Technical Report Summary

Serra Sul Complex
Brazil

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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. The purpose of this report is to support the disclosure of Mineral Resource and Mineral Reserve estimates for the Serra Sul Complex as of December 31, 2021. 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. With operations on five continents, the company has a global and diversified shareholder base, and its shares are traded on the leading stock exchanges in the world.

A world leader in producing iron ore pellets, and nickel, Vale also produces manganese, ferroalloys, coal, copper, gold, silver, cobalt, and platinum group metals. Its ores are of high quality and produced to meet customers' needs in steel mills worldwide.

To deliver products with agility, 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 sectors directly and through affiliates and joint ventures.

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

1.2. Property description 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 process where the mining operations are located within the National Forest of Carajás (FLONACA) and 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 properties are not owned by Vale, but both are covered mining easement report issued by the National Mining Agency (ANM). These surface properties are owned by the Government.

For the development of the Serra Sul Complex, there are three easement areas. These three easements are contiguous and make a unique shape which encompasses all current and future industrial installations necessary for the Serra Sul life of mine

1.3. History

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

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

1.4. Geological setting and mineralization

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

The Serra 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 in the NW-SE direction. Its shape is segmented, with directions that vary sharply between N-S and E-W, configuring a kink-type pattern. The deposit includes A, B, C, and D bodies, the latter is the one of the highest economic interests. The plateau is predominantly composed of rocks from the Carajás and Igarapé Cigarra formations, which contact the Parauapebas Formation to the south, and Águas Claras Formation to the north. The layers present variable dips and azimuths shifting between the north and east directions, in general configuring a normal stratigraphic stacking.

At the eastern portion of the S11 plateau, which comprises the active part of the S11D mine, the geological information was obtained by mapping on a 1:2,000 scale, diamond drilling, trenches and channels.

Therefore, most of the geological information regarding this plateau was obtained from diamond drill cores and surface mapping of alteration materials, due to the strong/deep weathering and the absence of cuts and excavations, making the outcrops scarce.

The Carajás Formation corresponds to the thickest domain of the iron formations. It coincides with the highest elevations. The iron formations of the Carajás Formation domain occur as 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. Its actual thickness has not been determined; however, it can exceed 450 m depth in section and varies between 200 m and 1,200 m in plan.

The S11 iron formation layout expresses strong structural control. Faults and folds conditions the thickness and continuity of the iron formations. The structures are correlated to the Transamazonian and Braziliano tectonics events, such as: Nucleation of the Carajás Syncline, folding with sub-horizontal axes of NW-SE direction, verging towards SW, development of faults that imprint at SS11 plateau segmentation in kink style, formation of discontinuities filled by mafic dikes with NW-SE direction and implementation of normal faults that originate a horsts and grabens system, responsible for localized lifting of jaspillite bodies.

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

The cangas occur with wide expression on the surface of SS11 Plateau and represent the product of weathering on the different rocks in the region. Thus, they are differentiated according to the substrate and divided in chemical canga, which covers mafic rocks, enclosing or intrusive in the iron formation, and structured canga, developed directly over the iron formations and capable of economic use. It is a very hydrated lithotype with mineralogy with average Fe content of 64.2%, which contains alumina and phosphorus as main contaminants, in addition to high values of loss on ignition.

1.5. Exploration

1.5.1. Exploration

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

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

1.5.2. Drilling

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

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. S11C has a 200x200m grid which corresponds to optimal drilling grid for resource definition. In S11D, long-term and short-term drilling campaigns were performed with the purpose to close the resources definition (100x100m) and ore control (50x50m).

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

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

Orebody	N° Drillholes	Meters (m)
S11D	1,631	292,765
S11C	136	27,286
TOTAL	1,767	320,051

1.5.3. Hydrology

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

The numerical modelling software MODFLOW was used by MDGEO, in 2020, for the simulation of water table drawdown. The simulated outflow will be about 1,138 m^3/h, of which, a portion of 260 m^3/h in the pit of S11C and another 878 m^3/h, in S11D. To calibrate the model, 92 instruments were used.

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

1.5.4. Geotechnical

Core logging, surface mapping, and laboratory tests are the main source of geotechnical information. For core logging or mapping the data collected follows tables proposed by ISRM (1997), Bieniawski (1989) and Martin & Stacey (2018) adjusted by Vale (2019) to agree on iron formation deposits. These characterization parameters are applied to define different rock mass classification systems and to build the geomechanical model. The geomechanical models from Serra Sul Complex were build using about 288,927 m of geotechnical core logging and 414 geotechnical superficial mapping points.

A combination of historical closer sites and current geotechnical data, with the mining site experience of internal teams supported by national and international consultants, are used to establish internal guidelines and procedures in the slope stability design and operation for S11C and S11D pits.

1.5.5. Sampling

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

1.5.6. Density Determinations

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

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

1.5.7. Sample preparation and analyses

The drill holes completed in the 1970s were prepped and assayed at Serra Norte laboratory and at the laboratory of Companhia Vale do Rio Doce, located in Belo Horizonte. Only global assays were done for Fe, SiO2, P, Al2O3, Mn, FeO and LOI (Loss on ignition). Measurements of the percentage of magnetite in the ore were also taken using Satmagan equipment.

The assay of the RC drilling campaigns from 2003 to 2005 were under the responsibility of the GADIN Chemical Analysis Laboratory of the Carajás Iron Mine, Brazil. In 2005 and 2006, Vale contracted 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%, SiO2%, Al2O3%, P%, Mn%, MgO%, TiO2%, CaO% and Cu ppm.

In 2013, Fe started to be assayed wet in all fractions. The other analytes are determined by X-ray fluorescence and Loss on Ignition by gravimetry. From 2009 onwards, no more assays were made for Cu.

1.5.8. Quality Assurance and Quality Control

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

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

1.6. Data verification

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

Mineral resources and mineral 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 the qualified person/competent persons from respective department: resources, reserves, mineral processing, geotechnics (pit, project and dam), hydrogeology, production, strategy, environmental, speleology, finance, mining rights, mining future use and engineering.

Alongside the activities of mining operations, periodic reconciliations are performed in each site. Annual consolidate results report comparing short term model, mineral resource, and reserves model, besides production grades and tons are discussed in annual technical meeting to promote continuous improvement between all areas 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 inside the domain(s); compositing of drill hole information on a consistent support size (length, density, recovery), validation through statistics on lengths and variables before and after compositing; comprehensive understanding of the statistical characters of the variables; in each estimation domain and at the contacts between domains; characterization of the spatial continuity of each variable to be modelled (variograms); understanding of the influence of outliers and variables with highly skewed distributions and selection of an appropriate handling strategy (restricted neighborhood); spatial distribution of drillhole and sample data, mining method and production rates under consideration; selection of an appropriate modelling technique and definition of proper parameters and options to be used (e.g., kriging plan, search strategy, variogram models to be used, post-processing methods); validation of the estimates (visual inspection, checks for global and local bias, confirmation of the kriging plan, and a check on the degree of grade smoothing resulting from the interpolation); and confidence classification.

Estimation was made by Vale personnel. The mineral resource estimate is supported by core drilling. Software used in estimation includes 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 assigned according to Risk Index methodology which combines orebody continuity and estimation error. Measured blocks estimated using only one drillhole were downgraded to indicated blocks. Subsequently, this automated classification was compared with 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 projected piles capacities. Pit inter-ramp slope angles varies according to lithology and range from 19-42°.

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 support of 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 stated as 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	479.9	66.0	388.0	64.6

Notes to accompany mineral resources tables:
1. The effective date of the estimate is 2021/Dec/31.
2. Tonnage stated as metric million tons inclusive of 7.10% 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 US$78/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	123.5	64.3

Notes to accompany mineral resources tables:
1. The effective date of the estimate is 2021/Dec/31.
2. Tonnage stated as metric million tons inclusive of 7.10% 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 US$78/dmt for 62% iron grade.
4. Numbers have been rounded.

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

1.8. Mineral reserves estimate

The Serra Sul ore body is divided into four bodies, A, B, C e D. Bodies A and B are currently under study and are in potential. Only bodies C and D have models already estimated and officially declared, and body D is currently in operation. The 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 located in the area, process and mine costs that consider additional deepening increments, sales costs, commodity price curve, geotechnical parameters, mine recovery and dilution.

The cost methodology also took into consideration two phases within the optimal pit, one for the mobile crushing method and another for the conventional method with excavators and trucks. This procedure is done to separate the costs for each method. For the separation of these phases a pit geometry was used for the mobile crushing method and all blocks below this geometry were considered for conventional mining.

Finally, based on these parameters, a family of pits was generated, and the optimal pit was chosen based on the best possible economic criteria (more details are given in chapters 12 and 13). After this first step, the pit is submitted to first geotechnical evaluation and again submitted to post optimization for it to absorb the corrections of some geotechnical parameters. Only after this second round of optimization, the pit goes to operationalization and a final geotechnical analysis for final corrections to the operationalized geometry to ensure safety and stability of the slopes. Table 1 4 presents the results of proven and proven reserves.

Table 1-4 - Proven and Probable Mineral Reserve Statement 2021

Pit/Operation	Classification	Tonnage (Mt)	Grade
			Fe (%)
S11CD	Proven	1,825.8	66.0
	Probable	2,447.2	65.6
	Total Proven + Probable	**4,273.0**	**65.8**

Notes to accompany mineral reserves tables:
1. The effective date of the estimate is 2021/Dec/31.
2. Tonnage stated as metric million tons inclusive of 7.22% 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 US$70/dmt for 62% iron grade.
4. Numbers have been rounded.

1.9. Processing and recovery methods

The Serra Sul complex is very important to Vale's production system, both in terms of volume and in terms of quality. This complex has installed capacity of 90 Mta with all ROM being processed at natural moisture with mass recovery of 100%. The deposit of this complex allows the generation of products with iron content of around 65% with low variability. For natural moisture processing, different crushing and screening steps are used, with no need for routine process tests.

1.10. Mining methods

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

The mining of the material in the areas indicated for mining by belt, is carried out by electric cable/hydraulic excavators and fed in the mobile crushers. These materials, which can be ore or waste, are reduced to granulometry favorable to belt conveyors and taken to processing plants or waste piles. The separation of materials is carried out in transfer houses for the belts proper for their destination.

In addition to cable/hydraulic excavators and mobile crushers, wheel loaders are used in order to guarantee higher flexibility in the mine, in addition to various cleaning and backup jobs for the excavators, when necessary. A fleet of off-road haul trucks is used for situations where truckles mining is not possible. Bulldozers are designed to maintain production areas and bench cleaning. Wheel tractors, graders and water trucks complete the rest of the auxiliary equipment fleet.

Currently, the estimated production target per year is 90 Mtpy with projects to expand its production to 120 Mtpy.

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

1.11. Infrastructure

Most of the infrastructure to support mining operations is in place. There is no accommodation camp on site. Most of the workforce resides in Canaã dos Carajás.

Water can be abstracted from streams and downgradient wells selected under licenses granted. The process replacement water comes from the same sources already mentioned in the text. Potable water also comes from wells located in the mine. This water is treated in a WTP - Water Treatment Plant. Serra Sul operations monitor levels, flows and water balances regularly.

The electric power is supplied by the NIS - National Interconnected System and is connected at voltage of 230KV. Part of the energy consumed is also captured from the TCLD's regeneration system, some 6% of consumption.

The internal distribution system is carried out through Vale's own 34.5kV electrical networks.

The 2020 consumption of the Plant and Mine was about 281,384.97 MWh, 63.10% of which fed the mineral processing plants, 28.81% were consumed at the mine and the remaining 8.09% were consumed by other support structures.

1.12. Market studies

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

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 analyst and bank forecasts. The sole purpose of the presented figures is to demonstrate the economic viability of the mineral reserve, therefore it can differ from other information we publish and should not be considered as a guidance.

By the time this report was prepared, the price consensus for iron ore prices at 62% Fe in 2022 of the analysts was USD112/t, with a downward trend going forward until prices reach the long-term level of around USD 70/t and the price consensus for iron ore prices at 65% Fe in 2022 of the analysts was USD 127/t with a downward trend going forward until prices reach the long-term level of around USD 84/t. Additionally, we believe that the expected future production, relative to our iron ore reserves, can be absorbed by the market in the long term given the expected demand by market analysts.

1.13. Environmental

Vale's operations in Serra Sul complex started in 2016 with the start of the S11D Mine. To support the assessment of environmental feasibility and issuance of environmental licenses necessary to start operations, Vale has carried out numerous baseline environmental studies in accordance with the legislation in Brazil relating to land use, topography, regional geology, local geology and mineralogy, soil, climate and hydrology, hydrogeology, biotic environment, socio-economics and mine closure plan, among others.

As mines facilities areas are expanding, supportive environmental studies are carried out to assess the environmental conditions and to support the environmental agency license applications and decision-making. Most recently highlighted by licensing for production increase by 10Mtpy, carried out in 2018, environmental license for which was obtained in 2019 and is under implementation.

The current operating license is valid until 2026 and includes environmental plans and programs developed and implemented for all sites currently operating in the complex and aims to mitigate environmental impacts or immediately identify possible operational failures that could generate them.

Additionally, a licensing process is underway to obtain an environmental license to increase production to 120 Mtpy and other studies to support the discussion with the licensing agency to reduce cavity radius and modify the Carajás National Forest Management Plan to release areas to be mined.

1.14. Capital and operating costs

1.14.1. 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 the assets, including acquisition and replacement of equipment and readjustment of operating structures. They are estimated based on a diagnosis made by the Engineering area on the asset base, on a maintenance backlog and on the investment, target defined by the company for future years.

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

The sole purpose of the presented figure is to demonstrate the economic viability of the mineral reserve, therefore it can differ from other information Vale publishes and should not be considered as 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$ 15,615 million as shown in Table 1-5.

Table 1-5 – LOM capital cost estimate

Capital Cost Type	Unit	Value
Sustaining CAPEX	US$ M	***11,909***
Non-routine	US$ M	**866**
Mine and plant	US$ M	353
Logistics and Other	US$ M	513
Routine	US$ M	**11,043**
Capital projects CAPEX	US$ M	**3,706**
Mine and plant	US$ M	1,801
Logistics and Other	US$ M	1,905
TOTAL	US$ M	**15,615**

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 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: 4.0 US$/ton of product;
  - Logistics and Distribution: 19.0 US$/ton of product;
  - Royalties: 2.4 US$/ton of product;
  - Sales expenses, R&D, others: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 25.6 US$/ton of product.

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

The overall costs and expenses estimate for LOM or evaluation period, is US$ 109,531 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	17,049
Logistics and Distribution	US$ M	81,355
Royalties	US$ M	10,406
Sales expenses, R&D, others	US$ M	721
TOTAL	**US$ M**	**109,531**

Note: numbers have been rounded.

1.15. Economic analysis

1.15.1. Introduction

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

1.15.2. Methodology and Assumptions

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

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

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

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

Table 1-7 – Long Term Exchange rate.

Exchange rate – real terms	2022	LP
R$ / US$	5.25	5.00

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

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

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

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.

The overall costs and expenses estimate for LOM or evaluation period is US$ 109,531 million as shown in Table 1-8.

Table 1-8 – Operational Costs and Expenses

Type of costs and expenses	Unit	Value
Mine and plant	US$ M	17,049
Logistics and Distribution	US$ M	81,355
Royalties	US$ M	10,406
Sales expenses, R&D, others	US$ M	721
TOTAL	**US$ M**	**109,531**

Note: number have been rounded.

Vale’s discount rates are re-calculated annually by the Treasury and Corporate Finance Department. For supporting mineral reserve declarations, Vale WACC must be used. In 2021, Vale WACC of 7.5% was calculated and used to demonstrate the economic viability for mineral reserves.

1.15.3. Economic Analysis

The economic valuation model of reserves considered the discounted cash flow method and it took into account annual processed tonnages and grades. The associated process recovery, metal prices, operating costs, logistics costs, royalties, and capital expenditures were also considered. The economic analysis confirmed that Serra Sul are economically viable. The after-tax NPV at a 7.5% discount rate and following a mid-year convention is US$ 42,460 M. The summary of the results of the cash flow analysis is presented Table 1-9.

Table 1-9 – Economic Evaluation.

Net present value of overall cash flow	Unit	Value
Total revenue	**US$ M**	**104,471**
Total costs and expenses	US$ M	-38,600
Mine and plant	US$ M	-6,229
Logistics and Distribution	US$ M	-28,453
Royalties	US$ M	-3,628
Sales expenses, R&D, others	US$ M	-278
Closure costs	US$ M	-13
Income Tax and working capital change	US$ M	-16,396
Operational Cash Flow	**US$ M**	**49,475**
Total CAPEX	US$ M	-7,015
Free Cash Flow	**US$ M**	**42,460**

1.15.4. Sensitivity Analysis

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

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

2. Introduction

2.1. Terms of reference and purpose

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

The new SEC rules align the disclosure requirements with global regulatory practices and standards, as incorporated in the standards developed by the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) which VALE is accustomed to using. As this is the first Technical Report Summary issued by VALE for the Serra Sul complex, previously filed reports of this nature will not be mentioned.

The effective date of this Technical Report Summary is 31st December 2021.

The assumptions adopted in the preparation of this report involve inherent uncertainties and risks, and the information in this report is not a guarantee of future performance. This report contains estimates, 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 its QPs cannot guarantee that such forward-looking statements will prove to be accurate. The risks and uncertainties related to our estimates and projections include, among others, 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 its QPs emphasize that the actual results referring to Vale's mineral resources and reserves may materially differ from the plans, objectives, expectations, estimates, and 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 large Brazilian exporter and one of the main private companies in Brazil. With operations on the five continents, the company has a global and diversified shareholder base, and its shares are traded on the main stock exchanges in the world. World leader in the production of iron ore, pellets and nickel, VALE also produces manganese, ferroalloys, coal, copper, gold, silver, cobalt and metals from the platinum group. Its ores are of high quality and produced to meet the needs of the customers in the steelwork industry worldwide competitively. To deliver products quickly, the mining company operates an integrated and efficient logistics chain globally, which includes railways, maritime terminals and ports, in addition to floating transfer stations and distribution centers. VALE is publicly traded on the New York Stock Exchange

(NYSE) and in Brazil on the B3.

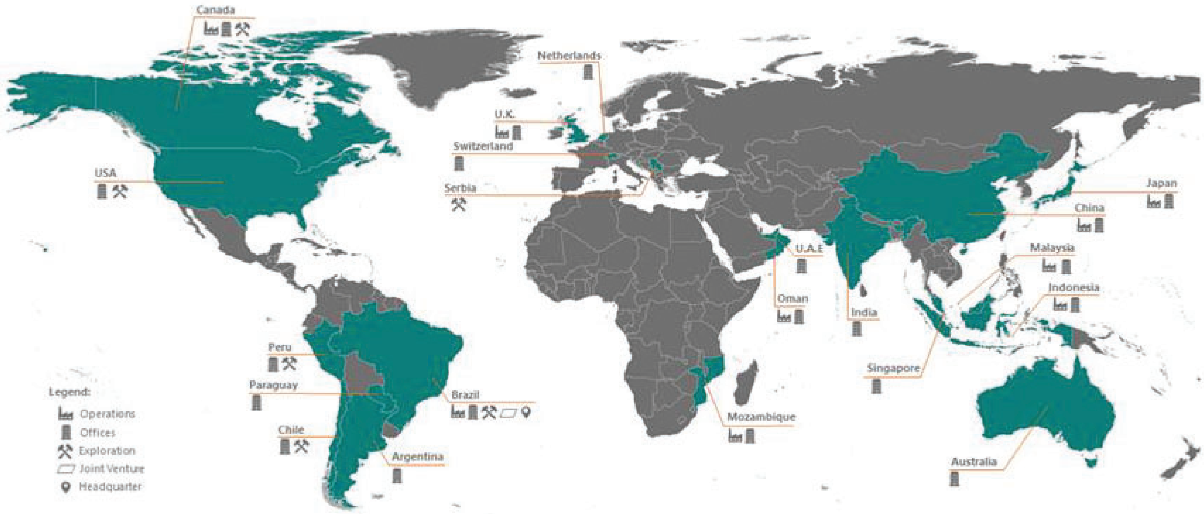


Figure 2-1 shows the location of VALE's business segments in the world.

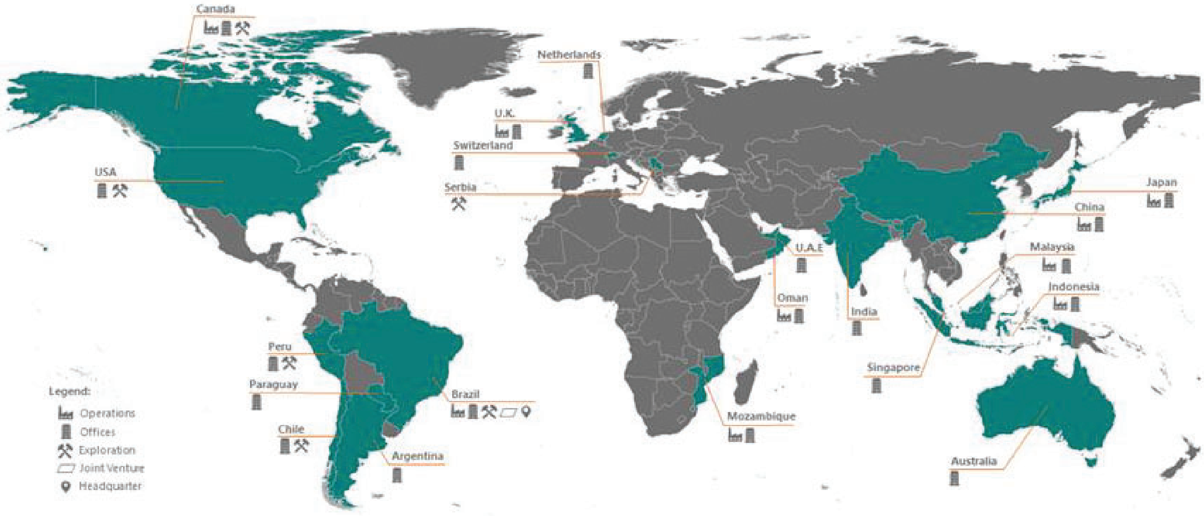


Figure 2-1 - Location of VALE's business segments.

2.3. Site Visits

Qualified persons (QPs) involved in the estimation of mineral resources and reserves at Serra Sul are professionals with extensive experience in their areas of operation make repeated visits to the respective sites described in this report. Due to the COVID 19 epidemic, these visits were impaired. Table 2-1 shows the latest visits and future schedule

Table 2-1 - QPs site visits

QP	Last visit	Visit scheduled
Arnor Barbosa de Couto Junior (Mineral Reserves)	March/2021	First half/2022
Guilherme Paiva da Silva (Mineral Reserves)	March/2021	First half/2022

Carlos Eduardo Reinaldo Delgado (Geology)	August /2019	First half/2022
Evandro Machado da Cunha Filho (Mineral Resource)	November/2018	First half/2022

2.4. Qualified Persons

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

Table 2-2 - QPs list

Qualified Persons (QPs)	Role	Sections of responsibility
Alessandro Resende, PQR CBRR	Engineer Specialist	1; 2; 3; 20; 21; 22; 23; 24 and 25
Arnor B. Couto Jr., PQR CBRR	Mineral Reserves Technical Specialist	1; 2; 4; 12; 13; 15; 16; 17; 18; 19; 20; 21; 22; 23; 24 and 25
Carlos E. R. Delgado, PQR CBRR	Master Geologist	1; 2; 5; 6; 7; 8; 9; 20; 21; 22; 23; 24 and 25
Evandro M. Cunha Filho, MAusIMM	Specialist Geologist	1; 2; 5; 6; 8; 9; 11; 20; 21; 22; 23; 24 and 25
Guilherme Paiva da Silva, PQR CBRR	Specialist Mining Engineer	1; 2; 12; 13; 15; 20; 21; 22; 23; 24 and 25
Helder Reis, PQR CBRR	Mineral Reserves Engineer Specialist	1; 2; 12; 13; 15; 20; 21; 22; 23; 24 and 25
Hely Simões, PQR CBRR	Process Development Specialist Engineer	1; 2; 10;14; 20; 21; 22; 23; 24 and 25
Teófilo Costa, PQR CBRR	Senior Geotechnical Technical Specialist	1; 2; 7; 13; 20; 21; 22; 23; 24 and 25

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 (US$), converting into Brazilian Real per US Dollar. The exchange rate used to convert amounts in Brazilian reais to US dollars is BRL: US$ = 5.25 for 2022 and then long term mean of 5.00 BRL: US$.

Unless indicated otherwise, Dollars are US Dollars, and the weights are in metric tons of 1,000 kilograms (2,204.62 pounds).

Table 2-3 shows the units used in this report. Table 2-4 shows the abbreviations used in this report, and Table 2-5 shows the chemical symbols used in this report.

Table 2-3 – Units of measure used in TRS.

Unit	Abbreviation
American Dollar	USD
Bond Ball Mill Work Index (metric)	kWh/t
Brazil Real	R$ or BRL
Centigrade	°X
Centimetre	cm
Cubic centimetre	cm^3
Cubic metre	m^3

Unit	Abbreviation
Cubic metres per second	m^3/s
Day	d
Dead weight ton (imperial ton – long	Dwt
Dry metric tonne	dmt
GigaWatts	GW
GigaYears	Ga/Gy
Gram	g
Gram/litre	g/L
Gram/tonne	g/t
Hectare	ha
Hour	h
Hours per Year	h/yr
Kilogram	kg
Kilogram per tonne	kg/t
Kilometre	km
Kilopascal	kPa
Kilovolt	kV
Kilovolt amp	kVA
Kilowatt	kW
Kilowatt hour	kWh
Litre	T
Litre per second	L/s
Megawatt	MW
Megawatt per hour	MWh
Metre	m
Metre per hour	m/h
Metre per second	m/s
Metric tonne	t
Metric tonnes per Annum	t/a
Metric tonnes per day	t/d
Metric tonnes per hour	t/h
Micron	Mm
Milligram	mg
Milligram per litre	mg/L
Millimetre	mm
Million	M
Million Dollars	US$ M
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 metres	m2

Unit	Abbreviation
Tonnes per Day	t/d
Troy ounce	Oz.
Wet metric tonne	wmt
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 Tonnes
CAPEX	Capital Expenditure
	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	Coluvium
CQ	Chemical Canga
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
CS	Social Contribution
CPRM	Geological Survey of Brazil
CPT	Technological Research Center
CVRD	Vale do Rio Doce Company
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 north of Brazil, in the State of Pará. These are referred to as the North System of Vale. Serra Sul Mining Complex has the approximate coordinates 574,671 E; 9,291,735 N using UTM_SAD 69 datum.

The Serra Sul Mining Complex, also known as S11 is located in the District of Canaã dos Carajás, 66 km from the city of Canaã dos Carajás. Its main access is from Carajás airport towards Canaã dos Carajás via state roads PA-275 and PA-160, covering a distance of 79 km to the interchange for access road to the complex. From the access junction for S11 at the entrance of the city of Canaã dos Carajás to the plateau, a distance of 63 km is covered (Figure 3-1).

The Serra Sul Mining Complex corresponds to orebodies S11 and the blocks A, B, C and D. The mine in operation currently is S11D.

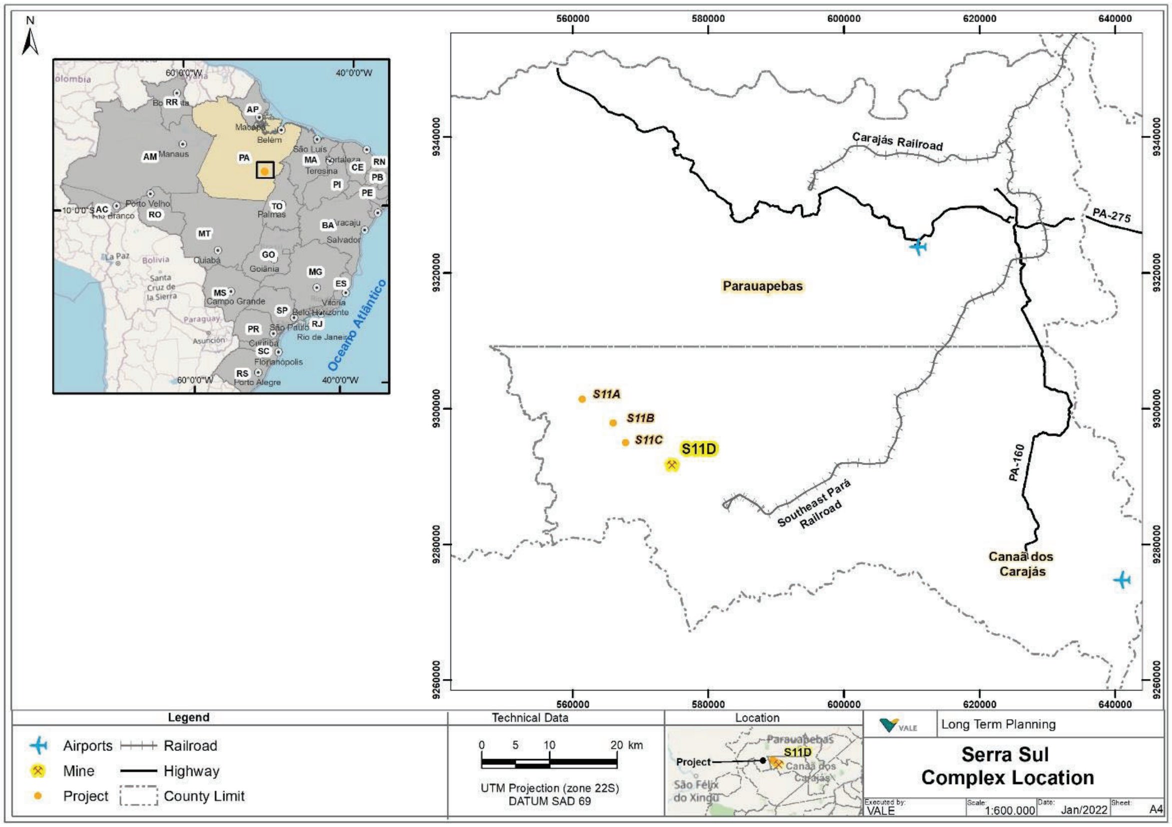


Figure 3-1 - Serra Sul Location Map.

3.2. Brazilian Mining Code

Under Brazilian laws, the Federal Government owns all mineral resources. Under Article 176 of the Brazilian Constitution, all mineral deposits (jazidas) belong to the Federal Government, whether or not the deposits are in active production. Mineral rights are distinct from surface rights.

Mining is regulated by Decree-Law 227, 1967 (the Mining Code), Mining Regulations that came into force in December 2017, and other regulations issued by the National Mining Agency (ANM), formerly known as National Department of Mining Production (DNPM), which controls the mining activities in Brazil.

Regarding the mining authorization and concession regimes, the objective is to obtain the mining title document that allows exploitation of the mineral resource which, in this case, is an administrative rule granted by the Minister of Mines and Energy, commonly known as Mining Concession. There is an intermediate title, an exploration permit granted by ANM General Director, which authorizes the interested party to prospect a certain mineral substance, in order to define its quantity, quality and spatial distribution.

The mining cycle starts with the Application for Exploration Permit, followed by the publication of the Exploration Permit (Alvará de Pesquisa) in the Federal Gazette – DOU. Its holder is authorized to carry out, within a period of 3 to 6 years, the research work, the goal is to define a deposit, that is, to qualify, quantify and spatially locate the mineral substance of interest.

At the end of the exploration stage, the holder must submit an Exploration Technical Report (Relatório Final de Pequisa) to ANM, according to the presented results. After analysis by ANM, and considering the approval of the document, the mining company will have 1 year to apply for mining concession. This application is based on the presentation of an Economic Exploitation Plan (Plano de Aproveitamento Econômico or PAE), which must be prepared by a legally qualified professional.

Once PAE is presented, ANM will demand presentation of the installation license (LI – Licença de Instalação), granted by an environmental licensing agency, and the mining company shall carry out due diligence with this agency every 180 days, to prove the progress in the environmental licensing process to ANM.

After obtaining the environmental license (LI), the mining company will be able to obtain the Mining Concession in the Federal Gazette – DOU. Figure 3-2 shows the flowchart of the Brazilian mineral licensing process.

