Technical Report Summary Sudbury Property

Ontario Operations
Canada

Report current as at: December 31, 2021

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1.1 INTRODUCTION

This technical report summary (the Report) was prepared for Vale S.A. (Vale) on the Ontario Operations in the Sudbury district of Ontario. Vale uses its wholly-owned subsidiary, Vale Canada Limited (Vale Canada), as operator of the Ontario Operations.

1.2 TERMS OF REFERENCE

The Report was prepared to be attached as an exhibit to support mineral property disclosure, including mineral resource and mineral reserve estimates, for the Ontario Operations in Vale's Form 20-F for the year ending 31 December, 2021.

Mineral resources are reported for the Blezard, Coleman, Copper Cliff, Creighton, Stobie, Garson, Copper Cliff Pit, Totten and Victor deposits. Mineral reserves are reported for the Coleman, Copper Cliff, Creighton, Garson and Totten deposits.

The integrated Ontario Operations consist of operating underground mines (Coleman, Copper Cliff, Creighton, Garson and Totten), processing and refining facilities in Ontario (Clarabelle Mill, Copper Cliff Smelter and Nickel Refinery, Port Colborne refining complex), supported by the Clydach Refinery in Wales, and non-operating mines, and non-producing properties.

Unless otherwise indicated, all financial values are reported in US currency. The metric system is used in the Report unless otherwise noted. Mineral resources and mineral reserves are reported using the definitions in Subpart 229.1300 – Disclosure by Registrants Engaged in Mining Operations in Regulation S–K 1300 (SK1300). The Report uses Canadian English.

1.3 PROPERTY SETTING

The Ontario Operations are located in the Sudbury district of Ontario. Sudbury is about 330 km north–northeast of Toronto.

There are excellent transportation routes that access the Sudbury area. Highway 17 is the main branch of the Trans-Canada Highway connecting the city to points east and west. Highway 69, also a branch of the Trans-Canada Highway, leads south to Parry Sound, where it connects to the Highway 400 freeway to Toronto. Highway 144 leads north to Highway 101 west of downtown Timmins. Access to the various mine and deposit sites is through a system of numbered municipal roads and private roads operated by Vale. Prospects and exploration areas are accessed via a network of municipal and local private roads.

The Greater Sudbury Airport is served by regional carrier lines. Sudbury is also served by rail. There are no other means of transportation that are used to access the operations.

The Ontario Operations are located in an area that has more than a hundred years of mining activity. As a result, local and regional infrastructure and the supply of goods available to support mining operations is well-established. Personnel with experience in mining-related activities are available in the Sudbury district.

There are no significant topographic or physiographic issues that would affect the Sudbury Operations. The dominant vegetation type is temperate boreal forest.

The Sudbury district has a humid continental climate with warm and often hot summers and long, cold, snowy winters. Mining operations are conducted year-round.

1.4 OWNERSHIP

The Ontario Operations are wholly-owned by Vale Canada, a Vale subsidiary.

The term "Vale Base Metals" refers to Vale's base metals division of Vale led by Vale Canada, comprised of nickel and copper mining, smelting and refining assets in Canada, Brazil, Indonesia, the United Kingdom and Japan, including the production and sale of cobalt, platinum group metals, and other precious metals as by-products of nickel and copper mining and processing operations. Vale Canada is the corporate head and holding company for its base metals operations and assets globally.

1.5 MINERAL TENURE, SURFACE RIGHTS, WATER RIGHTS, ROYALTIES AND AGREEMENTS

In the Sudbury district, Vale is the registered owner of mining rights and surface rights or a combination of both shown as fee simple lands, mining leased lands, mining license of occupation lands and unpatented mining claims.

Vale owns approximately 80,383 ha of patented mining rights and approximately 59,742 ha of patented surface rights which includes a combination of approximately 1,369 ha of mining and surface rights co-owned with other parties:

- Patented mining rights are granted to exploit and extract minerals on, in or under the land, and surface rights are rights to use the surface of the land. These rights remain in effect so long as Vale owns the land to which these rights apply;
- Vale holds approximately 14,026 ha of land leased from the Province of Ontario. These leased lands, which include a combination of mining and surface rights, are leased for either 10 or 21 years. Annual rentals of C$3.00/ha are paid to the Province of Ontario to keep the leases in good standing;
- Vale holds licenses of occupation covering approximately 2,952 ha in Ontario of which approximately 17 ha are held jointly with other parties. Annual rentals of C$5.00/ha are paid to the Province of Ontario to keep these mining licenses of occupation in good standing;
- Vale currently holds unpatented mining claims covering approximately 9,676 ha in Ontario of which approximately 6,596 ha are held jointly with other parties. Unpatented mining claims are issued by the Province for the purpose of exploring the mineral potential and require that assessment work be performed to continue holding the claims.

Municipal taxes and mining land taxes for each mine were paid in full for 2021. All assessment work due annually on the patented and unpatented mining claims was filed as at 31 December, 2021.

Vale has a number of third-party agreements in support of the Ontario Operations. Given the patchwork property holdings of mining companies within the Sudbury, Vale has multiple road and property easements with various mining companies, in particular Glencore Canada Limited (Glencore), to grant access between each party's properties for operation and exploration activities necessary for each other's operations. Vale and Glencore have various corridor agreements permitting development of underground corridors by the requestor through the permittee's subsurface rights area in order to access the requestor's deposit area. Glencore uses its infrastructure (including the Fraser Mine), local Sudbury work force and operational expertise to mine the adjacent Vale Bowtie deposit; Glencore purchases the ore mined from Vale. There is also an agreement with Glencore that allows reciprocity of ventilation to provide ventilation capacity necessary for each party's operations in the Fraser Mine/Bowtie area.

Vale and Silver Wheaton Corp (now Wheaton Precious Metals) executed an agreement in 2013 wherein Vale agreed to sell to Wheaton Precious Metals an amount of gold equal to 70% of the gold production from certain of its Sudbury mines, including the Coleman, Copper Cliff, Garson, Stobie, Creighton, Totten Mines and the Victor project for a period of 20 years. Wheaton Precious Metals made a total upfront cash payment in March, 2013 of US$570 million plus warrants to purchase 10 M shares of Wheaton Precious Metals common stock at a strike price of US$65, with a term of 10 years. In addition, Wheaton Precious Metals will make ongoing payments of the lesser of US$400/oz Au or the prevailing market price per ounce of gold delivered. There are no royalties or other similar payments made on the Ontario Operations mine properties within the Sudbury Basin other than that payable to Wheaton Precious Metals.

Vale holds Order-in-Council (OIC) permits that allow it to export nickel, copper and platinum group metals (PGM) products outside of Canada for further refinement. Each permit is granted for a five-year period, and to date, the permits have been renewed as required. The OIC permit for copper expires in June 2022. The nickel and PGM OIC permits are current until December, 2025. These permits are necessary for Vale to further refine its product to sell demanded products. There is a reasonable expectation that the OIC permits can continue to be renewed for the duration of the life-of-mine (LOM).

Vale holds applicable water take permits to support operations. Water take is permitted for the Vermilion River in the Sudbury mine, smelter, and refinery areas, and from the Swansea canal and the River Tawe for the Clydach Refinery. The Clydach Refinery undertook in 2017 to install a complex recycled, closed-loop, cooling water circuit. Once completed in 2022, water will no longer be sourced from either the river or the canal. The Port Colborne Refinery sources its water from the Welland Canal.

1.6 GEOLOGY AND MINERALIZATION

Deposits within the Sudbury Igneous Complex (SIC) are type examples of nickel–copper mineralization arising from a meteorite impact.

The Sudbury magmatic copper–nickel sulphide deposits are part of the Paleoproterozoic Sudbury Structure which comprises the SIC and associated dykes, and the overlying Paleoproterozoic Whitewater Group rocks. Footwall rocks to the Sudbury Structure are Archean gneisses and granitic and mafic igneous rocks to the north and Paleoproterozoic metavolcanic and metasedimentary rocks of the Huronian Supergroup to the south.

The Sudbury Structure is exposed as an elliptical ring with a northeast-trending long axis of ~72 km and a short axis of ~27 km. The upper northeast-trending contact of the surface expression of the SIC is often referred to as the North Range, similarly the South Range is associated with the areas along or near the southern surface exposure of the SIC contact. Margins of the SIC are characterized with an average inward dip of about 45º along the north part of the SIC; however, they are generally steeply dipping or overturned in the south and east sections.

Major components of the SIC include the differentiated norite–gabbro-granophyre Main Mass and a group of minor intrusions, collectively termed the Sublayer. Three major variants of the Sublayer are recognized: the first comprises igneous-textured gabbronoritic material, the second consists of igneous-textured quartz diorite, while the third variant comprises a wide variety of metamorphic-textured rocks collectively known as “footwall breccia”. The Sublayer is localized either at the contact between the Main Mass and footwall rocks or within radiating and concentric dykes cutting footwall rocks. Sublayer units are characterized by disseminated to massive sulphide and by the presence of a variety of xenoliths of both local and unknown or “exotic” derivation.

Rocks of the Whitewater Group are found only within the central portion of the Sudbury Structure. The Whitewater Group consists of three conformable formations, in ascending order, the Onaping impact-generated breccias, Onwatin siltstone and wacke, and Chelmsford turbidite.

All rocks defined as footwall to the Sudbury Structure are cut by occurrences of the Sudbury Breccia. This breccia occurs as small veins, irregularly-shaped patches and large bodies, which may extend for many kilometers along strike. The breccia consists of inclusions of locally-derived footwall lithologies within comminuted footwall rock.

The Sudbury Structure is cut by a number of regional and local mafic dyke swarms. The Murray and Creighton granitic plutons, part of the Cartier batholith, intrude the Huronian Supergroup, and predate the impact.

The Sudbury deposits host three principal styles of mineralization contact style, offset style and footwall style.

However, the three mineralization environments can be quite variable, transitional, and many exhibit characteristics fitting more than one mineralization environment description.

Two types of Footwall-style deposits are identified in the North Range. These are massive sulphide copper–PGM deposits and low-sulphide high-PGM deposits. Low-sulphide–high-PGM, and to a lesser extent massive sulphide copper–PGM deposits occur in the South Range.

Pyrrhotite is the most common sulphide mineral. Chalcopyrite is the main copper-bearing mineral and second most common sulphide mineral. Chalcopyrite is typically (but not always) associated with elevated PGEs and precious metals. Pentlandite is the main nickel mineral and is present in all ore types.

The Ontario Operations continue to actively explore within the current mining operations, and the majority of deposits remain open at depth. Brownfield exploration is focused on areas in the Sudbury basin within a reasonable radius of existing infrastructure. Greenfields exploration is conducted throughout the Ontario Operations area to identify new stand-alone nickel and copper deposits.

1.7 HISTORY

The Ontario Operations have over 100 years of active mining history, and exploration activities date back to 1856 when nickel was first discovered. Vale obtained its interest in the operations in 2006, with a takeover of Inco, formerly the International Nickel Company of Canada, Limited.

1.8 EXPLORATION, DRILLING, AND SAMPLING

1.8.1 EXPLORATION

Each mine has its own mine grid. Survey information is generally collected in Imperial units.

The primary geophysical exploration methods applied include University of Toronto Electro Magnetometer (UTEM-4), televiewer, radio imaging method (RIM) and down-hole induced polarization (IP). These methods are used to identify areas of sulphide mineralization. The geophysical information is integrated with the drill hole database to improve deposit model interpretations and to act as vectors for exploration drilling.

1.8.2 DRILLING

The primary drill method is core drilling. Drilling totals 66,014 drill holes for 10,091,174 m of drilling. Drill holes are spaced at intervals as required by the type of mineralization and the information required (i.e., exploration or resource definition drilling), with the typical spacing being >100 m for exploration and 10–50 m for resource definition drilling. The primary drill method is core drilling. Drilling totals 66,014 drill holes for 10,091,174 m of drilling. Drill holes are spaced at intervals as required by the type of mineralization and the information required (i.e., exploration or resource definition drilling), with the typical spacing being >100 m for exploration and 10–50 m for resource definition drilling. Current underground drill programs for exploration and operations purposes typically use a core size of BQ (36.4 mm diameter). AQTK (35 mm diameter) core has been used historically. Surface exploration drill programs are typically completed using NQ sized core (47.6 mm diameter).

Core recovery is generally good at all deposits. Areas of poor recovery are typically limited to fault and shear zones.

On surface, global positioning system (GPS) coordinates are used for collar locations, while underground, drill collar locations are measured from survey control points. Depending on the program, down-hole survey instrumentation could include single shot or multi-shot gyroscopic orientation tools. Earlier programs used acid tube tests. Historical boreholes with acid tube test surveys are occasionally resurveyed using a gyroscopic instrument for trajectory verification.

1.8.3 SAMPLING

The core sampling interval is established by minimum or maximum sampling lengths and geological and/or structural criteria. The minimum sampling length is 15 cm while the maximum is 3 m. The typical sample length in the Contact-style massive sulphide zones is 1.5 m. In the Footwall-style copper zones, a 0.3 m sampling length is typical due to the presence of narrow, massive chalcopyrite veins. Samples of barren rock bracketing the mineralized zone are 1.5 m in length, regardless of zone they are bracketing. The core from underground drilling is typically sampled in its entirety. Surface exploration programs split most mineralized intersections and store half of the core. Representative samples of each mineralized intersection are taken for future reference. One sample is taken for every 3 m of core or when the lithology changes. These "rep" samples are typically 10–15 cm in length and are not assayed.

1.8.4 DENSITY DETERMINATIONS

Density is currently estimated based on a multivariate regression of nickel, copper, and sulphur data which can be approximated using the following formula:

- Density = 100 ÷ (100 ÷ 2.88 + 0.0166 x Cu - 0.1077 x Ni - 0.328 x S).

Density data were reported using US customary tons per cubic foot (ton/ft^3). Values ranged from a minimum of 0.0874 ton/ft^3 to a maximum of 0.156 ton/ft^3, with averages ranging from 0.097–0.107 ton/ft^3.

1.8.5 SAMPLE PREPARATION AND ANALYSIS

Vale used both internal and external laboratories for its sample analysis.

Analytical methods have also varied over time. These have included, during the Inco operating period, a colorimetry method for copper and nickel, a multi-element X-ray fusion (XRF) method for copper, nickel, cobalt, iron, sulphur and arsenic; fire assay with silver bead being arced on an ARL spark emission spectrometer, direct current plasma and inductively-coupled plasma (ICP) analysis for gold, platinum and palladium, and occasionally for rhodium and silver; a base metal suite using Na_2O_2 fusion followed by ICP analysis; and PGM via fire assay/ICP-AES. Analytical methods requested by Vale include copper, nickel, cobalt, iron, sulphur, arsenic, lead and zinc using a sodium peroxide fusion with inductively-coupled plasma atomic emission spectroscopy (ICP-AES) finish; lime, magnesia and silica could also be requested by the same method; PGM via lead collection fire assay fusion/ICP-AES; and arsenic and lead using an aqua regia digestion followed by an ICP-AES finish.

1.8.6 QUALITY ASSURANCE AND QUALITY CONTROL

The sample preparation, analysis, quality control, and security procedures used by the Ontario Operations have changed over time to meet evolving industry practices. Practices at the time the information was collected were industry-standard, and frequently were industry-leading practices. The Qualified Person is of the opinion 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.

1.9 DATA VERIFICATION

Checks were performed by software data checking routines that rigorously verify data acceptance. All new assay data being added to the database were monitored daily and validated monthly for accuracy and consistency by comparing the data transferred to the Mines Exploration Borehole System (MEBS) database to the assay certificates received from ALS Vancouver. Several steps are employed to validate data and ensure the integrity of the MEBS database, the majority of which are performed by software data-checking routines. It is the operation qualified person's responsibility to ensure that the database is validated and its integrity maintained by the direct supervision of one person (the database manager) who reports directly to the operation qualified person.

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. In addition to these internal checks Vale contracted independent consultants to perform laboratory, database and mine study reviews. The process of active database quality control and internal and external audits generally resulted in quality data.

Vale currently uses a system of "layered responsibility" to ensure that only appropriately verified data are used for estimation purposes. The concept of a system of "layered responsibility" is that individuals at each level within the organization assume responsibility, through a sign-off or certification process, for the work relating to preparation of mineral resource and mineral reserve estimates that they are most actively involved in. Mineral reserve, mineral resource and exploration target estimates are prepared and certified by qualified persons at the mine site level, and are subsequently reviewed by qualified persons at the Vale Base Metals corporate level. Where there is more than one mine, the mine qualified persons prepare and sign on the estimates for their mine and provide them to the operations qualified persons, and then to the qualified persons at the Vale Base Metals corporate level.

