclusions

22.1. Property description and location

The resource and reserve pits of Serra Sul Complex do not interfere with any mining processes of other holders. The Serra Sul Complex is entirely included in Mining Group 43/1979, which is in the Development Concession phase.

22.2. Geological setting and mineralization

The current geological database satisfactorily enables the setting of a robust structural and stratigraphic model, as well as mineralization associations and understandings.

All current geological models have been audited and they satisfactorily reproduce the continuity of mineralized bodies, their enclosing and coverings. The models have been built by vertical sections or implicit modelling methods, which acceptably represent the geological units.

The presented structural/stratigraphic geometry settings result from three successive tectonic events and post mineralization mainly by supergenic enrichment, developed on jaspilites.

22.3. Exploration, drilling and sampling

All efforts developed at Serra Sul follow strict internal standards and the mining industry best practices. The various drilling programs carried out over the last decades, as well as all corresponding geological data, sampling and chemical analysis have been extensively discussed by the relevant technical teams so as to ensure a robust geological model.

22.3.1. Hydrogeological and geotechnical settings

The current geotechnical and hydrological database was considered satisfactory (in terms of amounts and quality) as regards achieving the main objectives, which encompassed building and calibrating models aimed to simulate future mining scenarios so as to provide input to slope stability analysis, support failure mechanism evaluation, provide short- and long-term geotechnical information, and render mining and environmental assistance.

The hydrogeological simulations showed reliable and feasible results with operational flow rates for the drawdown of Serra Sul Mine Complex pits. The geotechnical and hydrological data obtained and used in the slope stability analyses have been reasonable predictors of current conditions, and therefore, they have satisfactorily supported the mineral reserve estimates. The slope stability analyses run for Serra Sul Mine Complex (S11C and S11D) produced reliable and feasible results, with factors of safety consistent with the minimal international standards established 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, affecting operating costs due to mitigation measures that may need to be imposed, impacting the economic analysis which supports the mineral reserve estimates.

22.4. Data verification

Data verification programs concluded that the data collected from Serra Sul adequately support the geological interpretations, comprising a sufficiently qualified database to be used in mineral resource and mineral reserve estimation.

22.5. Mineral resource estimates

Mineral resources are reported for Serra Sul Mining Complex, which comprises the deposits of S11 orebodies C and D. VALE has a set of protocols, internal controls, and guidelines in place to support the estimation process, which the estimators must abide by. 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–K 1300 and are reported without converting mineral resources 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 Sul Mining Complex has proven to have reasonable prospect of economic extraction, and therefore the mineral resource estimates can be supported.

22.6. Mining and Mineral Reserves

- As of December 31, 2023, Proven and Probable Mineral Reserves are estimated to total 3,430.8 Mt.
- The methodology, assumptions, and parameters used for the Serra Sul Mineral Reserves estimate are appropriate for the mineralization and the mine method used.
- Mine fleet, infrastructure, and operational practices are appropriate to ensure continuity of the mine operation.

22.7. Mining methods

Serra Sul mine operation is based on the open-pit method, which splits mine operation into zones that are favorable for belt operation mining and high geometric complexity zones, operated via the conventional Truck and Shovel system.

The current annual production plans are around 80 Mt, but the target is to reach a production rate of 120 Mt per year. This might slightly vary up or down depending on the company strategy during life of mine.

22.8. Mineral Processing

To improve the beneficiation plant performance, the following projects must be implemented:

Semi mobile crushing in area 5.

Compact crushing.

Additional 10 Mtpy (million tons per year).

Additional 20 Mtpy (million tons per year).

Secondary crushing in the 5th crushing plant.

22.9. Environmental and Permitting

Serra Sul holds the environmental permits required to operate.

There is an ongoing discussion with the legal authorities in terms of changing the Protected Area management plan so as to facilitate expansion of the mining zone.

22.10. Capital and operating costs

22.10.1. Capital costs estimates

Economic valuations consider the sustaining CAPEX, necessary for the maintenance of existing assets/operations, and capital projects that aim to maintain and/or increase productive capacity in cash flows. 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, a 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 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 feasibility 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 consider capital projects that aim to maintain and/or increase productive capacity. The overall capital cost estimate for LOM or evaluation period is US$ 15,573 million.

22.10.2. Operating costs 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 implementation.

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

- LOM average unit operating cost and expenses:
  - Mine and plant: 6.7 US$/ton of product.
  - Logistics and Distribution: 17.3 US$/ton of product.
  - Royalties: 4.9 US$/ton of product.
  - Sales expenses, R&D, other: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 29.1 US$/ton of product.

The sole purpose of the presented figures is to demonstrate the economic feasibility of the mineral reserve; therefore, it can differ from other information VALE publishes and should not be considered as a guidance.