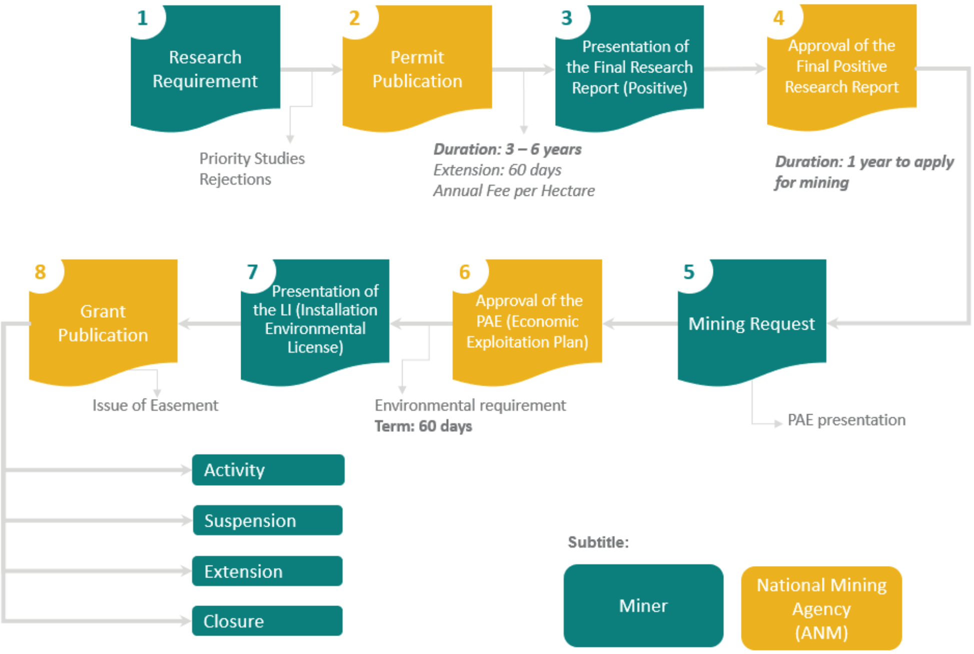


Figure 3-2: License process flowchart.

3.3. Land Tenure

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

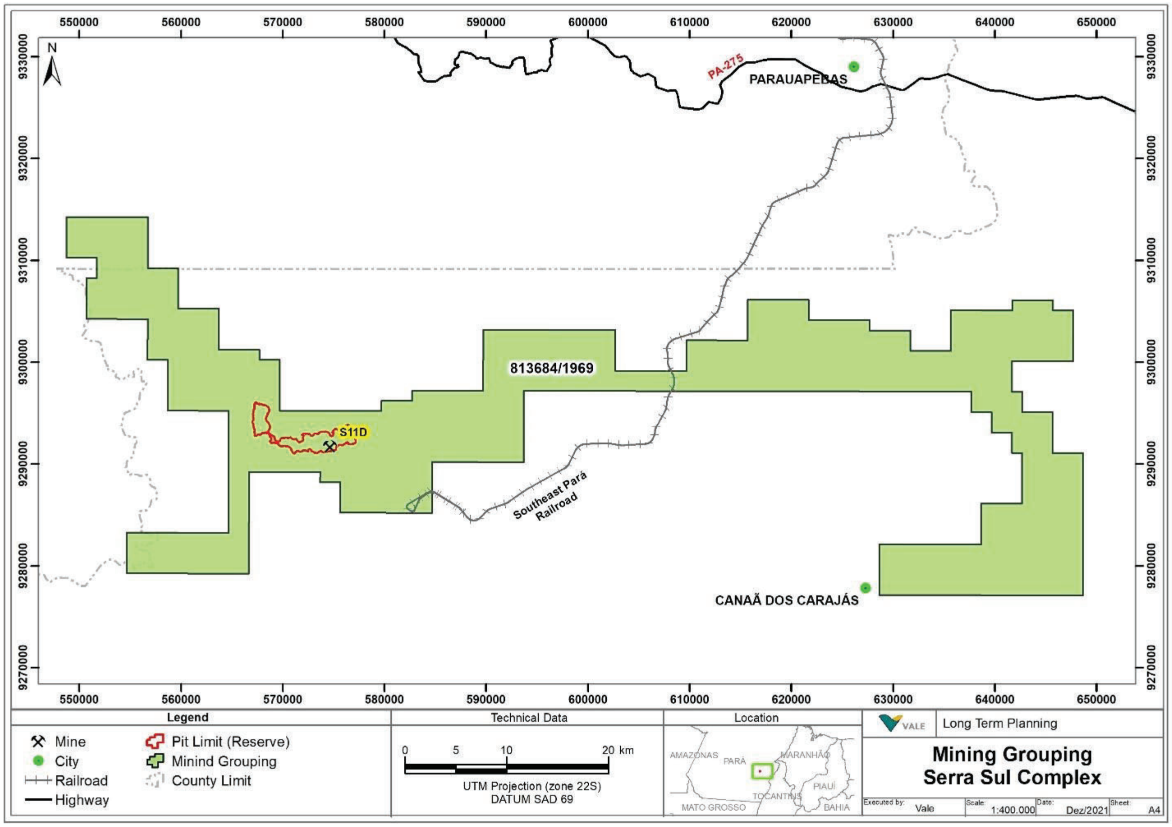


Figure 3-3 – Serra Sul Concession Grouping.

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

ANM Process	City	Area (ha)	Title	Number	Issue date	Element	Mine
813.684/1969	Canaã dos Carajas	100.000	Mining right	75508	06/09/1974	Iron	S11D

In 2021, Vale decided to relinquish its mineral rights in Indigenous Lands in Brazil. Therefore, the company filed for an area reduction application regarding mining right number 813.684/1969, reducing its area from 100.000,00 ha to 98.910,42 ha. To make it official, ANM must still publish the area reduction in the Official Gazette. Figure 3-4 illustrates the area to be reduced from Mining Concession.

Vale understands that mining in Indigenous Land may take place only upon Free, Prior and Informed Consent (FPIC) from the indigenous people themselves, and in light of a regulatory framework that contemplates the participation and the autonomy of indigenous people.

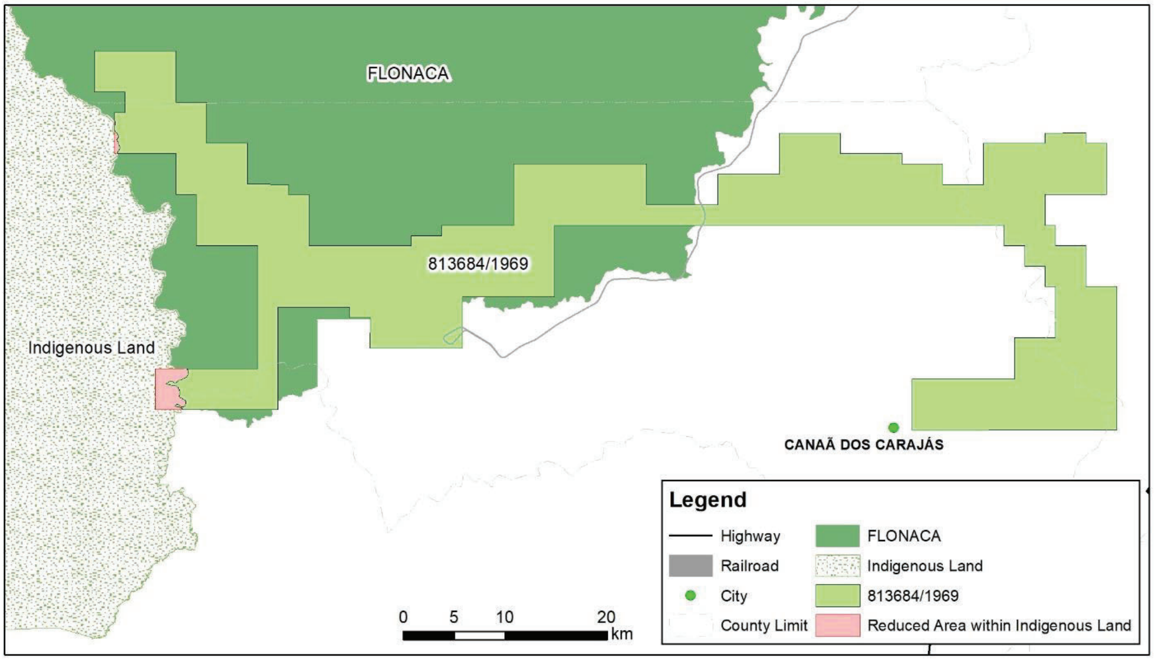


Figure 3-4– Serra Sul Mining Concession after area reduction (from 100,000.00 ha to 98,910.42 ha).

Currently, the Serra Sul complex has three mining easements as follows.

- Easement 1, with an area of 966.77ha, whose technical report was approved on 21/10/2010;
- Easement 2, with an area of 29,315.45 ha, whose technical report was approved on 25/01/2013;
- Easement 3, with an area of 17,914.58 m^2, whose technical report was approval on 25/01/2013.

These three easements are contiguous and make a unique shape which encompasses all current and future industrial installations necessary for the life of mine Serra Sul.

Vale is required to pay a monthly fee known as Financial Compensation for the Exploitation of Mineral Resources (“CFEM”) over the sales of iron ore, at the current rate of 3.5%. The state of Pará also impose a tax on mineral production (“TFRM”), which is currently assessed at a rate of R$ 4.1297 per metric ton of minerals produced in or transferred from the state.

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

3.4. Surface Rights and Easement

According to the General Mining Law and related legislation, surface rights are independent of mineral rights.

The law requires that the holder of a mineral concession either reach an agreement with the landowner before starting relevant mining activities (i.e., exploration, exploitation, etc.) or complete the administrative easement procedure, in accordance with the applicable regulation. Surface property is acquired through:

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

As indicated by Vale, the Serra Sul is located within 77 properties belonged to Vale and two interferences with federal government’s properties. Both properties are covered by a mining easement report issued by the National mining Agency (ANM).

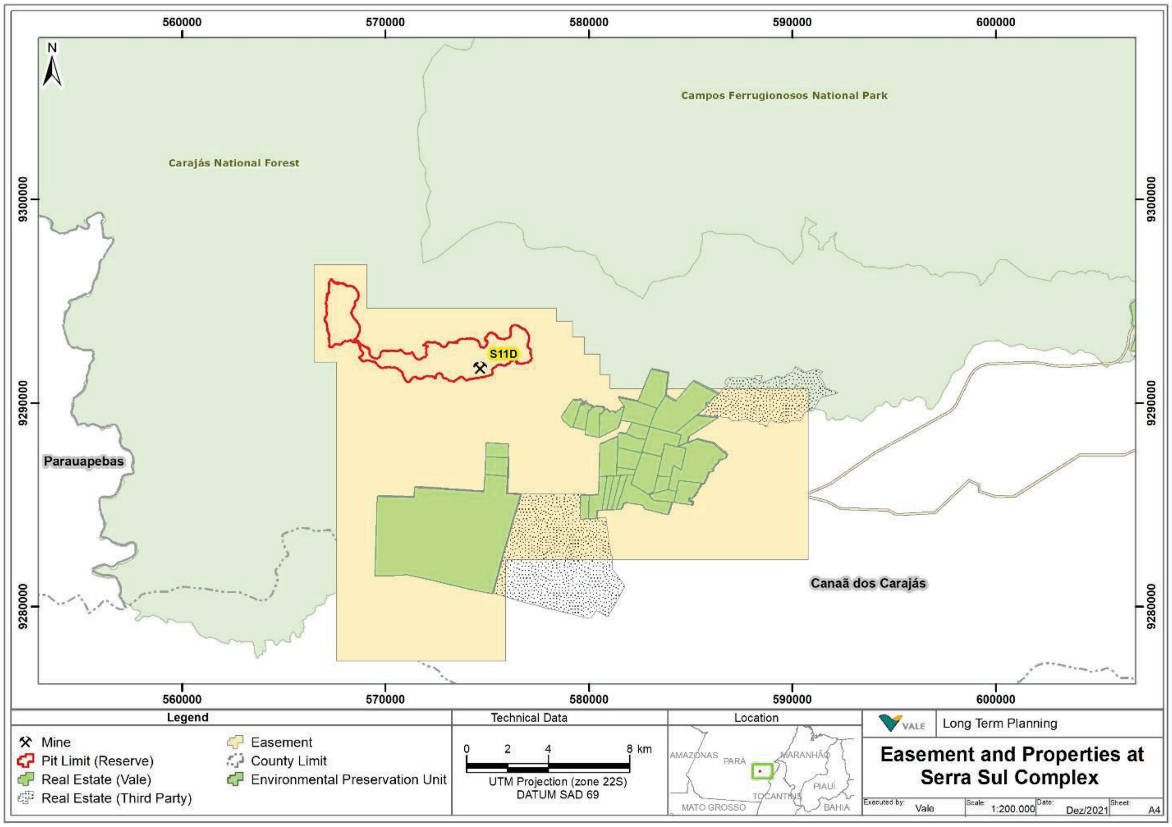


Figure 3-5– Easements and properties at Serra Sul

3.5. Material Government Consents

This section details the material Governmental Consents required to operate in compliance with applicable Brazilian laws and regulations. These material Governmental Consents correspond to permits, licenses, authorizations, etc., issued by the applicable governmental authorities, which entitle Vale to build the components and/or perform activities critical and typical for a mining operation. These components/activities may include: (i) mining activities and related facilities; (ii) process plant and related activities; (iii) water supply; (iv) effluent discharge and related facilities; (v) use of explosives; and (vi) power supply.

Table 3-2 shows the main operating licenses and (1) According to Brazilian legislation we can continue to operate during the renewal process.

Table 3-3, the water consumption grants.

Table 3-2 – Serra Sul operating licenses

License	Government Department	Description	Expiry date	Status
LO nº 031/2019 086/2019	SEMA-PA	Fuel station	13/09/2021	License being renewed (Process nº 086/2019) (1)
LO_1361/2016 02001.000711/2009-46	IBAMA	Mining for S11D, expansions, plant and infrastructures	09/12/2026	Valid license

(1) According to Brazilian legislation we can continue to operate 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	20/03/2022
Water usage license nº 3590/2019 – Process 2018/0000047840	SEMAS/PA	Process	13/02/2024
Water usage license nº 4082/2019 – Process 2018/0000043086	SEMAS/PA	Human consumption	28/12/2024
Water usage license nº 3918/2019 - Process 2018/0000027122	SEMAS/PA	Human consumption	17/12/2029
Water usage license nº 4219/2020 – Process 2018/0000043090	SEMAS/PA	Process	03/03/2025
Water usage license nº 4424/2020 - Process 2019/0000052144	SEMAS/PA	Human consumption	18/06/2025
Water usage license nº 4746/2020 - Process 2020/0000008735	SEMAS/PA	Human consumption	29/082030
Water usage license nº 4520/2020 - Process 2019/0000004930	SEMAS/PA	Lowering water table	16/09/2030
Water usage license nº 1164/2016 - Process 02501.000073/2013	ANA	Process	29/09/2026

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

4.1. Accessibility

The main access to Serra Sul Mining Complex is from Carajás airport towards Canaã dos Carajás via state roads PA-275 and PA-160, covering a distance of 79 km to the interchange for the access road to S11D. From the access junction for S11D at the entrance of the city of Canaã dos Carajás to the plateau, a distance of 63 km is covered. Production ore is transported via railway of the southeast of Pará where it connects to the Carajás Railroad and the Ponta da Madeira port terminal in São Luís in the State of Maranhão.

4.2. Climate

The climate in the region is humid tropical monsoon, with dry spring, hot weather, and high average temperatures. The coldest months correspond to the period from January to March (averages 18°C to 21°C), coinciding with the highest rainfall and the greatest presence of cloudiness. The highest temperatures are recorded from June to August (averages 33 °C to 36 °C).

The region has two well-defined seasons: the rainy season, which lasts from November to April, where it rains 80% of the annual total, with maximum average monthly rainfall reaching 400 mm, and the dry season, which runs from May to October, with the driest quarter (June, July, and August) it has monthly averages of just 24 mm, which means little rain by Amazon standards. The average annual rainfall for the region varies from 1,500 to 1,900 mm, with, on average, 270 days of rain in the year. The average yearly temperature is between 23.5 and 25.5°C, with the maximum monthly average temperature reaching 32.5 and the minimum is never lower than 18°C. The Mine operates year-round.

The air humidity in the region remains between 70 and 85% average. In the driest months, from June to August, humidity is slightly reduced, reaching minimum levels of around 50% and average around 70%. During the rainy months, from October to May, the maximum average can exceed 95%.

4.3. Local Resources

The nearest city to the mine complex is Canaã dos Carajás (population 38,100, estimated 2020). Canaã has two hospitals to serve the city population. In the city center, there are basic food and accommodation services. The economy is focused on mineral extraction, agriculture, and livestock.

Various services, including temporary and permanent accommodations, are available in Parauapebas (population 213,576, estimated 2020), located approximately 70 kilometers north of Canaã dos Carajás. A greater range of general services is available at the capital of the State, Belem, located approximately 770 km to the northeast.

4.4. Infrastructure

The S11D operational complex (Serra Sul) is integrated via a 230kV line to the Sistema Interligado Nacional (SIN). The power system is supplied through a transmission line from the Integrating Substation owned by Eletronorte (a subsidiary of Eletrobrás).

The internal distribution system is carried out through Vale's electricity networks of 34.5kV. The consumption of the plant and mine was around 281,385 MWh in 2020, 63.1% of which were fed to the mineral processing plants, 28.8% were consumed in the mine, and other support structures consumed the remaining 8.1%.

The Serra Sul Complex area has a complete Maintenance Workshop structure, equipped with boxes for mobile machines, machining, sub-assembly maintenance workshop, electrical workshop, electronic workshop, warehouse, and tooling. The Lubrication Center, the Vehicle Washing, the

Rubber Shop, and the Heavy and Light Vehicle Refueling Station are located adjacent to the General Maintenance Workshop shed.

All the quality control of the ore is carried out using the structures of the Serra Sul Mine Laboratory, where physical tests and chemical assays of the entire production chain are carried out.

Masonry offices group the administrative areas of Vale S.A. and its contractors. It comprises offices for direction, management, coordination, meetings, technicians, files, reception, and restrooms, which serve all administrative personnel.

There is a canteen that serves all employees, both in-house and outsourced, with lunch, dinner, and snacks. Vale outsources its operation as for other operating units of Vale.

The clinic is installed in masonry construction, with a small office, for first aid care and a restroom, and is equipped for first aid. More severe cases are sent to an existing hospital in the urban center. An ambulance is available and parked next to the clinic with a driver on permanent standby.

The entire staff of the company resides in the city of Canaã dos Carajás. The personnel transport is done through an outsourced company, in intercity buses, departing both from the city of Canaã dos Carajas. The mine access road undergoes constant maintenance and is in excellent condition.

4.5. Physiography

The Ombrophila Forest occurring in the region is predominantly represented by the Open feature which is characterized by its smaller size and biomass, a greater presence of vines and/or palm trees when compared to the Dense Ombrophila Forest in the surroundings. The Altered Ombrophila Forest feature is also observed, which corresponds to the forest areas that underwent anthropic intervention and are in the process of regeneration in different successional stages.

On the plateaus covered by ferruginous outcrops in the project areas, there is a rich mosaic of predominantly open phytophysiognomies directly associated with the rocky substrate. Over each pattern of edaphic structure, rock subtypology is developed, with botanical communities.

Near the Serra Sul units, there are large farms and livestock activity has been replacing forest areas, characterizing the landscape with a mixture of pasture with exotic forage plants and small forest remnants.

Regarding the protected areas close to the Mining Complexes, there are the National Forests of Tapirapé-Aquiri, Itacaiúnas, and Carajás; the Campos Ferruginosos National Park; the Tapirapé Biological Reserve; the Xikrin Indigenous Land of the Cateté River; and the Igarapé Gelado Environmental Protection Area. It is a block of approximately 1.2 million hectares, relatively well preserved, in contrast to the anthropized areas in the surroundings.

5. History

5.1. Exploration and development history

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

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

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

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

On July 31, 1967, the first helicopter landed in the Serra Arqueada hematite canga glade. In August, an overflight was made, at low altitude with a single engine plane, in the clearings of Serra Norte verifying the great similarity with the canga cover of Serra Arqueada and an aeromagnetic survey was carried out in Sereno, Serra Leste, Serra Norte, and Serra Sul. Preliminary field surveys of 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 the United States Steel, in Pittsburgh (USA).

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

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

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

5.2. Past Production

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

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

6. Geological Setting and Mineralization

6.1. Regional Geology

The Carajás Mineral Province (CKS) comprises an area of approximately 30,000 km2 located 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 the oldest core, of Archean age, limited by the Geochronological Province of the Central Amazon (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 the classifications of the Amazon Craton are a matter of debate in the scientific literature, the subdivision of its southeast portion is well accepted and justified, both from the geochronological point of view and from the orientation of its main structures. In this sense, the domains Rio Maria, of Mesoarchean age, with preferential N-S orientation, Carajás (Neoarquean), with WNW-ESE orientation, and Bacajá (Paleoproterozoic), with NW-SE orientation, are recognized. The tectonic evolution of this portion of the craton is not clear, and the boundaries between these domains are fuzzy and usually transitional.

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

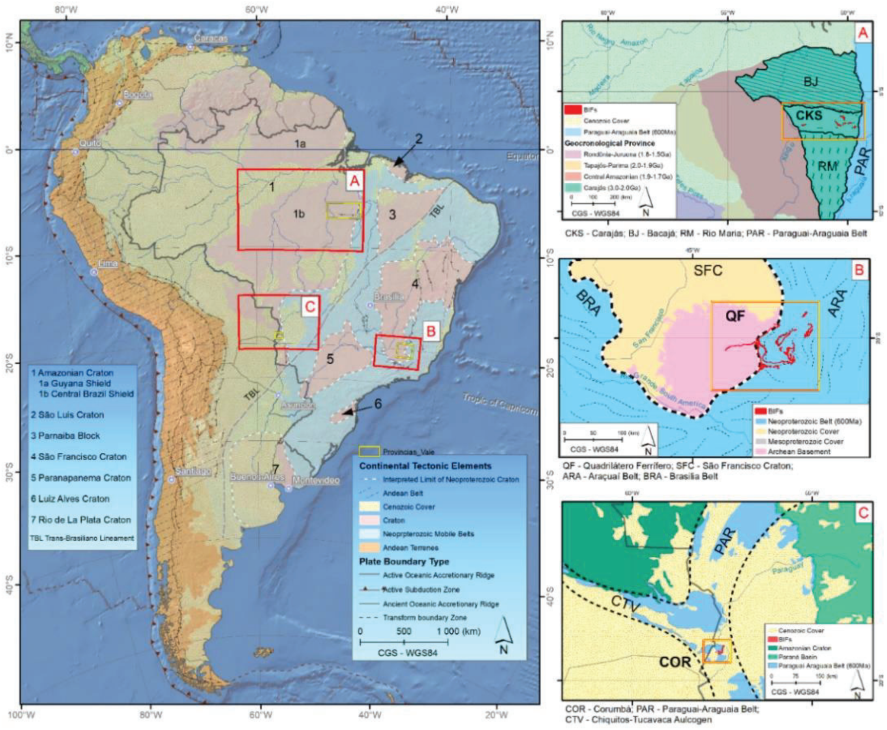


Figure 6-1- Tectonic map of South America (Cordani et al. 2016; Gómez et al. 2019), with localization of the Brazilian mining provinces operated by Vale.

6.1.1. Stratigraphy

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

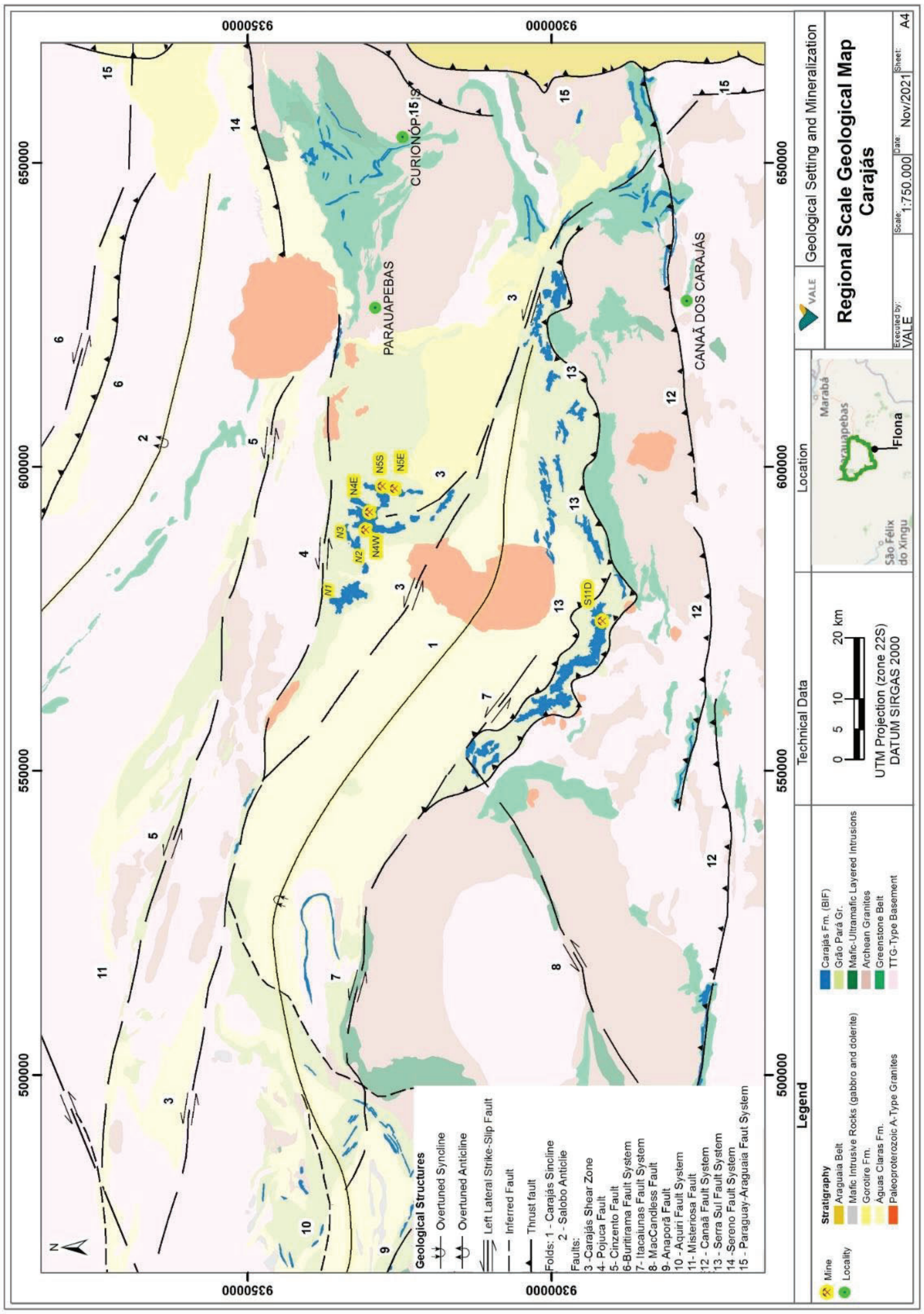


Figure 6-2 - Geological Map the Carajás Mineral Province (Costa et al., 2017).

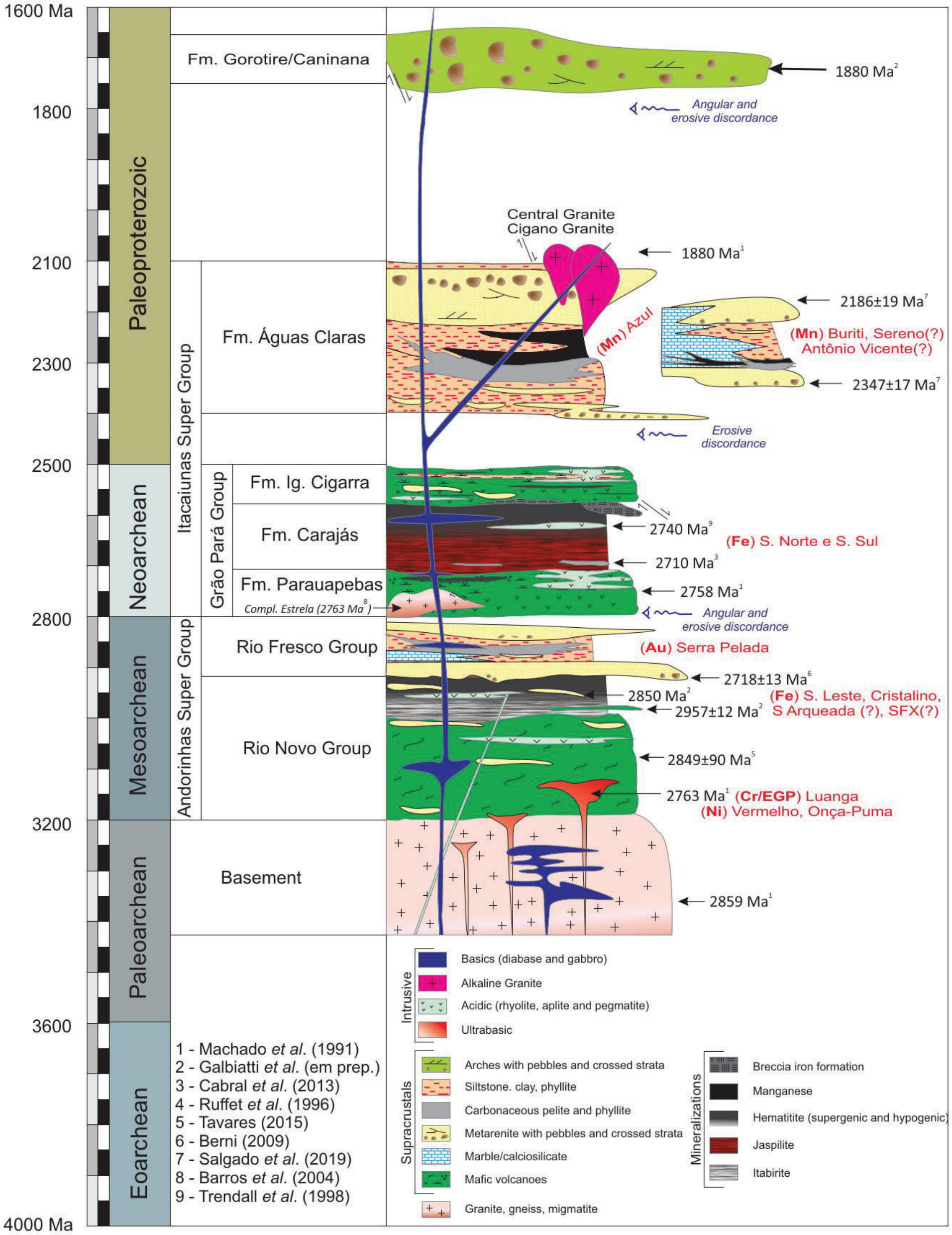


Figure 6-3 – Stratigraphic column of the Carajás Mineral Province.

6.1.2. Granite-gneiss terrains

The granite-gneiss terrains 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) which, with the increase in geological knowledge, has been reviewed and subdivided, mainly in the southern portion of the Carajás Mineral Province.

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

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

6.1.3. Andorinhas Supergroup

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

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

Rio Fresco Group: originally defined as the entire Carajás cover (Hirata et al., 1982; Meireles et al., 1982; DOCEGEO, 1988), is now restricted to metasediments that cover the rocks of the Rio Novo Group in the Serra Leste and Serra Pelada region. This unit is composed of a succession of meta-sandstones and metapelites (locally carbonaceous), with discontinuous levels of dolomitic marble (Figure 6-1and Figure 6-2).

6.1.4. Mafic-ultramafic complexes

They are 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), dated 2,763 Ma (Machado et al., 1991) which 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 metamorphism of the Gabro Santa Inês (DOCEGEO, 1988), which occurs as an intrusive anorthositic leucogabbro body in the basement and base of the Rio Novo Group, suggest chrono-correlated placement to the ultramafic rocks.

6.1.5. Itacaiúnas Supergroup

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

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

The Parauapebas Formation was originally defined by CVRD/AMZA team (1972) as the Lower Paleovolcanic Sequence and later renamed due to the occurrence of felsic volcanics (Machado et al., 1991). The age of this unit is well defined by U/Pb dating, with results around 2,750 Ma (Wirth et al., 1986; Lindenmayer et al., 1998; Tavares, 2015). The succession occurs according to a stratiform body of indeterminate thickness (>200 m), which represents the stacking of several flows in 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, which inhibit the growth of the tropical forest, typical of the surrounding region (Figure 6-4).

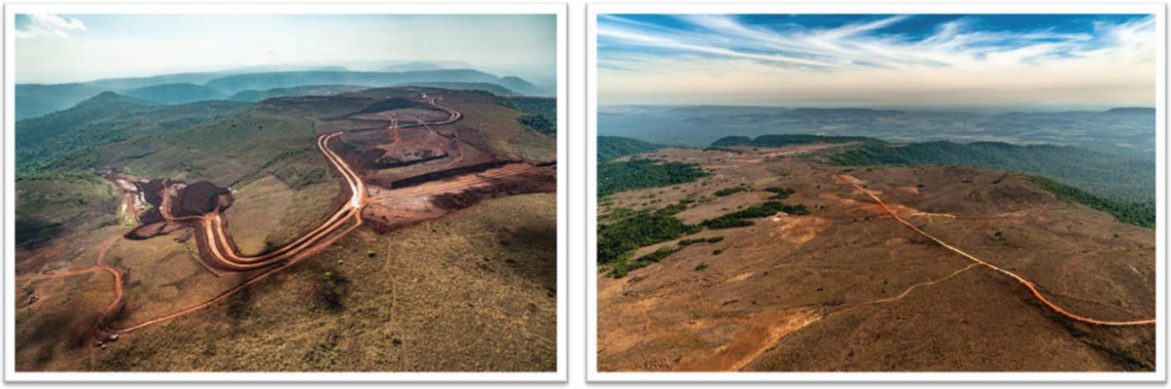


Figure 6-4 – Plateaus of S11D (left) and N1 (right) of Carajás Mineral Province.