Vale staff perform a number of internal studies and reports in support of mineral resource and mineral reserve estimation for the various Ontario Operations mines. These include reconciliation studies, mineability and dilution evaluations, investigations of grade discrepancies between model assumptions and probe data, drill hole density evaluations, long-range plan reviews, and mining studies to meet internal financing criteria for project advancement.

Vale and its predecessor companies commissioned a number of audits and third-party reviews of block models, mineral resources and mineral reserves.

As a result of these activities, 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.

1.10 METALLURGICAL TESTWORK

The mineralogy and metallurgical performance of the sulphide deposits at the Ontario Operations is generally well understood due to the extensive drill hole coverage, mill performance records and mineralogical and metallurgical studies conducted over the last 100 years. These metallurgical studies, ranging from bench-scale to multi-tonne pilot testing, have included academic and industrial research and development of mineral separation. Based on these studies, flowsheet evolution and optimization has included processes such as magnetic separation, regrind circuits and various reagent additions.

The anticipated metal recoveries at the Clarabelle Mill are based on an empirical mill process model based on ore attributes (nickel: pyrrhotite ratio, nickel grade, etc.) which were developed internally by Vale personnel. The model rejects the same percentage of pyrrhotite from all the mineralization going to the mill at the same metal grades (annually adjusted to plan). Similarly, the rock tailings are rejected at the same metal grades (annually adjusted to plan) for all mineralization. The model contains assumptions as to the behavior of typical ores based on grade and pyrrhotite content. Maximum allowable values for recoveries are set for ores that may exceed the known expected recoveries.

Tests were performed on samples that are considered to be representative for the different orebodies/zones and the mineralogy of the various orebodies and zones.

The deleterious elements for smelting are arsenic, lead, zinc, and chromium. With these typical deleterious element concentrations, the mill concentrate feed (nickel concentrate currently) for the smelter routinely meets smelter specifications. The element of the greatest concern is arsenic and the overall blended feed into the plant is kept below 0.008% As.

1.11 MINERAL RESOURCE ESTIMATES

1.11.1 ESTIMATION METHODOLOGY

Vale has a set of protocols and guidelines in place to support the estimation process, which the estimators must follow.

Estimation was performed as a team effort involving several technical disciplines.

All mineralogical information, exploration boreholes and background information were provided to the estimators by the geological staff at the mines or by exploration staff. Commercially-available Datamine software was used for estimation.

The mineral resource confidence categories were initially assigned based on a combination of factors, including geological understanding and confidence, drill hole support, grade estimation confidence relative to planned production rates, and identified risk factors. The initial assignments were reviewed to assess the impacts of factors such as metallurgical recoveries, geomechanical studies, mine design work, and representative mineability and recovery reconciliation analysis. Where mining has occurred or is currently active, the mined-out volumes were wireframed, classified as either void or fill, and overprinted upon the resource model to account for mining depletion.

For each mineral resource estimate, an initial assessment was undertaken that assessed likely infrastructure, mining, and process plant requirements; mining methods; process recoveries and throughputs; environmental, permitting and social considerations relating to the proposed mining and processing methods, and proposed waste disposal, and technical and economic considerations in support of an assessment of reasonable prospects of economic extraction. All material is assumed to be blended at the Clarabelle Mill, and milling throughput rates will depend on the blending strategy in place at the mill at the time the material is processed.

Commodity prices used in mineral resource estimation are 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. The estimated timeframe used for the price forecasts is the 23-year LOM that supports the mineral reserve estimates.

The mineral resources are reported at varying cut-off values, which are based primarily on the mining method that will be used. Process and G&A costs are based on the assumption that material will be sent to, and blended at, the Clarabelle Mill.

1.11.2 MINERAL RESOURCE STATEMENT

Mineral resources current as at of 31 December, 2021, are reported using the mineral resource definitions set out in SK1300, and are reported exclusive of those mineral resources converted to mineral reserves. The reference point for the estimate is in situ.

The measured and indicated mineral resource estimates for the Ontario Operations are provided in Table 1-1. The inferred mineral resource estimates are included in Table 1-2. The Qualified Person for the estimate is Chris Gauld, P.Geo., a Vale employee.

Table 1-1: Ontario Operations, Measured and Indicated Mineral Resource Statement

Mine/Area	Category	Tonnage (kt)	Grade Cu (%)	Ni (%)	Co (%)	Pt (g/t)	Pd (g/t)	Au (g/t)
Blezard	Measured	—	—	—	—	—	—	—
	Indicated	7,887	0.68	0.99	0.04	0.26	0.27	0.08
	Sub-total measured + indicated	7,887	0.68	0.99	0.04	0.26	0.27	0.08
Coleman	Measured	234	1.08	2.12	0.07	0.43	0.57	0.04
	Indicated	2,290	4.33	1.57	0.04	3.62	4.83	1.77
	Sub-total measured + indicated	2,524	4.03	1.62	0.04	3.33	4.44	1.61
Copper Cliff	Measured	2,065	1.70	1.35	0.05	1.12	1.35	0.52
	Indicated	4,207	1.07	1.32	0.04	1.04	1.42	0.35
	Sub-total measured + indicated	6,273	1.28	1.33	0.04	1.07	1.40	0.41
Creighton	Measured	—	—	—	—	—	—	—
	Indicated	6,213	3.29	4.52	0.09	0.98	1.16	0.33
	Sub-total measured + indicated	6,213	3.29	4.52	0.09	0.98	1.16	0.33
Garson	Measured	230	1.24	1.79	0.11	0.64	1.60	0.44
	Indicated	2,598	1.49	1.35	0.06	0.98	1.87	0.50
	Sub-total measured + indicated	2,828	1.47	1.39	0.06	0.95	1.85	0.49
Copper Cliff Pit	Measured	4,340	0.50	1.13	0.06	0.12	0.21	0.02
	Indicated	3,177	0.44	0.78	0.04	0.11	0.15	0.05
	Sub-total measured + indicated	7,517	0.47	0.98	0.05	0.12	0.18	0.03
Stobie	Measured	—	—	—	—	—	—	—
	Indicated	10,035	0.42	0.47	0.02	0.20	0.22	0.09
	Sub-total measured + indicated	10,035	0.42	0.47	0.02	0.20	0.22	0.09
Totten	Measured	441	1.33	1.13	0.03	1.53	0.67	0.48
	Indicated	278	1.18	0.66	0.01	1.53	0.79	0.51
	Sub-total measured + indicated	719	1.27	0.95	0.02	1.53	0.72	0.49
Victor	Measured	—	—	—	—	—	—	—
	Indicated	13,859	4.39	1.75	0.03	1.48	1.82	0.60
	Sub-total measured + indicated	13,859	4.39	1.75	0.03	1.48	1.82	0.60
Total	***Measured***	***7,311***	***0.93***	***1.24***	***0.05***	***0.51***	***0.61***	***0.20***
	Indicated	***50,546***	***2.19***	***1.59***	***0.04***	***0.92***	***1.17***	***0.38***
	Total measured + indicated	***57,857***	***2.04***	***1.54***	***0.04***	***0.87***	***1.10***	***0.35***

Table 1-2: Ontario Operations, Inferred Mineral Resource Statement

Mine/Area	Category	Tonnage (kt)	Grade					
			Cu (%)	Ni (%)	Co (%)	Pt (g/t)	Pd (g/t)	Au (g/t)
Blezard	Inferred	—	—	—	—	—	—	—
Coleman	Inferred	877	3.3	0.5	0.01	2.4	3.2	1.1
Copper Cliff	Inferred	2,535	1.6	1.0	0.03	1.6	1.5	0.6
Creighton	Inferred	3,302	3.2	4.0	0.08	1.6	2.2	0.5
Garson	Inferred	916	1.9	1.4	0.05	0.6	0.9	0.3
Copper Cliff Pit	Inferred	—	—	—	—	—	—	—
Stobie	Inferred	—	—	—	—	—	—	—
Totten	Inferred	398	1.9	1.2	0.03	1.2	1.3	0.3
Victor	Inferred	537	3.4	0.7	0.01	0.5	0.8	0.3
Total	***Inferred***	***8,564***	***2.5***	***2.1***	***0.05***	***1.5***	***1.8***	***0.6***

Notes to accompany mineral resources tables:

1. Mineral resources are reported using the mineral resource definitions in SK1300. The reference point for the mineral resource estimate is in situ. The estimate is current as at 31 December, 2021. The Qualified Person for the estimate is Chris Gauld, P.Geo., a Vale employee.
2. Mineral resources are not converted to mineral reserves as they have not demonstrated economic viability. Mineral resources that are reported, are those exclusive of those mineral resources converted to mineral reserves.
3. The estimate uses the following key input parameters: open pit mining methods or underground bulk stoping or narrow vein cut-and-fill mining methods; copper sale price of US$5,250-7,000/t, nickel sale price of US$13,376-18,000/t, cobalt sale price of US$27,500-45,000/t, platinum price of US$1,150-1,225/oz, palladium price of US$750-1,093/oz, gold price of US$1,200-1,373/oz; variable copper recovery ranging from 79–95%, variable nickel recovery ranging from 45–91%; mine operating costs ranging fromUS$32–$247t mined, process costs ranging from US$15–$112/t milled; general and administrative (G&A) costs ranging from US$2–$39/t milled; mining recovery ranging from 81–100%, and mining dilution of 5–20%.
4. Rounding as required by reporting guidelines may result in apparent summation differences.

Areas of uncertainty that may materially impact all of the mineral resource estimates include: changes to long-term metal price and exchange rate assumptions; changes in local interpretations of mineralisation geometry such as pinch and swell morphology, extent of brecciation, presence of unrecognized mineralization off-shoots; faults, dykes and other structures; and continuity of mineralised zones; changes to geological and grade shape, and geological and grade continuity assumptions; changes to unfolding, variographical interpretations and search ellipse ranges that were interpreted based on limited drill data, when closer-spaced drilling becomes available; changes to metallurgical recovery assumptions; changes to the input assumptions used to derive the potentially-mineable shapes applicable to the assumed underground and open pit mining methods used to constrain the estimates; changes to the forecast dilution and mining recovery assumptions; changes to the cut-off values applied to the estimates; variations in geotechnical (including seismicity), hydrogeological and mining method assumptions; and changes to environmental, permitting and social license assumptions.

1.12 MINERAL RESERVE ESTIMATES

1.12.1 ESTIMATION METHODOLOGY

To publicly report a mineral reserve estimate, Vale Base Metals must intend to mine the mineralization as demonstrated by the inclusion of the mineral reserves in an operation or project's “Mineral Reserves only” life-of-mine (LOM) plan. The mineral reserve estimate must be supported by a mine plan, an annual technical report, and supporting files (including and not limited to: safety plan, driving layouts, execution schedules, production schedules, cost reports, capital outlay/procurement schedule and asset integrity system) for mineralization that is to be exploited from existing mine infrastructure (typically funded with operating costs or limited sustaining capital).

Mineral reserves were estimated using underground mining methods, which are typically a combination of bulk mining and cut-and-fill approaches. For each mine and mineral zone with mineral resources to be mined, a mining plan was developed that included selection of mining method, stope production sequencing, consideration of development, equipment and infrastructure requirements, and estimation of capital and operating costs.

Mining plans and engineering studies were completed for all mineral reserve estimates. All engineering studies were at a minimum prefeasibility-level studies.

Based on the selected mining method, and using the resource block model, a mine design was prepared for each individual stope. Only measured and indicated mineral resources were converted in the stope design to estimate proven and probable mineral reserves. No measured mineral resources were converted to probable mineral reserves.

Economic cut-off grades were estimated for each mine and mining area and used to optimize the design of each stope. The mineralized zones contain multiple metals, each with different metal prices, resulting in a net processing return (NPR) formula being used to assign a dollar value to mineralization. The full mining operating cash cost per short ton is compared to the NPR value per short ton to determine if a given amount of material is ore or waste. Following stope design, the mineral resources contained within the stope outline were determined. Internal (planned) dilution was included in the mineral resource estimates.

Mining recovery (mineability) and external dilution factors were applied. These factors were estimated based on historical experience with the various mining methods at each of the mines, and were applied to each stope on stope-by-stope basis after consideration of both the mining method and any local considerations at each mine that could impact mining.

The resulting mineral reserves in each stope for each mine were scheduled in the mine operations life-of-mine production plan. The LOM plan included capital, operating and corporate costs estimates, and was assessed for economic viability. All mineable units or stopes that were scheduled for mining were included in the mineral reserves, and were tested in the overall Ontario Operations production plan. Material within any stopes that did not meet economic criteria following the financial analysis of the production plan were not converted to mineral reserves.

1.12.2 MINERAL RESERVE STATEMENT

Mineral reserves were reported using the mineral reserve definitions set out in SK1300. The reference point for the mineral reserve estimate is the point of delivery to the process plant. Mineral reserves that are reported in Table 1-3 are current as at December 31, 2021. The Qualified Person for the estimate is Nick Gardner, P.Eng., a Vale employee. Tonnages in the table are metric tonnes.

Areas of uncertainty that may materially impact all of the mineral reserve estimates include: long-term commodity price assumptions; long-term exchange rate assumptions; long-term consumables price assumptions; changes to mineral resources input parameters; changes to constraining stope designs; changes to cut-off grade and NPR assumptions; changes to geotechnical (including seismicity) and hydrogeological factors; changes to metallurgical and mining recovery assumptions; the ability to control unplanned dilution; and assumptions as to the continued ability to access the site, retain mineral and surface rights titles, maintain environment and other regulatory permits, and maintain the social license to operate.

Table 1-3: Proven and Probable Mineral Reserve Statement

Deposit	Category	Tonnage (kt)	Grade					
			Cu (%)	Ni (%)	Co (%)	Pt (g/t)	Pd (g/t)	Au (g/t)
Coleman	Proven	3,157	3.58	1.43	0.04	1.72	2.77	0.93
	Probable	2,065	2.77	1.12	0.02	2.19	2.92	0.76
	Sub-total Proven + Probable	5,222	3.26	1.31	0.03	1.90	2.83	0.86
Copper Cliff	Proven	6,797	1.42	1.06	0.03	1.22	1.03	0.51
	Probable	29,059	1.28	1.16	0.03	1.08	1.48	0.39
	Sub-total Proven + Probable	35,856	1.30	1.14	0.03	1.11	1.39	0.41
Creighton	Proven	2,245	2.53	3.05	0.06	0.85	1.01	0.32
	Probable	1,474	2.27	3.07	0.06	0.93	0.99	0.18
	Sub-total Proven + Probable	3,719	2.43	3.06	0.06	0.88	1.00	0.27
Garson	Proven	3,470	1.24	1.55	0.05	0.64	0.55	0.25
	Probable	1,966	1.03	1.34	0.05	0.60	0.52	0.16
	Sub-total Proven + Probable	5,436	1.17	1.48	0.05	0.63	0.54	0.22
Totten	Proven	3,213	1.74	1.39	0.03	1.64	0.80	0.52
	Probable	390	1.65	0.86	0.02	1.89	1.32	0.86
	Sub-total Proven + Probable	3,603	1.73	1.33	0.03	1.67	0.86	0.56
Total Ontario Operations	***Proven***	***18,882***	***1.94***	***1.51***	***0.04***	***1.22***	***1.19***	***0.51***
	Probable	***34,954***	***1.40***	***1.24***	***0.03***	***1.12***	***1.49***	***0.39***
	Sub-total Proven + Probable	***53,835***	***1.59***	***1.33***	***0.04***	***1.16***	***1.38***	***0.43***

Notes to accompany mineral reserves table:

1. Mineral reserves are reported using the mineral reserve definitions set out in SK1300. The reference point for the mineral reserve estimate is the point of delivery to the process plant. The estimates are current as at December 31, 2020. The Qualified Person for the estimate is Nick Gardner, P.Eng., a Vale employee.
2. The estimates use the following key input parameters: bulk stoping or narrow vein cut-and-fill mining methods; copper sale price of US$6,100/t, nickel sale price of US$13,376/t, cobalt sale price of US$45,000/t, platinum sale price of US$1,225/oz, palladium sale price of US$925/oz, gold sale price of US$1,300/oz; variable copper recoveries ranging from 85–95%, variable nickel recoveries ranging from 69–86%; mine operating costs ranging from US$66–220/t mined, process costs ranging from US$51–187/t milled; mining recovery ranging from 75–99%, and unplanned dilution of 6–20%.
3. Rounding as required by reporting guidelines may result in apparent summation differences.

1.13 MINING METHODS

The Ontario Operations use conventional bulk stoping or narrow vein cut-and-fill mining methods, depending on the mine and geological setting. Mines are Owner-operated, and use conventional equipment.

Vale has technical guidelines and procedures in place to ensure that valid geotechnical data are collected and interpreted using appropriate methods, and that existing or planned risk mitigation measures that support mine designs are based on those data and interpretations. Geotechnical data collection and rock mass characterization are used to define geotechnical domains.