The overall costs and expenses estimate for LOM or evaluation period is US$ 99,988 million.

22.11. Economic analysis

The aim of the economic evaluation presented in this chapter is to demonstrate the economic feasibility 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 Sul is economically feasible. The after-tax NPV at a 7.0% discount rate and following a mid-year convention is US$ 44,505 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 a 7.0% 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 Resources and Mineral Reserves

Factors that may affect the mineral resource and mineral reserve estimates were identified in Chapter 11 and Chapter 12, respectively.

Other risks noted include:

- 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 land zoning, encompassing the "Mining Zone" category. The Management Plan has legal provision to be reviewed and the last revision was in 2016. The S11C deposit (Serra Sul) 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. In case of approval, there is opportunity to develop satellite deposits, which are still in the preliminary exploration stage, in addition to the resources and reserves disclosed.
- According to Brazilian environmental legislation, environmental regulators can approve an operation permit request around preservation areas, considering a protection buffer. Although in 2023 our reserve pit was updated to increase the protection buffer, still a portion of S11D deposit (Serra Sul) requires the approval of a request to reduce the protection buffer for two lakes (and its hydric contribution zone). In one of the lakes there is an endemic plant specie, which must be preserved. We have a reasonable expectation that the permit will be granted, however, depending on the "buffer size" to be approved by Brazilian federal environment institutes, a portion of the mineral reserve and resource could be affected.

  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, but, on the other hand, it allows impacts on the other caves categories, following proper environmental permit and/or compensation. A regulation defines a 250-meter 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 Sul mineral reserve estimation considered a 150 meters buffer for their protection, but, in the case of mineral resources, no constrains 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 is still temporarily suspended until further decision of the court.

- 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 required. 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 the economic analysis that supports the mineral resource estimates.
- Due to the low selectivity inherent to the IPCC, the occurrence of jaspilite lenses can impact operational performance and associated costs. Additional studies on the geological continuity of these lenses are underway in order to mitigate such operational impacts.

Opportunities include:

- The mineralization of Serra Sul deposits remains open at depth under the current open pit outline. Additional exploration evaluation is required.
- Potential conversion of the measured and indicated mineral resources reported exclusive of mineral reserves, mainly related to maximum caves regulation, to mineral reserves.
- Potential conversion of inferred mineral resources, with supporting studies, to higher confidence mineral resource classifications.

23. Recommendations

23.1. Geological Setting and mineralization

Upholding routine geological data collection with mappings, sampling, and developing drilling programs (short and long terms) are recommended to continuously improve knowledge on high-grade ores, structural aspects and stratigraphy.

Further efforts are required to determine exploration potential below the current open-pit operations and unoperated plateaus. Exploration targets are mainly bound to outcrops of structured canga, soft hematite and jaspilite, or geophysical anomalies.

23.2. Exploration

Regarding the geotechnical and hydrogeological remarks, the development of an effective Ground Control Management Plan and complete Quality Assurance and Quality Control Program is recommended, in addition to a continuously improved database (boreholes and testing) so as to reduce the identified database backlog and include information from new areas. This will provide a robust basis for geotechnical and hydrogeological evaluation, modelling and mitigation measures.

To achieve the maturity level of geotechnical and hydrogeological studies of the mines throughout the project life cycle, it is necessary to continuously fine-tune the hydro and geotechnical database, models, and monitoring programs.

23.3. Mineral resource estimates

Continuity of geological drilling annual plans so as to further assess in-depth geology, improving the geological knowledge and confidence to convert inferred and indicated classes into indicated and measured categories.

23.4. Mining and Mineral Reserves

Improvement of mining dilution and ore loss measurement controls for increased confidence on both factors.

Investigation of different solutions and technologies for clay material disposal and minimization of waste dump lining requirement.

23.5. Costs and economics

Keeping focus on capital allocation discipline and potential inefficiency elimination, to guarantee, with operational safety, cost competitiveness, and consequently, healthy margins and balance sheets over any pricing scenario.

23.6. Environmental

Upholding monitoring and environmental programs that ensure mitigation of environmental impacts arising from operations.

Within the scope of Serra Sul, it is important to keep holding discussions with the Conservation Units agency aimed at developing studies and sharing information on the decision to change the management plan zoning to facilitate mining zone expansion, which is currently restricted.

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25. Reliance on Information Provided by 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 2016;
- 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 feasibility 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 feasibility of the mineral reserve estimates in Chapter 12.

25.4. Legal Matters

Information relating to 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 feasibility 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 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 18, 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 feasibility 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 18, 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 feasibility 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 18, 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 feasibility of the mineral reserve estimates in Chapter 12.