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

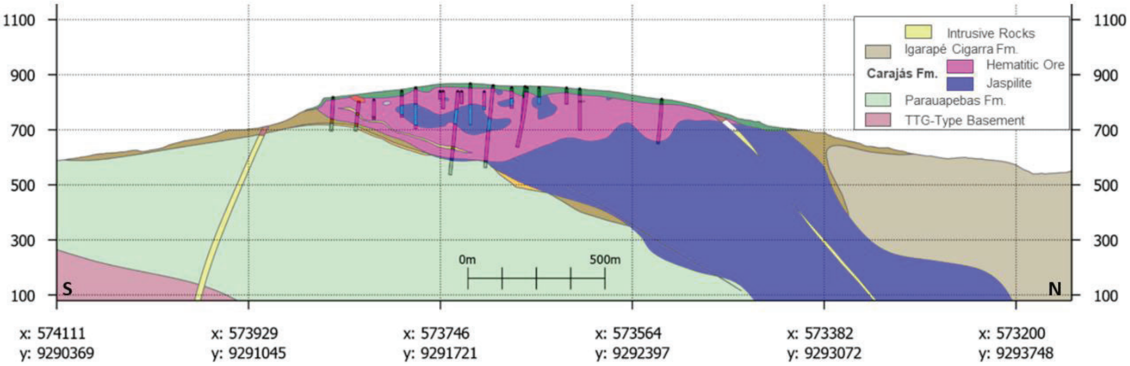


Figure 6-5 - Geological section at the S11D mine, Carajás Mineral Province.

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

6.1.6. Proterozoic covers and intrusions

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

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

The Gorotire Formation: also known as the Caninana Unit (Pereira, 2009; Pereira et al., 2009), constitutes a siliciclastic cover composed of conglomerates and Arcosean sandstones about 300 m thick (Barbosa et al., 1966), formed in an anastomosing river environment (Oliveira & 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 dykes with direction close to N-S, cutting all the aforementioned units. These dikes continue for hundreds of kilometers and have a strong magnetic signature, being easily observed in aerial survey products.

6.1.7. Cenozoic units and recent coverage

Cangas 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. They usually have high concentrations of aluminum, phosphorus, and manganese, which do not favor their use as ore. Nevertheless, they can make up a fraction of ROM in a diluted form; therefore, being subject to economic use. A big part of the iron ore caves recorded in Carajás are associated with cangas domains, mainly on the edge of the plateaus.

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

Alluviums: do not form significant iron ore deposits.

6.1.8. Metamorphism and deformation

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

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

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

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

The Paleoproterozoic Cycle is the event responsible for the current geometry of the province. It occurred 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 the geometry of iron formations and may have been responsible for the hypogenic formation of high-grade bodies.

The Neoproterozoic/Paleozoic Cycle is equivalent to the Brasiliano orogeny (700-450 Ma), which defines the current cratonic limits of the interior of the South American Platform (Almeida et al., 1973; Almeida et al., 1981; Cordani et al., 2016; Gómez et al., 2019). This event expresses the development of a moving belt that verges westward and is characterized by a sequence of 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 dykes with orientations similar to these fold axes.

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

6.2. Local Geology

6.2.1. Physiography

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

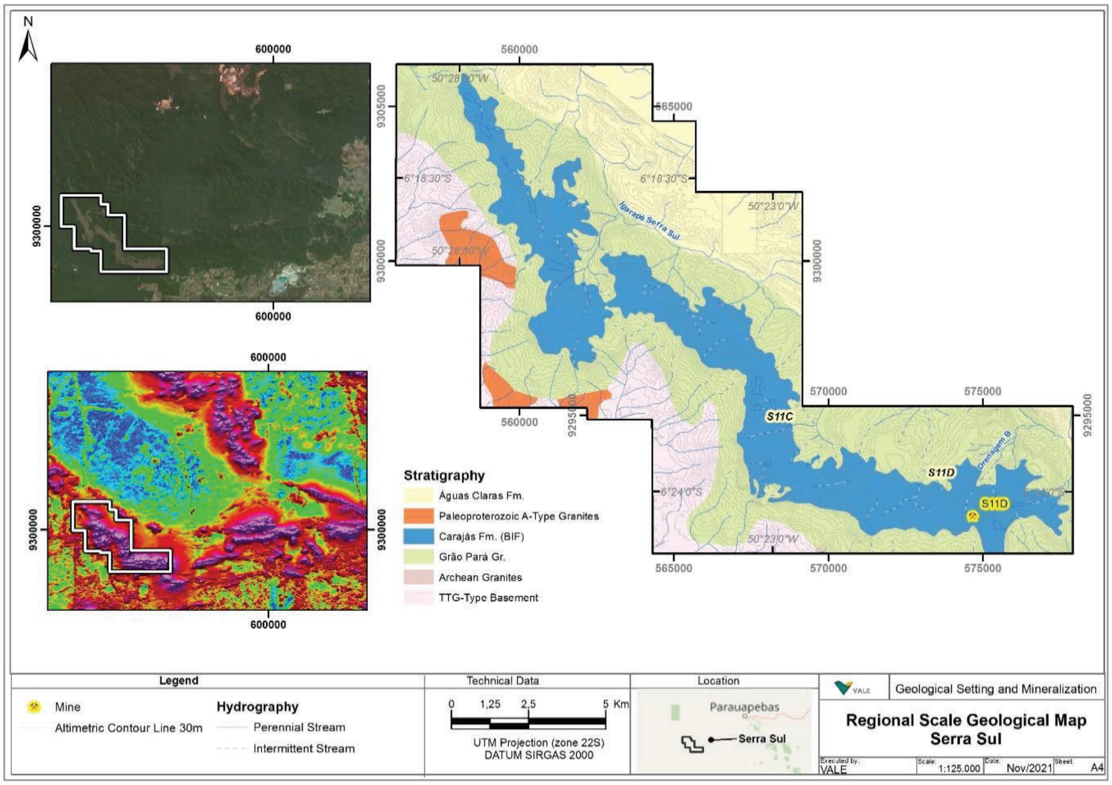


Figure 6-6 – Geology of the Serra Sul Complex (right) and satellite and airborne geophysics (MAG) images.

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

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

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

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

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

6.2.1. Mineralization

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

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

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

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

Chemical canga (CQ) – represents the iron-aluminous crusts that usually cover the decomposed mafic rocks. It has colloform texture and high porosity. It often has high content of Al2O3GL, evidenced by the light coloring of gibbsite and clay minerals. Hematite fragments are scarce or absent. In general, the iron content is under 55%, with high phosphorus and Al2O3GL.

Structural canga (CE) – term commonly used by Vale to designate ferruginous lateritic crusts. It is usually located over iron ore outcrops *in situ*. It also occurs as transported canga, but at short distance from the source area, being a good indicator of the location of ore bodies. The thickness is variable, reaching more than 20 meters. It has iron content above 55% and relatively low Al2O3GL and phosphorus grades, thus allowing its potential use as iron ore.

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

Friable hematite (HF) – is the predominant type of ore, occurring throughout all Serra Sul mine. It is commonly banded, locally showing primary lamination planes. It consists of a gray friable hematite material with a metallic luster with high porosity. It can be powdery or 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 magnetites pseudomorphs (Lobato et al. 2005). It is predominantly formed by the supergenic enrichment of the ore protolith (jaspilites). It has a variable thickness in the enrichment profile, reaching up to 350 m and great continuity throughout the dip.

Compact hematite (HC) – a material rich in iron and, like HFs, generated from the weathering alteration of jaspilite. Its color varies from black to reddish-brown, the latter is typical for goethite/limonite cementation, which is deemed responsible for the high compactness of this lithotype. HC occurs subordinately throughout the entire deposit, like lenses inside the large friable hematite mass, usually with thicknesses around 5 to 10 m, without considerable lateral continuity (few tens of meters). Locally, it can reach thicknesses of up to 50 m. The color of HC is bluish-gray with metallic luster. It is dense, with low porosity, and it can be banded, characterized by the original banding of the preserved jaspilite, defined by compact layers alternating with porous or brecciated layers. This lithotype can also be massive, with the original texture destroyed, composed of aggregates of hematite crystals. The Fe contents are between 59 and 69%. Al2O3GL represents an important contaminant in this lithology.

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

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

6.2.2. Structural

In general terms, the main Carajás iron ore deposits are associated with flat-topped elevated plateaus, defined along two main morphological alignments corresponding to Serra Norte and Serra Sul. These alignments materialize the flanks of the structure defined as 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 Água Boa plateau, corresponds to the closure zone of this syncline and has large concentration of jaspillite-type ore protolith. This region must not have experienced the ideal conditions for the formation of significant iron ore deposits or even for the preservation of possible deposit previously formed.

The Serra Sul Complex corresponds to the normal flank domain of the Carajás Syncline, characterized by a lower degree of deformation when compared to the inverse flank, which is reflected in the greater continuity of the 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 m 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 being the one of greatest economic interest. The plateau is predominantly composed of rocks from the Carajás and Igarapé Cigarra formations, of the Grão Pará Group, which contacts those of the Parauapebas Formation, to the south, and rocks of the Águas Claras Formation to the north. In general, the layers present variable dips and azimuths varying between the north and east directions, configuring a normal stratigraphic stacking.

Except for the eastern portion of the plateau, which comprises the active part of the SSD mine, where geological information was obtained by mapping on a 1:2,000 scale, the strong weathering and the absence of cuts and excavations make the rocky outcrops scarce. Therefore, most of the geological information regarding this plateau was obtained from diamond drill cores and mapping of surface alteration materials, such as cangas, developed over the iron formations, and laterite (or "chemical canga"), developed over the mafic rocks, whether they are enclosing or intrusive of the iron formations.

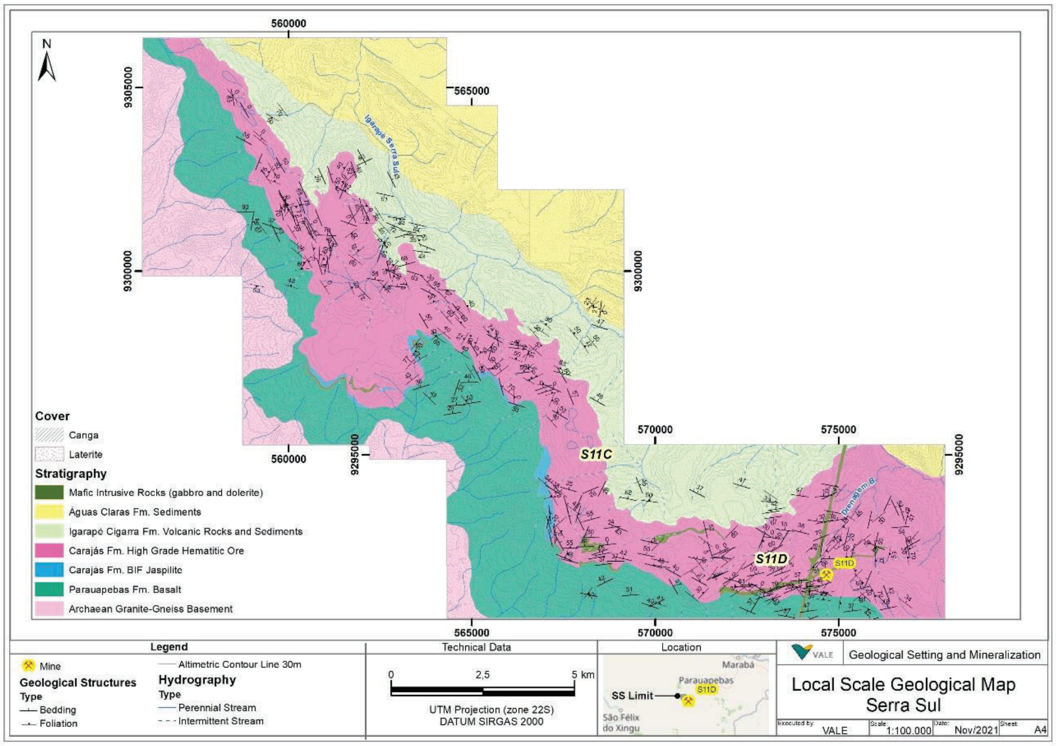


Figure 6-7 – Geological map of SSCD.

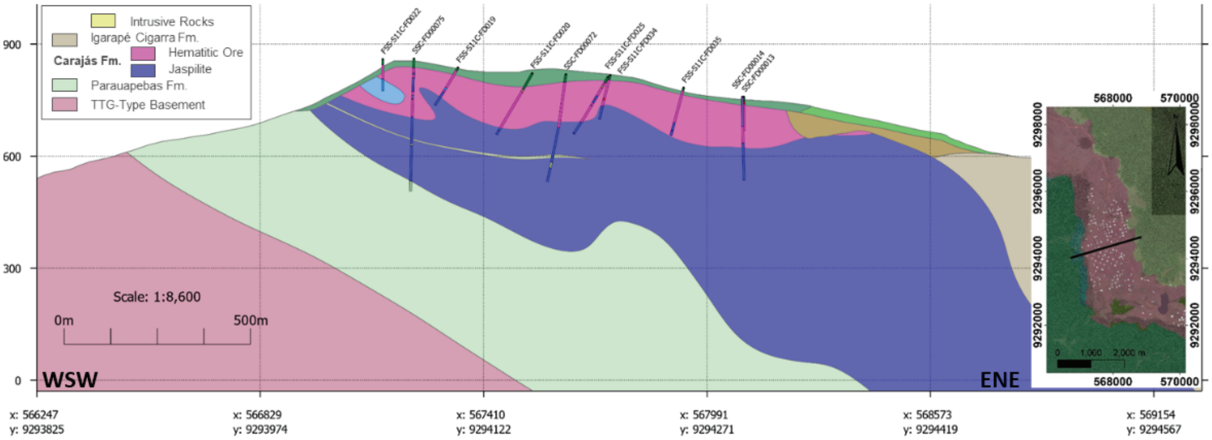


Figure 6-8 – Geological section of SSC.

6.3.1.2. Lithologies

The Parauapebas Formation is recognized 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, commonly affected by hydrothermal alteration, underlaying the rocks of the Carajás Formation, by a conformable transitional contact, locally marked by a level of breccias in the iron formation.

The Carajás Formation comprises about 50% of the plateau area and corresponds to the thickest domain of the iron formations. It coincides with the highest elevations and occurs continuously throughout the central portion of the plateau, from the proximity of the contact with the rocks of 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 as a tabular layer with medium to low dip angle to the north and in the EW oriented bodies, such as SDD, and medium to high dip angle to the east and northeast in the NS oriented bodies, such as SSC. Its actual thickness has not been determined; however, it can exceed 450 m depth in section and varies between 200 m and 1,200 m in plan.

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

The terrigenous sediments of the Águas Claras Formation overlap the domain of the Igarapé Cigarra Formation 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 is also observed, both in drill cores and in outcrops, that the entire package of the Grão Pará Group and the Águas Claras Formation is cut by mafic rocks, with variable orientation, generally of small thickness. These bodies have a basic/intermediate composition and make contacts that are conformable or non-conformable with the compositional banding of the iron formations, configuring sills and dykes (Figure 6-8).

6.3.1.3. Structures

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

These will be presented below in chronological order, from the oldest to the youngest structure, and related to the probable tectonic events responsible for its generation:

Structures correlated to Transamazonian tectonics:

- Nucleation of the Carajás Syncline, reflected by the tilting of the entire metavolcanosedimentary package which, in the Serra Sul region, tends to dip with a medium angle to the north;
- Folding with sub-horizontal axes of NW-SE direction, verging towards SW. These structures can occur rotated, due to the superposition of tectonic events, as in the case of body D, where the axes assume an E-W direction 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 geometry according to the kink style (Figure 6-7);
- Formation of discontinuities filled by mafic dikes of NW-SE direction;
- Implantation of normal faults that originate a horsts and grabens system, responsible for the localized lifting of jaspillite bodies (Figure 6-9).

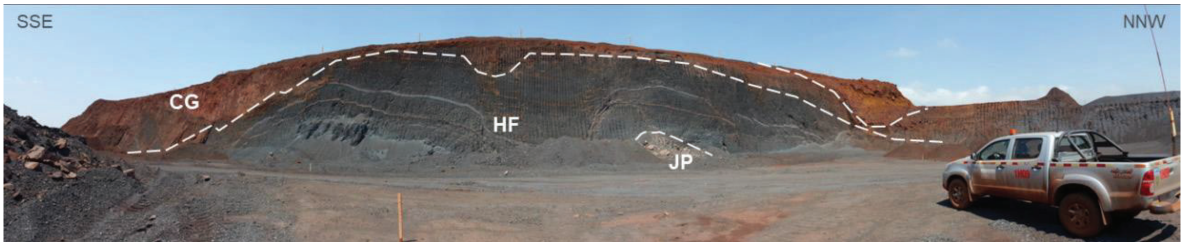


Figure 6-9 – SSD outcrop. CG – Canga; HF – friable hematite; JP – Jaspillite.

6.3.1.4. Mineralization

The mineralization at Serra Sul is mainly formed from alteration on jaspillites, which constitutes the Carajás ore protolith. The high-grade ore consists of friable hematite, compact hematite, and manganese hematite, which occur in a sub-horizontal tabular layer, which tends to follow the topographical surface, commonly covered by a canga carapace, 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 jaspillitic ore protolith, in addition to kaolin and clay minerals, which occur more locally, from the alteration of volcanic rocks. HF occurs from near the surface to depths greater than 450 m and presents average Fe grades around 68.8%, with relatively low levels of phosphorus, silica, alumina, and loss on ignition. Loss on ignition and phosphorus are generally associated with contacts with the cangas, where a transition zone can be identified at a centimetric to metric scale; alumina is most commonly associated with centimetric to metric intercalations of mafics. In the contacts with jaspillites, there is a sharp drop in iron content, and gradational contacts are rarely observed, which, when verified, 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, preferably as lenses below the canga, and more rarely, in-depth, interlayered with jaspillites, suggesting a hypogenic origin. It has a massive or foliated structure, a thickness of up to 30 m, and an average Fe content of around 66%, with slightly higher levels of contaminants than HF.

Manganese hematite (HMN) is very subordinate and has no representation in the deposit. It occurs under low continuity lenses, up to 50 m thick, usually close to contacts with jaspillites 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 jaspillite (JP) is not a mineralized type in Carajás, it will be described here, as it is genetically related to mineralization. They are iron formations, characterized by the alternation between hematite bands and jasper/silica, subordinately, chlorite and carbonates bands. They can be grouped, according to mineralogy and texture, into carbonate, siliceous, chloritic, and breccia types. The SS11 jaspillites are grayish and may resemble itabirites, but present geomechanical characteristics similar to those of Serra Norte jaspillites, constituting an extremely compact lithotype, difficult to sample. They have average content of 45.6% Fe and contaminant levels lower than HF, with alumina as the main contaminant, around 0.6%, which may be higher in the vicinity of contacts with mafic rocks. They occur at the base of the package of iron formations, in contact with mafic rocks, of unknown thickness, but also in the form of centimeter-thick lenses up to 200 m, immersed in the large mass of friable hematites.

The cangas occur with a wide expression on the surface of Plateau SS11 and represent the product of weathering on the different rocks in the region. Thus, they are differentiated according to the substrate and divided between 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 capable of economic use, therefore considered ore. CE represents 14% of the mineralization and occurs with thickness ranging from a few meters to 60 m, average of around 15 m, being locally observed in the hillside regions, indicating a low transport rate. It is predominantly compact and can preserve banded texture. It is a very hydrated lithotype with mineralogy difficult to be defined by the naked eye, with average Fe content of 64.2%, which has alumina and phosphorus as main contaminants, in addition to high values 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.

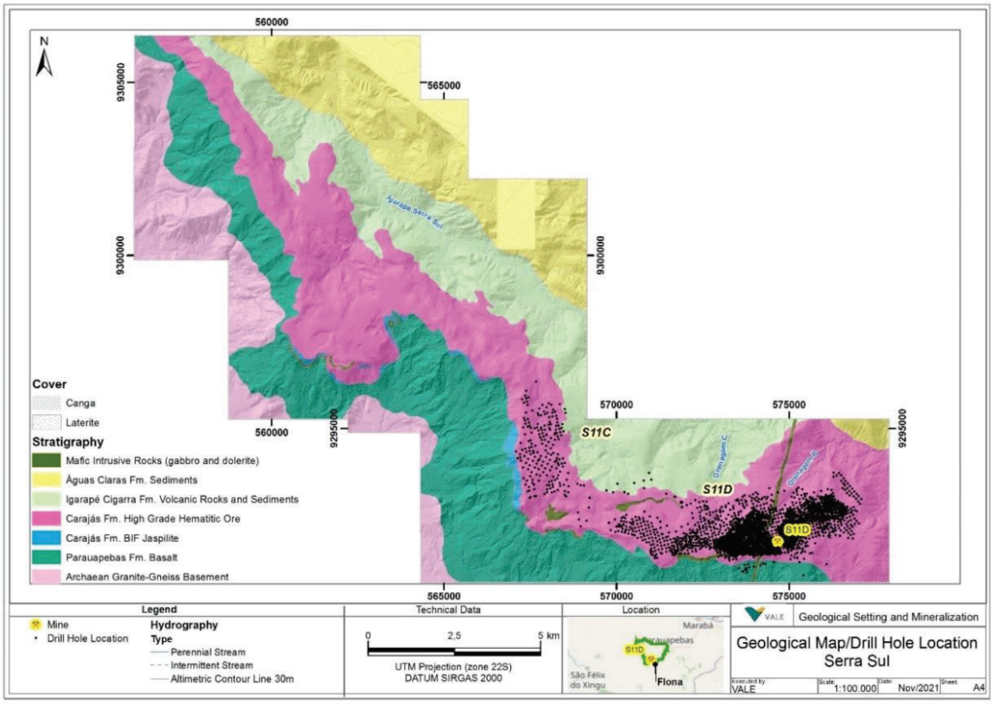


Figure 7-1– Geological map with drilling distribution in SSCD.

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

Table 7-1– Serra Sul drilling campaigns.

Drilling Campaigns	2008 Model		2013 Model		2016 Model		2017 Model		2020 Model	
	Drill holes	Meters (m)	Drill holes	Meters (m)	Drill holes	Meters (m)	Drill holes	Meters (m)	Drill holes	Meters (m)
S11D	290	64,421	466	99,448	706	147,346	1,192	228,926	1,631	292,765
S11C	58	8,893	58	8,893	71	11,609	72	11,846	136	27,286
TOTAL	348	73,314	524	108,341	777	158,955	1,264	240,772	1,767	320,051

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. Drill 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 (63.5mm) 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 in order 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 jaspillite 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. Overview

Hydrogeological characterization mainly starts during the exploration campaign phase, observing and gathering geological and groundwater information, which will serve as a basis to studies developed during all phases of a mine site.

In this phase, the monitoring program is implemented, and it’s composed by rainfall gauges, piezometers, water level indicators, and flowmeters installed on springs, streams and rivers. At this stage, a pre-dewatering program is established if necessary, and all monitoring data will be used to setup drawdown targets.

The hydrogeological model was built in 2019 with available database until 2018. A complete Vale's QA/QC program for the hydrogeological database is under development. Currently, the data is analyzed by Vale and sent to consultancies responsible for building the hydrogeological models, which made a cross check validation from all data used as input.

The demand for water in this mining complex is supplied by underground sources.

7.3.2. Parameter Determinations

According to Beale & Read (2013), laboratory tests are the most accurate water flow parameters determination method; however, it presents disadvantage that the used samples may not be representative and can be disturbed during sampling, transport, and handling. For this reason, in Vale mines, multiple-hole tests in field and comparison with literature to determine the main aquifer parameters (transmissivity, hydraulic conductivity, and storage coefficient) were preferably used.

7.3.3. Groundwater Model

Hydrogeological models are tools used to represent the dynamics of groundwater in a simplified way and enable the simulation of different scenarios. The main objectives in these models are estimate outflow rates, water availability, and provide water level data which will be used as inputs to geotechnical stability analysis.

The dewatering is done by pumping wells and or dewatering tunnels located in the iron formation, which also corresponds to the main aquifer. The slope depressurizations are performed by pumping wells, horizontal drain holes and natural discharge.

To build the hydrogeological model, the following steps were followed:

- Data compilation: Compilation, verification, and analysis of preexisting hydrogeological monitoring data: groundwater level, rainfall, stream gauge, in addition to the geological information;

- Hydrogeological conceptual model: Interpretation of the data compiled into a model that will serve as a “sketch” for the numerical model, containing the hydrogeological units, potentiometric surface, recharge zones, discharge zones, and pumping wells;
- Preparation of the numerical model: From the conceptual model, the data is entered into the modeling software (Visual MODFLOW or FEFLOW), where the governing flow equations and mass balance calculations will be solved;
- Calibration of the numerical model (permanent/transient): Calibration consists of comparing the calculated hydraulic heads with those observed in the monitoring instruments (water level indicators and piezometers). The hydrodynamic input parameters are modified from a factor called nRMS (Normalized Root Mean Squared), which works as an indicator of confidence. Best factor reaches a value of less than 10% (nRMS<10%), as well as the evaluation of the mass balance (inputs/outputs) of the boundary conditions used in the model. The models were calibrated to ensure the confidence between monitored and calculated data.

The database used to build the model data was considered satisfactory to achieve the main objective as the model was calibrated and for S11D and C, it reaches nRMs=4.4 Table 7-2 summarizes the main information and the variables considered in the analysis stages, considering the results of the simulated flows for the maximum drawdown of the pits as well.

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 (m³/h)	Number of instruments considered in the calibration
HIDROVIA	S11	2019	FEFLOW	4.40	1,138	92

7.3.4. Comment on Results

The monitored data was considered satisfactory to achieve the main objective, which is build, calibrate and simulate future mining scenarios in a groundwater numerical model.

Vale is currently improving its ground water monitoring network and the QA/QC program is under development, which will increase the confidence on data and numerical models.

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

7.4. Geotechnical

7.4.1. Overview

The geotechnical information is constituted of previous experience in closer mines and data obtained during early stage. The geotechnical evaluations are complemented by data obtained during the mining activities.

Geotechnical core logging and geotechnical mining mapping are the main data collection methods. The core logging follows an internal procedure (PRO-030016 rev0) that defines the steps to be followed for the geotechnical description, which are essential to obtain the adequate individualization and characterization of the geotechnical intervals. For site mapping, geological, geotechnical, and structural data described are used to define the geotechnical domains. The structural mapping is obtained from regional and local surface geological mapping and drillhole interpretation.

The main structures with possible trigger failure mechanisms are pervasive joints settings, bedding and foliations. The structural domains and their respective structures stereonets were used for kinematic analyses and failure mechanism interpretation.

For core logging or mapping, the data collected follows the tables proposed by ISRM (1997), Bieniawski (1989) and Martin & Stacey (2018) adjusted by Vale (2019) to fit the iron formation deposits. The geotechnical parameters described are compressive strength, weathering, degree of fracturing, RQD, type of discontinuity, alpha angle of main discontinuity, main discontinuity conditions (opening, roughness, spacing, wall alteration, wall filling, type, and thickness). These characterization parameters are applied to define different rock mass classifications systems used in Vale mines.

Vale's open pit are mainly composed by weak and friable rocks. To classify these rocks, the Weak Rock Classification presented by Martin & Stacey (2018) is used, applied to materials whose uniaxial compressive strength is less than 10 MPa, equivalent to the compressive strength range bellow to R2- (Figure 7-2). Rocks with compressive strength equal or above R2+ are classified according to RMR (1989).

The GSI classification is also used and they are obtained through empirical correlation with the RMR value proposed by Hoek (2001), where GSI = RMR - 5. For some mines, where this correlation was tested, it is possible to have a different empirical value, and in some cases, GSI are obtained from mine site superficial GSI mapping.

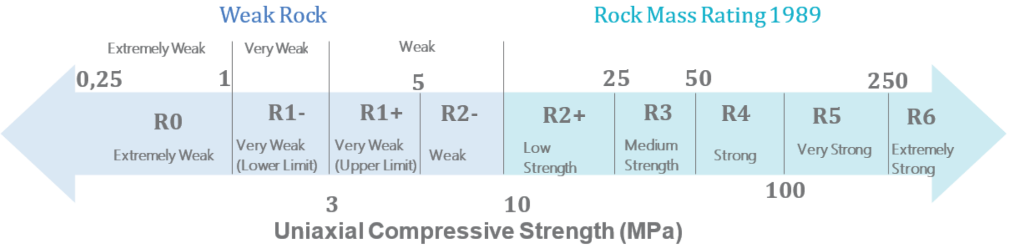


Figure 7-2- RMR and Weak Rock classifications as a function of the material strength (Modified from Martin & Stacey (2018).

Typical structural characterization consists of describing and defining joint sets (including bedding and foliation), faults, shear zones, and dykes through structural mapping. The use of geophysical core logging (televiewer surveys, electrical resistivity and sonic method) is still in stage of test and implementation at Vale to determine geotechnical intervals and parameters as Poisson ratio, Young´s module, total porosity, bulk density, and structures dip-direction.

The geomechanical models of all mines located at Serra Sul Mine Complex were build using about 288,927 m of geotechnical logging and 414 geotechnical superficial mapping points. These databases were performed and/or validated by independent consultants.

Vale and contractors commissioned geotechnical model assessments for Serra Sul, including Vale in 2020, VOGBR in 2008, Golder in 2012 and 2013, Geominas in 2017, SRK in 2020, MDGEO in 2020 and TEC3 in 2020.

For S11C, VOGBR completed a geomechanical 2D modelling exercise and evaluation of the overall stability conditions within the mine, and for S11D, SRK completed a geomechanical 3D modelling exercise.

Samples for geotechnical tests (disturbed and undisturbed) are obtained from drill cores and in situ (mines surface). Sampling methods follow internal criteria that guarantee quality, control, and representativeness of the samples.

Routine site visual inspections and monitoring conducted by internal geotechnical team to identify geotechnical anomalies as cracks, surface drainage inefficiency, blasting overbreak's, rockfall hazard or any feature that can impair the slope stability are conducted to guarantee the continuous operational safety control. All identified unconformities are registered and forwandered directed to the responsible for operational solution through an internal system.

The use of integrated monitoring systems with prisms (TDR), water level indicators, piezometers, inclinometers, extensometers, crack meter, ground radar and orbital radars supported by routines visual inspections guarantee the early alarms and continuous monitoring 24/7 for specific slopes controlled by a proper monitoring center.

The hydrological model is used to promote the operational pits superficial dewatering. The Surface Drainage Master Plan were elaborated for the control and direction of the superficial water from the dewatering and rainwater. It guides the planning and operational teams on the drainage system project in the pits.

The objectives of mine drainage system are recovery and reuse of mine water within the mining operations for processing of ores, conveyance of materials, operational use (e.g., dust suppression), and environmental protection, specifically related to the impacts of mining water on surface water and groundwater resources. Off-site run-off water can also be diverted away from the mine and waste facilities to reduce the water volume to be treated.

Local regulatory requirements stipulate mine water discharge quality or associated discharge pollutant loads. Mine drainage treatment may be a component of overall mine water management to support a mining operation over the mine entire life and enhances post-closure and sustainable use of the mine property long after the ore deposit is depleted.

7.4.2. Parameter Determinations

The used strength and elastic parameters are obtained from direct geotechnical testing which typically comprises: triaxial shear tests (CU, CD and Hoek cell), direct shear test, UCS (Unconfined Compressive Strength), Brazilian-tensile test, P and S waves velocities, as well as indirect methods, such as Schmidt Hammer and PLT (Point Load Test). The direct geotechnical tests are carried out by several private laboratories and public institutions which follow international and national standards for execution, and in general, are ISO 9001 certified. The main test methodologies used are set out in: ASTM D4767, ASTM D7181, ASTM D5407, ASTM D7012, ASTM D3080, ASTM D4543, ASTM D3967, ASTM D4428, ASTM D5873 and ASTM D5731.