For each domain, ground support designs are specified that take into account geotechnical conditions, excavation service life and geometry, proximity to present and future openings, personnel exposure, local historical experiences, and local regulations. Geotechnical recommendations for vertical development, lateral development, and mining stopes, are provided. Legacy workings and drill holes with respect to mine plans are considered to ensure these hazards are mitigated.

All underground mines must have an effective Ground Control Management Plan, also referred to as the “Mine Design Package”, which is a single coherent document that must be developed through application of sound geotechnical engineering practices, conform to local mining regulations, and be aligned with Vale’s safety standards. Within the mine design package of each seismically active mine, there is a Seismic Management Plan. Five mines are seismically active at the Report effective date, consisting of the Coleman, Creighton, Copper Cliff, Garson and Totten Mines.

Either sand or mill tailings are used as a hydraulic backfill, with the type of fill materials dependent on the proximity of a mine to the Clarabelle Mill, and the availability of proximal alluvial sand sources. High-density (paste) backfill is only used at the Main zone of the Garson Mine.

Hydrological planning relies on historical norms and information. Most of the water that reports to the underground operations is from three sources: pumped in, surface runoff and ground water. A large percentage of a mine’s process water is pumped in (approximately 50–70%); about 30–50% is derived from surface depending on the season, and, other than the Garson Mine, only minor amounts are contributed from ground water.

Mines are accessed using a combination of shafts, declines, and internal ramps.

Several mining methods are used across the Ontario Operations: open stoping (longitudinal, transverse, slot–slash); post-pillar cut-and-fill; narrow vein cut-and-fill; vertical retreat; uppers retreat and mechanized cut-and-fill. Each mine has a substantial history of which mining methods work best under various geological and geotechnical conditions. This production record is considered when selecting the mining method.

The ore and waste handling system varies at each mine. Ore can be transported using load–haul–dump vehicles to a central loading area or ore pass, and then trucked to an underground crusher, from where it is hoisted to surface; or, if the mine has decline access, it is trucked to surface. Most of the waste rock is used underground as fill, although some rock hoisting of rock can occur.

Each mine has a ventilation system in place. Some ventilation circuits are shared with Glencore operations.

Each mine has a production schedule that incorporates production and cost information for each producing area within the mine, based on mineral reserve estimates. Production schedules were limited by process and infrastructure constraints such as ventilation, drift development, LHD/haulage, backfilling, and muck circuit/storage. The assemblage process activities were used to derive costs based on a combination of historical and budgeted rates. These plans were collated into an overall production schedule for the Ontario Operations. Based on this schedule, the forecast mine life is 22 years (2022–2043).

1.14 RECOVERY METHODS

The process plant design was based on a combination of metallurgical testwork and familiarity gained during historical processing. The Clarabelle Mill was originally built in 1971 and subsequently underwent a number of major modifications. The hourly design throughput of the plant was based on a yearly throughput of approximately 8 M tons. The utilization calculation was that the plant would operate 350 days per year, with an availability of 92%, for a net utilization of 88.2%.

At the concentrator, the ore is crushed and ground and fed to the froth-flotation cells. The multi-staged froth flotation separates the sulphide minerals into a nickel concentrate and a copper concentrate. The tailings are disposed of in tailings ponds. The nickel concentrate typically averages 10% Ni and 8.5% Cu. The copper concentrate typically averages 33% Cu and 0.4% Ni. The plant is operated in such a way to place as much copper into the saleable copper concentrate as possible, then recover remaining copper and maximum possible nickel into a high-grade nickel–copper bulk concentrate to maximize the product NSR values.

The copper concentrate is filtered and shipped to market buyers. The nickel–copper bulk concentrate is dewatered at the smelter, and upgraded to Bessemer matte by processing through fluid-bed roasters, electric furnaces, and Pierce–Smith converters. The magnetic metallics (containing nickel, copper, and precious metals) are sent to the Copper Cliff Nickel Refinery. The nickel sulphides are roasted in a fluid-bed roaster to produce nickel oxides which are then sent to the Copper Cliff Nickel Refinery or the Clydach Nickel Refinery in Wales.

The Copper Cliff Nickel Refinery complex includes three areas: nickel refinery converter (NRC), Inco pressure carbonyl (IPC) and electrowinning (EW). Nickel sulphides and oxides from the smelter complex and other feeds are blended and fed to top blown rotary converters, which produce a high-grade nickel matte. This matte is granulated and fed into one of three carbonylation reactors in the IPC, where nickel and trace iron are extracted by reaction with carbon monoxide. The mixture is separated into a pure nickel carbonyl stream and an iron/nickel carbonyl stream. Material from both streams is decomposed at high temperature to produce pure nickel pellets, pure nickel powders and ferro-nickel pellets, which are sold directly to market. The residue left in the reactor, high in copper, cobalt and precious metals, is ground and pumped to the EW plant as a slurry.

In the EW process, copper is removed from IPC residue. Copper cathodes are plated from solution and sold to market. Three other products are made at EW: a nickel–cobalt carbonate slurry, a slurry-rich in precious metals containing platinum-group metals, silver and gold and a slurry enriched in platinum-group metals and selenium–tellurium. These are sent to Port Colborne for further processing.

An overview of the process flowsheet from the mill to smelter and refinery is provided in Figure 14-1.

Consumables used in the Clarabelle process plant include grinding media, lime, xanthate, electrical materials, lubricants, and maintenance supplies. Water for process and potable needs is sourced from the Vermilion River, or is recycled from the plant. Consumables used in the smelter and refineries include spare parts, electrical materials, maintenance supplies, refractories, sand, lime, soda ash, sodium hydroxide, acid, and chlorine. Water requirements and water sources vary by smelter/refinery location. The Copper Cliff smelter and Copper Cliff Nickel Refinery source freshwater from the Vermilion River, and recycle process water from the plant operations. The Port Colborne Refinery sources its freshwater and process water needs from the Welland Canal. Fresh and process water is sourced from the Swansea Canal or Tawe River for use at the Clydach Refinery; however after 2022, this source will no longer be used, and water will be sourced from a closed-loop recycling system.

A total of 118 persons are employed at the Clarabelle Mill, 421 persons at the Copper Cliff smelter, 306 persons at the Copper Cliff Nickel Refinery, 164 persons at the Port Colborne Refinery and 173 persons at the Clydach Nickel Refinery.

1.15 INFRASTRUCTURE

All major infrastructure to support the Ontario Operations mining activities envisaged in the LOM is in place. No accommodations camps are operated. Personnel live either in Sudbury or in surrounding settlements.

Major infrastructure for the mine sites includes head frames, open, cold, and heated warehouses, mechanical and electrical shops, hoist room buildings, fan houses, sand plants, paste fill plant, backfill plant, first aid/security stations, training rooms, offices and change/shower facilities, management and technical services offices, sewage treatment plants, process water storage tanks and pump houses, fuel storage facilities, mine water treatment systems, surface repair facilities, slick line systems, dewatering pipelines, and fresh and return air ventilation systems.

Ontario Operations infrastructure also includes a tailings impoundment area, a slag disposal area and an oxygen plant.

The processing facilities in Sudbury include a concentrator, a combined nickel and copper smelter, matte processing facilities, a carbonyl nickel refinery, a copper anode casting plant, a sulphuric acid plant and a sulphur dioxide liquefaction plant. Processing facilities at Clydach consist of a carbonyl nickel refinery. Processing facilities at Port Colborne include an electro-cobalt refinery and precious metals upgrading facility.

The Copper Cliff tailings impoundment or Central Tailings Area became operational in 1936 and has become the primary management site for tailings generated from the Ontario Operations. The facility encompasses some 2,430 ha, and is divided into several areas according to eras of tailings disposal. The Upper Pond Area (UPA) and associated Upper Pond Dam received tailings from operations prior to the 1930s. The dams were subsequently used as water reservoirs for smelter operations.

Vale meets the requirements of the Ontario Ministry of Natural Resources (MNR), Lakes and Rivers Improvement Act, uses safety guidance provided by the Canadian Dam Association, and internal risk management frameworks to ensure dam safety. Vale has undertaken numerous studies on the Central Tailings Area to update various aspects of the facility to meet current dam engineering practices. A detailed Operations Manual was developed and is regularly updated.

The smelter operation generates approximately 1 Mt of slag annually. Slag is taken to one of three locations on the Copper Cliff property, emptied, and the slag is allowed to cool. It is then broken up and sent to storage in one of two storage areas in the central and northeastern areas of the smelter that were designated for storage of cooled slag.

The general water management strategy for several facilities peripheral to the Central Tailings Area involves collecting and treating impacted runoff. The strategy is common to the Copper Cliff, Creighton and Stobie Mines, Clarabelle Mill, the Central Tailings Area, UPA, smelter complex, Nickel Refinery, and the Copper Cliff and Nolin Creek waste water treatment plants. Surface water over areas potentially affected by acid rock drainage is managed using two systems; the Copper Cliff and Nolin Creek water management systems.

Electrical power for the Ontario Operations is primarily sourced from grid supply (approximately 80%). Power is transmitted on the Hydro One transmission system and is connected to two locations in Sudbury and one in Port Colborne. In Sudbury, all incoming grid-connected power and hydroelectric generation is distributed to mines and processing plants through Vale's electrical distribution network, consisting of 69 kV distribution power lines, substations, transformers, breakers, disconnects and other electrical equipment. This distribution system is owned, operated, and maintained by Vale. A portion of the demand (about 20%) is met by Vale's hydroelectric power facilities. Vale consumes 100% of its self-produced hydro generation behind-the-meter, i.e., Vale does not supply power to the Ontario grid. The Clydach Nickel Refinery obtains all of its power from a local utility.

1.16 MARKET STUDIES

Vale has established contracts and buyers for the products from the Ontario Operations. Vale has an internal marketing group which monitors markets for its key products. Together with public documents and analyst forecasts, these data support that there is a reasonable basis to assume that for the LOM plan, that the key products will be saleable at the assumed commodity pricing.

None of the products from the Ontario Operations are subject to product specification requirements from end users to be saleable.

Vale uses a combination of contract pricing, knowledge of its key markets from a long production record, short-term versus long-term price forecasting, public documents and analyst forecasts when considering long-term commodity price forecasts. The long-term commodity price forecasts for the Ontario Operations are:

- Nickel: US$18,000/t;
- Copper: US$7,500/t;
- Cobalt: US$50,000/t;
- Platinum: US$1,200/oz;
- Palladium: US$1,400/oz;
- Gold: US$1,450/oz.

The long-term exchange rate assumptions is:

- 1.26

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 published and should not be considered as a guidance.

Vale has agreements at typical nickel industry benchmark terms for sales of refined nickel and cobalt. For all of Vale's sales contracts, the risk of the refined nickel and cobalt transfers either at the load port or discharge port according to the standard International Commercial Terms (Incoterms); whereas the title to the refined metal transfers either at the load port or discharge port according to the standard Incoterms or upon payment.

The cobalt is sold under annual contracts or as spot into the market under market terms negotiated at the time of sale. As metals contained in copper products, the terms for PGMs are determined through a payable mechanism on metal content based on typical market terms. As typical for concentrates, the product is generally contracted under a medium-term contract. PGM concentrate and gold sands are typically sold using spot pricing terms with end-users based on prevailing market conditions.

Contracts may be entered into for goods and services required to operate underground mining operations. On occasions, mining contractors may be employed for specific mine development projects. The largest in-place contracts include transportation, purchase of fuel, reagents and other process consumables, ground support and mining equipment leases. The terms contained within the contracts are typical of, and consistent with, standard industry practices.

Intercompany agreements between Vale affiliates are negotiated at arm's length based on market terms and rates that would be achieved had the contract been negotiated with an unaffiliated third party.

1.17 ENVIRONMENTAL, PERMITTING AND SOCIAL CONSIDERATIONS

1.17.1 ENVIRONMENTAL STUDIES AND MONITORING

Vale's Ontario Operations are one of the largest integrated mining complexes in the world, including both mines and processing operations, some dating back to the early- and mid-1900s.

Environmental regulations and awareness has progressed significantly from the beginning of our operations in Ontario and the company has engaged in baseline studies, various improvement and legacy reclamation initiatives and other activities to ensure compliance as the regulatory regime changes.

All pertinent baseline information as per standard of the day is available in the Closure Plans for the mine sites and surface plants, including: land use, topography, regional geology, local geology and mineralogy, soil, climate and hydrology, hydrogeology, terrestrial plant and animal life and aquatic plant and animal life, with relevant updates provided in the subsequent Closure Plan amendments.

As the mines and plant sites have continued to expand, supporting environmental studies have been completed to assess site environmental conditions, and to support permit applications and decision-making processes.

Characterization studies were completed for all environmental media including soil, water, waste, air, noise and closure. Plans were developed and implemented for all Ontario Operation mine sites to address waste management, spill prevention and contingency planning, water management and fugitive dust management.

1.17.2 CLOSURE AND RECLAMATION CONSIDERATIONS

Vale has 16 closure plans for aspects of the Ontario Operations, covering the Central Tailings Facility, Clarabelle Mill, the Copper Refinery, Crean Hill Mine, Creighton Mine, Frood–Stobie Mine, Garson Mine, Levack–Onaping-Coleman Mines, the nickel refinery, Copper Cliff North Mine, Port Colborne Refinery, Shebandowan Mine and mill, Copper Cliff Smelter complex, Copper Cliff South Mine, Whistle Mine and Totten Mine. Closure plans for all operating sites were submitted to the relevant regulatory authorities, and there are plans in place for three closed sites (Whistle Mine, Shebandowan Mine and mill site, and Crean Hill Mine) in accordance with Part VII of the Ontario Mining Act.

While Ontario Operations uses "self-assurance" as its form of financial assurance for surface facilities, a performance bond of C$206 million, in the form of letters of credit, was provided for 10 properties. Such bonding is a requirement in Ontario when the half-life of a mine is exceeded or where a facility has formally ceased operations.

Vale developed closure cost estimates associated with the chosen rehabilitation strategy for each property. The estimate also includes an expected schedule for closure-related expenditures. Closure costs are included in the mine site financial models as cash costs, on an annual basis for all sites. The largest closure costs are associated with the process plant and mining infrastructure. The escalated closure cost estimate for the Ontario Operations, as at year-end 2021, is US$2,060 million.

1.17.3 PERMITTING

All known and anticipated permits and approvals are in place to support operations. These include permits for air quality, noise emissions, taking and discharging water, and tailings, waste rock and waste disposal.

Where permits have specific terms, renewal applications are made of the relevant regulatory authority as required, prior to the end of the permit term.

For new mining projects that may be incorporated into future mine plans, assuming mineral resources can be converted to mineral reserves with the appropriate supporting studies, the expectation is that environmental/impact assessments (if required) will be near completion, and the permits required for mine development will be understood and advancing, where possible, with baseline and supporting studies completed to facilitate application submissions and detailed design.

1.17.4 SOCIAL CONSIDERATIONS, PLANS, NEGOTIATIONS AND AGREEMENTS

Vale routinely engages with four Indigenous communities in the Sudbury Basin and the Métis Nation of Ontario. Vale has signed agreements with AAFN, WFN, SAFN and the MNO – Region 5. With respect to the Totten Mine, Vale has a signed Impact Benefit Agreement with the Sagamok Anishnawbek First Nation. There are currently no known consultation obligations which would materially impact the mineral reserve estimates. However, consultation obligations may need to be satisfied before new areas that currently only have mineral resource estimates can be developed.

Due to the proximity of the local communities to the Central Tailings Area, mill, refinery and smelter operations, especially the Town of Copper Cliff, Vale also continues to engage the local communities of interest that may be impacted by future development. Various programs have been implemented, including Annual Reports to the general public, a Liaison Committee that regularly meets with representatives from the Town of Copper Cliff, as well as a designated telephone line and company website to provide current information about the Sudbury operations. Any complaints are immediately followed up and addressed as applicable.

1.18 CAPITAL AND OPERATING COST ESTIMATES

1.18.1 CAPITAL COST ESTIMATES

Capital costs are based on recent prices or operating data. Unit costs for in-house mine development are based on historical actual costs. Mobile equipment that is leased is included in operating costs. Lease periods typically range from two to five years. Lease costs are charged to capital while the equipment is doing capital work. Purchased equipment is allocated for in the capital plan. Mobile equipment and fixed asset costs are based on supplier quotations and/or current examples.

Sustaining capital cost forecasts are based on forecast mine development and construction needs, mobile equipment re-build/replacement schedules and fixed asset replacement and refurbishment schedules.

The overall capital cost estimate for the LOM is US$5,429 million as shown in Table 1-4. 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.