The indirect methods and tactile-visual tests, based on geological hammer blows or other elements for strength assessment, are applicable during mapping or in the description of drill cores (ISRM, 1997) and are carried out by internal geotechnical team in warehouses for the storage and description of drill cores and follow the standards described in internal procedures. For weak rocks (compressive strength bellow or equal than R2-), Mohr Coulomb strength envelope was obtained from existing geotechnical tests. Materials with strength anisotropy were tested in different directions (parallel, perpendicular, and oblique). The strength properties of hard rocks (compressive strength above or equal than R2+) were directly obtained through laboratory geotechnical tests and the rock mass parameters were obtained according to Generalized Hoek-Brown criterion (Hoek, 2001).

Discontinuities properties were obtained through direct shear tests in which the maximum strength (pick resistance) occurs on the discontinuity surface itself. In addition, from surface mapping data and drill core descriptions were obtained, according to the criterion of Barton and Bandis (1990), setting JRC (Joint Roughness Coefficient) and JCS (Joint Compressive Strength) parameters. For the lithotypes that do not have tests in the evaluated mine, the parameters obtained for nearby mines with similar lithostratigraphic, tectonic and geomechanical contexts were used.

7.4.3. Slope Stability Analysis

Two-dimension slope (2D) stability analyses were made through the Equilibrium Limit Method (ELM), using software Slide2®, developed by Rocscience Inc., to assess potential non-circular and/or circular failures, considering the most actual geological, hydrogeological, and geotechnical models, possible failure mechanisms and strength parameters. These analyses were made along the entire pit, based on the representative sections that may influence instabilities (critical sections), evaluating mainly inter-ramp and overall slope scale failures. Bench scale analyses were made through Kinematic analyses and specific analysis. Based on the analysis, the bench, inter-ramp and overall angles were defined to design the pit.

Additionally, the water table used were supported by final pit drawdown simulations from the hydrogeological models.

In general, final pit slopes design with no near mine interferences may reach deterministic Safety Factor (FoS) equal to or greater than 1.3. However, final pit slopes design with near mine interferences (external roads, waste piles, railway, neighborhoods and other) should be dimensioned to reach FoS equal to or greater than 1.5. The acceptance criteria specificities were based on international references and good practices suggested by Read & Stacey (2009) as presented in Table 7-3.

Table 7-3- Typical FoS acceptance criteria values. Source: Modified from Read & Stacey (2009)

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

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

As Brazil is located in an intracratonic region, the occurrence of high magnitude earthquakes is not expected, but the seismic activity in Brazil is known and monitored internally (Vale has a set of seismographs installed in several mines that contribute to this national seismographic network) and by external institutes. Local seismic studies for the Iron Quadrangle and Carajás regions are under development. For this reason, theoretical seismic accelerations were adopted.

Pseudo static (dynamics) slope stability analyses, that consider earthquakes effects, were made basically for post mine closure. In operational and short-term assessments, the seismicity is not considered due to the low incidence and the low levels of the earthquakes. Additionally, for post mine closure recovery of the water level to the original levels (pre mining level) was considered. In general, the expected safety factor must meet the safety assumptions of FoS ≥ 1.1 as established in 2009 by Stacey & Read (Table 1).

7.4.4. Quality Assurance and Quality Control

A complete Vale´s QA/QC program for the geotechnical core logging description is under development. Currently, the cross-validation techniques used were based mainly on three empirical correlations. The first cross validation for iron formations correlates Vale´s crusher test with the estimates of rock compressive strength. The second correlates the estimated compressive strength with the weathering degree for each material. The third criterion consists of the relationship between the fracture degree, RQD and joint spacing.

The strength and elastic laboratory tests results were validated by Vale's geotechnical team or independent supplier companies. Specimens with inconsistent and/or inconclusive results were discarded.

Duplicated samples were required when evaluations errors were identified. Additionally, duplicate samples are sent to different laboratories, but there is no routinely established control program or even external audits to evaluate the equipment and test results to ensure that all information and recommendations are consistent. On this issue, Vale has been setting up an internal rock and soil geotechnical laboratory following international standard since 2019. This laboratory will be used to carry out periodic check routine and audits in the private and public laboratories used by Vale.

Actually, quality assurance resume to demand regular calibration of equipment by outsourced laboratories and own equipment (according to criteria specified for each of them). The contracts with the laboratories follow international quality assurance criteria and standards for the delivered result, incorporating actions to be taken if test results do not comply with the required specifications. These verification systems are still not implemented as mandatory; however, it includes occasional checks in transport, storage, testing and presentation of results, seeking protection against physical damage, quality, and control of the tested samples, including information on test types, test quantity and evaluation measures.

7.4.5. Comment on Results

A combination of historical, near mine, and current geotechnical data with the mining site experience of internal teams supported by national and international consultants is used to establish, based on international standards and best practices, internal guidelines and procedures in the slope stability design and operation of Vale’s open pit mines.

Vale is currently improving its laboratory tests and drill holes investigation in waste rocks to better support the geotechnical models and slope stability analysis and the QA/QC program is under development, which will increase the confidence on data and numerical models.

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

8. Sample preparation, analyses, and security

8.1. Overview

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

8.2. Sampling methods

The drill core samples were taken at Vale core shed facilities, following the standard adopted for the 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. In N4E, a laboratory was inaugurated, where physical preparation activities and chemical analysis of exploration and production samples of iron and manganese ores were performed. As of August 2008, the samples from the geological exploration were prepared in an outsourced laboratory of the company SGS Geosol Laboratório Ltda located in Parauapebas, in state of Pará. Between August 2009 and April 2013, the samples were prepared by the company Intertek do Brasil Inspeções Ltda. The physical preparation works outsourced by SGS Geosol and Intertek were carried out under the supervision of VALE. Since April 2013, the samples began to be prepared in Vale's laboratory, located at the N4 mine, where chemical assays are also carried out.

In the drillholes of the 70's campaign, only global assays were done for Fe, SiO_2, P, Al_2O_3, Mn, FeO and LOI (Loss on Ignition). Measurements of the percentage of magnetite in the ore were also taken using Satmagan equipment. For hematite samples, assays of SiO_2, P, and Al_2O_3 were done by X-ray fluorescence and other constituents by the wet method (Fe, Mn, and FeO). For jaspillites, all analytes were assayed by wet method. For mafic rocks and cangas, only the assay of P was done by X-ray fluorescence, and for the other analytes, by the wet method. In part of the results the sum of SiO_2 and Al_2O_3 was recorded without discrimination of the individual parts.

The assay of the rotary percussive drilling campaigns from 2003 to 2005 were under the responsibility of GADIN Chemical Analysis Laboratory of the Carajás Iron Mine, Brazil. In 2005 and 2006 Vale contracted 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%: GADIN routine, Fe% determined by difference, for verification, it was performed by 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 in X-Ray fluorescence;
- LOI (Loss on ignition): by gravimetry.

Since November 2008, Fe started to be wet assayed. Verification of the Fe calculation was performed by comparing the Fe analyzed by the wet method of the most representative fraction with the calculated value. If the difference was less than 0.70%, the calculated contents were validated. Otherwise, Fe was assayed wet in all fractions. The sieving is done dry using four sieves (19mm, 8mm, 1mm, 0.5mm, and 0.15mm), generating five granulometric fractions. From these, the mass and chemical recoveries of each fraction are determined. Since June 2013, Fe started to be assayed wet in all fractions. The other analytes are determined by X-Ray fluorescence, and LOI by gravimetry.

Regarding the chemical closure, up to 2006, results within the 98%-101% range were considered acceptable. Since 2007, acceptance thresholds is 99%-101%.

8.3. Sample security methods

8.3.1. Quality assurance and quality control

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

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

Assays for Al2O3, Fe, Mn, P, LOI, and SiO2 follow Vale standard PTP-000915 Version 02 of 08/08/2019 and relate to the following quantities: 1,640 crushed material duplicates, 3,380 pulp duplicates, and 1,938 samples of 7 types of standards.

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

The last laboratory QA/QC assessment was done in April 2019 by Vale personnel. In general, the laboratory performance is classified as satisfactory (compliant results ≥ 90% or very close to 90%) and/or admissible (compliant+acceptable results ≥ 90% or very close to 90%). In most cases, sampling/chemical assays accuracies are good and analytical biases/flaws are small or insignificant compared to the involved grade ranges.

For Fe, the technical performance of the laboratory is satisfactory and considered acceptable. For contaminants, the technical performance varied from satisfactory to unsatisfactory (there are some points of attention at lower grades). Crushed material duplicates and pulp duplicates DP show higher percentages of non-conforming results and higher mean relative inaccuracies (although still acceptable), most likely influenced by the higher frequency of lower grades for Al2O3, Mn, P, LOI and SiO2 analytes.

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

The standard control samples indicate a trend of small overestimation at very low grades for Al2O3, Mn and P. The most important points of attention are under investigation by geology and laboratories teams.

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. The QAQC data revealed general indicators of non-compliance, precision and accuracy considered satisfactory, not compromising the database related to them.

8.3.1.1. Database management system

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

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

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

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

8.3.1.2. Header table validations

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

Validation of Holes with Topography

Validation of the position of the holes, verifying the existence of conflicts of positioning in relation to the original and current topographies. If there are any relevant discrepancies, the hole is excluded from the database.

Validation of New Holes in the Database

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

Drillhole Recovery Validation

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

Validation of Duplicate Coordinates

This validation aims to identify holes with the same East and/or North coordinates.

DATUM Validation

This validation intended to assure that all hole position data is in the same Coordinate System and Datum. Vale defined for Serra Sul Horizontal Datum SAD69 and the Vertical Datum Imbituba projected at UTM-22S. The coordinate data of the drillholes in Vertical Datum PD04, were surveyed again and the data corrected in the database.

Coordinate Validation

In this validation, the coordinates of the original files, from the Survey Monitoring spreadsheet, are compared to the coordinates taken from Geological Database Management System.

8.3.1.3. Survey table validations

The items below describe the validations carried out in the Survey table in the database of Serra Sul model. The original logging data was acquired using the following equipment: DEVIFLEX, MAXIBOR I, MAXIBOR II, REFLEX GYRO and the Azimuth of the topographic survey.

General Profile Validation

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

Header x Survey Depth Validation

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

Validation of Dip and Azimuth x Drilling Follow-up Worksheet

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

Dip and Azimuth Consistency Validation

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

8.3.1.4. Assay table validations

The items below describe the validations performed in the Assay table of the long, short term and geotechnical borehole database of Serra Sul geological model. Regarding the items checked routinely during the preparation of the database for modeling, all inconsistencies were handled and, in some cases, the analytical results had their values discarded.

Duplicate Sample Validation

This validation serves 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 serves to identify the correct arrangement of the intervals, considering the “From” and “To” interval. This validation aims to highlight Gap errors (intervals with missing length) or Overlap (intervals with overlapping length). The check is done directly by crossing “From” and “To” information.

Validation of Calculated Global Content

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

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

Validation of Anomalous Values

The check of anomalous values consists in verification of whether the maximum and minimum values are coherent with each analyzed element. It is possible, for example, to highlight column changes (P and Al_2O_3, for example). In the database, there cannot be chemistry values equal to 0, the minimum must always be the limit of detection. It is also possible to detect negative values.

Granulometry Versus Chemical Validation by Range

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

Validation of Equal Analytical Results in Different Samples

This is a simple but important check that considers the existence of equal results for some analytes. The check is done in the Assay, element by element, sorting and checking the difference or existence of equal results. This check must be done for all analytes and it is considered an error when there are the same results for two different samples.

Sample Recovery Validation

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

Particle Size Closing Validation

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

Chemical Closing Validation

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

$(Fe*1.4297)+SiO2+(P*2.2913)+Al2O3+(Mn*1.2912)+CaO+MgO+TiO2+K2O+(Cu*1.2518)+LOI$

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

Depth Validation between Assay, Header and Survey Tables

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

8.4. Density Determinations

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

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

8.4.1. Direct acquisition methods

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

- Volume Fill Method: Consists of digging a hole with regular walls, removing the material and weighing it, coating the hole with thin plastic, and filling it with known volume of water.
- Sand Flask Method: Consists of digging an opening in the floor with regular walls, removing and weighing the extracted material. This hole is then filled with selected sand of known

density, and from the selected sand volume and mass data, the material density is determined.

- Volume Displacement Method: Density is calculated from the relationship between sample weight and water displacement caused by immersing the sample in a graduated container.
- Hydrostatic Weighing Method: Density is derived from the ratio between the weight of the sample divided by the loss of weight when the same sample is immersed in water, using the Jolly scale.

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

8.4.2. Indirect acquisition methods

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

8.4.3. Mineralogical Normative Calculation (CNM)

The normative calculation works were developed by Ribeiro (2003) for the lithotypes of Banded Iron Formations of the Iron Quadrangle, complemented by observations made by Voicu et al. (1997) regarding the calculation of the paragenesis of rocks with a relevant weathering profile. The first studies coordinated by Ribeiro in Vale´s internal project was carried out in 2010 only for siliceous compact itabirites, where the paragenesis is basically composed of quartz and iron oxides. Considering the proportions of each mineral, obtained based on global chemistry, and their respective theoretical densities, the total density of each sample was calculated. The correlations obtained by comparing these results with the data collected by direct methods were very good, and therefore, it was decided to extend the application of this technique to the other iron-enriched lithotypes in VALE deposits.

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

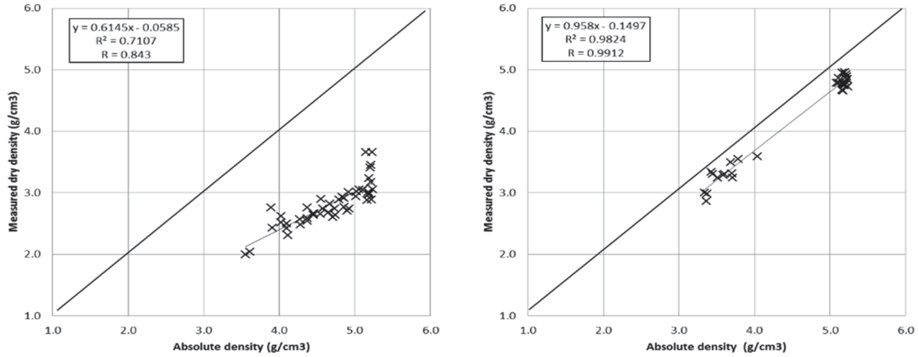


Figure 8-1 - Linear regression between the mineralogical density and the measured dry base density for friable (left) and compact (right) samples, according to Motta et al. (2016).

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

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

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

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

9. Data Verification

9.1. Internal data verification

9.1.1. Data collection and storage

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

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

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

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

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

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

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

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

9.1.2. Mineral resource and mineral reserve estimates

A Mineral Resource and Reserves Committee was established within Vale's Ferrous Division to document the information supporting the mineral resource and mineral reserve estimates, including all technical and economic premises, and ensure its reliability. The committee is composed by qualified person/competent persons from different areas, and departments (resources, reserves, mineral processing, geotechnics (pit, project and dam), hydrogeology, production, strategy, environmental, speleology, finance, mining rights, mining future use, engineering) which sign off or certify the assumptions for the work relating to preparation of mineral resource and mineral reserve estimates.

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

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

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

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

Technical reviews of the mineral reserve and mineral resource estimates are made by the Resource Management Group annually (or as needed) for each operation and mine. The Ferrous Mineral Resource and Reserves Committee prepares and issues a technical review report to each mine and operation with risks identified. All identified risks require mitigation and addressing, consistent with the risk rating that has been assigned thereto, to be consistent with the disclosure requirements of SK1300, and to be compliant with Vale Global Guidelines for Mineral Resources and Mineral Reserves Management.

9.1.3. Studies

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

9.1.4. Reconciliation

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

9.2. External Data Verification

In Serra Sul Complex audit performed in 2008, the mineral resource and mineral reserves were reviewed by Pincock Allen & Holt. The work included a review of the geology, mineral resources and reserves, metallurgy, processing plants and environmental management. In 2016, this deposit undergone a new audit process, where Runge Pincock Minarco (RPM) reviewed the current mineral resource and reserves estimation techniques and concluded that they comply with the industry standards for iron deposits.

9.3. Qualified Person’s Opinion on Data Adequacy

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

10. Mineral processing and metallurgical testing

10.1. Summary

Serra Sul deposit are characterized by high iron content, requiring few metallurgical tests to define the process route and monitor the process. In general, the process route is defined based on the evaluation of the chemical analysis of the geological model of the deposit. This analysis makes it possible to determine whether the ROM of a given deposit should be concentrated or not.

For additional characterizations that may be necessary, samples can be collected from the mine or directly from the plants in operation.

In Serra Sul, there are deposits with iron contents above 65% that do not require concentration to obtain the products. The process route considers the processing of natural moisture material, with crushing and screening operations to adjust products granulometry.

10.2. Test laboratories

Beneficiation testing is primarily done either at the Technological Research Center (CPT) of Vale or external process laboratory. There is no international standard of accreditation provided for beneficiation testing laboratories or beneficiation testing techniques. All chemical analysis are carried out using the structures of Vale's laboratories where the entire production chain are carried.

10.3. Recent Testwork

For the design of roller type crushers, it is necessary to know the compression strength of the materials that will be processed. The Serra Sul roller crusher were scaled considering compression strength of 160 MPA. Recent testwork indicated the need to replace these crushers by higher compression strength machines. This was due to the increased participation of jaspilite during mining as a dilution ore, which increased the compressive strength of the ore to be processed. The Figure 10-1 below shows the jaspilite compression strength histogram. The results show that for 89.7% of the 117 characterized samples, they presented values lower than 400 MPa. For design purposes, 500MPa was considered

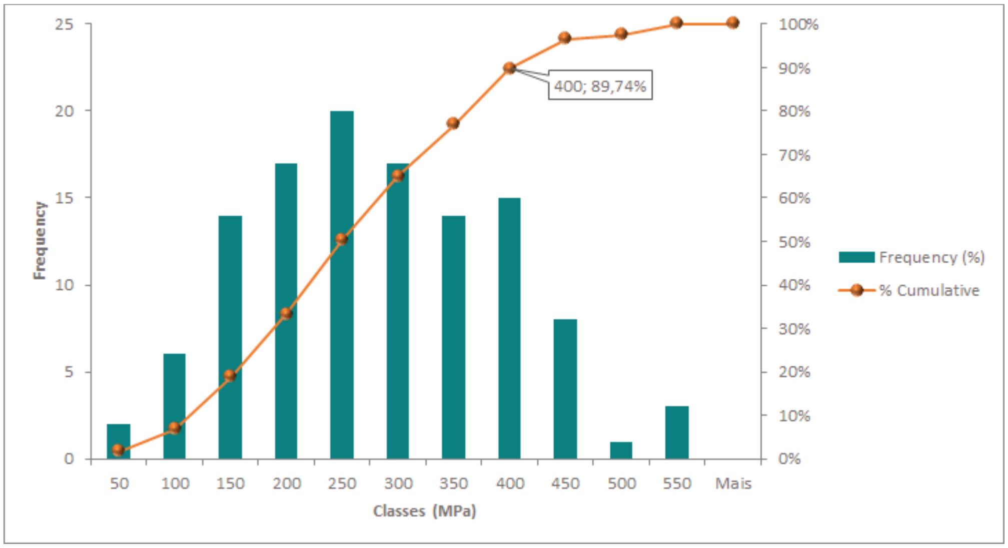


Figure 10-1 – Jaspilite compression strength histogram.

10.4. Current Performance

Serra Sul operates at natural moisture and at a metallurgical recovery of 100%.

10.5. Deleterius elements

The deleterious elements for iron ore products are silicon, alumina, phosphorus and manganese. The contents of natural moisture productions are directly controlled by the quality of the ROM itself and for those productions.

The Serra Sul mine are characterized by a high iron content with low contaminants. The Sinter feed is generally used to adjust the content of Vale's south and southeast systems in the ports when it is not sold directly on the market.

Due to the high quality of Serra Sul products, no commercial penalties are applied to its products.

10.6. Qualified person’s opinion on mineral processing and metallurgical testing

The performance of ore bodies in beneficiation plants is well known. The production experience and the most recently developed projects provide a solid basis to forecast production.

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

11. Mineral resources estimate

11.1. Summary

Resource estimation includes the steps of geological modeling, grade estimation, and mineral inventory classification. This item will detail the nature of the deposit, the reliability of the geological information with which the lithological, structural, mineralogical, alteration 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, implicit, 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). For both cases, the majority lithology is assumed. Lithology is always used to interpolate grades and in the classification of the mineral inventory.

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

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

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

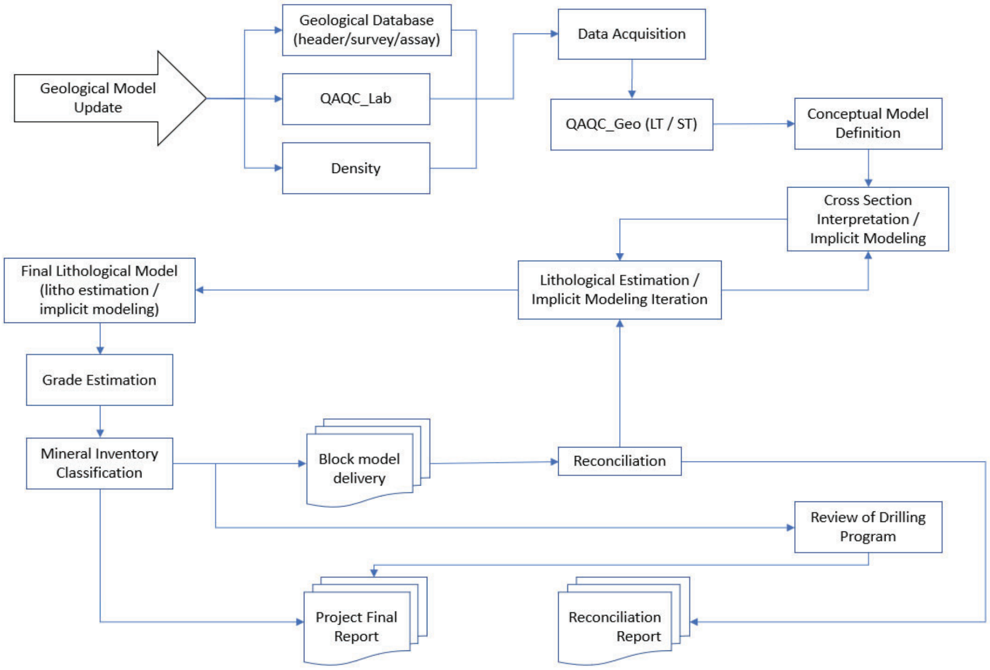


Figure 11-1 – Macro processes flowchart of modeling, estimation of grades, and classification of mineral inventory of ferrous deposits.

11.2. Resource Database

The database used to estimate the content of the Serra Sul deposits is composed of chemical assays of: Fe, SiO2, P, Al2O3, Mn, LOI, TiO2, 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). The update of the geological models of the Serra Sul deposits was done after extensive revision of the entire database.

11.2.1. Database verification

The isotopy process comprised the following steps:

- Removal of sample intervals without assays;
- Removal of samples from the RSUL_SILAB analytical flux, as they present problems in the sampling procedure and do not have enough mass for a second sampling validation. This information was used carefully in the geological modeling, but not in the grade estimation step;
- Removal of samples for isotopy of the global Fe, SiO2, P, Al2O3, Mn and PF grades;
- Removal of samples with chemical closure outside the established limits of 95% and 102%;
- Chemistry and grain size fraction consistency check. The database is isotopic in all analytes, except for <5% of samples that did not present global values of Ca, Ti and Mg, this heterotopy was treated in the post-estimation process;
- Removal of samples with less than 60% recovery.

11.3. Geological Interpretation and Modelling

11.3.1. Implicit modeling with percentile model

Currently, only for bodies C and D there is enough drilling to define the mass and quality of the ore satisfactorily. The SSCD geological model has EW orientation, approximate dimension of 12 x 7 x 1 km and was prepared with 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 internal structure of the iron formation. This model was audited in 2016 by RPM Global and satisfactorily reproduces the continuity of mineralized bodies, their host rocks, coverings, and intrusive rocks.

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

Currently, the implicit modeling is built with the help of 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 control the shape of mineralized body;
- Input of data into the software;
- Interpolation parameters;
- Validation of the resulting model.

The great advantage of this method is the dynamism in updating information and the ease of viewing the deposit in 3D at all stages of the interpretation. As a result, two basic models that control the mineralized bodies are interpreted, namely: the lithostratigraphic units and the weathering domains. From the combination of these macro domains, the necessary refinements of the lithotypes inside the main body are made (Figure 11-2).

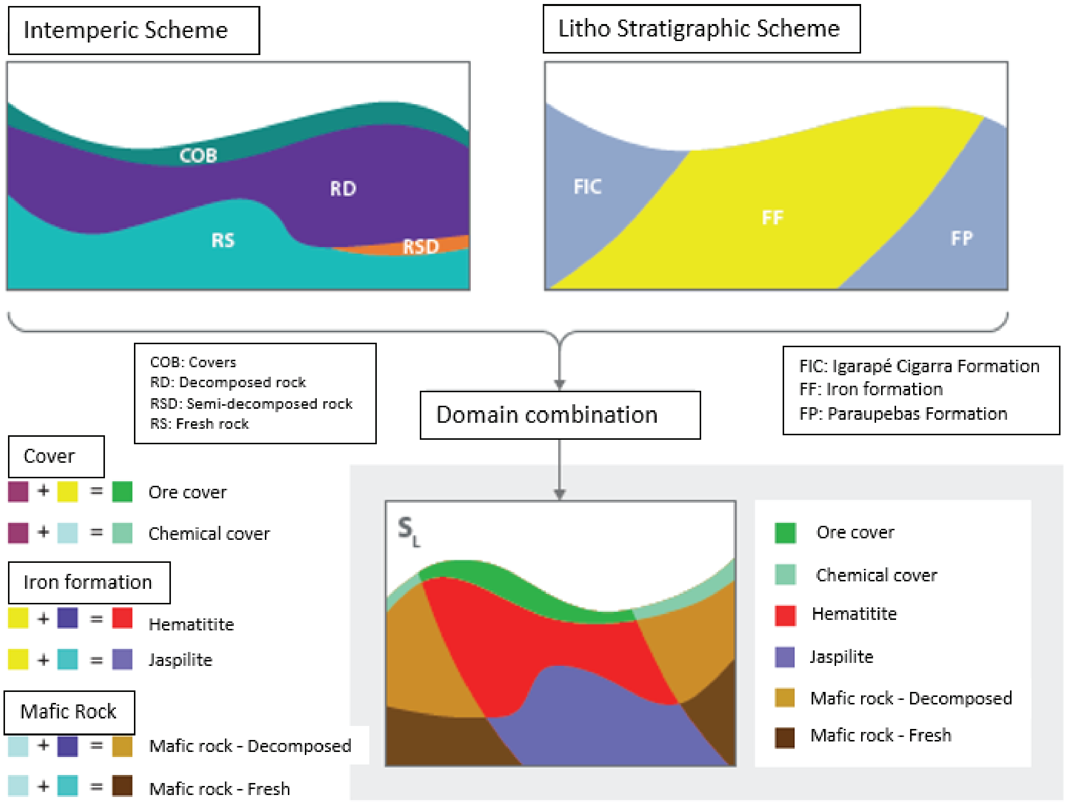


Figure 11-2 – Leapfrog simplified interpretation model of Carajás-type iron ore deposits.

The final product of the interpretation stage is 3D solids which are saved and imported into Vulcan, where the mass model is generated. The 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).

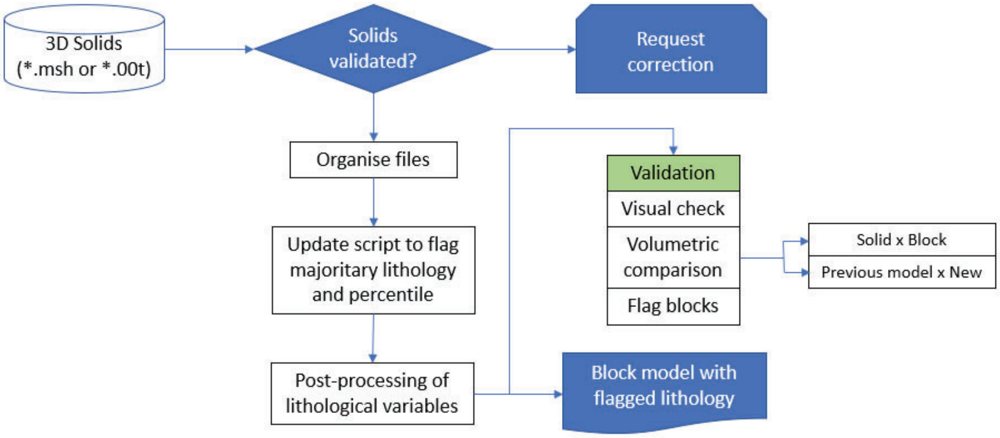


Figure 11-3 – Flowchart of the lithological estimate for Vale iron ore deposits (percentile models).

Mathematical checks for percentile models (mostly automated) require analysis and interpretation of the generated information. 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, in which the indicators were calculated by the percentage of each lithotype in the block from the solids generated in Leapfrog. The amount of drilling data used in the interpretation is presented in Table 11-1.

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

Drilling Campaigns – Serra Sul		2008 Model		2013 Model		2016 Model		2017 Model		2020 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. 2020 vs. 2017
Orebody D	Short Term	-	-	-	-	111	11,008	374	33,541	666	51,951	18,410
	Long Term	290	64,421	466	99,448	595	136,338	818	195,345	965	240,814	45,429
	Sub Total	290	64,421	466	99,448	706	147,346	1,192	228,926	1,631	292,765	63,839
Orebody C		58	8,893	58	8,893	71	11,609	72	11,846	136	27,286	15,440
TOTAL		**348**	**73,314**	**524**	**108,341**	**777**	**158,955**	**1,264**	**240,772**	**1,767**	**320,051**	**79,279**

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

The geological model of S11 C and D was completed in two different stages. In the first stage, the implicit modeling of the major events controlling the mineralization (weathering and tectonostratigraphic contacts) was carried out, resulting in the model of the large contacts as a product of the combination of these events. In the second stage, the internal detailing of the lenticular bodies of the iron formation is carried out in vertical sections, in which the external contacts and the covering respect the implicit modeling. For the implicit modeling, Leapfrog® software was used, and the vertical sections were interpreted in Vulcan®.

Application of 3D Seismic in Geological Interpretation

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

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

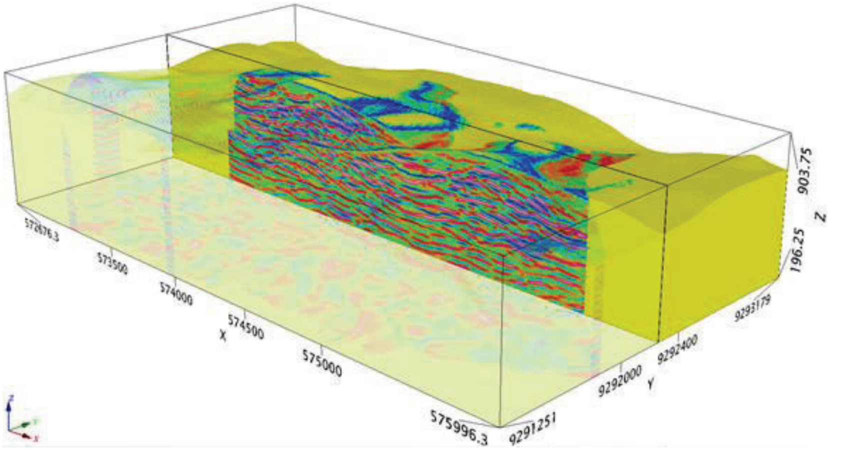


Figure 11-4 – Representation of the seismic cube.

The amplitude signal associated with the drilling information was used as input to simulate the probability of the block being jaspillite, considering the geological continuity (that controls the mineralization) through dynamic anisotropy. This probability simulation was migrated to the implicit modeling software and used in the interpretation of the jaspillite bodies (Figure 11-5).

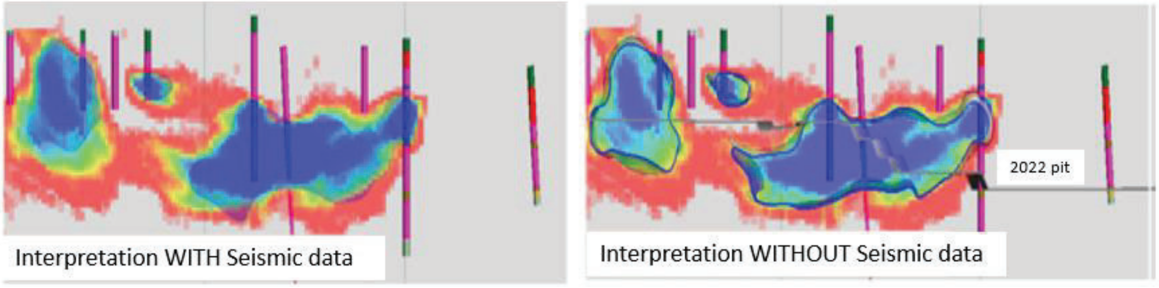


Figure 11-5 – Modeling of S11D sections using seismic information.

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

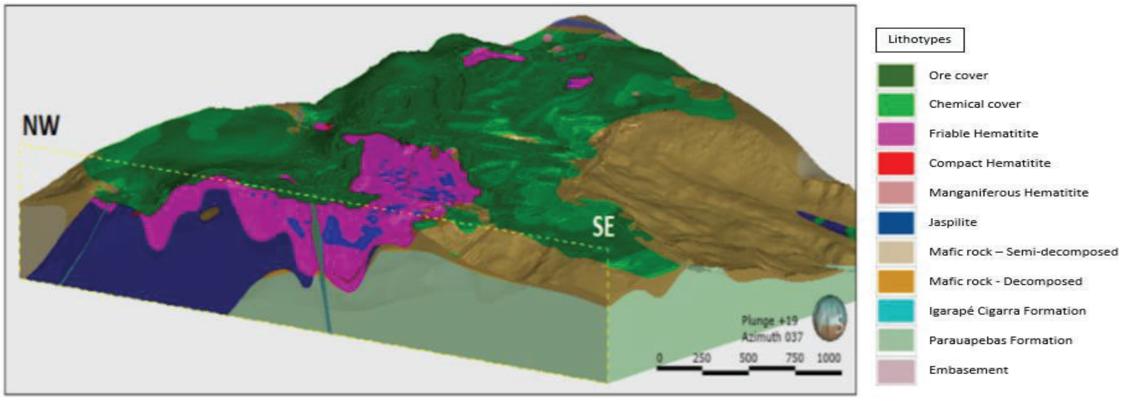
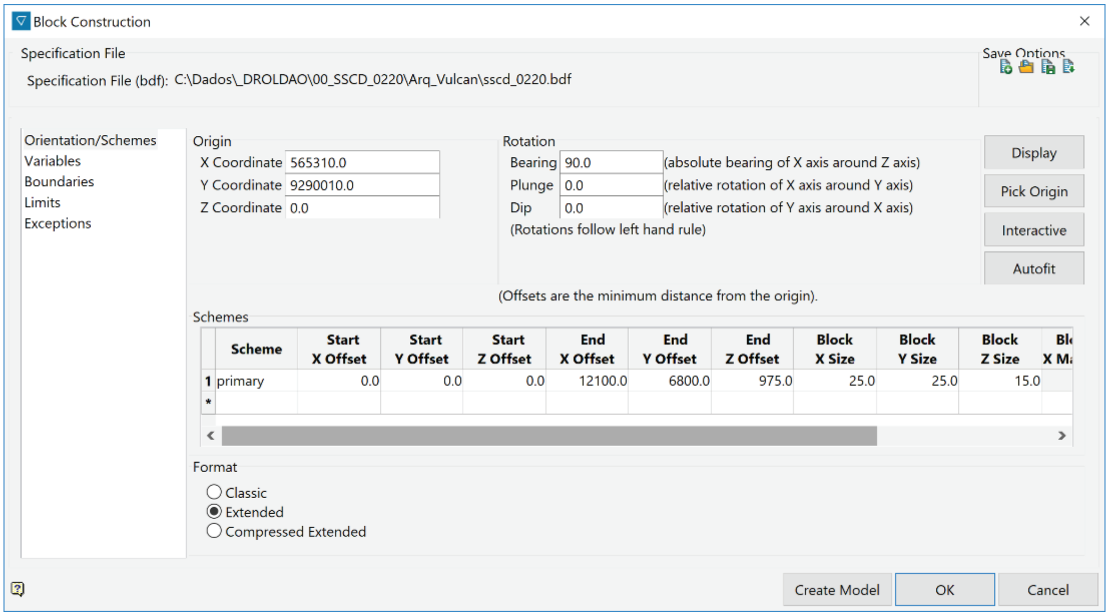


Figure 11-6 – Interpreted geological model of Serra Sul, detail of body D.

11.3.3. Estimation of Serra Sul lithotypes

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



Block Construction

Specification File

Specification File (bdf): C:\Dados_DROLDAO\00_SSCD_0220\Arq_Vulcan\sscd_0220.bdf

Origin

X Coordinate 565310.0

Y Coordinate 9290010.0

Z Coordinate 0.0

Rotation

Bearing 90.0 (absolute bearing of X axis around Z axis)

Plunge 0.0 (relative rotation of X axis around Y axis)

Dip 0.0 (relative rotation of Y axis around X axis)

(Rotations follow left hand rule)

(Offsets are the minimum distance from the origin).

Schemes

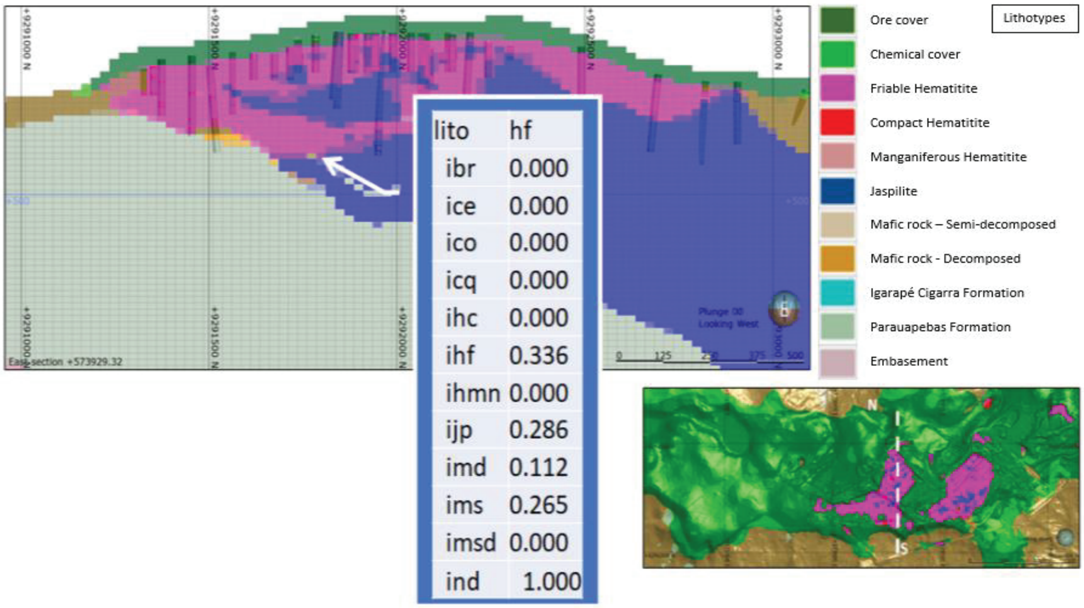
	Scheme	Start X Offset	Start Y Offset	Start Z Offset	End X Offset	End Y Offset	End Z Offset	Block X Size	Block Y Size	Block Z Size	Bl X M
1	primary	0.0	0.0	0.0	12100.0	6800.0	975.0	25.0	25.0	15.0	
*											

Format

○ Classic
● Extended
○ Compressed Extended

Figure 11-7 – Parameters adopted in the definition of the Serra Sul block model box.

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



lito	hf
ibr	0.000
ice	0.000
ico	0.000
icq	0.000
ihc	0.000
ihf	0.336
ihmn	0.000
ijp	0.286
imd	0.112
ims	0.265
imsd	0.000
ind	1.000

Figure 11-8 – Block model with the lithological indicators and the majority lithology, with the exploration and ore control drilling used in the interpretation.

Validation

After the block modeling process is finished, visual validation of interpretation and block model is conducted.

11.4. Domain Modelling

The geological model was built based on the categorical field called CLI (interpreted geological classification). This field is generated from the consolidation between CLV (Visual Lithological Classification), global chemistry results, the classification key, and spatial continuity of geological bodies.

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

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

In the classification key, the proposal adopted in the 2016 model 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 interpreted Lithotypes.

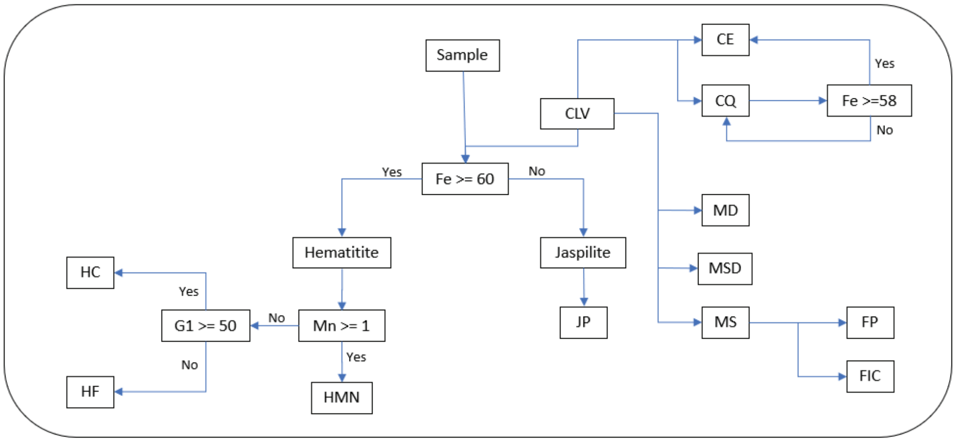


Figure 11-10 – Classification key used in the Serra Sul model.

Modeled Lithotypes

The modeled lithotypes resulting from the process are: cangas (structural canga – CE and chemical canga – CQ), hematites (friable hematite – HF, Compact hematites – HC, and manganese hematites – HMN), jaspillites (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; box plots to compare geology domain statistics, and contact plots to investigate grade profiles between estimation domains. Figure 11-11, show the distribution of global iron (FEGL).

Hematites have normal distribution with low dispersion. They are extremely rich bodies, with average iron content close to 66%. Only manganese hematite has lower grades, due to the high levels of manganese, above 2%.

The mafic rocks, internal of the Carajás Formation, sequentially present high iron grades. This is due to the interdigitation of the ore with the mafic rocks, very common in this deposit. The sills and dykes in Serra Sul are not very expressive, rarely exceeding 10 m.

Low iron content for jaspillite (<20%) indicates thicker chert levels. It is considered that the average jaspillite grades do not represent the entire interpreted package, as only the lenticular bodies (immersed in the hematite package) and a horizon of 30 meters of the base jaspillite are sampled. This effect causes a positive bias in the grades of this unit, as jaspillites tend to be poorer in depth.

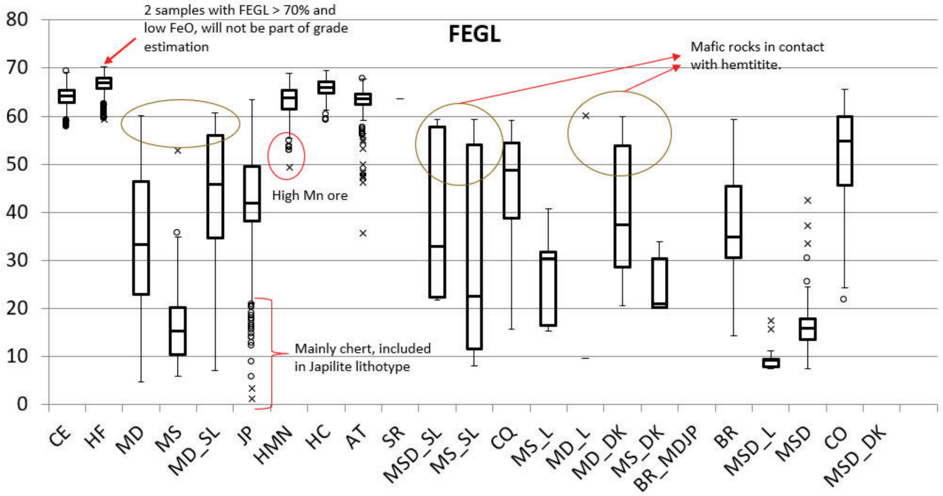


Figure 11-11 – Global iron distribution for the interpreted lithotypes.

Higher values of phosphorus may be present in hematites, a pattern not identified in jaspillites, indicating that phosphorus is strongly controlled by weathering.

The high values of loss on ignition in hematites, as well as phosphorus, are strongly related to weathering, or locally, to incipient hydrothermalism in compact hematites. The jaspillite also shows high levels of loss on ignition, which can be related to secondary carbonation, which can be associated with hydrothermalism.

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

11.6. Treatment of High-Grade Assays

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

11.7. Compositing

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

11.8. Trend Analysis

Grades 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 of structural canga and hematites, and the second the jaspilite domain. Initially, the analysis was based on the FEGL variable and then validated in the matrix of simple and cross-variograms of the six global variables and 40 size fraction and chemistry by fraction variables (four physical variables and 36 chemistries by particle size fraction variables).

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

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

The search parameters for the two groups are shown in Table 11-2.

Table 11-2 - Search parameters applied to the estimation in S11CD model

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

The iron ore deposits of Vale constitute one of the most complex cases in the multivariate domain. For the Carajás Iron deposits, generally, there are nine global variables, four particle size fractions and nine more chemical variables retained in each fraction, totaling 49 variables that must be estimated honoring their stoichiometric ratios and particle size closure. Estimation of these variables to honor this stoichiometry is possible only with (co)kriging.

In 2008, a study was carried out to standardize the estimation method for Vale iron ore deposits. The main multivariate methods adopted by the industry were compared: Correlogram, Linear Coregionalization Model (MLC), and Intrinsic Correlation Model (MCI). MCI was considered the most suitable for Vale deposits.

The MCI method can be considered simplification of MLC, but it has the same theoretical robustness. The easiness of the method is that, as it works with proportional variograms, the crossed variograms start to act as a residue, and are annulled during the kriging process. The main advantage of this method is that the estimation can be made in software that works with both multivariate and univariate data, making it easy to implement the estimation process in operational areas (short-term geology). The main advantage of the method is that, like the correlogram, it practically cancels the post-processing of the data, considering that it honors the stoichiometry and the sampling range for isotopic cases.

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

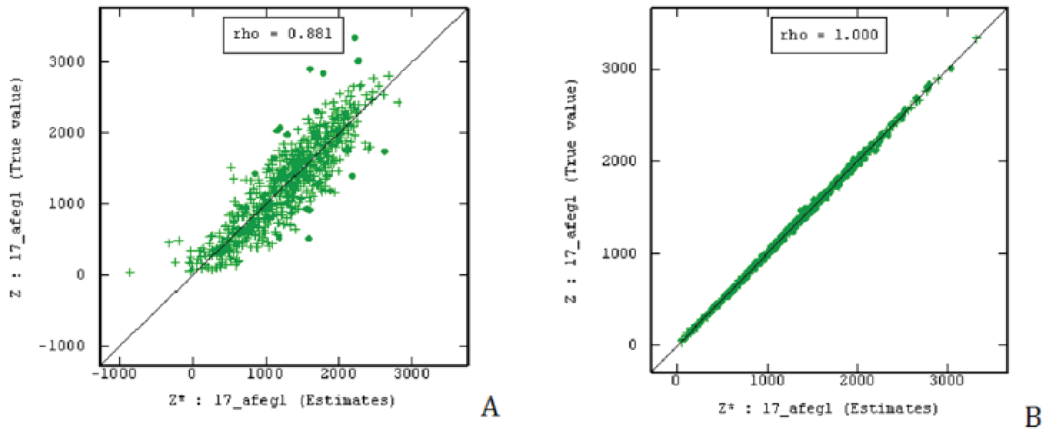


Figure 11-12 – Cross-validation of FEGL estimated by kriging (A) and by (co)kriging (MCI, B).

As previously presented, MCI is a method that guarantees proportionality between simple and crossed variograms. Thus, (co)kriging and kriging have 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 in the form of a linear combination, and consequently, the variable Z(x) can be decomposed into k variables Y(x) from a linear combination not correlated at the same point (Rivoirard, 2003).

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

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

Another established standard regards drill cores, which are regularized respecting the height of the bench and the lithological contacts. The method adopted in regularization (composites) is the Vulcan standard, which respects the pre-established constant length and lithological contacts. In the grade estimation step, the acceptance limit of broken intervals (residuals) during regularization is 30% of the 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 the interpolated grades. Variography is performed using Isatis® software. All steps of database preparation, grade estimation, post-processing and validation are performed in Vulcan®. Figure 11-13 shows the details of each step of the grade estimation.

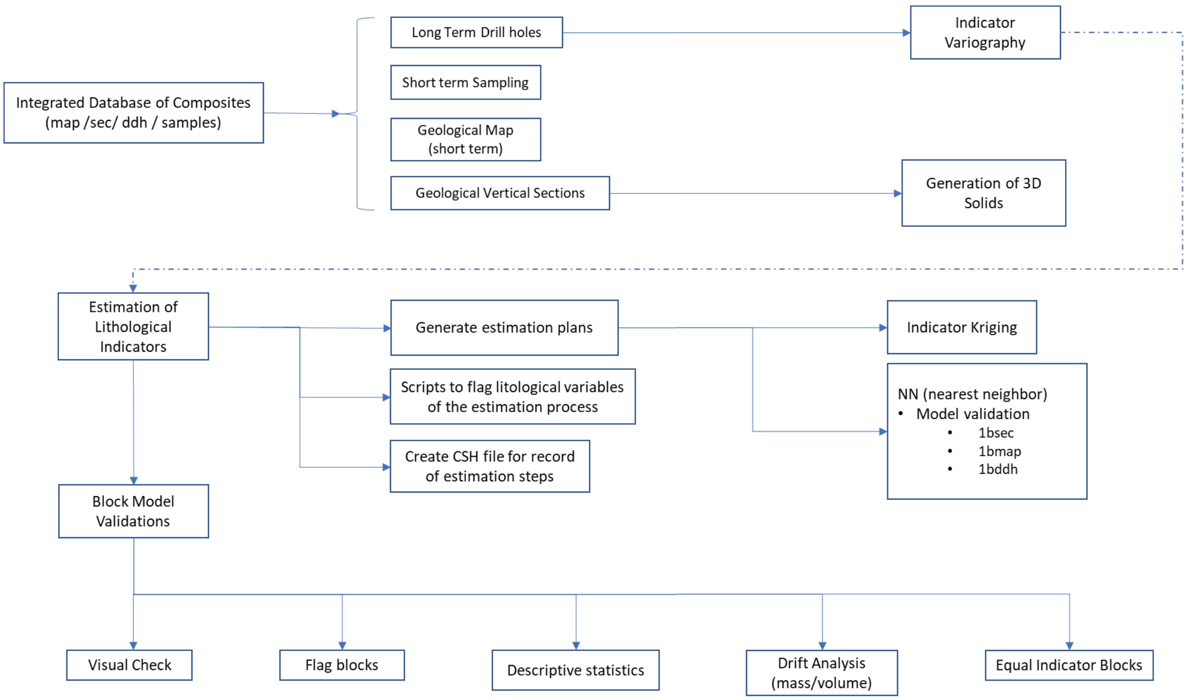


Figure 11-13 – Flowchart of the grade estimation process for Vale iron ore deposits.

Serra Sul Grade estimation parameters

Grades were estimated using the principle of ordinary (co)kriging using variographic models of intrinsic correlation (MCI). As explained above, based on this method, both variable-independent kriging and (co)kriging have the same results since the variograms are proportional. For the estimate, normalized levels of variance were used. This normalization of values is simplification of the method which enables the estimation process for software with basic geostatistics modules. The S11CD model was estimated in the Geostats module (GSLIB algorithms) of the Vulcan® software.

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, G1B, G2, and G3;

- Nine grades for each of the physical fractions.

In summary, the total of estimated variables concerning grades and physical fractions totaled 49 variables.

Although more comprehensive lithological groupings were used to adjust the variographic model, in the kriging process, the lithological units were respected, that is, composites of certain lithotype only estimate blocks of the same lithotype. The estimation parameters are shown in Table 11-3.

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

Parameters		Indicator Kriging	Nearest Neighbor
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	
	N° of structural sectors	5	

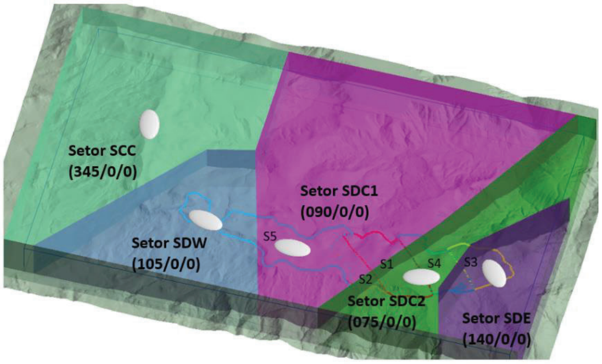


Figure 11-14 – Representation of the five sectors considered in the grade estimation with their respective ellipsoids.

11.9.1. Grade estimation post-process

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

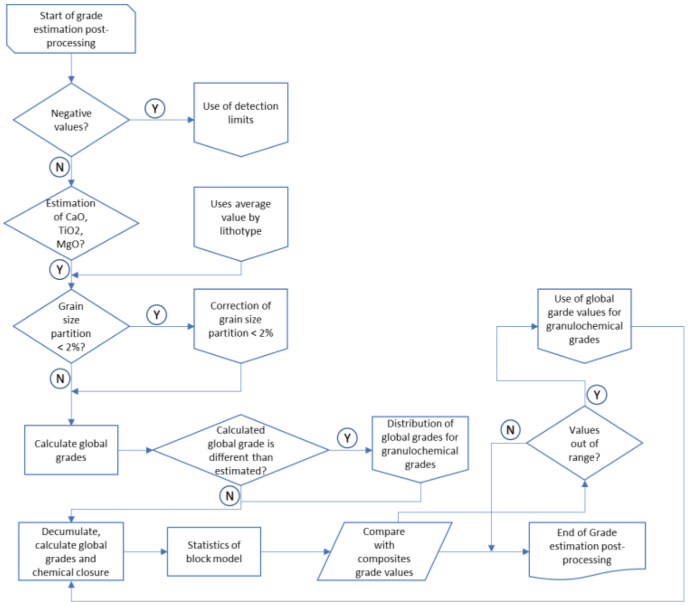


Figure 11-15 – Flowchart of the post-process adopted in the estimation of grades in the Serra Sul model.

After the end of the estimation, the post-processing step was started, in which the following checks were made:

- Existence of blocks with negative grades;
- Treatment of blocks without CaO, MgO, and TiO2 grades;
- Detection and correction of very low values in the particle size fraction;
- Compatibility of the chemistry of the fractions with the estimated global grade;
- Marking and correction of anomalous stoichiometric closing values.

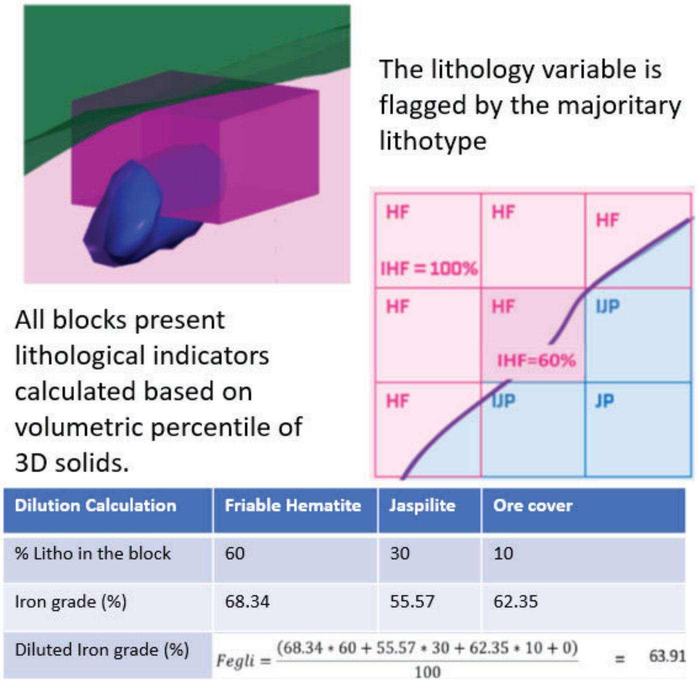
11.9.2. Dilution of grades and density

All Carajás iron ore deposits have both diluted (mass and grade) and undiluted variables. It is up to the short and long-term planning to use these variables as a function of the production scale (low operational selectivity). Dilution is calculated by weighting the block grade variables and their neighbors by the pre-established lithological indicators (Figure 11-16) and as per the following indicators.

• Limit of 0.8 for ore indicators: this value informs that if any of the informed ore indicators (ice, ihc, ihmn, ihf and ijp) is greater than or equal to 0.8, the block will not have its grades diluted. This case implies that the majority of the block is ore, making dilution unnecessary. This case occurs in blocks located in the central portions of the ore bodies and away from the contact zones between ore and overburden. If any of the indicators has a value lower than 0.8, the dilution process is applied.

• Limit of 0.4 for waste rock indicators: in this case, the sum of the values of waste rock indicators (icg, imd, imsd and ms) is considered. If the sum of the values is lower than or equal to 0.4, the dilution process is applied.

These tolerance values may vary depending on the operational flexibility and calculation method of the lithological indicators. The adoption of these values is done in collaboration between the geology and mine planning teams, both short and long term.



The lithology variable is flagged by the majoritary lithotype

All blocks present lithological indicators calculated based on volumetric percentile of 3D solids.

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.

After completing the grade estimation, grade dilution is applied (Figure 11-17) and the density is adjusted. The indicators threshold values to consider for grade dilution applied in the Serra Sul model were:

- 95% for ore lithologies (CE, HF, HMN and HC) and JP. It means that blocks with ore indicator above 95% will not be diluted.
- 40% for waste lithologies (CQ, CO, MD, MSD, MS FP, FIC and BR). The sum of waste rock indicators above 40% will not start the dilution process.

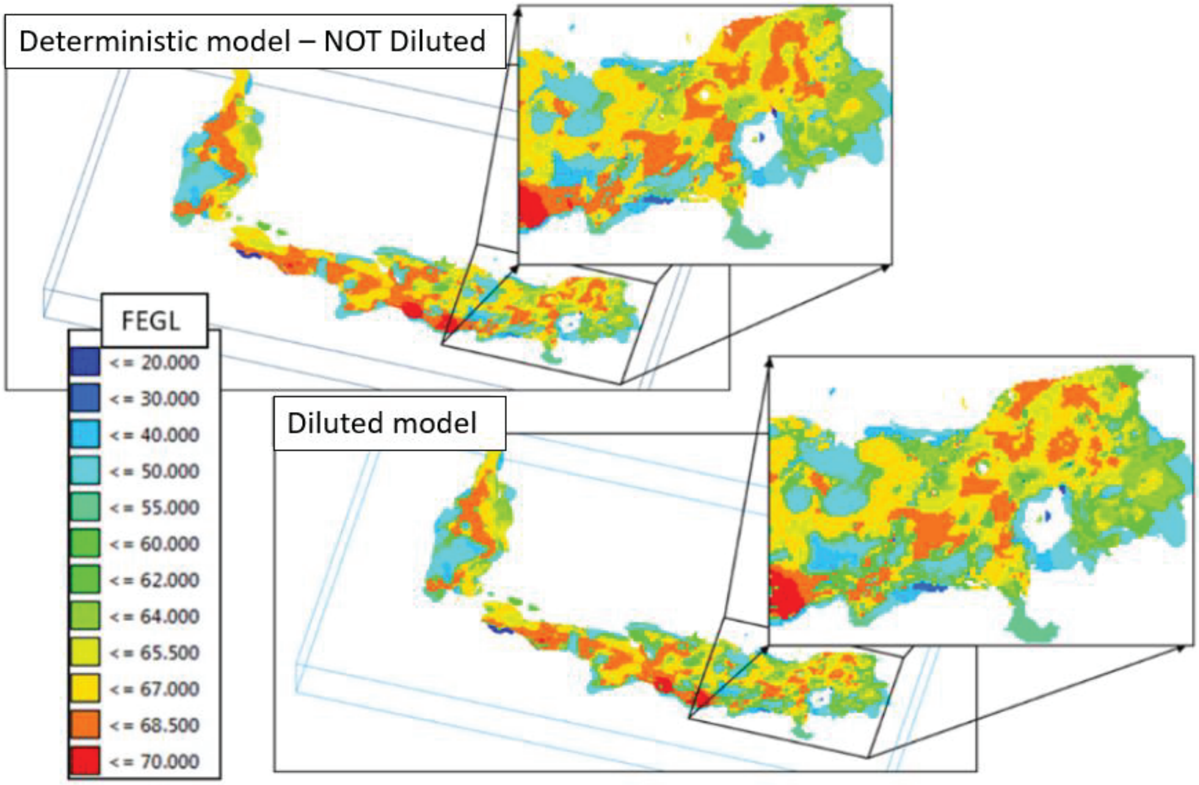


Figure 11-17 – Comparison between deterministic and diluted models for Serra Sul.

11.10. Bulk Density

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

The assignment of density values depends on the lithotype. For hematites, a combination was made between estimating geophysical parameters (density by gamma-gamma survey, variogram analysis, mineralogical calculation and variable density with depth). Lithotypes JP (jaspillite), MD (decomposed mafic), MSD (semi-decomposed mafic), and MS (fresh mafic) had their densities estimated by geophysical survey and density variable with depth. For structural canga (CE), the mean of the valid values of geophysical density was used. For the other waste and chemical canga, conventional density tests (single value) were adopted.

In Serra Sul, four different methods were combined:

- Density estimate, with the values obtained by gamma-gamma survey;
- Density derived from mineralogical density with variable porosity;
- Variable density according to the distance between the block and the topographic surface;
- Mean density value.

Table 11-4 summarizes the density values applied in the block models and 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	
Coluvium - 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 the Carajás iron ore deposits / *5 - values adopted from MS*

The moisture data adopted in the model was calculated from the reverse circulation drilling results (RC). The RC samples were sealed in the field to obtain correct moisture values. This information was consolidated using the conventional density acquisition methodology.

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

Conclusions and Recommendations

The density values for the 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 weighted by the number of samples are representative of the density of each lithotype.

The weighting considered samples from gamma-gamma logging and conventional tests.

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

11.11. Block Models

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

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

The opinion of RPM QP (2016 audit) was that the block size is appropriate, based on the drill spacing and proposed mining method, and is suitable to support the estimation of Mineral Resources and Mineral Reserves.

11.12. Net value Return and Cut-off Value

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

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

11.13. Classification

The mineral inventories of the block models for Vale iron ore deposits are classified based on the calculation of the “Risk Index” (IR), which follows the classification method proposed initially 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, combining geological continuity, measured by the “ore” kriging indicator (IK), and estimation error, measured by the variance of the indicator kriging (σ2IK), to classify the blocks into measured, indicated, and inferred. The calculation of IR is given by the following equation, which represents simplification of the original 1996 equation:

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

where:

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

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

The graphic representation of the presented equation can be seen in Figure 11-18. This figure shows the horizontal axis of geological continuity, $(1 - I_K(u))$, the vertical axis of the estimation error, (σ2IK(u)), the vector IR and the limits used for the classification into measured, indicated, and inferred blocks.