Table 1-4: LOM Capital Cost Estimate

Area	Capital Cost Type	Unit	Value
Mining	Annual capital development	US$ M	1,288
	Stoping and Development	US$ M	642
	Asset integrity	US$ M	515
Copper Cliff Mine Project	Project	US$ M	1,269
Milling	Sustaining	US$ M	256
Smelting and Refining	Sustaining	US$ M	942
Other[1]	Sustaining	US$ M	516
Total		***US$ M***	***5,429***

Note:
Numbers have been rounded.
[1]Other costs include provision for elements such as the power department (electrical power generation and distribution), the divisional shops (custom parts repair and manufacturing), the transportation department, the environment department and the central engineering department

1.18.2 OPERATING COST ESTIMATES

Operating costs are based on actual costs seen during operations and are projected through the LOM plan.

Historical costs are used as the basis for operating cost forecasts for supplies and services unless there are new contract terms for these items.

Labour and energy costs are based on budgeted rates applied to headcounts and energy consumption estimates.

The long-term mine operating cost model accounts for the impact of varying production rates on the direct variable costs. As a mine approaches the end of mine life, indirect and distributed costs are reduced in line with the projected lower production rates.

Table 1-5: Operating costs and expenses

Area	Unit	Value
Mining	US$ M	6,095
Milling	US$ M	756
Smelting and Refining	US$ M	3,224
G&A and Corporate Overhead	US$ M	2,649
Site Services and Other	US$ M	682
R&D	US$ M	156
Logistics and Distribution Costs	US$ M	218
Total	***US$ M***	***13,781***

Note: All numbers have been rounded.

The processing operating cost estimates are the budget year cash costs applied to the mineral reserves mined throughout the LOM plan. Such processing costs include both variable and fixed plant components. Since the throughput for the processing plants decreases over the LOM plan, the fixed cash cost component of these processing plants is stepped down in a logical progression as the feed decreases.

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.

Operating costs total US$ 13,781 million over the LOM (Table 1-5).

1.19 ECONOMIC ANALYSIS

1.19.1 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 Vale publishes 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.

1.19.2 METHODOLOGY AND ASSUMPTIONS

The financial model that supports the mineral reserve declaration is a standalone model that calculates annual cash flows based on scheduled ore production, assumed processing recoveries, metal sale prices and C$/US$ exchange rate, projected operating and capital costs and estimated taxes. The financial analysis is based on an after-tax discount rate of 7.5% following a mid-year convention. All costs and prices are in unescalated “real” dollars. The currency used to document the cash flow is US$. All costs are based on the five-year plan approved budget. Post 2026, costs were estimated based on the 2022–2026 period.

The economic analysis is based on 100% equity financing and is reported on a 100% project ownership basis.

The basis of the economic analysis is the mineral reserve estimate. Revenue is calculated from the recoverable metal and the long-term forecast of metal prices and exchange rates. Revenue from the sale of a copper concentrate is included, based on the contained metal, accountability factors and the long-term forecast for metals prices and exchange rates.

The Ontario Operations also receives revenue from the sale of mined material by Glencore, known as the Bowtie material. In this arrangement, Glencore mines and processes material that is located within Vale’s claims. Vale then receives a gross metal value-type payment for the material mined.

The financial estimates are based on a combined federal and provincial statutory tax rate of 25% and a provincial mining statutory tax rate of 10%, before processing allowance. Depreciation rates for corporate income tax purposes have been applied, on a declining basis, at the base rates of 25% for depreciable tangible capital property and 30% for mine development. For mining tax purposes, depreciation was approximated on a declining balance basis for mining (30%) and processing property (15%). Provincial mining processing allowance is further deducted as applicable. The mining tax paid is deductible for corporate income tax purposes.

The LOM plan assumes that active mining operation ceases in 2044; however, closure costs are estimated to 2148.

1.19.3 ECONOMIC ANALYSIS

The post-tax $NPV_{7.5\%}$ is US$1,177 M. As the cashflows are based on existing operations where all costs are considered sunk to 1 January 2022, considerations of payback and internal rate of return are not relevant. The financial analysis is based on an after-tax discount rate of 7.5% following a mid-year convention.

1.19.4 SENSITIVITY ANALYSIS

A Sensitivity analysis was performed on metal prices, metal recovered, capital costs and operating costs. Ontario Operations are most sensitive to the following, arranged in order from most to least sensitive:

- Nickel price
- Nickel recovered
- Copper price
- Operating cost
- Copper recovered
- Capital costs

1.20 CONCLUSIONS & RECOMMENDATIONS

Under the assumptions presented in this Report, the Ontario Operations have a positive cash flow, and mineral reserve estimates can be supported.

- Historical monthly, quarterly, and annual reconciliation evaluations indicate that tonnages and grades of the long-term model, and modifying factor assumptions including recovery and dilution, metallurgy and geotechnical are supported within acceptable limits.
- The permitting and environmental requirements to operate the Ontario Operations are well understood and can support mineral resource and mineral reserve estimation.
- The site developed mineral resource models follow industry practices and is a reasonable representation for the mineralization in Ontario

The QPs make the following recommendations totalling approximately:

- Complete detailed study for Copper Cliff Mine Expansion Project. This project envisages the development of the 191, 178, and 712 orebodies to sustain production through the North and South shafts at the Copper Cliff Mine. The recommended budget and includes provision for engineering and advanced development for collection of geological, geotechnical, and metallurgical data, and studies into alternate low-cost mining methods;
- Complete a study that will examine developing the Copper Cliff Mine Pit. The deposit has the potential to provide low-cost mill feed from an open pit mine, and use available capacity at the Clarabelle Mill.
- Complete a study on the development of the 400 and 310 deposits, located at depth in the Creighton Mine. work should focus on studying alternate mine access alternatives, including development of a winze or extension of ramp network at depth, to mine high-grade mineralization below the 8590 Level;
- Complete, in conjunction with Glencore, a study on developing the 24N, BL28, and NR14 zones, located at 1500–2800 m below surface at the Victor Mine. The study should focus on using existing Nickel Rim South infrastructure for the development evaluation.

2 INTRODUCTION

2.1 REGISTRANT

This technical report summary (the Report) was prepared for Vale S.A. (Vale) on the Ontario Operations in the Sudbury district of Ontario. Vale uses its wholly-owned subsidiary, Vale Canada Limited (Vale Canada), as operator of the Ontario Operations. Figure 2-1 is a location plan for the operations.

2.2 TERMS OF REFERENCE

2.2.1 REPORT PURPOSE

The Report was prepared to be attached as an exhibit to support mineral property disclosure, including mineral resource and mineral reserve estimates, for the Ontario Operations in Vale's Form 20-F for the year ending 31 December, 2021.

Mineral resources are reported for the Blezard, Coleman, Copper Cliff, Creighton, Stobie, Garson, Copper Cliff Pit, Totten and Victor deposits.

Mineral reserves are reported for the Coleman, Copper Cliff, Creighton, Garson and Totten deposits.

2.2.2 TERMS OF REFERENCE

The Ontario Operations consist of all Vale's operating underground mines (Coleman, Copper Cliff, Creighton, Garson and Totten), processing and refining facilities in Ontario (Clarabelle Mill, Copper Cliff Smelter and Nickel Refinery, Port Colborne refining complex), the Clydach Refinery in Wales, and non-operating mines, and non-producing properties.

The term "Vale Base Metals" refers to Vale's base metals division of Vale led by Vale Canada, comprised of nickel and copper mining, smelting and refining assets in Canada, Brazil, Indonesia, the United Kingdom and Japan, including the production and sale of cobalt, platinum group metals, and other precious metals as by-products of nickel and copper mining and processing operations. Vale Canada is the corporate head and holding company for its base metals operations and assets globally.

Unless otherwise indicated, all financial values are reported in United States (US) currency (US$) including all operating costs, capital costs, cash flows, taxes, revenues, expenses, and overhead distributions.

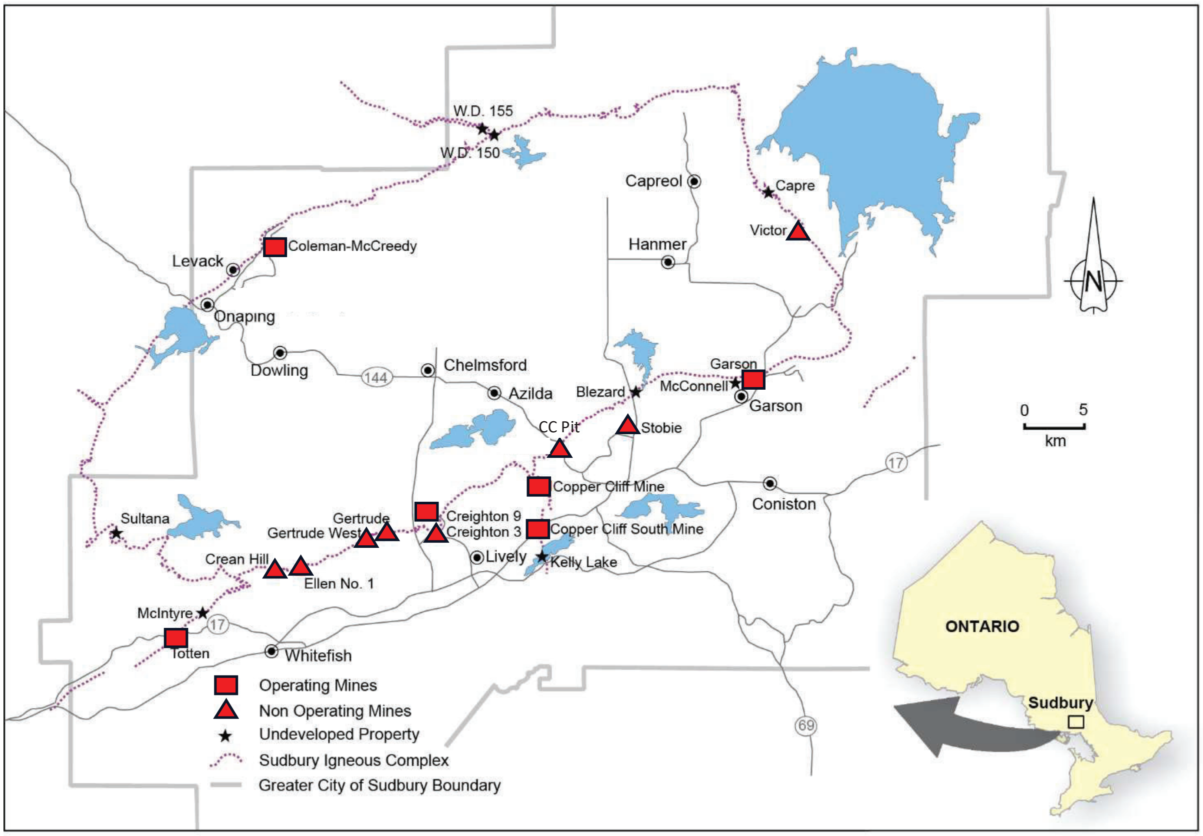
Ontario Operation's day to day work and database records are in the U.S. Customary system of units, which are used to refer to mining equipment capacities, skip, hoist and ore pass capacities, back fill rates, development rates and mine level designations as well as some analytical results.

Unless otherwise indicated, the metric system is used in this Report.

Mineral resources and mineral reserves are reported using the definitions in Subpart 229.1300 – Disclosure by Registrants Engaged in Mining Operations in Regulation S–K 1300 (SK1300). The Report uses Canadian English.

The Report uses Canadian English.

Figure 2-1: Ontario Operations Location Plan



Note: Figure prepared by Vale, 2021.

2.3 QUALIFIED PERSONS

The following Vale employees serve as Qualified Persons (QPs)

- Christy (Chris) Gauld, P.Geo., Manager Base Metals, Resource Management;
  - Responsible for sections: 1, 2, 3, 4, 5, 6, 7.1, 7.2, 8, 9, 10, 11, 14, 20, 21, 22.1-22.8, 22.10, 22.20, 23, 24, and 25
- Nick A. Gardner, P.Eng., Manager Base Metals Integrated Planning;
  - Responsible for sections: 1.1-1.2, 2.1-2.5, 12, 13, 15.1-15.4, 15.9 -15.11, 16, 17, 18, 19, 22.1, 22.11 - 22.12, 22.14 - 22.19, 22.20.1 - 22.21, 23, 24, and 25
- Alex Hossack MAusIMM (CP), Manager Base Metals, Geotechnical;
  - Responsible for sections: 1.1-1.2, 1.21.1-1.21.2, 1.23, 2.1-2.4, 2.6, 7.3-7.4, 15.4, 22.1, 22.14, 22.20.1-22.20.2, 23-24.3, 25.1-25.7, 25.8.3
- Greg Puro, P.Eng., Manager Base Metals, Dams.
  - Responsible for sections: 1, 2, 15, 22, 23, 24, and 25

2.4 SITE VISITS AND SCOPE OF PERSONAL INSPECTION

Chris Gauld has visited the Ontario Operations on numerous occasions since 2015 in his corporate role as Principal Geologist (2015–2019) and then Manager (2019-current), visiting all mines and plants and discussing grade control, geological mapping, exploration and delineation drill practices, quality assurance and quality control (QA/QC), reconciliation and mineral resource and mineral reserve estimation practices. His latest visit was to the exploration core facility at Copper Cliff on September 10, 2021 and the Stobie Central Core Facility on September 15, 2021 where he reviewed and discussed core logging practices and procedures, data collection and chain of custody processes. From 1996–2015, Mr. Gauld worked directly at the Ontario Operations, and participated in ongoing exploration, mining, and mineral resource estimation activities over that timeframe.

Greg Puro has visited the Ontario Operation on numerous occasions, most recently on November 24, 2021. Particular emphasis was placed on the M and P Area tailings storage facilities (TSFs) as part of this visit.

Alex Hossack has visited the Ontario mining operations on a number of occasions, most recently from 8th – 12th November, 2021. During the most recent site visit, Mr. Hossack inspected the Coleman underground operation, reviewed the current geotechnical model, and assessed the effectiveness of geotechnical processes associated with design, planning, operation, monitoring and optimization with the operation, mine planning, and geotechnical groups at Coleman Mine. Mr. Hossack also reviewed the progress of mining, and relevant technology projects occurring at the site.

Nick Gardner has visited the Sudbury mining operations on several occasions since 2007. His most recent site visit was from 11-15 November 2019. During the visits, he inspected stopes and underground mining operations, toured the maintenance facilities, viewed infrastructure, and discussed geology, exploration, mine planning, and mining practices with site staff.

2.5 REPORT DATE

Information in the Report is current as at 31 December, 2021.

2.6 INFORMATION SOURCES

The reports and documents listed in Chapter 24 and Chapter 25 of this Report were used to support Report preparation.

2.7 PREVIOUS TECHNICAL REPORT SUMMARIES

Vale has not previously filed a technical report summary on the Ontario Operations.

3 PROPERTY DESCRIPTION

3.1 PROPERTY LOCATION

The Ontario Operations are located in the Sudbury district of Ontario. Sudbury is about 330 km north–northeast of Toronto.

The centroid for the Ontario Operations is approximately N46°29'29.0, W81°04'05.0, representing where the bulk of the estimated mineral reserves and resources are located.

The co-ordinates for the main districts within the Ontario Operations that are included in this Report are summarized in Table 3-1.

Co-ordinates for the mine sites are provided in Table 3-2 and the locations of the smelting and refining sites are included as Table 3-3.

3.2 PROPERTY AND TITLE IN ONTARIO

3.2.1 INTRODUCTION

Until 1913, surface rights and mineral rights were acquired with land purchase. At that time, the Ontario government enacted legislation reserving land mineral rights to the Crown and granting leases to individuals or companies seeking to extract minerals. Where mineral rights are privately owned due to granting prior to 1913, they can be sold independently of surface rights, so that surface and mineral rights on the same property can be held by different owners.

The Ministry of Northern Development, Mines, Natural Resources and Forestry (MNDMNRF) is the main regulatory body. The Canadian Federal Government may also be involved in the mining process where Indigenous matters arise, or where the subject lands are federally regulated, such as when the lands are classified as navigable water bodies.

Much of the Ontario area was originally subject to the Dominion Land System. The base of this system is the township, which contains 36 square miles. Townships are divided into 36 “sections”, each containing one square mile (640 acres or approx. 260 ha). Each section is further divided into four 160 acre quarter-sections. The townships are arranged in a grid system and are numbered consecutively from south to north beginning with Township 1, running along the US–Canada border. To provide the grid index from east to west, each north–south tier of townships is designated a range, and numbered consecutively, generally from east to west, from one of six meridians. Much of the Sudbury area is demarcated into townships using this practice.

3.2.2 MINERAL TITLE

There are four main types of mineral title: mining claim, mining lease, patented claim, and mining licence of occupation. Vale’s Ontario Operations’ landholdings include each of these title types.