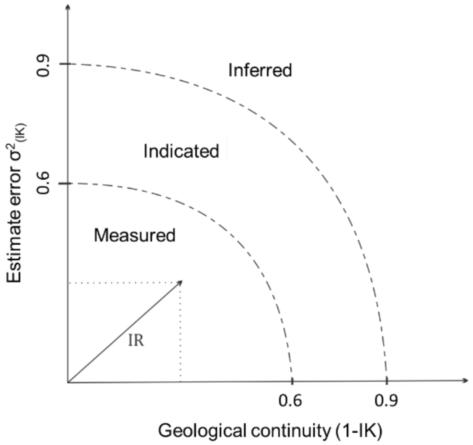
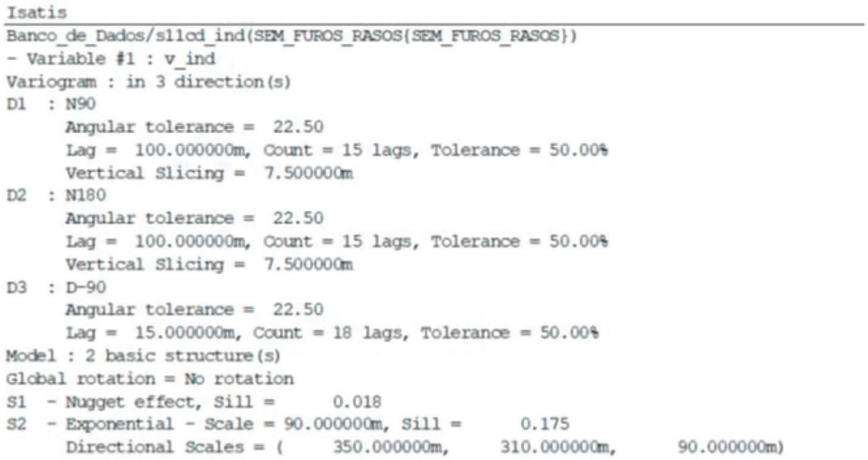