3.2.2.1 MINING CLAIM

A mining claim is a square derived from the Ontario Mineral Tenure Grid from an area of open Crown land (land that belongs to the Province of Ontario) or Crown mineral rights that a licensed prospector can stake online. The Ontario Mineral Tenure Grid (mining claims) splits the province into more than 5.2 million cells on a latitude and longitude grid, ranging in size from 17.7 ha in the north to 24 ha in the south. A cell claim is a mining claim that relates to all of the land included in one or more cells on the provincial grid. Cell claims can be amalgamations of up to 25 claim cells.

The Government of Ontario requires that work be performed on mining claims to retain an interest in the mineral rights. This work must amount to between C$200–C$400 per cell claim per year and be reported to the Mining Lands section of the MNDMNRF. Claims are forfeit if the work is not performed and reported on.

Table 3-1: District Locations

Property	Latitude (north)	Longitude (west	Area (ha)	General Location of Mining Rights (Townships)
Copper Cliff	46º30'7"	-81º5'24"	2,295	Snider and McKim
Kelly Lake	46º26'39"	-81º04'03"	620	McKim, Snider, Waters and Broder
Creighton	46º28'23"	-81º11'06"	1,147	Snider and Creighton-Davies
Stobie	46º32'22"	-80º59'28"	711	Blezard and McKim
Garson	46º33'41"	-80º51'39"	820	Garson
Coleman	46º40'1"	-81º21'1"	368	Levack
Totten	46º22'59"	-81º26'55"	444	Drury
Ellen	46º25'41"	-81º19'23"	66	Denison
Capre	46º41'49"	-80º50'18"	414	Capreol and MacLennan
Copper Cliff Pit	46º31'05"	-81º03'33"	706	Snider and McKim
Victor	46º40'31"	-80º48'50"	353	Capreol and MacLennan
Crean Hill	46º25'55"	-81º20'34"	278	Denison
Cryderman	46º35'01"	-80º46'19"	304	Falconbridge
Blezard	46º33'30"	-80º58'43"	278	Blezard

Table 3-2: Mine Locations

Mine	Latitude (north)	Longitude (west)
Coleman	46°40'37"	-81°20'21"
Copper Cliff	46°29'29"	-81°04'05"
Creighton	46°28'23"	-81°11'06"
Garson	46°34'02"	-80°51'26"
Totten	46°22'55"	-81°27'09"

Table 3-3: Smelter/Refinery Locations

Process Facility	Latitude (north)	Longitude (west)
Clarabelle Mill	46°29'46"	-81°03'19"
Copper Cliff Smelter	46°28'35"	-81°03'26"
Copper Cliff Refinery	46°27'30"	-81°04'30"
Port Colborne Refinery	42°53'00"	-79°14'28"
Clydach Refinery	51°41'44"	-3°53'21"

3.2.2.2 MINING LEASE

A mining claim can be converted into a mining lease. To convert a mining claim into a lease a letter of intent must be submitted to the Provincial Recording Office's Technical Services Unit any time after assessment work has been performed on the land and the work has been submitted and approved. After submitting the letter of intent, the land covered by the mining claim must be surveyed and the surface rights to the land must either already be owned by the lease applicant, be acquired if Crown land, or, an agreement for surface lands use must be executed with non-Crown landowner.

A lease grants the lessee with mineral resource rights ownership within the leased land, permits the extracting and sale of extracted mineral resources and removes the requirement to perform yearly assessment work. A mining lease cannot be transferred or mortgaged by the lessee without the prior consent of the MNDMNRF. Transfers require the lessee to submit various documentation and pay a fee.

To maintain a lease, rent must be paid annually. A lease expires after 21 years but can be renewed if the lessee can demonstrate continuous production of minerals for at least one year since the issuance or if the lessee can show that it has taken a reasonable effort to bring the property into production.

3.2.2.3 PATENTED CLAIMS

The title owner of freehold lands in Ontario holds a fee simple real property interest. Historically, the holder of a mining claim interested in removing minerals from the ground could, instead of obtaining a mining lease, apply to the MNR to acquire the freehold interest in the subject lands through the granting of a mining patent.

Such patents can include surface and mining rights, or may only comprise mining rights. They give the patentee all of the Crown's title to the subject lands and/or to all mines and minerals, as applied for, relating to such lands, subject to any reservations set out in the patent.

No regulatory consent is required for the patentee to transfer or mortgage those lands.

Patented claims are subject to annual Ontario mining taxes and, where surface rights are held, Ontario mineral land and municipal property taxes.

3.2.2.4 MINING LICENSE OF OCCUPATION

Mining licenses of occupation allow the holder to use the land in the manner specified in each license, including the right to dig, excavate and remove ores and minerals from and under the land. The Province of Ontario has the right to revoke licenses of occupation on 30 days prior notice.

3.2.3 ORDER IN COUNCIL

In Canada, an Order-in-Council (OIC) is an executive instrument which, following formal approval by the Lieutenant Governor, functions as the official recorded Order of the Lieutenant Governor in Council. The instrument originates as a Recommendation to Council signed by a Minister or Premier, and is presented to Executive Council for consideration and subsequent approval by the Lieutenant Governor.

Subsection 91(1) of the Mining Act, R.S.O. 1990, c. M.14 provides that "all lands, claims or mining rights patented, leased or otherwise disposed of under this or any other Act or by any authority whatsoever, are subject to the condition that all ores or minerals raised or removed therefrom shall be treated and refined in Canada so as to yield refined metal or other product suitable for direct use in the arts without further treatment". Given Vale's refining processes includes operations outside of Canada, Vale regularly obtains exemptions from the operation of subsection 91(1) under OICs for the export of a portion of its production (see discussion in Chapter 3.5.7).

3.2.4 SURFACE RIGHTS

Surface rights refer to any right in land that is not a mining right. The process of acquiring surface rights for mining purposes depends on the owner of the rights:

- No action is required if the surface rights are owned by the claim holder;
- Ownership of the surface rights will be granted to the claim holder during a lease application process if the Crown owns the surface rights;
- If the surface rights are privately owned by an individual or company then an agreement to allow the claim holder to use the land must be made with the surface rights holder. The agreement should include the compensation given if the land covered by the surface rights sustains any damages. Confirmation of an agreement with the surface rights owner is

required for grant of a mining lease, or, upon application by the claim holder, the issuance of an order of the Mining Lands Commissioner indicating that surface rights compensation, if any, has been paid, secured, or settled.

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3.3 OWNERSHIP

The Ontario Operations are wholly-owned by Vale Canada, a Vale subsidiary.

3.4 MINERAL TITLE

3.4.1 OVERVIEW

In each township, Vale is the registered owner of mining rights and surface rights or a combination of both shown as fee simple lands, mining leased lands, mining license of occupation lands and unpatented mining claims. Table 3-4 provides a summary of the types of title held.

Vale owns approximately 80,383 ha of patented mining rights and approximately 59,742 ha of patented surface rights which includes a combination of approximately 1,369 ha of mining and surface rights co-owned with other parties.

Patented mining rights are granted to exploit and extract minerals on, in or under the land, and surface rights are rights to use the surface of the land. These rights remain in effect so long as Vale owns the land to which these rights apply.

Municipal taxes and mining land taxes for each mine were paid in full for 2021. All assessment work due annually on the patented and unpatented mining claims was filed as at 31 December, 2021.

Mining rights cover a portion of, or all of the areas of, the townships shown in Figure *3-1*. Mining operations within the townships are also indicated in the figure. The total Mineral Rights area of the MRMR footprint is 163 Licenses, approximately 8,437 ha as illustrated in Figure 3-2.

3.4.2 MINING AND SURFACE RIGHTS ON LANDS LEASED TO VALE

Vale holds approximately 14,026 ha of land leased from the Province of Ontario. These leased lands, which include a combination of mining and surface rights, are leased for either 10 or 21 years. Annual rentals of C$3.00/ha are paid to the Province of Ontario to keep the leases in good standing. Details of lease areas and locations are available via Table 3-4.

Based upon experience in renewing similar leases, Vale does not expect any problems in obtaining renewals of the leases covering any of the land noted above which Vale would want to renew on a timely basis, since the only requirement for renewal is payment of a nominal renewal fee.

3.4.3 MINING LICENSES OF OCCUPATION

Vale holds licenses of occupation covering approximately 2,952 ha in Ontario of which approximately 17 ha are held jointly with other parties.

Annual rentals of C$5.00/ha are paid to the Province of Ontario to keep these mining licenses of occupation in good standing.

Details of lease areas and locations are available via Table 3-4.

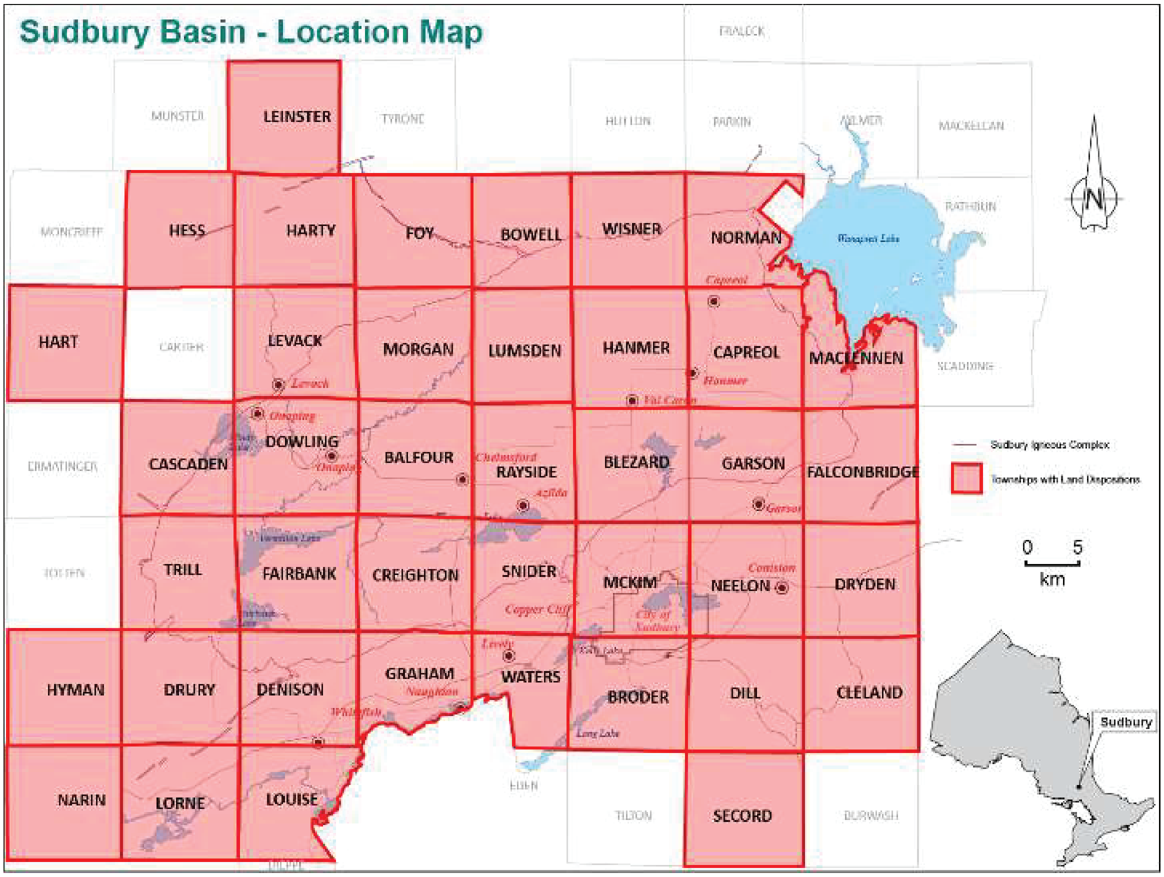
Table 3-4: Mineral Title Summary, Ontario Operations

Deposits	Licenses	# of Licenses	Area (ha)
Blezard	73497-0096, 73497-0156, 73497-0159, 73498-0612, 73498-0537	5	262
Coleman	73342-0003,73342-0006, 73342-0009, 73342-0026, 73342-0028, 73342-0029, 73342-0030, 73342-0032, 73342-0033, 73342-0034,73342-0130, 73342-0924, 73342-0950, MLO-12817	14	446
Copper Cliff	73599-0070, 73599-0071, 73599-0072, 73599-0580, 73599-0593, 73599-0755, 73599-0828, 73600-0254, 73600-0271, 73370-0005, 73370-0036, 73370-0037, 73370-0038, 73370-0039, 73370-0041, 73370-0042, 73370-0057, 73370-0064, 73370-0065, 73370-0066, 73370-0067, 73370-0068, 73370-0069, 73370-0070, 73370-0071, 73370-0072, 73370-0073, 73370-0076, 73370-0079, 73370-0082, 73370-0084, 73371-0033, 73371-0035, 73371-0036, 73371-0039, 73371-0051, 73371-0077, 73371-0082, 73371-0094, 73371-0115, 73371-0117, 73371-0198	43	2,912
Creighton	73368-0297, 73368-0016, 73368-0042, 73371-0046, 73371-0113, 73371-0174, 73371-0175, 73368-0089, 73368-0091, 73368-0094, 73368-0095, 73368-0096, 73368-0097, 73368-0098, 73368-0099, 73368-0100, 73368-0101, 73368-0105, 73368-0116, 73368-0117, 73368-0119, 73368-0121, 73368-0240, 73368-0246, 73368-0264, 73368-0265	26	1,177
Garson	73492-0141, 73495-1212, 73495-1213, 73495-1298, 73495-1044, 73492-0355, 73492-0398, 73492-0487, 73493-0067, 73493-0150, 73493-0151, 73493-0161, 73493-0282, 73493-0297, 73493-0298, 73493-0299, 73493-0315, 73493-0316, 73493-0326, 73493-0331, 73493-0334, 73493-0379, 73495-0351, 73495-0454, 73495-0837, 73495-1313, 73495-1305	27	825
Copper Cliff Mine Pit (Murray)	73601-0195, 73601-0196, 73601-0198, 73601-0052, 73601-0068, 73601-0070, 73601-0208, 73601-0192, 73601-0199, 73601-0219, 73601-0194, 73601-0243, 73370-0119,73370-0005	14	941
Stobie	73497-0015, 73601-0027, 73601-0029, 73601-0084, 73601-0230, 73497-0149	6	525
Totten	73383-0275, 73383-0302, 73395-0206, 73395-0207, 73395-0208, 73395-0251, 73383-0001, 73383-0089, 73383-0221, 73383-0222, 73383-0248, 73383-0309	12	993
Victor	533510, 73510-0085, 73510-0086, 73510-0198, 73510-0244, 73511-0257, 73511-0258, 73511-0259, 73511-0261, 73511-0262, 73511-0263, 73511-0276, 73511-0277, 73511-0285, 73511-0299, 73511-0300, 73511-0301	16	355
Total		**163**	**8,437**

Notes

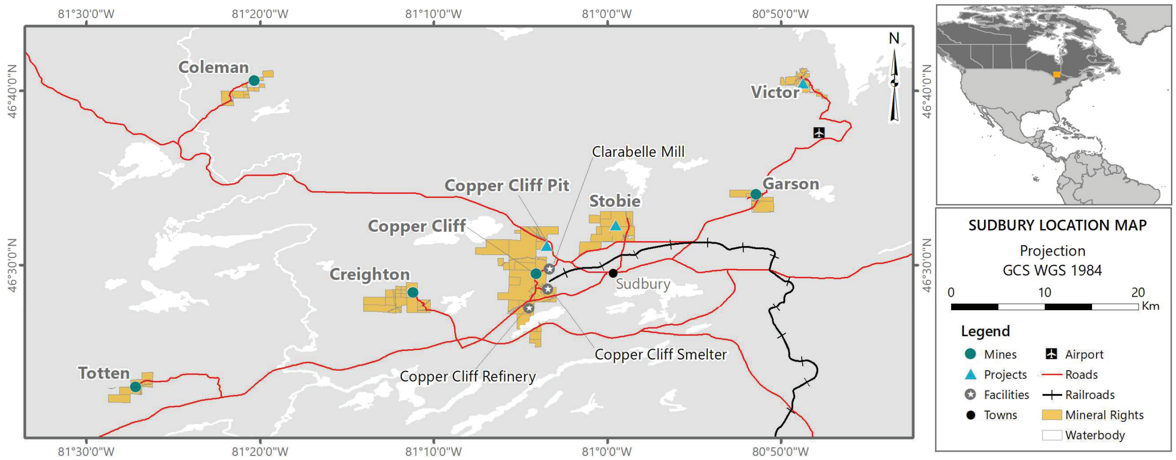
This reflects relevant titles supporting disclosed mineral reserves and resources (For more details refer to Appendix A – which provides more details on mineral titles)
Total Ontario licences outside of the MRMR foot print total 97,032 Ha
Some of the Licences are jointly held by Vale and 3rd Parties

Figure 3-1: Townships with Land Depositions, Ontario Operations



Note: Figure prepared by Vale, 2020.