Figure 11-18 - Graphic representation of the IR calculation and class limits

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

11.13.2. Classification of the Serra Sul mineral inventory

For this deposit, the indicative variable was created with a unit value (one) for the regularized drilling intervals considered “ore” (structural canga and hematites) and zero for the lithotypes considered “waste” (chemical canga, jaspillites and mafic rocks). Figure 11-19 shows the variographic parameters applied to estimate the indicator for calculating the Risk Index for this deposit.



```
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 for calculating the Risk Index.

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

To estimate the Risk Index, composites of long-term and short-term samples were used. The distribution of indicators 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 as optimal two samples per octant, and the discretization of the blocks was 5 x 5 x 1. In this step, the variable IK (Risk Index indicator) and the IK variance for the kriged blocks were obtained during the process. The Risk Index is calculated using a script from these variables, where: up to 0.6 for measured, between 0.6 and 0.9 for indicated, and above 0.9 for inferred. The indexes are defined from the texture analysis (visual) of the block model and the comparison with an auxiliary method (dilation and erosion method).

The final classification of blocks into measured, indicated, and inferred was further conditioned to contain valid grade values; otherwise, the block is assigned as “n” (potential). Blocks classified as measured but estimated with samples from a single drill hole were downgraded to indicated.

11.13.3. Validation of Serra Sul mineral inventory classification

The validation of the classification of the mineral inventory was carried out through visual inspection, in vertical and plan sections, to notice possible inconsistencies and distortions of the method. The comparison of classification by the Risk Index method with the traditional classification by dilation/erosion from the drilling grid was also conducted (Figure 11-20).

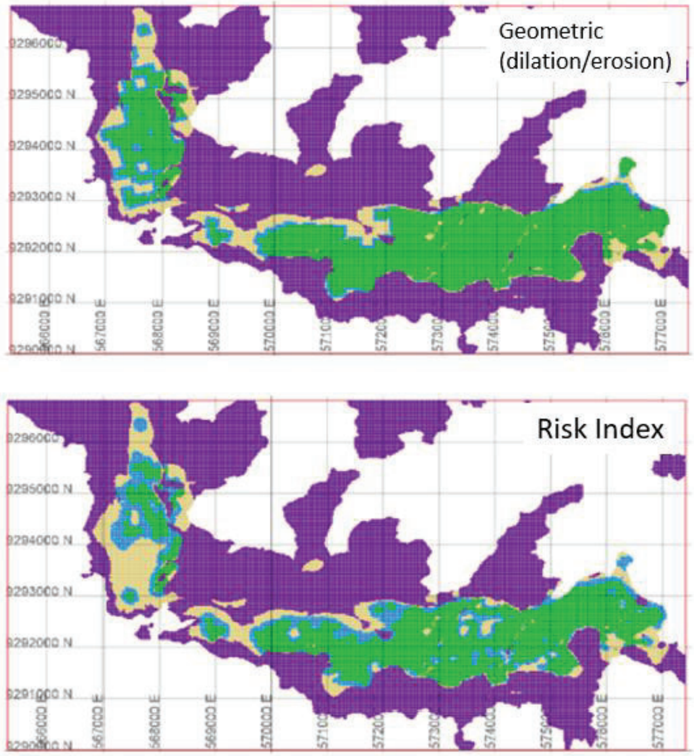


Figure 11-20 – Visual comparison between the two types of mineral inventory classification, by Risk Index and dilation/erosion for level 700.

11.13.4. Serra Sul Mineral Inventory

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

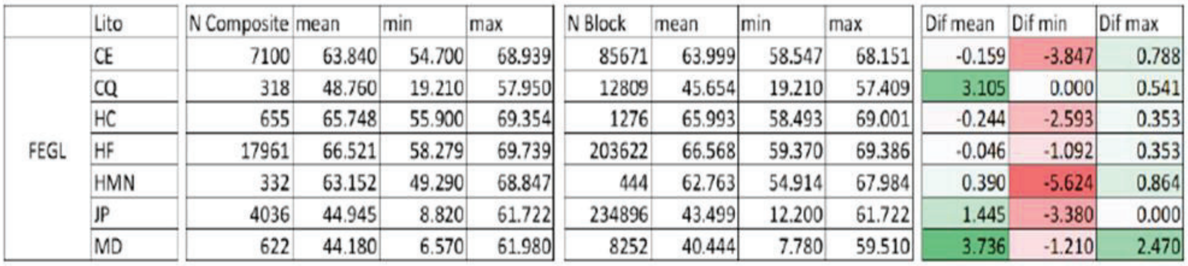
11.14. Block Model Validation

The mathematical checks made during the grade estimation step (mostly automated), and the lithological estimation require analysis and interpretation of the information generated. 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 numbers of blocks have been estimated for the same process;
- Block Length: checks whether all blocks in the model have the same dimensions, proving that the model has not been corrupted during the process;
- Sampling range: this check is made through the statistical analysis of the kriged values in comparison with the values of the composite samples;
- Drift Analysis: this check aims to validate whether there has been no bias in the estimates. A parallel estimation process was performed for the global grades and physical fractions using the nearest neighbor method during the grade kriging process;
- Visual check: it is the visual inspection of the estimated grade distribution.

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 Eventual Mineral Extraction for Serra Sul Mineral Resources

The Mineral Resource is not the inventory of all drilled or sampled mineralization, regardless of cut-off grades, likely mine dimensions, location, or continuity. Instead, it is 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 were applied to the Classified Mineral Inventory (mining method, geotechnical, process engineering, restrictions of conservation units, hydrogeological, speleological and surficial restrictions, mining rights, among others) and economic (cost and price) for delimitation of the mass that will be declared as a Mineral Resource.

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

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 long-term pricing policy of the company. The considered average moisture of the product was 8.17% in this price analysis.

The prices of products from these deposits were regularized only with the Fe grades curves above 60%, considering that Vale uses blending centers in Asia to sell its products (BRBF – Brazilian Blend Fines).

Mine costs were defined as the average cost per mined ton (ore+waste) calculated from the assumptions of mine costs and mine movements used in Strategic Planning Cycle.

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

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

11.15.3. Mineral process parameters

The recovery function and product grades take into account the use of the following materials in the current mineral processing plant:

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

Such lithotypes are grouped into the groups below:

- Hematites (HEM): hc, hf, hgo and hmn
- Rolled (ROL): ce

From these evaluations, the qualities and the respective mass recoveries, block by block, were obtained from equations provided by Vale process engineering team.

Due to the quality of the material, and as the processing will be based on natural moisture, the mass recovery was 100%.

11.15.4. Mining method parameters

Due to the characteristics of the deposit, which presents superficial to subsurface iron mineralization, low waste/ore ratio, and similarity to deposits that are already mined at the Carajás Mineral Complex, the open pit mining method was chosen.

The current mode of transporting ore and waste is through conveyor belts. However, as the current operation uses trucks for locations whose geometry is restricted, 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 slope stability evaluations have the geomechanical model considered for the mine rock mass, based on geological and structural database, as their starting point. This information is mainly collected in the geological-geotechnical description of drilling cores and surface mapping. Detailed information regarding to geotechnical procedures is presented in section 7.4.

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

Table 11-6 - Geotechnical parameters used in generating 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 reserves pit may cross the resource pit, which is perfectly acceptable due to the definitive geotechnical sectors of the mines, the geomechanical and structural characteristics of the materials, and the final design of ramps and accesses to this pit.

The demand for water in this mining complex is supplied by underground sources.

11.15.6. Waste/tailings disposal parameters

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

11.15.7. Mining/surficial rights parameters

Vale mineral rights (DM) cover the entire area of the model box, therefore, it is not a constraint for the development of a mineral resource pit. (Figure 11-22).

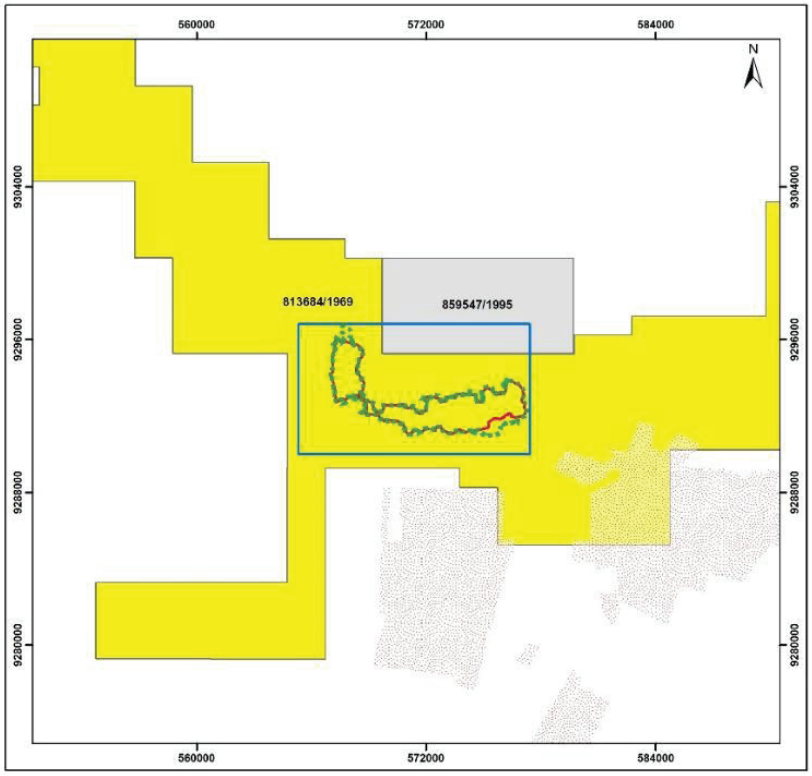


Figure 11-22 – Vale DM limits and S11 model box limits (blue polygon).

11.15.8. Environmental / sustainability / speleological parameters

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

Licenses for any expansion of this pit or opening new mine fronts encompassing the areas of the resource pit/reserves will be requested within the time necessary for the mining of these respective areas, according to the Ferrous Master Plan. Body “C” is located in the sustainable management zone, in which geological exploration is allowed. Body “D” is located in the mining zone. There are reasonable prospects for review of the FLONACA Carajás management plan in the next 10 years, expanding the mining zone and encompassing body C, allowing the mining of this body.

The buffers with a radius of 150 m around the most relevant iron ore caves, categorized as maximum relevance with low probability of change, and the buffer around two lakes and the water contribution area were considered environmental restrictions.

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 according to the production needs.

11.15.10. Mineral Resource

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

Due to the restrictions imposed by the described environmental limits and the economic reasonability, not all mineral inventory was converted to mineral resources. The resource/inventory conversion rate for Serra Sul models were greater than 83%.

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

Table 11-7 shows the tonnages and grades of the total Mineral Resource exclusive of Reserves considering the optimized pit.

Table 11-7 - Mineral Resources (exclusive of Mineral Reserves)

Mineral Resources exclusive of Mineral Reserves	**Measured**		**Indicated**		**Inferred**		**TOTAL**	
Lithology	**Tonnage (Mt)**	**FeGL (%)**	**Tonnage (Mt)**	**FeGL (%)**	**Tonnage (Mt)**	**FeGL (%)**	**Tonnage (Mt)**	**FeGL (%)**
CE	12.4	63.2	25.8	63.7	12.3	62.3	50.5	63.2
HC	2.1	65.0	0.9	63.3	-	-	3.0	64.5
HF	447.7	66.2	349.6	64.7	108.6	64.5	905.9	65.4
HGO	16.3	64.7	11.0	63.8	2.5	63.0	29.8	64.3
HMN	1.3	60.0	0.7	58.4	0.1	56.7	2.1	59.4
TOTAL	**479.9**	**66.0**	**388.0**	**64.6**	**123.5**	**64.3**	**991.3**	**65.2**

The Mineral Resource estimate (exclusive of Mineral Reserves) is effective as of December 31, 2021 of in situ material. The estimate of Mineral Resources (exclusive of Mineral Reserves) is between the minimum topographic base between October, 2018 and September, 2021, delimited by the resource pit with economic reasonableness. The iron grade is expressed on a dry basis, and the mass is on a natural basis.

The generation of the resource pit was obtained using economic, legal, geotechnical, environmental, and other modifying factors.

The totals in the presented table are rounded to reflect the uncertainty of the estimate. The values for total of tons and grades may differ due to this rounding.

Mineral Resources are in accordance 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.

11.15.11. Conclusions and Recommendations

Upon assessment of the resource pit geometry, it can be seen that it is fully adherent to the resource classification and limited by environmental constraints (lakes and iron ore caves). Despite these restrictions, there is potential to convert inferred to measured+indicated resources and increase Mineral Resources, especially around the lakes and in the body referred to as C.

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

11.15.12. Uncertainties that may affect the mineral resource estimate

- Areas of uncertainty that may materially impact all the mineral resource estimates include:
- Changes in long term metal price and exchange rate assumptions;
- Changes in local interpretations of mineralization geometry with additional drillings campaigns; faults, dykes and other structures; and continuity of ore bodies;
- Changes in geological and grade shape, and geological and grade continuity assumptions;
- Changes in variographical interpretations and search ellipse ranges which have been interpreted based on limited drill data, when closer-spaced drilling becomes available;
- Changes in metallurgical recovery assumptions;

12. Mineral Reserves

12.1. Summary

Table 12-1 summarizes the Mineral Reserve estimate effective as of December 31, 2021.

Table 12-1: Mineral reserve estimate

Pit/Operation	Classification	Tonnage (Mt)	Fe (%)
S11	Proven	1,825.8	66.0
	Probable	2,447.2	65.6
	Total Proven + Probable	**4,273.0**	**65.8**

Notes to accompany mineral reserves tables:
1. The effective date of the estimate is 2021/Dec/31.
2. Tonnage stated as metric million tons inclusive of 7.22% of moisture content and dry %Fe grade. The point of reference used is in situ metric tons.
3. The mineral reserve economic viability was determined based price curve with the long-term price being US$70/dmt for 62% iron grade.
4. The estimate assuming open pit mining methods uses the following key input parameter: mining cost 2.3 US$/t mined; process cost from 1.02 US$/t processed; other cost include sells cost from 30.2 US$/t product, variable mass recoveries; Mining recovery of 96.4% and dilution of 1.35%.
5. Numbers have been rounded.

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

Reserve modifying factors were first added to the optimization software. The software NPV Scheduler® was used to generate the pit shell but there is no economic cut-off grade applied to the mineral reserve and this is mainly because of the grade of the resource, which has average of 60% Fe, and the recovery factor is 100% because there is no process for concentration at S11D, thus, all material is treated as ore. Environmental constraints, the presence of iron ore caves and the limits to mining concessions are also uploaded to NPVScheduler prior to the pit optimization.

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

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

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

12.2. Methodology

12.2.1. Dilution

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

12.2.2. Mining Recovery

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

12.2.3. Net Value Return and Cut-off Value

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

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

Costs and other parameters used to calculate the cut-off grade are shown in Table 12-2. The cut-off grade is 10% considering plant parameters. There is no economic cut-off grade applied to the mineral reserve and this is mainly because of the grade of the resource, which has average 60% Fe and is above an estimate of the cut-off grade. The cut-off is not material to the estimate of the Reserves nevertheless, a check is made.

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

Item	Units	Parameters
Metallurgical Recovery	%	100
Fe Product Payable	%	65.5
Price	US$/t product	64.2
Mining Cost	US$/t rock.	2.3
Processing Cost	US$/t fed	1.02
Selling Cost	US$/t product	30.2

12.2.4. Costs

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

Table 12-3 - Modifying factors for pit optimization

Item	Unit	Costs
Mining cost - Ore	US$/t $_{ore}$	2.30 to 4.78
Mining cost - Waste	US$/t $_{waste}$	2.41 to 4.89
Processing Plant	US$/t crusher feed	1.02
Other Costs	US$/t product	30.2
Vertical rate cost	US$/m	0.0045
Mining recovery	%	96.4
Mining dilution	%	1.35

12.2.5. Price

The price curves are provided by Vale Market department and elaborated from a market estimated price model, upon which client characteristic, offer and demand for iron ore transoceanic, bonus and the deleterious according to the quality of the product are considered. As a reference price it was used US$ 60/dmt (62% Fe) which varies according to the iron ore grades.

12.2.6. Caves

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

12.2.7. Mass Recovery

A constant recovery factor of 100% was used as there is no concentration in the process. Historical data based on mass balance in and out is used.

12.2.8. Wall Slope Angles

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

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

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

12.3. Factors, which might affect the mineral reserve estimate

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

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

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

13. Mining Methods

13.1. Summary

Serra Sul has been operating since 2016, with production rates of approximately 80 Mtpa in the recent years. It is mined by open pit with berms and benches and uses large truck, shovel equipment and also In Pit Crusher Conveyor (IPCC) mining method.

13.2. Mine Design

The mine design includes benches 15m high, berms 15m wide, bench face angles from 50 to 85 degrees, according to the lithology in the mine. Ramp access is 40m width with 10% gradient. The open pit design is presented in Figure 13-1.

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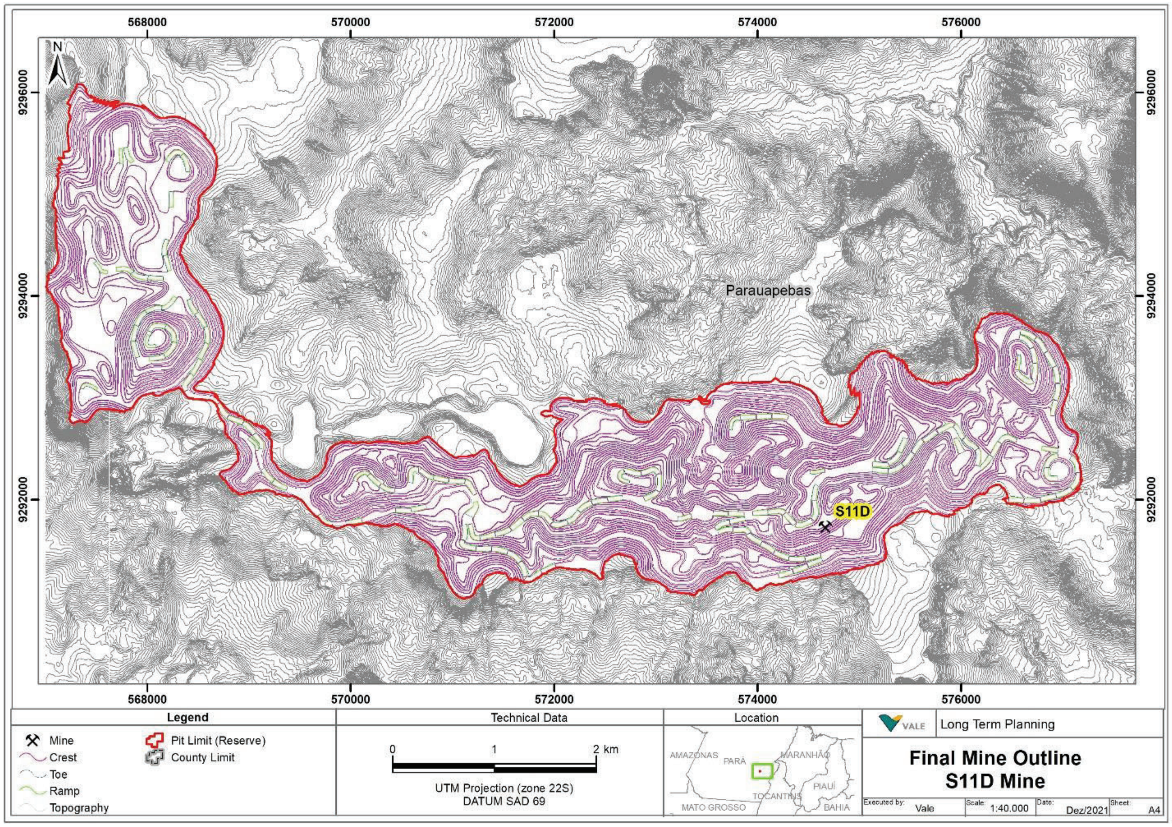


Figure 13-1: Open pit design

13.3. Mine Method

The mining method at Serra Sul is open pit. Materials that require drilling and blasting and whose geometry does not favor to IPCC, are mined by normal truck and shovel, otherwise IPCC mining method is applied.

The movement of material is done by electric cable and/or hydraulic excavators into mobile crushers. The mobile crushing plants are equipped with a “sizer” (friable materials) or jaws crushers (compact material). Once the particle is reduced to the appropriate size for the conveyor belt, both the ore and the waste are sent to a transfer house where the conveyors are provided with a mobile head and adjust to transfer the ore onto a belt that takes it to a stockpile and the waste to another belt that sends to spreaders, which build the waste dumps.

13.4. Geotechnical Considerations

Final slope design geotechnical evaluations are developed by internal team and follows the methodology presented in section 13.4.1. To support the geotechnical assessments for S11D, previous evaluations were used: Vale in 2020, VOGBR in 2008, Golder in 2012 and 2013, Geominas in 2017, SRK in 2020, MDGEO in 2020 and TEC3 in 2020.

For S11C, VOGBR completed a geomechanical 2D modelling exercise and evaluation of the overall stability conditions within the mine and for S11D, SRK completed a geomechanical 3D modelling exercise. These assessments provide recommended design standards for the ultimate pit and end of period designs.

13.4.1. Geotechnical Overview

The main lithological units have been described and modelled with acceptable detail to support geotechnical characterization and hazard evaluation related to mining activities. As for the used mining method (Open pit), the rock mass conditions are well understood and appropriate for the current mining depths, the rock reinforcement types, and geotechnical input into the mine production.

The geotechnical mapping and data analysis protocols include standard practices of the industry, such as detailed descriptions of the different structural domains and their characteristics based on field mapping, geological modelling, and limited geotechnical core drilling.

The geotechnical evaluation for the S11C ultimate pit were sourced from the 2D geomechanical model elaborated by WALM in 2008, and for S11D, elaborated by SRK in 2020. This model permits evaluation of the rock mass response in terms of slopes and mine workings stability.

The used 3D Geomechanical model was compiled by including logging from the geotechnical drill holes and mapping carried out by SRK in 2020

13.4.2. Geotechnical and Rock Mass Models

The S11D geomechanical model was built according to RMR and Weak Rock classifications, subdividing the rock mass in the following classes: I, II, III, IV, Weak, Very Weak and Extremely Weak. Meanwhile, S11C geomechanical model was built according to RMR classification, subdividing the rock mass in the following classes: I, II, III, IV, V and VI. The structural mapping, presenting the main structures domains and their respective stereonets and the reports with general information used to build the geomechanical and structural models for Serra Sul mine sites are summarized in Table 13-1.

Table 13-1 - Summary reports used to build structural model and 3D geomechanical model – Serra Sul Mine Complex

Mine	Consultants responsible for Structural Mapping and Geomechanical Model	Year of Structural Mapping / Year of Geomechanical Model	Drillholes with geotechnical assay		Surface Mapped Points	Geomechanical Vertical Sections
			Amount of drillholes	Total drilled (m)		
S11C	VOGBR	2008	20	2,800	None	6
S11D	SRK & GEOESTRUTURAL / SRK	2020 / 2020	1,585	286,127	414	80

The geotechnical parameters were defined according to the lithotype obtained from the geological model, the rock mass classification from the geomechanical model and the structural features (anisotropies and discontinuities) were obtained from structural mapping and geological sections. The strength laboratory tests report used to define the geotechnical parameters used in S11C and

D slope stability analysis is summarized in Table 13-2. For the lithotypes without tests in the evaluated mine, the parameters of nearby mines with similar lithostratigraphic, tectonic, and geomechanical contexts were used.

Table 13-2 - Geotechnical laboratory tests 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

13.4.3. Hydrological Model

The Surface Drainage Master Plan with the layout and device sizing was developed in 2020 by TEC3 (MD-1016KS-X-00001-00) for S11C and S11D pits.

13.4.4. Slope Stability Analysis

For the slope design evaluation of S11C nine geomechanical vertical sections that crossed all geomechanical domains of this mine were used. For S11D, the evaluation was based on compiling and interpretating fourteen geomechanical vertical sections.

With the ultimate pit design and the geomechanical model, Vale carried out studies to determine possible mechanism of failure with the adopted geotechnical parameters, in some sections along the pit, to verify the safety factor for stability analysis for each mine.

Deterministic limit equilibrium analyses were made to assess potential translation failures (circular and non-circular), based on geotechnical model, and the water level used were presented at Chapter 13.5.

These analyses were made along the entire pit, based on the representative sections of conditions that may influence instabilities (critical sections) in the inter-ramp or overall scale and the evaluated cross sections. Figure 13-2 shows the sections locations and Table 13-3 - Factor of safety and other information from S11C final pit slope design. Table 13-3 shows the main analysis information and results.

The main failure mechanisms identified along Serra Sul Complex Mines are circular and non-circular mainly at Friable Hematites and Weathered Mafic, predominantly classified as Weak in the geomechanical model. In S11C, the failure surfaces were influenced by the contacts between Weathered Mafic/Fresh Mafic and Iron Formation/ Fresh Mafic. Meanwhile, in S11D, the failure surfaces were conditioned by the lower intact rock strength materials.

The summary of the slope stability analyses results represented by FoS, the near mine interferences considered in each section and other information are presented in Figure 13-3 showing the sections locations and Table 13-4 shows the main analysis information and results.

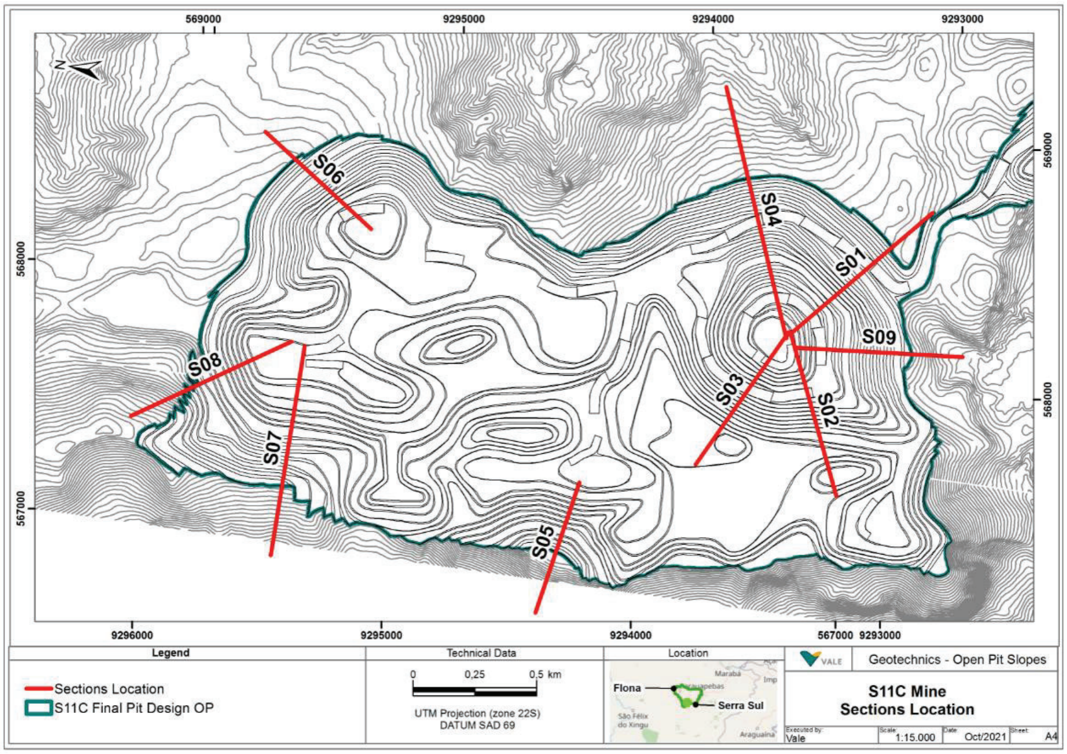


Figure 13-2 - Slope stability analysis cross section location – S11C Mine.

Table 13-3 - Factor of safety and other information from S11C final pit slope design

Pit	Section	Acceptable criteria		Results			
		FoS (required)	Near mine interference	FoS	Surface Type	Failure Scale	Failure Trigger
S11C	S01	1.30	-	1.65	Non-Circular	Bench scale	Intact rock strength
	S02	1.30	-	1.63	Circular	Bench scale	Intact rock strength
	S03	1.30	-	1.61	Planar	Inter-ramp	Anisotropic rock mass
	S04	1.30	-	1.33	Non-Circular	Overall	Geological regional contact
	S05	1.30	-	1.36	Circular	Overall	Intact rock strength
	S06	1.30	-	1.52	Planar	Inter-ramp	Anisotropic rock mass
	S07	1.30	-	1.31	Non-Circular	Overall	Geological regional contact
	S08	1.30	-	1.30	Non-Circular	Overall	Intact rock Strength and Geologic regional contact
	S09	1.30	-	1.43	Non-Circular	Overall	Intact rock Strength and Geologic regional contact

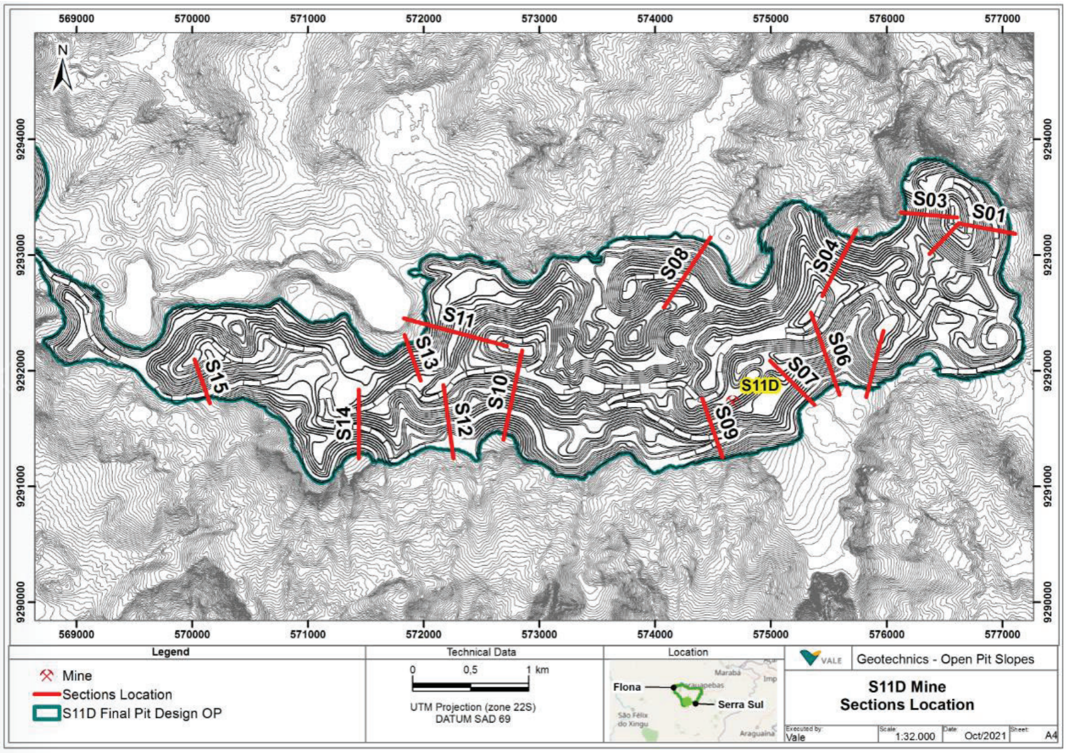


Figure 13-3 - Slope stability analysis cross section location – S11D Mine.

Table 13-4 - Factor of safety and other information from S11D final pit slope design

Pit	Section	Acceptable criteria		Results			
		FoS (required)	Near mine interference	FoS	Surface Type	Failure Scale	Failure Trigger
S11D	S01	1.30	-	1.59	Circular	Inter-ramp	Intact rock strength
	S02	1.30	-	2.14	Non-Circular	Bench scale	Intact rock strength
	S03	1.30	-	1.40	Circular	Inter-ramp	Intact rock strength
	S04	1.30	-	1.32	Circular	Overall	Intact rock strength
	S05	1.50	Industrial facilities	1.53	Circular	Overall	Intact rock strength
	S06	1.30	-	1.30	Circular	Inter-ramp	Intact rock strength
	S07	1.30	-	1.47	Circular	Inter-ramp	Intact rock strength
	S08	1.30	-	7.09	Planar	Bench scale	Geologic regional contact
	S09	1.50	Conveyor belt	1.70	Non-Circular	Overall	Intact rock strength
	S10	1.30	-	1.34	Circular	Overall	Intact rock strength
	S11	1.30	-	1.39	Non-Circular	Overall	Intact rock Strength and Geologic regional contact
	S12	1.30	-	1.30	Circular	Overall	Intact rock

							strength
	S13	1.30	-	1.46	Circular	Overall	Intact rock strength
	S14	1.30	-	1.39	Circular	Overall	Intact rock strength
	S15	1.30	-	1.73	Circular	Bench scale	Intact rock strength

13.4.5. Comment on Results

The slope stability analyses made in Serra Sul Complex mines (S11C and S11D) obtained satisfactory safety factor, superior to the minimal international standards (Read & Stacey, 2009). Therefore, the proposed geometry was considered geotechnically practicable.

13.5. Hydrogeological Considerations

13.5.1. S11C and S11D Hydrogeological Model

The numerical modelling software MODFLOW (MDGEO, 2020) was used for the simulation of water table drawdown. The simulated outflow will be about 1,138 m³/h, of which, a portion of 260 m³/h in the pit of orebody C and another 878 m³/h in the pit of orebody D. Total of 92 instruments were used to calibrate the model, and the resulting root mean square error (nRMS) was 4.4%.

Figure 13-4 shows the equipotential (20 in 20 m) generated in the simulation of the maximum drawdown condition and the direction of groundwater flow. Those surfaces were used as input for stability analysis.

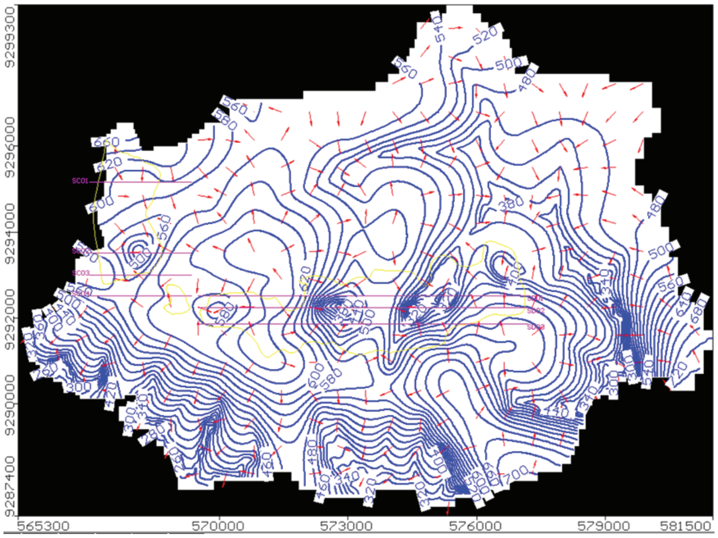


Figure 13-4 - Equipotentials of the water level resulting from the simulation of the maximum drawdown of the long-term horizon (final pit) — layer 20, referring to elevation 270 m — S11.

Figure 13-5 shows the water table (equipotential) below final pit.

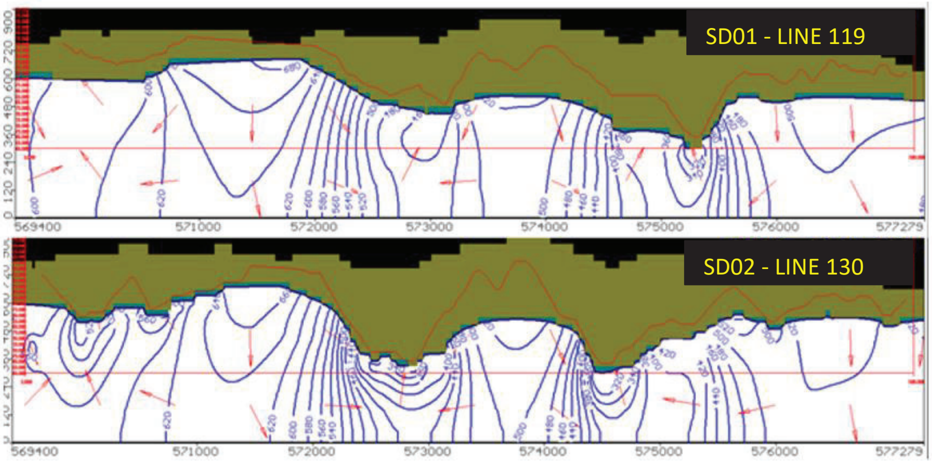


Figure 13-5 - Cross sections of maximum drawdown.

13.6. Life of Mine Plan

The life of mine production plan is shown in Figure 13-6. The production from 2022 through 2062 will include approximately 4,3 Bt with average grades of 66.07 % FeGL, 1.7 %SiO2GL, 0.9 %Al2O3GL, 0.059 %PGL, 2.6 % LOI. Strip ratio for the LOM is 0.2.

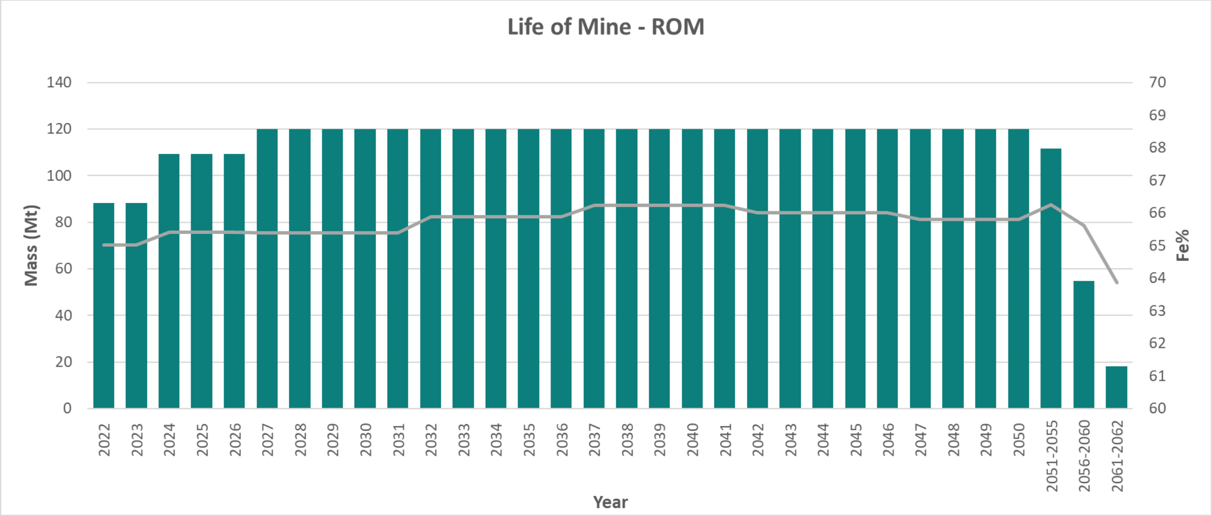


Figure 13-6: Life of Mine vs Fe grades

13.7. Infrastructure

13.7.1. Workshops

There is a complete maintenance workshop in the Serra Sul area equipped with bays for large mobile equipment, as well as workshops for machining, maintenance of diesel generators, electrical, electronics; warehouse and tooling. Its construction is a metallic structure and there is an office and a locker room attached to the shed, built of masonry. In areas adjacent to the General Maintenance Workshop shed, the Lube Bay, the Vehicle Washing Bay, the Tire Shop, the Heavy and Light Vehicle Refueling Station, the Parking Lot and the patio are located.

13.7.2. Laboratory

All quality control of the ore is carried out using the structures of Serra Sul, where physical tests and assays of the entire production chain are carried out.

13.7.3. Offices

Masonry offices are grouped in the administrative areas of Vale S.A. and its contractors. It is made up of offices for senior management, management, coordination, meetings, technicians, files, reception, and restrooms, which serves all administrative personnel.

13.7.4. Warehouses

The warehouse shed, built partly of masonry and partly of metallic structure, is surrounded by an outdoor area surrounded by gates. The covered area includes service desks, offices and restrooms and the external area for storage of materials at the time, includes annexes for the storage of lubricants, fuels and tires. The fuel storage is equipped with horizontal tanks for filtered diesel, with drainage basins and a water-oil separation system.

13.7.5. Meal Room

A meal room has been implemented to serve all staff, both in-house and outsourced, to provide lunch, dinner and snacks. Its operation is outsourced by Vale in a way similar to that adopted in other operating units of the company.

13.7.6. Clinic

The clinic is installed in a masonry construction and is intended to house a small office for first aid care and a rest room. The clinic is equipped for first aid care, and the more serious cases are sent to the existing hospital in the urban center, for which an ambulance is available parked next to it with a driver on permanent standby.

13.7.7. Firefighting System

The firefighting water is stored in concrete tanks, divided into two compartments that allow the tank to be cleaned, keeping half of the fire water reserve available for use.

Fire hydrants are located at strategic points, in addition to a fire truck parked 24 hours at the entrance.

13.7.8. Housing

The entire staff of the company resides in the town of Canaã dos Carajás.

13.8. Mine Equipment

The peak requirements for primary and auxiliary mining equipment is shown in Table 13-5.

Table 13-5: Mining Equipment

Equipment	Units
Crusher	9
Hooper	2
Spreader	2
Connecting conveyor	6
Belt wagon	4
Mobile Conveyor	11
Loading	19
Hauling	26
Drilling	16
Auxiliary Equipment	77

13.9. Workforce

The workforce of Serra Sul consists of company personnel and contractors. Vale personnel and the list of main contractors for mining operations are presented in Table 13-6 and Table 13-7, respectively. The number of Vale employees required for mining operations is not expected to change significantly for the foreseeable future. The number of contractors varies month to month depending on the labor requirements at the mine site.

Production is carried out by the company´s mine personnel, while contractors carry out the auxiliary services. Administrative staff works on 5x2 roster in 8 hours shift and operation and maintenance on a 3x3 roster in 11h shift.

Table 13-6: Vale's workforce

Serra Sul	Manager	Supervisor	Coordinator	Staff and Technical Specialist	Total
Mine	10	45	6	1,059	1,120
Plant	6	43	8	998	1,055
Others	2	9	7	187	205
Total	18	97	21	2,244	2,380

Table 13-7: Contractor's workforce

Serra Sul (Contractors)	Permanent	Project	Part time	Total
Mine	136	2	10	148
Plant	0	0	3	3
Others	1,398	328	90	1,816
Total	1,534	330	103	1,967

14. Processing and Recovery Methods

14.1. Summary

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

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

The average mass recovery, utilization, and capacity is shown in Table 14-1.

Table 14-1: Plant recovery, utilization and capacity

Metallurgical Recovery (%)	Physical Utilization (%)	Nominal Capacity (Mta)
100	79.9	90.0

The Truckless System delivers ore to a homogenization stockpile. After the pile, the material is directed to the primary screening where the oversize (+90 mm) is directed to the secondary crushing and the undersize together with the secondary crushing product is sent to the tertiary screening. The tertiary screening oversize (+19 mm) is directed to tertiary crushing where the product of this crushing returns as circulating load and the undersize of the screening constitutes the final product.

The ore is processed in the primary screening, consisting of 6 vibrating screens. The oversize of the primary screen (+90 mm) is directed to the secondary crusher, consisting of 6 cone crushers. The tertiary screen underflow constitutes the fine product. A simplified flowsheet is shown in Figure 14-1.

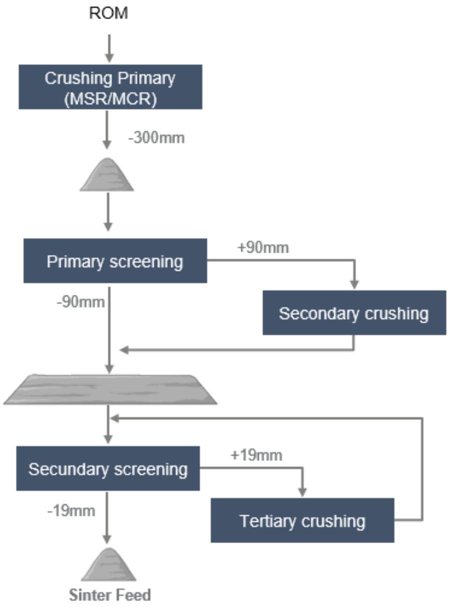


Figure 14-1: Simplified flowsheet.

14.2. Production, recovery, quality and equipment

Table 14-2 summarize the current production, quality, and recovery of the Plants I, II and III, and Table 14-3 summarizes the main process equipment list for each plant.

Table 14-2 - Production, recovery and quality carried out

Product	Production (Mt)	Fe (%)	SiO2 (%)	Mass Recovery (%)
2016	0.38	66.22	1.39	100
2017	22.2	65.9	1.06	100
2018	58.0	65.2	0.96	100
2019	73.4	65.06	1.31	100
2020	82.8	64.64	1.58	100
2021	73.7	64.49	2.02	100

Table 14-3 - Equipment list

Unit operation	Quantity	Type of Equipment	Dimensions/Model
Primary Crushing	6	Vibrating screen	12' x 28'
Secondary Crushing	6	Cone crusher	CS440
Secondary Screening	30	Vibrating screen	8' x 32'
Tertiary Crushing	12	Cone crusher	CH660

14.3. Logistics

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

The EFC ("Estrada de Ferro Carajás") railroad connects the productive complexes of Serra Norte (Mina de Carajás), Serra Sul (Mina do S11D) and Serra Leste, all located in the Brazilian state of Pará, to the Ponta da Madeira port complex, in São Luís, Maranhão State. The trains are loaded at Carajás terminal or Serra Sul terminal. The unloading process takes place at the Ponta da Madeira terminal.

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

15. Infrastructure

The in-situ and operating infrastructure at Serra Sul includes the following:

- An open pit mine accessed by 3 main ramps;
- Surface ore stockpiles and waste rock dumps;
- A 90 Mtpa processing plant;
- Main site power supply;
- Site access roads;
- Mine workshops, offices, warehouse facilities

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

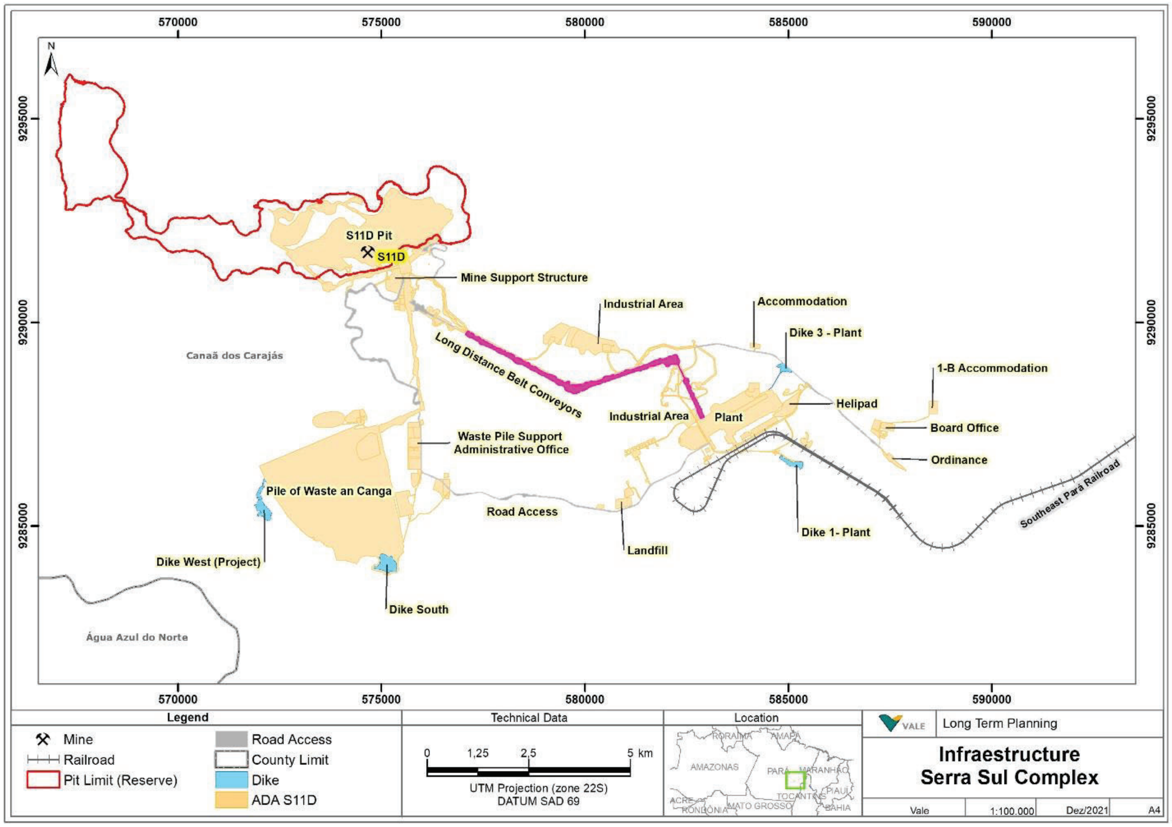


Figure 15-1: Mine site infrastructure map

15.1. Site Access

Provided in chapter 3.

15.2. Power Supply

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

The internal distribution system is carried out through Vale's 34.5KV networks. In 2020, the consumption of the Plant and the Mine was around 281,385 MWh, of which 63.1% were fed to the mineral processing plants, 28.8% were consumed in the mine and the remaining 8.1% were consumed by other support structures.

15.3. Water Supply

S11D has a permit for up to 21 boreholes for dewatering and water supply, and by August 2021, a total of eight deep tubular wells were drilled, located on the S11D plateau.

These boreholes are between 210 and 330m deep and have flows varying from 67 to 250m^3/h. Currently, only six wells are in operation and two are waiting for the completion of the electrical infrastructure at the site. The estimate is that by December 2022, the remaining will be in operation. The average pumping flow is 800m^3/h, and is expected to reach 1100 m^3/h when all eight wells are in operation.

15.3.1. Industrial Water Collection and Supply

Water consumption is estimated at around 0.0176 m^3/ton per crusher feed. The water catchment sites come from the mine wells, small diameter wells located in offices outside the mine and at the Igarapé Sossego catchment.

15.3.2. Drinking Water Supply System

There are two wells located in the mine, close to industrial areas, which pump into a fire reservoir, which flows, when full, to a raw water reservoir. From this raw water reservoir, the water is distributed to a filling station for water trucks. Another part is supplied to the mine water treatment plant, WTP, where it is stored in another treated water reservoir and distributed for use in offices, workshops, restaurant and drinking water.

The other four wells in operation were drilled in the pit area, with the purpose of lowering the aquifer, with 90 to 95% directed to the Igarapé Sossego and another 05 to 10% directed to the dust control on roads.

15.4. Site Buildings

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

15.5. Mine Waste Management

15.5.1. Tailings Management

There is no generation of tailings at Serra Sul as it uses a dry process to produce ore.

15.5.2. Tailings Storage Facility

As there is not wet process at Serra Sul, no Tailings storage facility is built on site.

15.5.3. Waste Dumps

Waste rock from the open pit is dumped on surface at a single location shown in Figure 15-2. The Serra Sul medium to long-term waste rock disposal plan consists of a triangular-shaped waste pile with capacity of 641 Mm3, located 4.7 km far from the mine, between the transfer house (CT1) and the belt pivot point.

The waste is transported by two belts called TR-1083KS-02 and TR-1084KS-02, where it is stacked using Spreader equipment, consisting of a rolling system and a stacking boom. Spreaders work connected along the belt via a bridge which directs the material flow to the stacking system. The waste dump is built using longitudinal low dump and high dump stacking, using a segment belt as shown in Figure 15-2.

Figure 15-2: S11D waste dump location

16. Market Studies

16.1. Markets

16.1.1. Introduction

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

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

Under the economic recovery from the pandemic, iron ore prices faced a price fly up moment in the first half of 2021, as the demand recovery largely overpassed supply. In the second part of the year the energy crises in the main markets helped balance demand and supply bring iron ore prices closer to its cost support.

16.1.2. Demand

China has been the main driver of global demand for minerals and metals over recent decades. In 2021, Chinese demand represented 74% of global demand for seaborne iron ore. Therefore, any contraction of China's economic growth or change in its economic profile could result in lower demand for our products, leading to lower revenues, cash flow and profitability.

In 2021, China's crude steel production was 1032.79 Mt, a decrease of -3% year-on-year. The economic recovery in the country continued in 2021, with GDP growth rate reaching 8.1% year-on-year in 2021 vs. 2020. Industrial production and exports continued outperforming in the fourth quarter of 2021. GDP growth in the fourth quarter of 2021 reached 4.0% year-on-year, slowing from 4.9% year-on-year in the third quarter of 2021, as Fixed Asset Investment (FAI) moderated in fourth quarter driven by property and infrastructure. In the rest of the world, easing of restrictions with the rollout of vaccines, rebound of economic activity, manufacturing and supply chain improvements in 2021 contributed to steel demand leading to a total steel production of 879.1Mt, an increase of 12.1% year-on-year. Major steel producing regions such as Brazil and EU28 have fully recovered compared to pre-pandemic levels of 2019 whereas JKT and USA are still slightly below pre-pandemic levels.

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 2022, the World Steel Association (WSA) forecast in October 2021 that steel demand should grow by 2.2% to 1,896.4Mt. Demand is expected to continue and strengthen its recovery momentum following reduction in supply chain bottlenecks, continued pent-up demand and rising business and consumer confidence.

In China, a weaker real estate sector and government environment targets might limit growth in steel output in 2022. While rising inflation and demand deceleration in China can present a downside risk, progress on vaccinations across the world and potential new variants being less damaging and disruptive compared to previous waves can support the recovery trend.

For the longer term, the slow down on China's economic growth might impact iron ore demand.

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.

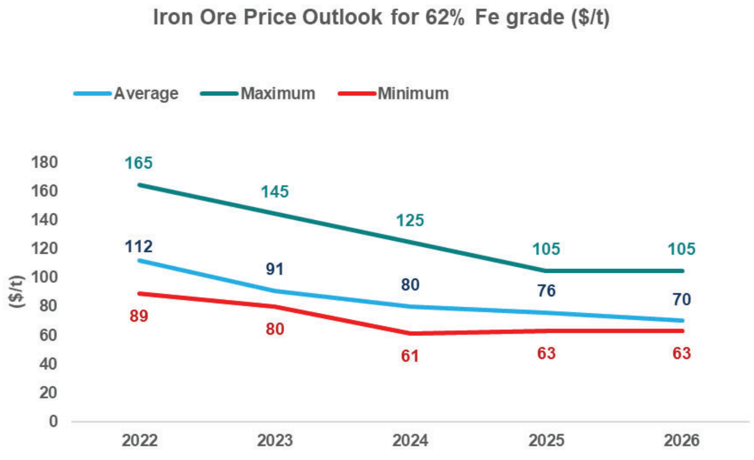
Our main competitors are different locations than our sites and compete with Vale mainly on their regional markets. For the Asian market, the main competitors are in Australia and include subsidiaries and affiliates of BHP, Rio Tinto Ltd ("Rio Tinto") and Fortescue Metals Group Ltd. For the European 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 for the local steel production.

While for 2022 there is no relevant iron ore capacity addition from main competitors, 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, to depletion, as several iron ore reserves are located in countries differently from the nationality of the mining company, the risk of nationalization of the reserves and operations it is present, as it happened in the past, as new iron ore frontiers will need to be explored to attend global demand.

16.1.4. Price outlook

Looking into 2022, most analysts expect that China policymakers will continue their strict control on crude steel production at least during the first quarter, when the Winter Olympic games will be held in Beijing and the country will focus on keeping air quality at higher levels and blue sky during the event. However, if China does not relax its stance against property speculation and deleveraging developers in 2022, most analysts believe that investment in infrastructure will be brought forward to sustain GDP growth. This should be positive for steel demand in 2022, supporting iron ore prices during the year.

By the time this report was prepared, the price consensus for iron ore prices at 62% Fe in 2022 of the analysts was $112/t (table below – prices in USD), with a downward trend going forward until prices reach the long-term level of around $70/t. Additionally, we believe that the expected future production, relative to our iron ore reserves, can be absorbed by the market in the long term given the expected demand by market analysts. Figure 16-1 shows the iron ore price for 62% Fe.

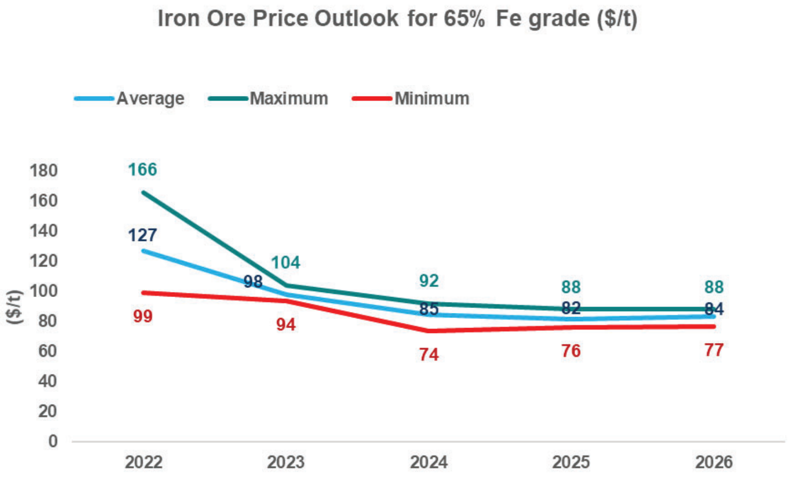


Source: Bank reports published between September and October 2021

Figure 16-1 - Iron ore 62% prices (US$/dry metric ton).

The price differential between the 65% index and the 62% depends on a few market-based driven 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. In recent years, clear evidence of this point was the implementation of the winter cuts in China, where steel production was curbed to reduce emissions. The cut on steel supply led to higher steel prices that were followed by a spike on the 65% price differential. In 2021, the higher steel margins and high coking coal prices lift the 65% premium to historical highs.

By the time this report was prepared, the price consensus for iron ore prices at 65% Fe in 2022 of the analysts was $127/t (table below – prices in USD), with a downward trend going forward until prices reach the long-term level of around $84/t. Figure 16-2 shows the iron ore price for 65% Fe.



Source: Bank reports published between September and October 2021

Figure 16-2 - Iron ore 65% prices (US$/dry metric ton).

As the trend for 2022 for both steel margins and coal/coke prices remain positive, 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)

	2022	2023	2024	2025	LT
VIU per additional percentage point Fe	1.81	1.46	1.28	1.22	1.13

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

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

	2017	2018	2019	2020	2021	Average*
Platts iron ore 62% Fe IODEX CFR China	71.3	69.5	93.4	108.9	159.5	100.5

16.2. Contracts

16.2.1. Northern System operations TRS: logistics/distribution contracts

We operate the EFC railroad under a concession agreement, which has been recently renewed and will expire in 2057. The EFC railroad links our Northern System mines in the Carajas region in the Brazilian state of Para to the Ponta da Madeira maritime terminal, in São Luis, in the Brazilian state of Maranhão.

We rely on long-term contracts of affreightment to secure transport capacity and enhance our ability to offer our products in the Asian market at competitive costs on a CFR basis. To support our commercial strategy for our iron ore business, we have long-term agreements with seventeen ports in China, which also serve as distribution centers.

16.2.2. Northern System operations TRS: logistics – full

Our production from Serra Sul is transported by railway to the port through Carajás railroad (''EFC''). The EFC railroad links our Northern System mines in the Carajás region in the Brazilian state of Para to the Ponta da Madeira maritime terminal, in São Luis, in the Brazilian state of Maranhão. We operate the EFC railroad under a concession agreement, which has been recently renewed and will expire in 2057. EFC extends for 997 kilometers from our 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 2021, the EFC railroad transported 188,335 thousand metric tons of iron ore. In 2021, EFC had a fleet of 298 locomotives and 21,175 wagons, which were operated by Vale and third parties.