Figure 3-2: Ontario MRMR Mineral Rights



3.4.4 UNPATENTED MINING CLAIMS

Vale currently holds unpatented mining claims covering approximately 9,676 ha in Ontario of which approximately 6,596 ha are held jointly with other parties. Unpatented mining claims are issued by the Province for the purpose of exploring the mineral potential and require that assessment work be performed to continue holding the claims. Details of lease areas and locations are available via Table 3-4.

The mining claims in the Sudbury area were established based on Method 118 for Sectional Townships with Single Fronts under Survey Methods, R.R.O. 1990. Reg. 1029 under the Ontario *Surveys Act*, R.S.O. c. S.30.

3.5 PROPERTY AGREEMENTS

Vale has a number of third-party agreements in support of the Ontario Operations.

3.5.1 ROADWAYS AND EASEMENTS

Given the patchwork property holdings of mining companies within the Sudbury, Vale has multiple road and property easements with various mining companies, in particular Glencore Canada Limited (Glencore), to grant access between each party's properties for operation and exploration activities necessary for each other's operations.

3.5.2 ACCESS AGREEMENTS

Vale and Glencore have various corridor agreements permitting development of underground corridors by the requestor through the permittee's subsurface rights area allowing access to the requestor's deposit area.

3.5.3 GLENCORE CANADA LIMITED BOWTIE AGREEMENT

In order to facilitate the conduct of their respective mining and mineral processing businesses in the Sudbury, Ontario area, including at or about the Vale lands and the Glencore Fraser Mine lands, Vale and Glencore entered into an agreement in 2011 under which Glencore will:

- Use its infrastructure (including the Fraser Mine), local Sudbury work force and operational expertise to mine the adjacent Vale deposit;
- Purchase the ore from Vale, all pursuant to and in accordance with the terms of the Agreement. The agreement permits ore extraction through an economically viable process.

3.5.4 VENTILATION

Under the Bowtie Agreement, Glencore and Vale agreed to provide ventilation capacity necessary for each party's operations in the area.

3.5.5 EXPORT AGREEMENTS

Vale holds OIC permits (see definition in Chapter 3.2.3) that allow it to export nickel, copper and platinum group elements (PGM) products outside of Canada for further refinement. Each permit is granted for a five-year period, and to date, the permits have been renewed as required. The OIC permit for copper expires in June 2022. The nickel and PGM OIC permits are current until December, 2025. These permits are necessary for Vale to further refine its product to sell demanded products. There is a reasonable expectation that the OIC permits can continue to be renewed for the duration of the LOM.

3.6 SURFACE RIGHTS

Surface rights held by Vale are discussed with the mineral tenure in Chapter 3.4, with details of lease areas and locations available via Table 3 4.

3.7 WATER RIGHTS

Vale holds applicable water take permits to support operations (see also discussion in Chapter 15.4.3).

The permit for the Vermilion River is valid to 2030 and allows for an extraction rate of approximately 82 ML per day. There are reasonable expectations that the extraction permit could be renewed. The water is used by the mines, Clarabelle Mill, Copper Cliff Smelter and Copper Cliff Refinery.

The Port Colborne Refinery water usage is grandfathered in and currently has no expiry date.

Water supply for the Clydach Refinery is permitted from the Swansea canal and the River Tawe. In practice the refinery does not withdraw water from the canal except in unusual circumstances. The canal licence allows for a maximum water taking of 19,748 m^3/day and has no expiry date. The river licence allows for a maximum water taking of 2,273,000 m^3/a, and has no expiry date. The Clydach Refinery undertook in 2017 to install a complex recycled, closed-loop, cooling water circuit. Once completed in 2022, water will no longer be sourced from either the river or the canal.

3.8 ROYALTIES & STREAMING

There are no royalties or other similar payments made on the Ontario Operations mine properties within the Sudbury Basin other than those discussed below.

3.8.1 WHEATON PRECIOUS METALS STREAMING AGREEMENTS

Vale and Silver Wheaton Corp (now Wheaton Precious Metals) executed an agreement in 2013 wherein Vale agreed to sell to Wheaton Precious Metals an amount of gold equal to 70% of the gold production from certain of its Sudbury mines, including the Coleman, Copper Cliff, Garson, Stobie, Creighton, Totten Mines and the Victor project for a period of 20 years.

Wheaton Precious Metals made a total upfront cash payment in March, 2013 of US$570 million plus warrants to purchase 10 M shares of Wheaton Precious Metals common stock at a strike price of US$65, with a term of 10 years. In addition, Wheaton Precious Metals will make ongoing payments of the lesser of US$400/oz Au or the prevailing market price per ounce of gold delivered.

3.9 ENCUMBRANCES

Various utility and communication easements and right-of-ways traverse the surface rights held by Vale that provide utilities (gas, hydro, water) and communications (telephone landlines, cell) to the surrounding communities. There are no known encumbrances that would impact the LOM.

3.10 PERMITTING REQUIREMENTS

Permitting and permitting conditions are discussed in Chapter 17.8 of this Report for the Ontario Operations.

There are no relevant permitting timelines that apply to the Ontario Operations; the operations as envisaged in the LOM plan are fully permitted.

There are no current material violations or fines as understood in the United States mining regulatory context that apply to the Ontario Operations.

3.11 SIGNIFICANT FACTORS AND RISKS THAT MAY AFFECT ACCESS, TITLE OR WORK PROGRAMS

To the extent known to the QP, there are no other known significant factors and risks that may affect access, title, or the right or ability to perform work on the properties that comprise the Ontario Operations that are not discussed in this Report.

4 ACCESSIBILITY, CLIMATE, LOCAL RESOURCES, INFRASTRUCTURE AND PHYSIOGRAPHY

4.1 PHYSIOGRAPHY

The major topographic feature of the area is the Sudbury Basin that forms an elliptical ring some 72 km in the northeast direction by 27 km wide. The topographically-higher outer portions of the Basin are formed by igneous rocks of the Sudbury Igneous Complex (SIC). The northern, southern and eastern parts of the rim are referred to as the North Range, South Range and East Range respectively.

Elevations range from 222–445 m above sea level with local relief in the order of 30–60 m.

The topography of the “rim” of the Sudbury Basin consist of relatively rocky hills with intermittent swamps and marshes, covered to varying degrees with mixed forest along the south range of the basin, and predominately coniferous to mixed forests on the north side of the basin.

The central part of the basin is occupied by low-lying flat agricultural land. The dominant vegetation type is temperate boreal forest.

4.2 ACCESSIBILITY

Excellent transportation routes access the Sudbury Area. Highway 17 is the main branch of the Trans-Canada Highway connecting the city to points east and west. Highway 69, also a branch of the Trans-Canada Highway, leads south to Parry Sound, where it connects to the Highway 400 freeway to Toronto. Highway 144 leads north to Highway 101 west of downtown Timmins.

Access to the various mine and deposit sites is through a system of numbered municipal roads:

- The Blezard deposit is located approximately 9 km north of the city of Sudbury. Access to the deposit area is via Regional Road 80N from downtown Sudbury. The deposit is then accessed by turning right onto a gated gravel road adjacent to Highway 69N approximately 1 km east of the entrance to the abandoned Glencore Thayer-Lindsley mine;
- The Coleman Mine is located near the town of Levack, approximately 45 km northwest of the city of Sudbury. Access to the mine site is via Highway 35 (old Highway 144 then through the town of Levack. The private mine road from the town to the mine site is paved. For emergencies, a second road access is available to the mine site through Glencore’s operations;
- The Copper Cliff Mine is located in the town of Copper Cliff and has two head frames. Access to North Head frame is via Highway 35 (old Highway 144), then west on Clarabelle Road. Access to the South Head frame is via Highway 55 (old Highway 17), then south on Power Street;
- The Creighton Mine is located on the west side of the Greater Sudbury area. Access to the site is via McNaughton Street from Regional Road 24 or Main Street;
- The Garson Mine is located immediately northeast of the town of Garson. Access to the site is via Church St. and Mine Road from Regional Road 86;
- The McConnell deposit part of the Garson Mine and is accessed through the Garson Mine. The deposit is located approximately 14 km northeast of the city of Sudbury. Access to the mine is via the Greater Sudbury Regional Road 55 and Falconbridge Regional Road 86 to the town of Garson. It is then approximately 3 km north on Church Street followed by Pine Street to the paved, private Garson Mine road. The McConnell deposit is then accessed via the Garson Mine portal;
- The Copper Cliff Pit deposit is part of Copper Cliff Mine and is accessed through Copper Cliff Mine which is located 8 km west of the city of Sudbury. Access to the mine is via Regional Road 35 from downtown Sudbury, then Clarabelle Road which is a gated private Vale road.

The mine is located approximately 3 km along the Clarabelle Road on the right side of the road. The Copper Cliff Pit deposit is located 3 km northeast of the Copper Cliff Mine via an unpaved mine access road;

- The Stobie Mine is located close to the city centre of Sudbury. The mine is accessed from Frood Road (Rural Route 42) at the intersection of Lasalle Blvd;
- The Totten Mine is located approximately 40 km west of the City of Sudbury on the Worthington Offset dyke. Access to the property can be gained via Municipal Road 4 from Highway 17 West or by the Canadian Pacific Railway line that runs east west through the property immediately north of the Totten No. 2 shaft;
- The Victor deposit is located approximately 34 km northeast of the city of Sudbury. Access to the property is via the Greater Sudbury Regional Road 55 from downtown Sudbury, then Regional Road 86 through the town of Garson, and Skead Road passing Sudbury Airport and turning onto Nickel Rim South Mine Road, and then a further 7 km north following the Victor Mine Road.

Prospects and exploration areas are accessed via a network of municipal and local private roads.

The mill, refineries and smelter are accessed as follows:

- The Clarabelle Mill is located approximately 7.5 km northwest of the city of Sudbury. Access to the mill facilities is via the Greater Sudbury Regional Road 49, 38 and 35 for 6 km, and turning left onto Clarabelle Road which is a gated private Vale road. The mill is located approximately 1.5 km along the road, on the left side;
- The Copper Cliff Smelter is located approximately 8.5 km northwest of the city of Sudbury. Access to the smelter is via Greater Sudbury Regional Road 49 and 55 from downtown Sudbury, turning right onto Balsam Street and following Benjafield Road turning right onto Veterans Road which is a private Vale road to the smelter entrance;
- The Copper Cliff Nickel Refinery is located approximately 12 km southwest of the city of Sudbury. Access to the refinery is via Greater Sudbury Regional Road 49 and 55 from downtown Sudbury for 11 km, turning left onto Noront Road and then left onto Industrial Road, which is a private Vale road for approximately 2 km;
- The Port Colborne Refinery is located in the city of Port Colborne, Ontario. Access to the refinery is via Clarence Street from downtown Port Colborne for 1 km, turning right onto Welland Street and then left onto Nickel Street for approximately 1 km. The refinery is situated at the corner of Davis and Nickel streets;
- The Clydach Refinery is located in the city of Clydach, Wales. Access to the refinery from downtown Clydach is via Hebron Road/B4603 for approximately 1 km, at the roundabout, take the second exit onto Ynyspenllwch Road/B4291. At the second roundabout, take the second exit and stay on Ynyspenllwch Road/B4291 until the refinery gate is reached.

The Greater Sudbury Airport is served by regional carrier lines. Sudbury is also served by rail. There are no other means of transportation that are used to access the operations.

4.3 CLIMATE

Sudbury has a humid continental climate with warm and often hot summers and long, cold, snowy winters. The annual average temperature is 5.5ºC. Precipitation is on average 861 mm annually.

Mining operations are conducted year-round.

4.4 INFRASTRUCTURE

The City of Sudbury is the closest major regional centre.

The processing facilities in Sudbury include a concentrator, a combined nickel and copper smelter, matte processing facilities, a carbonyl nickel refinery, a copper anode casting plant, a sulphuric acid plant and a sulphur dioxide liquefaction plant. A copper refinery was closed in 2006. Major additional Ontario Operations infrastructure includes a tailings impoundment area, a slag disposal area and an oxygen plant.

An electro cobalt refinery and precious metals upgrading facility are located at Port Colborne, Ontario. A portion of the production is sent to a carbonyl nickel refinery in Clydach, Wales.

The Ontario Operations currently have all infrastructure in place to support mining and processing activities (see also discussions in Chapter 13, Chapter 14, and Chapter 15 of this Report). Those Report chapters also discuss water sources, electricity, personnel, and supplies.

5 HISTORY

Exploration and development undertaken in the Sudbury district from the date of the initial nickel discovery in 1856 is summarized in Table 5-1 to 2010. The majority of this work was undertaken by Vale's predecessor company Inco (formerly International Nickel Company). Vale obtained ownership of Inco in 2006. The period from 2010–2021 is provided in the table with some additional details to cover the most recent decade of mining.

Table 5-1: Exploration and Development Summary Table

Year	Comment
1856	Nickel mineralization identified near the present-day location of the Creighton Mine.
1884	Discovery of Copper Cliff No. 4, Copper Cliff No. 2, Elsie, Frood, Howland and Worthington deposits
1885	Discovery of Copper Cliff, Crean Hill, Evans, Stobie, Little Stobie and Totten deposits
1886	Ellen and Victoria deposits discovered. Creighton deposit re-discovered. Canadian Copper Company of Cleveland, Ohio incorporated
1887	Vermilion and Shepard deposit discovered
1888	Copper Cliff Smelter commenced operations
1889	Levack, Big Levack and Chicago deposits discovered.
1891	Garson, Trillabelle and Sultana deposits discovered. Orford process for separating nickel and copper in matte discovered
1892	Gertrude, McCreedy, Kirkwood and Cameron deposits discovered
1893	Tam O'Shanter deposit discovered
1897	Whistle deposit discovered
1899	North Star deposit discovered
1900	Mond Nickel Company incorporated
1902	International Nickel Company, Ltd. joint venture by the Canadian Copper Company, Orford Copper Company and American Nickel Works. Nickel Refinery at Clydach, Wales constructed by the Mond Nickel Company
1907	MacLennan deposit discovered
1912	Capre Lake deposit discovered.
1913	British American Nickel Corporation incorporated.
1918	Refinery built by International Nickel Company in Port Colborne
1919	International Nickel Company began using the trade name Inco
1924	Acton Precious Metal Refinery built by Inco
1925–1927	Inco acquired various assets from British American Nickel Corporation incorporated
1929	Inco merged with Mond Nickel Company
1930	First Copper Cliff Nickel Refinery begins operation
1935–1936	Inco acquires various assets from Canadian Nickel Company
1954	Upper and Lower Coleman deposits discovered
1959–1960	Totten No. 1 deposit discovered
1971	Clarabelle Mill constructed
1973	Opening of the second Copper Cliff Nickel Refinery
1975	Inco became the formal name of the International Nickel Company of Canada, Limited
1989	Decision to centralize all milling at Clarabelle Mill
1991	Closure of Frood–Stobie Mill
2006	Companhia Vale do Rio Doce (CVRD) announced a C$19.4 billion takeover of Inco
2007	CVRD rebranded itself to Vale and CVRD–Inco changed name to Vale Inco
2010	Vale Inco changed name to Vale Canada Limited
2011	Exploration and internal studies on the Victor/Capre and Copper Cliff deposits
2012	Implementation of the challenging ore recovery (CORe) flow sheet at the Clarabelle Mill. Production testing of the "Rail-veyor" material haulage system at the CC Mine 114 zone and Stobie surface test area. Discovery of the 163 zone at the Coleman Mine. Frood Mine operations suspended. Suspension of study activities at Victor/Capre.

Year	Comment
2013	CORe commissioning completed in October. Smelter complex to reduce to one furnace; later deferred to 2017. Underground expansion project completed at the 170 zone at Coleman. Totten changed status from a project to a mine. Mining studies at Copper Cliff Offset.
2014	Totten Mine formally opened. Ellen operations transitioned from open pit to underground. Mining studies underway at Copper Cliff and Creighton.
2015	Production affected by seismicity at Stobie and Coleman Mines. Matte processing capability affected by electrical switch room fire.
2016	Production at Stobie affected by seismicity. Creighton Mine production focused on new Division 6 area. Coleman transitioned from cut-and-fill to bulk mining methods.
2017	Transition at the smelter complex to a one furnace operation. Execution of the Clean AER project. Super stack will be decommissioned in 2019 and replaced by two smaller 450 ft. stacks. Stobie Mine placed on care and maintenance.
2018	Completion of the Clean AER project. Commenced construction of first phase of Copper Cliff Mine Expansion (South shaft construction). Production at Creighton, Copper Cliff and Garson affected by seismicity. Production interruption at Coleman to repair shaft. Mining studies underway on Copper Cliff (725/740 deposits). Closure of Acton precious metals refinery.
2019	Production at Garson affected by seismicity. Mining studies underway at NRD/Victor, Copper Cliff Pit, Capre and Cryderman.
2020	Five operating underground mines: Copper Cliff, Creighton, Coleman, Garson, Totten. One mill: Clarabelle Mill. One smelter: Copper Cliff Smelter. Three refineries: Copper Cliff, Port Colborne and Clydach.
2021	Production affected by labour disruption. Production interruption at Totten due to damage to shaft. Mining studies underway at NRD/Victor, Copper Cliff Mine (Copper Cliff Pit, 178/191/712 deposits), Creighton Mine, Blezard and Stobie.

6 GEOLOGICAL SETTING, MINERALIZATION, AND DEPOSIT

6.1 DEPOSIT TYPE

Deposits within the SIC are type examples of nickel–copper mineralization arising from a meteorite impact.

Deposit models for the Sudbury nickel deposits are based on the various relationships that arose in response to factors such as (Morrison et al., 1994):

- Meteorite impact;
- Crustal melting;
- Long-lived differentiation of superheated sulphide saturated silicate magmas;
- Gravitational accumulation of sulphides;
- Remobilization of sulphides into dilational structures in the footwall.

Nickel sulphide mineralization is located proximal to the base of the SIC in three main environments (Lightfoot, 2007):

- Sublayer: Mineralization occurs in both small embayments (~500 m wide, 500 m long, and ~200 m deep) and sometimes as more continuous zones within troughs (~1 km wide, ~1 km deep, and extending for over 3 km);
- Radial quartz diorite dykes: Mineralization occurs in plunging lenses of inclusion-rich quartz diorite distributed at irregular intervals along the Offset Dykes;
- Footwall: Mineralization forms sharp-walled veins that cross cut the Archean gneisses for distances of several hundred meters away from the original base of the SIC and as continuous zones for distances of up to 1 km; locally these veins are associated with patches of trace disseminated sulphides that carry elevated precious metal abundance levels.

Figure 6-1 is a schematic section illustrating the various deposit type models.

The geological exploration models are supported by deposit-scale surface and borehole geophysical surveys that effectively image the strongly-conductive sulphide mineralization in contrast to barren sulphides that can be hosted in the surrounding country rock (Lightfoot, 2007).

The meteorite impact model is appropriate for exploration purposes.

6.2 REGIONAL GEOLOGY

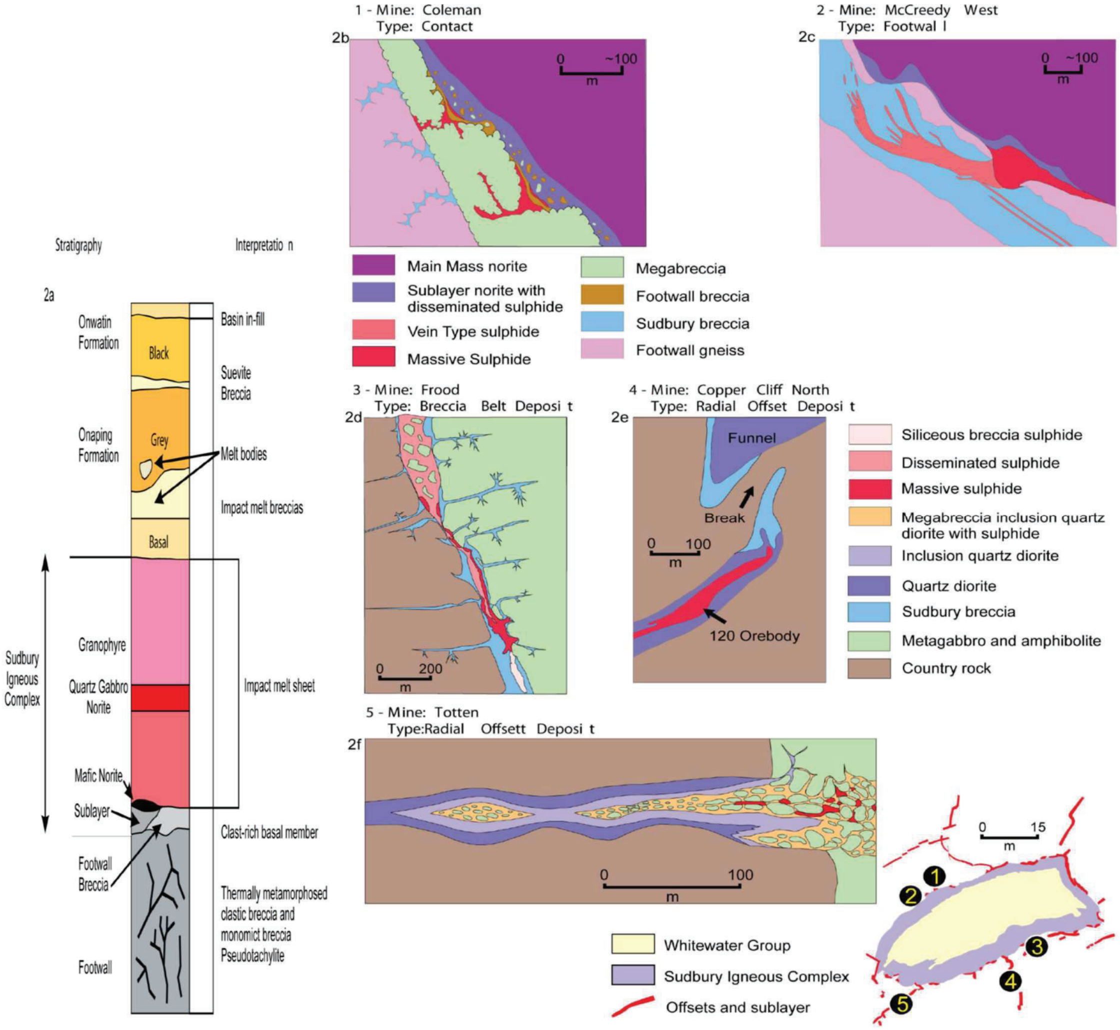
The Sudbury magmatic copper–nickel sulphide deposits are part of the Paleoproterozoic Sudbury Structure which comprises the SIC and associated dykes, and the overlying Paleoproterozoic Whitewater group rocks. Footwall rocks to the Sudbury Structure are Archean gneisses and granitic and mafic igneous rocks to the north and Paleoproterozoic metavolcanic and metasedimentary rocks of the Huronian Supergroup to the south.

6.3 LOCAL GEOLOGY

6.3.1 GEOLOGY AND STRATIGRAPHY

The SIC is interpreted to be a differentiated impact melt sheet from a bolide collision that occurred approximately 1,850 million years ago. The Sudbury Structure is exposed as an elliptical ring with a northeast-trending long axis of ~72 km and a short axis of ~27 km. The upper northeast-trending contact of the surface expression of the SIC is often referred to as the North Range, similarly the South Range is associated with the areas along or near the southern surface exposure of the SIC contact.

Figure 6-1: Deposit Models



Note: Figure from Lightfoot (2007).

Margins of the SIC are characterized with an average inward dip of about 45º along the north part of the SIC; however, they are generally steeply dipping or overturned in the south and east sections.

Major components of the SIC include the differentiated norite–gabbro-granophyre Main Mass and a group of minor intrusions, collectively termed the Sublayer. Three major variants of the Sublayer are recognized: the first comprises igneous-textured gabbronoritic material, the second consists of igneous-textured quartz diorite, while the third variant comprises a wide variety of metamorphic-textured rocks collectively known as “footwall breccia”. The Sublayer is localized either at the contact between the Main Mass and footwall rocks or within radiating and concentric dykes cutting footwall rocks. Sublayer units are characterized by disseminated to massive sulphide and by the presence of a variety of xenoliths of both local and unknown or “exotic” derivation.

Rocks of the Whitewater Group are found only within the central portion of the Sudbury Structure. The Whitewater Group consists of three conformable formations, in ascending order, the Onaping impact-generated breccias, Onwatin siltstone and wacke, and Chelmsford turbidite.

All rocks defined as footwall to the Sudbury Structure are cut by occurrences of the Sudbury Breccia. This breccia occurs as small veins, irregularly-shaped patches and large bodies, which may extend for many kilometers along strike. The breccia consists of inclusions of locally-derived footwall lithologies within comminuted footwall rock. The Sudbury Breccia has been interpreted as pseudotachylitic, formed by in-situ milling processes during formation of the Sudbury Structure. The Sudbury Breccia is known to occur more than 100 km from the SIC.

The Sudbury Structure is cut by a number of regional and local mafic dyke swarms. Archean footwall rocks on the North Range are crosscut by north–south-trending dykes of the Matachewan swarm. Northwest-trending olivine tholeiitic dykes of the Sudbury swarm crosscut the SIC and all rock units within and surrounding the Sudbury Structure. A set of east–northeast-trending lamprophyre dykes and a set of quartz–diabase dykes cut rocks of the SIC but are older than the olivine tholeiites.

The Murray and Creighton granitic plutons, part of the Cartier batholith, intrude the Huronian Supergroup, and predate the impact.

Figure 6-2 shows the general geology of the Sudbury Basin. Figure 6-3 shows a simplified stratigraphic column for the North Range and South Range of the Sudbury Basin.

Table 6-1 summarizes the major lithological and stratigraphic units. Table 6-2 summarizes the most common rock types proximal to, or hosting, the Sudbury-area deposits as logged by the mine geologists.

6.3.2 STRUCTURE

Rocks of the Sudbury Structure are variably affected by five major fault sets, as summarized in Table 6-3.

6.3.3 MINERALIZATION

The classifications included in Table 6-4 are employed to describe the variety of sulphide mineralization types at the Ontario Operations.

Pyrrhotite is the most common sulphide mineral. Chalcopyrite is the main copper-bearing mineral and second most common sulphide mineral. Chalcopyrite is typically (but not always) associated with elevated platinum group elements (PGEs) and precious metals. Pentlandite is the main nickel mineral and is present in all ore types. Pentlandite occurs as flames in or at grain boundaries of pyrrhotite. It commonly forms megacrystic “eyes” or elongated blebs in massive sulphide and in veins.

The Sudbury deposits host three principal styles of mineralization: Contact-, Offset-, and Footwall-styles. These mineralization environments can be quite variable, transitional, and many exhibit characteristics fitting more than one mineralization environment description. An example schematic for the North Range, showing the general relationship of the various mineralization types to the SIC, is included as Figure *6-4*.

6.3.3.1 CONTACT-STYLE DEPOSITS

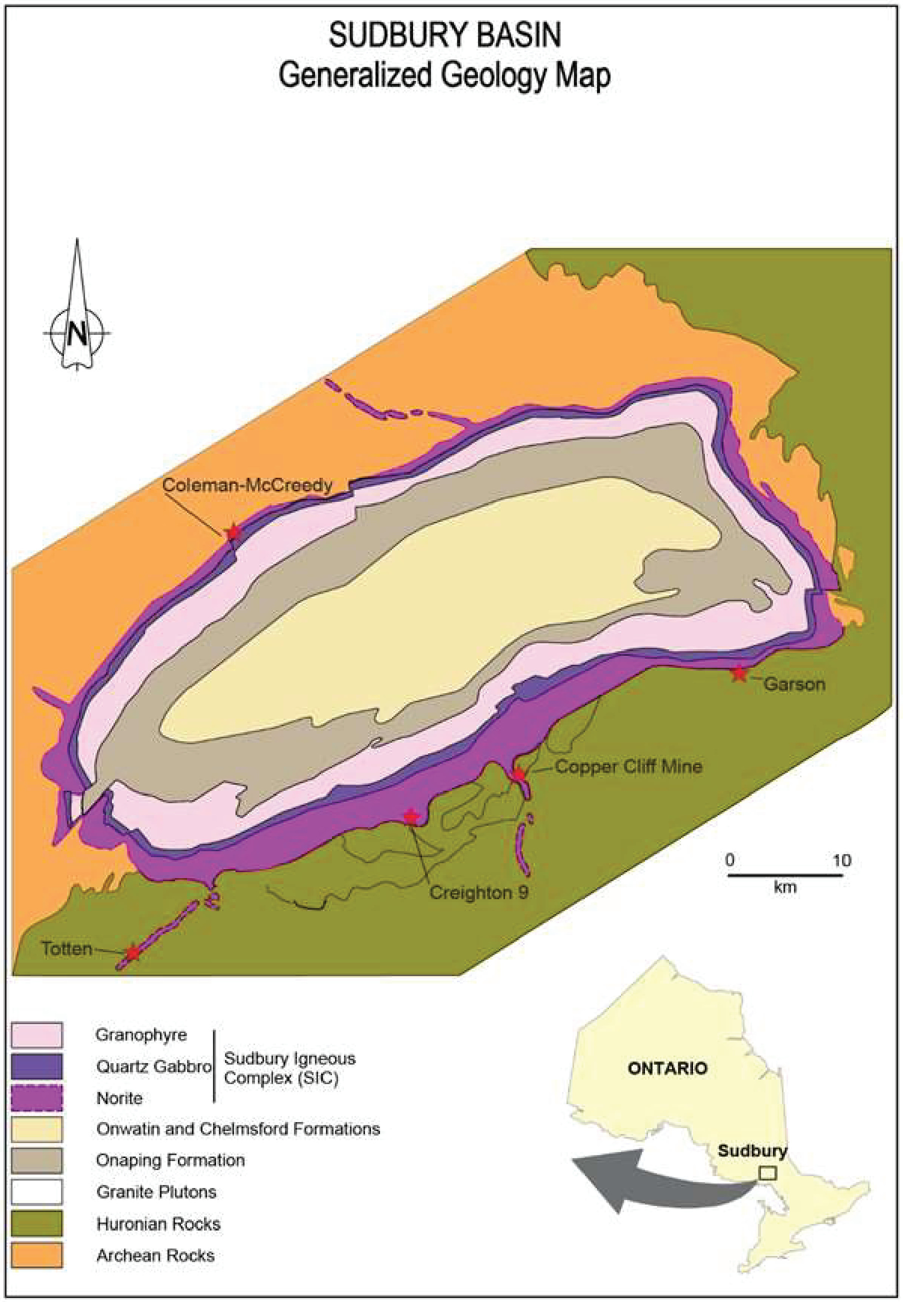
Contact-type deposits occur at the base of the SIC in association with the Sublayer. The Sublayer volumetric distribution is controlled by the shape and morphology of the basal contact of the SIC. It is absent in some areas and >700 m thick within trough and embayment features that are distributed around the basal contact of the SIC. Sulphide mineralization within the Sublayer is generally zoned from massive sulphide at the footwall to disseminated sulphide towards the hanging wall. The PGE–gold (PGM) content of the contact-style deposits is variable but low (<1 g/t combined PGE–Au).

6.3.3.2 OFFSET-STYLE DEPOSITS

Offset-style deposits consist of Sublayer norite and quartz diorite with a variable footwall breccia component occurring as dyke-like structures radial or concentric to the contact of the SIC. They can extend for many kilometres into the Sudbury Basin footwall rock. Mineralization consists of zones of disseminated blebby and massive nickel–copper–PGM sulphide that are spatially associated with inclusion-rich phases of quartz diorite and with local dyke structural complexities.

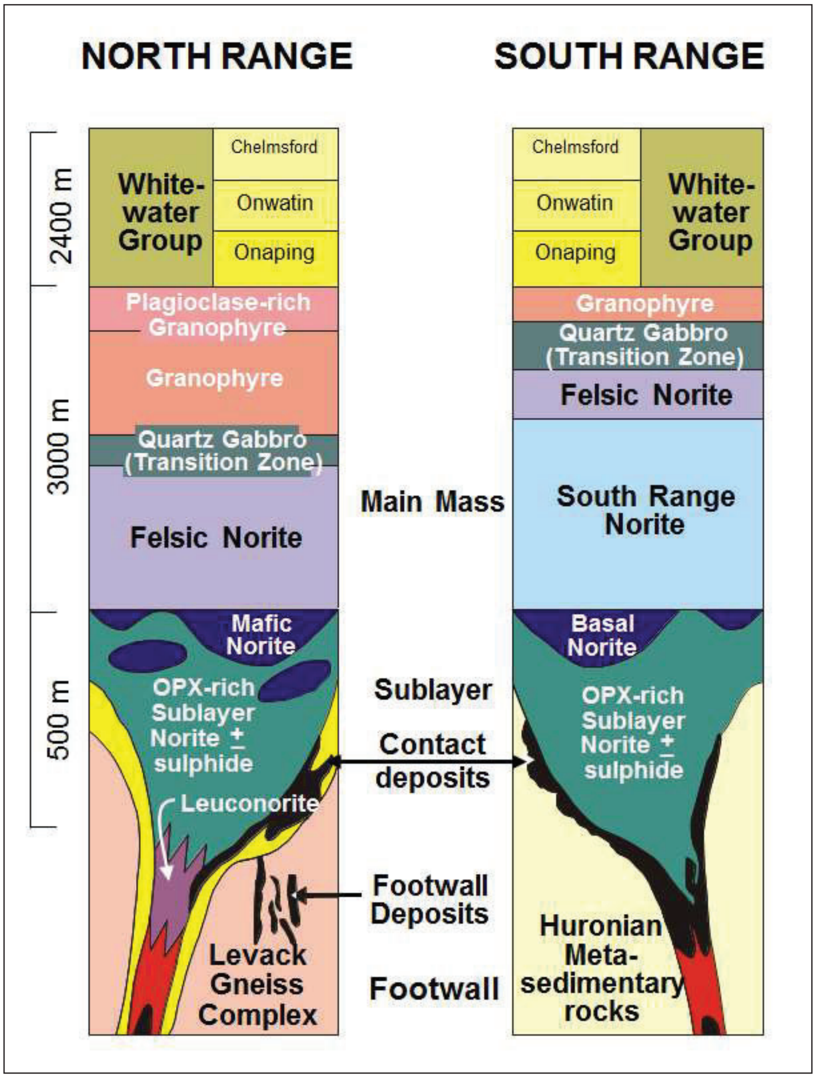
Inclusion-rich quartz diorite is commonly located in the center of the dykes but, on occasion, may occur at the contact with footwall rocks. Contacts between the inclusion-bearing and inclusion-free phases may be diffuse to extremely sharp in character.