We operate ports and maritime terminals mainly to complete the delivery of our iron ore and iron ore pellets to bulk carrier vessels serving the seaborne market. Production from Serra Sul is exported through Ponta da Madeira maritime terminal. Our Ponta da Madeira maritime terminal is located in the Brazilian state of Maranhão. Pier I can accommodate vessels of up to 420,000 DWT and has a maximum loading rate of 16,000 metric tons per hour. Pier III, where there are two berths and three shiploaders, can accommodate vessels of up to 210,000 DWT at the south berth and 180,000 DWT at the north berth (or two vessels of 180,000 DWT simultaneously), subject to tide conditions, and has a maximum loading rate of 8,000 metric tons per hour in each shiploader. Pier IV (south berth) is able to accommodate vessels of up to 420,000 DWT and there are two ship loaders that work alternately with a maximum loading rate of 16,000 metric tons per hour. In 2018, Vale received the customs authorization for the operations of Pier IV (north berth). Cargo shipped through our Ponta da Madeira maritime terminal consists of the Northern system production of iron ore, pellets and manganese. In 2021, 182.9 million metric tons of iron ore, pellets and manganese were shipped through the terminal. The Ponta da Madeira maritime terminal has a storage yard with static capacity of 7.2 million metric tons.

We rely on long-term contracts of affreightment to secure transport capacity and enhance our ability to offer our products in the Asian market at competitive costs on a CFR basis. To support our commercial strategy for our iron ore business, we operate two distribution centers, one in Malaysia and one in Oman and we have long-term agreements with seventeen ports in China, which also serve as distribution centers.

In 2015, we launched the Brazilian blend fines (BRBF), a product resulting from blending fines from 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 local individuals or group

There are different environmental and protected areas located in the vicinity of Serra Sul complex, such as the National Forests of Tapirapé-Aquiri, Itacaiúnas and Carajas; the Campos Ferruginosos National Park; the Tapirapé Biological Reserve; the Xikrin Indigenous Land of the Cateté River; and Igarapé Gelado. The total area comprises approximately 1.2 million hectares, relatively well preserved, in contrast to the anthropized regions in the surroundings.

17.1. Environmental Aspects

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

According to Resolution of the National Environmental Council - CONAMA No. 237/1997 and Federal Law LC No. 140/2011, the environmental licensing for mining projects is under the responsibility of the corresponding State, except when there is any condition, such as localization in indigenous lands, two or more states or when in federal lands.

In this sense, the environmental permit of Serra Sul (S11D) is under the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), which analyzes and technically approves the proposed projects for mining activities in this type of area.

In Brazil, the environmental licensing process which allows a company to operate within the technical and legal aspects established by law has three phases:

- Preliminary Permit (LP): it is requested even in the planning phase of the activity or project, approving its location and conception, attesting to the environmental feasibility and establishing the basic requirements to be met in the next phase of project implementation;
- Installation Permit (LI): authorizes the installation of the project or activity in accordance with the specifications in the approved plans, programs and projects, including environmental restrictions and control measures;
- Operation Permit (LO): authorizes the operation of the project, after verification of effective compliance with the conditions established in the two previous licenses, with environmental restrictions and control, mitigation and compensation measures determined for the operation;
- The S11D mine reached the operation permit in 2016, which allows it to operate under conditions established by the federal licensing agency. Recently, the operating permit has been renewed by IBAMA and is valid until 2026.

The ongoing expansion, production increase by 10Mtpy, largely maintained the operating conditions and control established in the initial issuance of the permit, with parameters, monitoring points and some programs being adjusted to ensure environmental assessment, control and mitigation of environmental impacts arising from the increase in production. Table 17-1 shows the Environmental Permits in place for Serra Sul.

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

Environmental License	Environmental Agency	Description	Expiry date	Status
LI nº 1329/2019 - 02001.000711/2009-46	IBAMA	production increase by 10Mtpy and addition to the fleet of conventional mining equipment	15/12/2029	Valid license
LO nº 031/2019 086/2019	SEMA-PA	Fuel Station (plant)	13/09/2021	License in revalidation (Process nº 086/2019) (1)
LO_1361/2016 02001.000711/2009-46	IBAMA	Mine/Plant	09/12/2026	Valid license

(1) According to Brazilian legislation we can continue to operate during the renewal process.

Below the environmental restrictions affecting Serra Sul complex are described:

- Presence of conservation units

Serra Sul is part of the Carajás National Forest, which is part of a group of conservation units designed to protect biodiversity, qualified as an area of extreme importance. Regionally, the set of these protected areas includes forest reserves and other conservation units, called special use areas, together with the set of indigenous lands. The Carajás National Forest belongs to the group of "sustainable use" protected areas that foresee multiple use within its limits, including mining.

Currently, discussions are under way with the conservation units managing agency to change the zoning of the Carajás National Forest Management Plan, which will allow advance in areas currently considered restricted to mining.

- Underground natural caves

Serra Sul is part of the Carajás National Forest, which is part of a group of conservation units designed to protect biodiversity, qualified as an area of extreme importance. Regionally, the set of these protected areas includes forest reserves and other conservation units, called special use areas, together with the set of indigenous lands. The Carajás National Forest belongs to the group of "sustainable use" protected areas that foresee multiple use within its limits, including mining.

Currently, discussions are under way with the conservation units managing agency to change the zoning of the Carajás National Forest Management Plan, which will allow advance in areas currently considered restricted to mining.

17.1.1. Climate

The current climate in the Amazon region and consequently in the Serra Sul region is a combination of several factors, the most important of which is the availability of solar energy, through the energy balance. The location between the 5° north and 10° south range receives constant and intense flows, providing that the air temperature presents a small variation throughout the year. Thus, typical climate is consolidated, with a lot of days of convection rain. Therefore, the region of interest has a typical climatic characteristic of equatorial regions; however, microclimatic aspects must be considered. In the following item, a specific description of the area of the project will be made, taking into account the main meteorological parameters available for the region of interest.

The region has two well-defined seasons: the rainy season, November to April, when it rains 80% of the annual total, and the dry season, which runs from May to October, with the driest quarter (June, July, and August) and monthly averages of 24 mm. The average annual rainfall for the region varies from 1,500 to 1,900 mm, and the yearly average temperature is between 23.5 and 25.5°C, with the maximum temperature of the monthly average reaching 32.5 and the minimum being never lower than 18°C.

The air humidity in the region remains between 70 and 85% average. In the driest months, humidity is slightly reduced, reaching minimum levels of around 50% and average around 70%. During the rainy months, from October to May, the maximum average can exceed 95%.

Figure 17-1 shows Serra Sul historical annual precipitation.

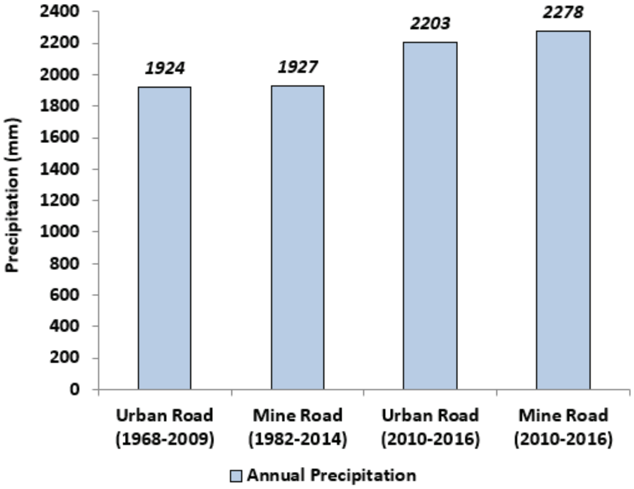


Figure 17-1: Serra Sul historical annual precipitation.

17.1.2. Hydrology

On a regional scale, Serra Sul is located in the hydrographic basins of the Parauapebas river (eastern portion) and the Itacaiúnas portion (western portion). The Parauapebas River is an important tributary of the Itacaiúnas River on the right bank and this, in turn, is a tributary of the Tocantins River on its left bank, with its mouth in the municipality of Marabá. The Tocantins River flows into the Pará River, which belongs to the Amazon River Basin.

The mines in operation at Serra Sul are basically developed in the sub-basins of Igarapés Pacu and Sossego.

17.1.3. Vegetation

The Serra Sul region is part of the Amazon Biome, whose most common form of vegetation is the Ombrophilous Forests, which are those adapted to humid climates, with rain during most of the year (8 to 9 months of rain and 3 to 4 dry months). They are located mainly on the slopes of the mountains and in the low parts.

However, other types of forest formations are also found, including 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 as small spots in the middle of the Ombrophilous Forests on the slopes of the Sierras.

Another type of vegetation is the “Stepic Savannas”, which grow on iron ore (in the so-called “canga”). Despite receiving a lot of rain, the canga remains dry for most of the year because the soil is rocky. As a result, the plants that grow on the “canga” need to withstand the scarcity of water and high temperatures. In the areas of the “Savanna Stepica”, there are four different environments: ruprestrial fields, marshy fields, low forests and thickets.

17.2. Environmental Management

The main environmental management programs are described below.

17.2.1. Environmental Management System

Through an environmental management system, Vale implements plans and procedures to identify non-conformities, develop correction plans and continuous improvement actions. The management system aims to prevent and control potential environmental and social impacts identified in the impact assessments submitted to the regulatory agencies.

Certification in ISO 14001:2015 is in progress for S11D to be completed by the end of 2022.

17.2.2. Removal and Storage of Topsoil

The surface soil of suppressed areas, formed by layers with higher organic matter content are stored and used in the process of rehabilitation of degraded areas. This material is rich in nutrients and has propagules from native vegetation, important for the recovery of altered or degraded areas.

17.2.3. Liquid Effluent Management

Water-oil separators are used to treat effluents generated in the maintenance workshops and from the vehicle refueling. The sanitary effluents generated in the administrative areas are treated in the Sewage Treatment Plant.

17.2.4. Drainage system

Operational areas and access roads are equipped with drainage systems to direct the rainwater to watersheds decantation ponds. Drainage systems are also important to conduct the water and prevent erosion. Those systems are constantly monitored and technically adjusted, when necessary.

17.2.5. Solid Waste Management

The solid waste generated is segregated and packaged properly, according to its characteristics, until the destination.

17.2.6. Air Quality

The emission of particulate material is controlled through humidification of unpaved roads with water trucks, use of fixed sprinklers, setting vehicles speed limits, washing paved roads, carrying out maintenance on machinery and equipment, revegetation of piles and mining areas, and active monitoring.

The monitoring of air and meteorological quality in the mine site is carried out by 03 automated stations that continuously generate data through specific analyzers and sensors.

17.2.7. Noise and Vibration Monitoring

This monitoring aims to assess noise and vibration, through periodic seismographic monitoring, allowing comparison with the standards defined by the current legislation.

At S11D, this monitoring is carried out periodically through a sampling network, in points distributed in 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.

17.2.8. Bioindicators

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

17.2.9. Water Resources

The water quality management program is responsible for monitoring underground, potable water, and liquid effluents. The results are consolidated in annual reports and provided to the environmental agencies.

17.2.10. Vegetal Suppression

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

17.2.11. Zoobotanical Park

Created in 1985, maintained and administered by Vale, the Zoobotanical Park is exclusively home to native species of fauna and Amazonian flora. Located within the National Forest of Carajás, in a Federal Conservation Unit, occupies an area of 30 preserved hectares, which allows free circulation of local fauna. The space receives around 100,000 visitors a year.

17.2.12. Degraded Areas Recovery Plan

This program aims to rehabilitate the areas morphologically altered by mining activities, aiming to restore the ecosystem functionality.

17.2.13. Fire Prevention

Vale works in partnership with Ibama and ICMBio to execute fire prevention and firefighting procedures to protect conservation units in Carajás.

17.3. Social or Community Requirements

The closest community to the Serra Sul Operation is the municipality of Canaã dos Carajás, located approximately 50 km west, with population of approximately 35.000 residents. The amount invested by Vale in the region in social programs in 2020 was about 12.1million dollars.

This section describes the main social actions and results related to the operation.

17.3.1. Environmental Education Program

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

17.3.2. Recruitment Program and Workforce Training

This program intends to hire the largest possible number of employees residing in the municipality where the project operates. Therefore, this program aims to qualify the local workforce through professionalizing technical courses.

17.3.3. Health Program

Through partnerships with the government, Vale makes investments in the infrastructure, education, and health areas, which involve construction and refurbishment of health posts, donation of hospital equipment, and ambulances.

17.4. Mine Closure

For the deactivation of S11D, its main structures were considered: caves, waste piles, containment dykes, basins and sumps, industrial facilities and support infrastructure.

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

17.4.1. Mine Pits

The S11D pit is in the initial mining phase, and therefore, there are no slopes or sectors in conditions of closure. However, the mining progress must be monitored by the mining planning team to anticipate the actions that seek final control of the execution of the slopes as recommended in the internal guidelines and the best engineering practices, seeking the progressive closure of this structure.

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

Table 17-2 - Closing activities - Pits

Typology	Structure	Activities
Pit	Oeste Leste	- Topographic survey; - Localized slope adjustments; - Localized superficial drainage adjustment; - Final adjustment of geotechnical monitoring system; - Final adjustment of water level monitoring system; - Localized slope revegetation; - Safety barrier implementation.

17.4.2. Waste Pile

The activities designed to deactivate it are briefly presented in Table 17-3.

Table 17-3 - Waste dump activities to closure

Typology	Structure	Activities
Waste Pile	Waste and Canga Piles	- Topographic survey; - Final adjustment of geotechnical monitoring system; - Localized slope adjustments; - Final adjustments of superficial and belt drainage system; - Vegetation reinforcement of slope and berm.

17.4.3. Sediment Containment System

The activities planned for the closure of the containment dykes in Serra Sul are briefly presented in Table 17-4.

Table 17-4 - Closing activities - Sediment Containment System

Typology	Structure	Activities
Dams and Sumps	Dam Sul, Dam Oeste, Dam 1 – Plant, Dam 3 – Plant, Maracanã, Mineirão.	- Topographic survey; - Geotechnical monitoring system final adjustment; - Vegetation reinforcement of slope and berm; - Superficial protection of the embankment final adjustment; - Localized superficial drainage adjustment; - Spillway final adjustment; - Revegetation; - Safety barrier implementation.

17.4.4. Industrial Facilities and Support Infrastructure

The activities designed for the 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 pear, facilities, gas station	- Survey of areas with potential contamination; - Systems Deactivation and Structure Disassembly; - Drainage system final adjustments; - Subsoiling; - Revegetation.

17.4.5. Monitoring and Maintenance

As part of the closure plan for S11D, the need for geotechnical and environmental monitoring and the maintenance of areas in the post closure stage should be considered. Table 17-6 summarizes the main activities proposed to measure the efficiency of the closure actions for all assets and for the area in general.

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

Activities	Attention points
Post-closure Monitoring and Maintenance	- Revegetation development. - Geotechnical stability; - Superficial and underground water quality.

17.4.6. Future Use Proposition

Although not entirely, there are important assets from the S11D mine within the limits of the Carajás National Forest, a conservation unit for sustainable use, created on 02/02/98. Its specific objectives follow those of its category and those established in its creation decree, which is managed by Instituto Chico Mendes – ICMBio.

This unit has the Carajás National Forest Management Plan (STCP, 2016), where, based on studies of abiotic, biotic and anthropogenic factors, a zoning for the Carajás National Forest was conceptualized.

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 to Sustainable Development in the Surroundings.

17.4.7. Future Use Skills

Based on the data collected and considering the different variables involved, especially those related to the Management Plan of Carajás National Forest, the most relevant aspects were identified in the territory to establish guidelines for the future use of the area.

- Research and Development: with the purpose to create a database on flora, fauna, human occupation and natural resources within its boundaries;
- Training and Biodiversity Conservation: aiming at both the continuity of the preservation of the Carajás National Forest and the development of activities that generate wealth for the region;
- Diversification of Vegetal Agroextractivism: to promote sustainable production, the articulation between community organization and technological development for the economic autonomy of Carajás National Forest;
- Ecological and Historical Tourism: following the example of the conservation of mining industrial heritage in other countries and similar initiatives in Brazil, and also because the S11D mine is one of the largest in the world, associated with historical and tourist interest in terms of its remaining structures and facilities;
- Environmental Conservation Area: which promotes the connection of already preserved vegetation fragments and favors the construction of habitats for different faunal groups, which

allows the occurrence of sufficient flora biodiversity to offer important sources of plant propagation and subsequent efforts to recover degraded ecosystems around.

17.4.8. Financial provision

The closure of activities at Mine S11D is scheduled in the project in 2058, considering progressive closure, with decommissioning and deactivation actions starting in the operation phase. The description of the actions planned for closing is presented in Table 17-7, which refers to the provision of financial resources for the demobilization of assets using the ARO model for 2021.

Table 17-7 - Provision of financial resources for the demobilization of assets using the ARO model for the year 2021

Assets	US$ M
Pit	16.42
Waste Dumps	6.83
Dams and Sumps	5.45
Industrial Infrastructure	81.27
Other structures	46.72
TOTAL	**156.70**

Note: numbers have been rounded

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 2021. 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 viability of the mineral reserve, therefore it can differ from other information Vale publishes and should not be considered as a guidance.

18.1. Capital Costs

The total capital costs for Serra 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$ 15,615 million as shown in Table 18-1.

Table 18-1: LOM Capital Cost Estimate

Capital Cost Type	Unit	Value
Sustaining CAPEX	US$ M	***11,909***
Non-routine	US$ M	**866**
Mine and plant	US$ M	353
Logistics and Other	US$ M	513
Routine	US$ M	**11,043**
Capital projects CAPEX	US$ M	**3,706**
Mine and plant	US$ M	1,801
Logistics and Other	US$ M	1,905
TOTAL	**US$ M**	**15,615**

Note: numbers have been rounded

18.2. Operating Costs

- LOM average unit operating cost and expenses:
  - Mine and plant: 4.0 US$/ton of product;
  - Logistics and Distribution: 19.0 US$/ton of product;
  - Royalties: 2.4 US$/ton of product;
  - Sales expenses, R&D, others: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 25.6 US$/ton of product.
-

The overall costs and expenses estimate for LOM or evaluation period is US$ 109,531 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	17,049
Logistics and Distribution	US$ M	81,355
Royalties	US$ M	10,406
Sales expenses, R&D, others	US$ M	721
TOTAL	**US$ M**	**109,531**

Note: numbers have been rounded

The average operating cost is based on a 30-year life of mine from 2022 through 2051, and for the years after 2051, the unit costs of 2051 were replicated. The operating cost inputs including labor, consumables, supplies, selling costs, commercial offices, operational and maintenance research & development, and were based on data from Vale’s 2021 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’s site workforce

Serra Sul	Total
Mine	1,120
Plant	1,055
Others	205
TOTAL	**2,380**

Table 18-4: Contractors´ workforce

Serra Sul (Contractors)	Total
Mine	148
Plant	3
Others	1,816
TOTAL	**1,967**

The main contractor at Serra Sul is related to mining, maintenance of the plant 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 viability of the mineral reserve, therefore the production rates, operating efficiencies, costs and expenditures, taxes and other information presented can differ from other information we publish and should not be considered as a guidance. Note that our planned production extraction may vary due to continuous mineral exploration and technical studies to add new mineral reserves.

19.2. Economic criteria

The economic analysis in this Technical Report Summary is based on the Mineral Reserves, economic assumptions, and the capital and operating costs as presented in Section 18 of this Technical Report Summary.

19.2.1. Physical

- Open pit ore tonnes mined: 4,273 Mt;
- Total ore processed: 4,273 Mt;
- Life of Mine: 2022 to 2062;
- Ore grade: 65.8 % Fe;
- Average LOM Recovery: 100%;
- Recovered Iron Ore: 4,273 Mt.

19.2.2. Revenue

Commodity prices were discussed in Chapter 16.

The average logistics costs considered for this model are: 19.0 US$/ton, around 70% of the total sells during Serra Sul mine life considered as foreign market and CFR (cost and freight) model.

The remaining 30% 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's iron-ore commercial strategy, the company operates two blend and distribution centers, one located in Malaysia and one in Oman. VALE also has long-term contracts with ports in China, which also serve as distribution centers.

The ore of Serra Sul 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: 4.0 US$/ton of product;
  - Logistics and Distribution: 19.0 US$/ton of product;
  - Royalties: 2.4 US$/ton of product;
  - Sales expenses, R&D, others: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 25.6 US$/ton of product;
- Overall costs and expenses estimate for LOM or evaluation period: US$ 109,531 million.

The 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$ 15,615 million;
- Sustaining CAPEX: US$ 11,909 million;
- Capital projects CAPEX: US$ 3,706 million.

19.2.5. Main Taxation and Royalties

- CFEM Royalty rate: 3.5%;
- Income tax rate with SUDAM tax benefit: 15.25 % (2022 – 2027);
- Income tax rate: 34% (2028 – 2062).

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 mineral reserve only cashflow for Serra Sul is used to confirm the economic viability. The annual cashflow is presented below, with the inputs presented as averages grouped for the first 2 years, followed by 3 years, and subsequently 5 years groups for the Life of Mine Plan. After 30 years the inputs are presented as averages grouped in 10 years period. 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	2022-23	2024-26	2027-31	2032-36	2037-41	2042-46	2047-51	2052-62
Iron Ore Recovered	Mt	88	109	120	120	120	120	120	70
Total Revenue	US$ million	8,462	7,722	8,111	8,212	8,406	8,479	8,405	4,919
Operating costs, expenses, royalties and closure costs	US$ million	(2,604)	(2,981)	(3,297)	(3,186)	(3,057)	(2,941)	(2,881)	(1,703)
Income Tax and working capital change	US$ million	(818)	(814)	(1,355)	(1,535)	(1,634)	(1,680)	(1,654)	(978)
Total CAPEX	US$ million	(1,058)	(469)	(743)	(317)	(318)	(318)	(317)	(185)

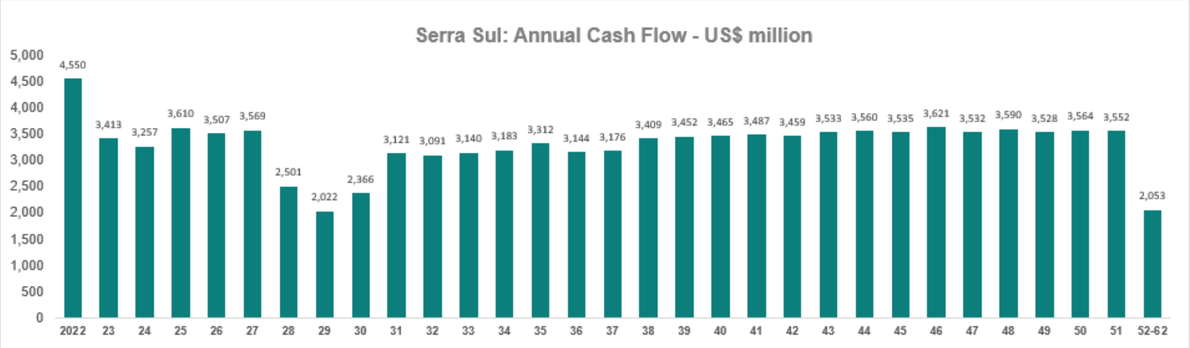


Figure 19-1 – Annual cash flow

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 viable. The after-tax NPV at a 7.5% discount rate and following a mid-year convention is US$ 42,460 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**	**104,471**
Total costs and expenses	US$ M	-38,600
Mine and plant	US$ M	-6,229
Logistics and Distribution	US$ M	-28,453
Royalties	US$ M	-3,628
Sales expenses, R&D, others	US$ M	-278
Closure costs	US$ M	-13
Income Tax and working capital change	US$ M	-16,396
Operational Cash Flow	**US$ M**	**49,475**
Total CAPEX	US$ M	-7,015
Free Cash Flow	**US$ M**	**42,460**

For this cash flow analysis, the internal rate of return (IRR) and payback are not applicable as there is no negative initial cash flow (no initial investment to be recovered).

19.4. Sensitivity analysis

Project risks can be identified in both economic and non-economic terms. Key economic risks were examined by running cash flow sensitivities on after-tax NPV at an 7.5% 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.

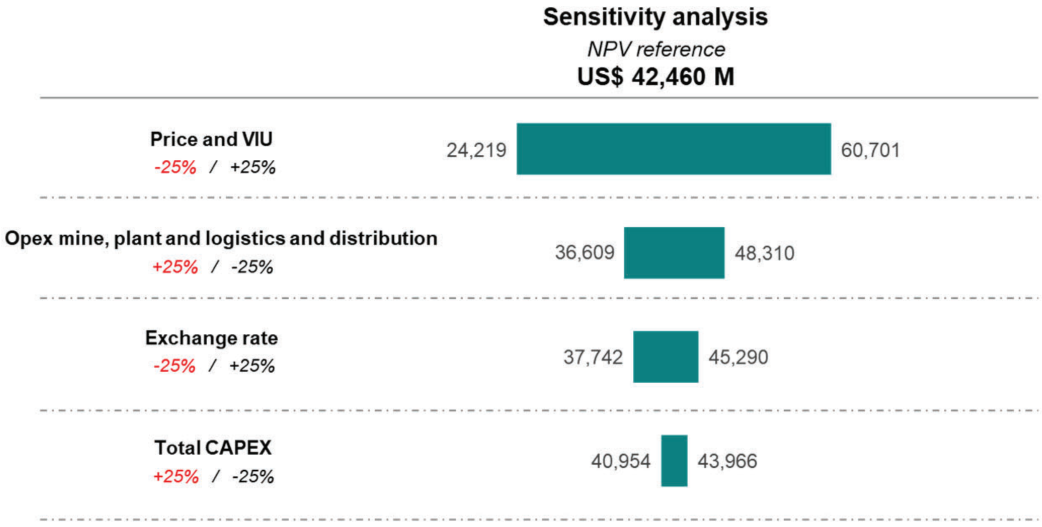


Figure 19-2- Sensitivity Analysis

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 allows to set a robust structural and stratigraphic model, as well as the mineralization associations and understandings.

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

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

22.3. Exploration, drilling and sampling

All work developed at the Serra Sul follows strict internal standards and the best practices of the mining industry. The various drilling campaigns carried out over the last decades, as well as all geological data, sampling and chemical analysis originated there from have been extensively discussed among the involved technical teams to ensure the robustness of the geological model.

22.3.1. Hydrogeological and geotechnical settings

The current geotechnical and hydrological database was considered satisfactory (amount and quality) to achieve the main objectives, which were build and calibrate models able to simulate future mining scenarios capable to provide input to slope stability analysis, support failure mechanism evaluation, provide short and long-term geotechnical information, and provide mining and environmental assistance.

The hydrogeological simulations showed reliable and feasible results with operational flow rates for the drawdown of the pits in the Serra Sul Mine Complex. The geotechnical and hydrological data obtained and used in the slope stability analyses has been a reasonable predictor of current conditions, and therefore, satisfactorily supported the mineral reserve estimates. The slope stability analyses made in the Serra Sul Mine Complex (S11C and S11D) obtained reliable and feasible results, with safety factors consistent with the minimal international standards stabled by Read & Stacey (2009). Therefore, the proposed geometry was considered geotechnically practicable.

It is important to emphasize that any changes in the geotechnical and hydrological assumptions could affect mine planning, indirectly affecting capital cost estimates if any major rehabilitation is required due to a geotechnical or hydrological event, affect operating costs due to mitigation measures that may need to be imposed, and impact the economic analysis that supports the mineral reserve estimates.

22.4. Data verification

The data verification programs concluded that the data collected from Serra Sul adequately support the geological interpretations and constitute a database of sufficient quality to support the use of the data in mineral resource and mineral reserve estimation.

22.5. 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 follow. Estimation was made by Vale personnel. The mineral resource estimate is supported by core drilling.

Mineral resources are reported using the mineral resource definitions set out in S–K 1300 and are reported without the mineral resources converted into mineral reserves.

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

Under the assumptions presented in this Report, the Serra Sul Mining Complex has proven to have reasonable prospect of economic extraction, and therefore the mineral resource estimates can be supported.

22.6. Mineral reserve estimates

The mineral reserves are estimated using open-pit mining assumptions with use of mobile crushing equipment and belts, as well as conventional mining equipment.

The mineral reserves were converted from measured and indicated mineral resources. Inferred mineral resources were discarded. Mining recovery and dilution factors were applied. It is worth pointing out that due to the mining method, the mining was divided into two mining stages, one using mobile crushing and belts, and another one, by the conventional method using excavators and trucks in order to differentiate the two mining methods.

The mineral reserves were classified using the definitions of mineral reserves set out in S – K1300.

Some uncertainties may affect the mineral reserve estimation: commodity prices; US dollar exchange rate; Brazilian inflation rate; geotechnical (including seismicity) and hydrogeological parameters; changes in capital inflows and operating cost estimates; changes in the pit projects in relation to the currently planned; inventory assumptions; ability of the mining operation to meet the annual production rate; process plant recoveries and the ability to control deleterious element levels within the expectations of the LOM plan; assumption that plants 1 and 2 will perform as expected; ability to meet and maintain environmental licenses and permit; and ability to maintain social license to operate.

22.7. Mining methods

The Serra Sul mine is operated by the open-pit method, dividing the mine operation into zones favorable to mining by belt operation and zones of high geometric complexity, operated by the conventional Truck and Shovel system.

The current annual production plans are around 80Mt, but the target is to reach production of 120Mt per year. There may be a small variation up or down depending on the company's strategy over the life of the mine.

22.8. Processing and recovery methods

For the processing of ROM with natural moisture, there is no need for process tests for operational control, as it is a technique dominated in the beneficiation of ore, where traditional equipment from the mining industry is used. For the plant to achieve the best performance, it is necessary to ensure that ROM is within the established limits of granulometry, the percentage of lithologies and the quality of each plant, with this procedure already being applied in this complex. Screening at natural moisture requires attention in the rainy season, since ROM with higher moisture generates drop in productivity, in addition to handling problems. During this period, a production drop is already considered in the production planning and an attempt is made to reduce the percentage of hydrated ore, as the processing of this type of ore is more difficult.

Due to the higher incidence of jaspilite rock in the mining of ores, it is planned to replace the current crushers with crushers with greater compressive strength, thus ensuring better performance of the system. The determination of the compressive strength was determined from several tests carried out with different samples.

QP's opinion: The process route for processing the S11 material is highly reliable because it involves traditional beneficiation equipment where Vale has extensive experience in this type of process. Through this route, it is able to generate high production volume with satisfactory quality.

22.9. Environmental

Serra Sul (S11D) has environmental controls and monitoring that aim to ensure or quickly identify possible operational deviations that could cause damage to the environment. The current production expansions did not require major expansions of controls and monitoring due to the robustness and suitability of the controls and programs on the site.

Mining activities close to the most restricted conditions, such as caves and lakes, have specific programs and monitoring that aim to ensure production without causing irreversible damage.

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, target defined by the company for future years.

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

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

Additionally, economic assessments of reserves consider capital projects that aim to maintain and/or increase productive capacity. The overall capital cost estimate for LOM or evaluation period is US$ 15,615 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: 4.0 US$/ton of product;
  - Logistics and Distribution: 19.0 US$/ton of product;
  - Royalties: 2.4 US$/ton of product;
  - Sales expenses, R&D, others: 0.2 US$/ton of product.
- Total average unit operating costs and expenses: 25.6US$/ton of product.

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

The overall costs and expenses estimate for LOM or evaluation period is US$ 109,531 million.

22.11. Economic analysis

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

The economic analysis confirmed that Serra Sul is economically viable. The after-tax NPV at a 7.5% discount rate and following a mid-year convention is US$ 42,460 million.

For this cash flow analysis, the internal rate of return (IRR) and payback are not applicable as there is no negative initial cash flow (no initial investment to be recovered).

Project risks can be identified in both economic and non-economic terms. Key economic risks were examined by running cash flow sensitivities on after-tax NPV at an 7.5% 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

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

Other risks noted include:

- In 2008, a federal decree established a criteria for classification of caves based on their relevance (maximum, high, medium or low). This decree prohibits irreversible negative impacts in maximum relevance caves and, however, it allows impacts on the other caves categories, following proper environmental permit and/or compensation. A regulation defined a 250 meters buffer as the default area of influence to be preserved around caves. Environmental studies can be submitted to the federal environment regulator to re-evaluate and better define the area of influence, allowing its reduction. Specifically for some maximum relevance caves, the Serra Sul mineral reserve estimation considered a 150 meters buffer for their protection, but, in the case of mineral resources, no constrains was considered. The request for alterations on protective influence area needs to be assessed and approved by the Brazilian federal environmental regulators and, depending on the decision, it can have positive or negative impacts on mineral reserves and resources disclosed. In January 2022, a new federal decree was enacted, revoking the regulation of 1990 and its subsequent amendments and establishing new rules for the protection of caves, including with respect to relevance classifications and forms of compensation, and the impact of it on our operations is under review. This 2022 decree, however, is currently being challenged in the STF by a political party on the grounds that such regulation is unconstitutional since it allegedly reduces the legal protection of caves and it has been temporarily suspended until further decision of the court.

- The Carajás National Forest (FLONA Carajás) was created in 1998 as a conservation unit in which the management of natural resources is allowed. FLONA Carajás has an environmental Management Plan, which defines a land zoning, encompassing the "Mining Zone" category. The Management Plan has legal provision to be reviewed and the last revision was in 2016. A portion of 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. A portion of S11D deposit (Serra Sul) requires the approval of a protection buffer for two lakes (and its hydric contribution zone) and endemic plant species, 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.
- 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;
- Better assessment of jaspilites lenses occurrences and continuity due to the truckless mining method could impact the performance and the operating costs of the mine, and therefore, it is important to continue to invest in the investigation of jaspilite lenses.

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, with supporting studies, to mineral reserves;
- Potential conversion of inferred mineral resources, with supporting studies, to higher confidence mineral resource classifications.

22.12.2. Mineral Reserves

In addition to the risks associated with prices, costs, process, commodity price volatility, as already mentioned in chapters 11 and 12, release of radius reductions in caves of maximum relevance around the pits (S11CD), in the necessary time, among other environmental licenses that are beyond our effective control, environmental weakness of area 5; compact and clayey material run-off, operational performance of the truckless systems, increase of conventional fleet, are considered risks.

As opportunities, we can mention studies of new mining methodologies with greater flexibility, which will bring higher production safety.

23. Recommendations

23.1. Geological Setting and mineralization

It is recommended to keep the routine works of geological data collection with mappings, sampling, and developing drilling campaigns (short and long terms), to keep improving the knowledge of the high-grade ores, structural and stratigraphy.

Further work is required to determine the exploration potential below the current open-pit operations and not operated plateaus. The exploration targets are mainly associated with the outcrops of structured cangas, friable hematites and jaspilites, or geophysical anomalies.

23.2. Exploration

Regarding to the geotechnical and hydrogeological considerations, it is recommended to develop an effective Ground Control Management Plan, a complete Quality Assurance and Quality Control Program, and promote continuous increase in database improvement (drillholes and testing) to reduce the identified database backlog and provide information from new areas. This will provide a robust basis for geotechnical and hydrogeological evaluation, modelling and mitigation measures.

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

23.3. Mineral resource estimates

The continuity of geological drilling annual plans to assess better the geology in depth increasing the geological knowledge and the confidence to convert inferred and indicated classes to indicated and measured categories.

23.4. Mineral reserves estimates

- As improvement, it is recommended to implement a mining dilution and recovery database through field measurement controls, as well as use of the dispatch and sampling system in the plant for us to have higher precision in the calculation of this factor;
- Implementation of an efficient solution for the disposal of clayey materials;
- Focus on 5th Crushing for compact waste processing until start-up of the Compact Crushing;
- Implementation of the Jaspilite Temporary Pile by the beginning of 2023.
- Seek new technologies to minimize the need of lining for operation of mainly the sterile piles and the mining fronts the floor of which is on soft material (mainly decomposed mafic).

23.5. Processing and recovery methods

Verification of existing process controls in order to identify opportunities, bottlenecks and/or improvements for process optimization, especially in the rainy season when the processing productivity is lower.

23.6. Costs and economics

Maintain the focus on the discipline of capital allocation and the elimination of possible inefficiencies, to guarantee, with operational safety, cost competitiveness, and consequently, healthy margins and balance sheets in any price scenario.

23.7. Environmental

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

Within the scope of Serra Sul, it is important to continue the discussions with the Conservation Units agency in order to develop studies and inform the decision to change the zoning of the management plan to enable the expansion of the mining zone, which currently prevents expansion of the mining.

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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 viability of the mineral reserve estimates in Chapter 12.

25.3. Markets

Information relating to market studies/markets for product, market entry strategies, marketing and sales contracts, product valuation, product specifications, refining and treatment charges, transportation costs, agency relationships, material contracts (e.g., mining, concentrating, smelting, refining, transportation, handling, hedging arrangements, and forward sales contracts), and contract status (in place, renewals), was obtained from the registrant.

This information is used in the economic analysis in Chapter 19. It supports the assessment of reasonable prospects for economic extraction of the mineral resource estimates in Chapter 11, and inputs to the determination of economic viability of the mineral reserve estimates in Chapter 12.

25.4. Legal Matters

Information relating to the corporate ownership interest, royalties, encumbrances, easements and rights-of-way, violations and fines.

This information is used in support of the property description and ownership information in Chapter 3, the permitting and mine closure descriptions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.

25.5. Environmental Matters

Information relating to baseline and supporting studies for environmental permitting, environmental permitting and monitoring requirements, ability to maintain and renew permits, emissions controls, closure planning, closure and reclamation bonding and bonding requirements, sustainability accommodations, and monitoring for and compliance with requirements relating to protected areas and protected species was obtained from the registrant.

This information is used when discussing property ownership information in Chapter 3, the permitting and closure discussions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.

25.6. Stakeholder Accommodations

Information relating to social and stakeholder baseline and supporting studies, hiring and training policies for workforce from local communities, partnerships with stakeholders (including national, regional, and state mining associations; trade organizations; fishing organizations; state and local chambers of commerce; economic development organizations; non-government organizations; and state and federal governments), and the community relations plan was obtained from the registrant.

This information is used in the social and community discussions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.

25.7. Governmental Factors

Information relating to taxation and royalty considerations at the Project level, monitoring requirements and monitoring frequency, bonding requirements, violations and fines was obtained from the registrant.

This information is used in the discussion on royalties and property encumbrances in Chapter 3, the monitoring, permitting and closure discussions in Chapter 17, and the economic analysis in Chapter 19. It supports the reasonable prospects of economic extraction for the mineral resource estimates in Chapter 11, and the assumptions used in demonstrating economic viability of the mineral reserve estimates in Chapter 12.