Figure 6-2: Regional Geology of Sudbury Basin



Note: Figure prepared by Vale, 2021. Red stars note the location of Vale mines operating in 2021.

Figure 6-3: Sudbury Basin: Simplified Stratigraphic Column



Note: Modified by Vale after Bailey (2012).

Table 6-1: Project Stratigraphy

Location	Group	Formation	Notes
Hanging wall	Whitewater Group Rocks	Chelmsford Formation	A thick sequence of proximal turbidites that exhibit well-developed Bouma sequences. Uppermost preserved unit of the Whitewater Group.
		Onwatin Formation	Is, in the absence of the Vermilion Formation, in gradational contact with the Black member of the Onaping Formation. Consists of carbonaceous and pyritic, massive to laminated, argillite and siltstone with minor interbedded wacke deposited in a stagnant, anoxygenic environment.
		Vermilion Formation	Discontinuously overlies Onaping Formation. Consists of bedded carbonate, siltstone, argillite and chert, locally containing significant concentrations of volcanogenic copper-lead-zinc-silver massive sulphide. Interpreted as an exhalite-rich sequence deposited during the waning stages of Onaping Formation sedimentation.

Location	Group	Formation	Notes
		Onaping Formation	Complex of heterolithic breccia units with a total estimated thickness of up to 1,600 m. Three major stratigraphic members: Basal, Gray and Black; each consisting of a variety of breccias in numerous units composed of any combination of country rock fragments, glassy material, finely comminuted matrix material and minor sulphide mineralization. Variably interpreted as a sequence of ash-flow tuffs and lavas, impact fallback breccia and melt or, more recently, as impact-generated breccias modified by internally generated volcano/sedimentary processes
Sudbury Igneous Complex	Main Mass		North Range: basal unit of poikilitic mafic norite with orthopyroxene as the only cumulus phase, a felsic norite unit with plagioclase, ortho- and clinopyroxene as cumulate phases, a quartz gabbro unit with plagioclase, clinopyroxene, magnetite and apatite as cumulate phases and an uppermost unit of granophyre. South Range: quartz-rich norite, south range norite, quartz gabbro and granophyre. Basal units of the SIC, i.e., the mafic norite on the North Range and the quartz rich norite on the South Range may contain minor, non-economic, disseminated sulphide mineralization
	Sublayer		Copper–nickel–PGE mineralized zones at Sudbury are spatially and genetically related to relatively small bodies of inclusion-rich material localized either at the contact between the main mass of the SIC and footwall rocks (contact sublayer) or within radiating and concentric dykes cutting footwall rocks (offset dykes). Three major variants of sublayer are recognized: igneous-textured gabbronoritic material; igneous-textured quartz diorite; and a wide variety of metamorphic-textured rocks collectively known as "footwall breccia". Gabbronoritic sublayer typically occurs in contact deposits and in the proximal (0–2 km from SIC contact) portions of the North Range offset dykes. Quartz diorite is the main component of South Range offsets and of distal (>2 km from SIC contact) portions of North Range offsets. Footwall breccia occurs as sheets and discontinuous lenses concentrated along the lower contact of the SIC and as a major component of some of the offset dykes. Igneous- and metamorphic-textured sublayer are characterized by disseminated to massive sulphide and by the presence of a variety of xenoliths of both local and unknown or "exotic" derivation.
Footwall	Footwall		Defined as rock units characterized by deformational and metamorphic features related to the 1.85 Ga Sudbury impact event; i.e., those rocks that can be shown to contain one or more inclusions of Sudbury Breccia, shatter cones or shock-induced microscopic deformation features. The impact-related features may extend more than 80 km north and east of the SIC, and to the Grenville Front south of the SIC. North Range: Archean migmatitic gneisses (Levack Gneiss) and granitoids; variably metamorphosed to amphibolite or granulite facies. Small relict Archean greenstone belts are locally present while unconformable patches of Paleoproterozoic Southern Province (Huronian) sedimentary strata and Nipissing suite mafic intrusive rocks are preserved within half graben-like structures that define a partial rim-syncline within the Sudbury Structure. South Range: Paleoproterozoic, Southern Province, basic and felsic volcanic rocks, co-eval mafic and felsic sub-volcanic intrusions, cyclic sedimentary sequences of coarse to fine clastic sediments and later mafic intrusions of the Nipissing Diabase suite.

Note: Table compiled from Muir and Peredery, 1984; Naldrett et al., 1970; Pattison, 1979; Lightfoot et al., 2002; Dressler et al, 1991.

Table 6-2: Mine-Scale Lithologies

Unit	Notes
Creighton Granite (CRGR, GYGR, GR)	Medium to coarse grained, pink to grey granite consisting primarily of quartz, feldspars and biotite. Local porphyritic lenses. Typically, massive, but zones of foliation and shearing exist, with varying degrees of alteration in the form of chlorite, sericite, biotite, and epidote. Quartz and/or carbonate veining can be found throughout the pluton.
Black porphyry (BKPR)	Aphanitic to fine grained black mafic matrix supporting medium to coarse-grained phenocrysts of Na-feldspar. Found sporadically throughout the footwall of the Creighton environment, and has similar whole rock and mineral chemistry as the footwall granites; interpreted as a phase of the larger Creighton granite intrusive pluton.
Meta-gabbro (MTGB)	Fine to medium grained, dark to light green-grey color, typically massive, but can be strongly sheared. Includes amphibolites that may be of intrusive or volcanic origin. Quartz and/or carbonate veins are locally intense and zones of brecciation are frequently filled with a stockwork of hairline carbonate veinlets. This term is frequently applied to the Nipissing Gabbro and other pre-Sudbury event mafic intrusions.
Meta-sediment (MTSD, QTE)	Represents Huronian sedimentary rocks and is common throughout the South Range deposits. The various formations consist of metamorphosed greywacke, quartzite and argillite, often with gradational contacts; commonly strongly foliated and locally schistose, is very fine to coarse grained, and consists of mostly quartz and mica.
Olivine diabase Dyke (OLDI)	Very fine-to-fine grained, black to dark grey, massive intrusive dykes that are mineralogically and texturally similar throughout the Sudbury Basin. Usually strongly magnetic due to abundant magnetite, and may have a plagioclase porphyritic texture. Aphanitic chill margins. Dated at ~1,240 Ma, and represent the youngest rock to cut the SIC.
Quartz diorite (QD and IQD)	Semi-continuous (or offset) dykes or lenses within metabreccia zones. Generally massive, fine to medium grained, equigranular and black to dark grey green. QD has a variable inclusion content, with the higher content referred to as inclusion quartz diorite (IQD), and commonly sulphide accumulations are associated with increased inclusion content. QD dykes extend radially and concentrically from the SIC on a scale of several kilometers, and are host to several major Ni–Cu–PGE deposits.
Sudbury Breccia (SUBX) – Metabreccia (MTBX)	Pseudotachylite unit forming irregular zones both parallel and perpendicular to the SIC. SUBX commonly has an aphanitic black matrix supporting sub-angular to sub-rounded fragments of footwall material. In the footwall zones the Sudbury Breccia is sometimes associated with chalcopyrite and PGE–Au mineralization. The Metabreccia variety has undergone varying degrees of thermal metamorphism and may be partially recrystallized.
Sublayer norite (SLNR)	Occurs as discontinuous lenses in troughs or embayments of the Sudbury Basin. Typically, a heterogeneous breccia consisting of a fine to coarse-grained dark green to grey–green, variably mineralized noritic matrix that contains inclusions of footwall and occasionally “exotic” origin. The SLNR is host to most of the “Contact” type deposits.
Diabase dyke (Trap Dyke) (TRAP, QDIA)	Very fine-to-fine grained, black to dark grey, massive intrusive dykes. Chill margins are aphanitic. Cross-cut SIC units and are thus younger than 1850 Ma. There is also an unrelated, undated Lamprophyre unit commonly logged as QDIA.
Meta-basalt (MTBS)	Medium to coarse grained, dark green to black, equigranular or foliated consisting of amphibole, (hornblende and actinolite), plagioclase, quartz and chlorite. Meta-basalts commonly form a footwall lithology although splintered-off segments occur in the hanging wall as well.
Murray Pluton (Granite, GR)	Medium to coarse grained unit, pink to grey granite consisting primarily of quartz, Na-feldspar (microcline), and K-feldspar (plagioclase) as a groundmass. Occurs high above the sulphide mineralized hanging wall. Local porphyritic zones can form lenses. Typically, massive, but zones of foliation and shearing exist, with varying degrees of alteration in the form of chlorite, sericite, biotite, and epidote.
Amphibolite (AMPH)	Very fine-to-very coarse grained, dark grey-green amphibole; commonly represents the metamorphic equivalent of the pre-event mafic dykes, Nipissing diabase or Huronian mafic volcanic rocks.

Unit	Notes
Footwall breccia (GRBX, FWBX)	Discontinuous heterolithic breccia unit; lies between the footwall rocks and the lower most SIC unit; commonly hosts significant sulphide accumulations on the North and East Ranges. Consists of variable footwall clasts, angular to subrounded, ranging from microscopic to greater than 120 m. Fragments are generally locally derived, however exotic fragments are observed. The breccias have been partly recrystallized and annealed by heat from the overlying SIC.
Granite gneiss or mafic gneiss (GRGN, MFGN, GDGN)	Footwall rocks on the North and East Ranges, mostly represented by the Levack Gneiss Complex of the Superior Province. Composed of Archean migmatitic rocks and tonalitic to quartz–dioritic gneiss, with local mafic layers ranging from amphibolite to granulite facies. At least two generations of mafic Archean diabase dykes intrude these gneisses.

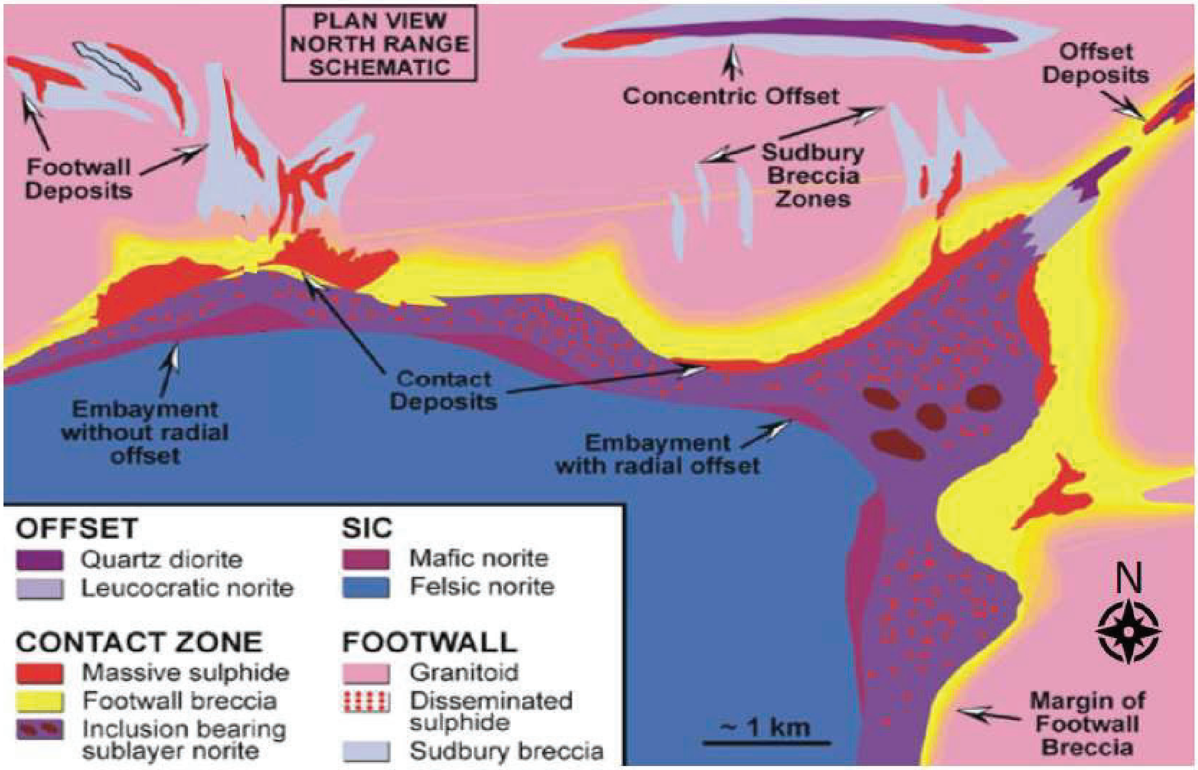
Table 6-3: Key Structures, Sudbury Region

Fault Orientation	Fault Type	Note
East–northeast to northwest-trending	Major, south-dipping, curvilinear, reverse faults	Form the South Range Shear Zone and include the Cliff Lake Fault
North–northwest-trending	Steeply dipping structures with a generally sinistral sense of displacement	Cut the North Range of the Sudbury Structure. Faults crosscut the mineralization at the Coleman Mine. Displacement of as much as to 914 m on the Fecunis Lake Fault
Northerly-trending	Sinistral sense of displacement	Cut at a shallow angle on the east side of the Sudbury Basin
East–west-trending	Steeply-dipping faults, displacement is right-lateral	Cut the South Range of the Sudbury Basin. Include the Murray Fault system and Creighton fault.
Late-stage	Formed by the current tectonic stress field	Commonly infilled with galena, marcasite, and carbonate minerals; sometimes associated with poor ground conditions

Table 6-4: Sulphide Mineralization Styles

Sulphide Type	Notes
Massive sulphide (MASU)	Generally, appears to be composed entirely by sulphide minerals, but commonly contains as much as 15% silicate as indiscrete clots and blebs plus variable amounts of magnetite. For the majority of deposit types, it contains approximately 80–85% pyrrhotite (Po), while pentlandite (Pn) and chalcopyrite (Cp) content is approximately equal. In the footwall hosted high copper vein-style deposits such as the Coleman 153 Orebody the MASU is essentially chalcopyrite with minor amounts of cubanite, pentlandite and silicate inclusions. The MASU grades into other sulphide mineralization types and locally occurs as inclusions in the quartz diorite.
Breccia sulphide (BXSU)	Composed of subrounded to angular breccia of sublayer norite and lesser amounts of surrounding wall rocks within a fine-grained matrix. It generally contains less than 50% sulphide. The sulphide consists of the typical Po–Pn–Cp assemblage and is generally fine to medium grained.
Gabbro–peridotite inclusion sulphide (GPIS)	Consists of a matrix of massive sulphide with more than 10% inclusions. The inclusions are generally derived from the sublayer but may include footwall rocks, and range up to 50 m in size. The inclusions generally differ from the adjacent footwall rocks and may represent cognate xenoliths, which may represent earlier crystallized deeper layers of the irruptive. The sulphide assemblage includes typical mineralogy (Po–Pn–Cp) and is generally medium grained. Many of the inclusions have highly altered serpentinized or talcose edges.
Disseminated (DISS)	Low sulphide mineralization containing rounded to subrounded sulphide disseminations. It generally contains less than 30% sulphide and the sulphide is composed of the typical Po–Pn–Cp assemblage.
Ragged disseminated sulphide (RGDI)	Similar to disseminated sulphide mineralization but the sulphide forms as irregular cuspate blebs within a sparse noritic matrix enclosing small, altered gabbroic inclusions. The inclusions may be related to the better preserved gabbroic and ultramafic inclusions found in gabbro–peridotite inclusion sulphide, and this mineralization type is commonly gradational to gabbro–peridotite inclusion sulphide.
Inclusion massive sulphide (INMS)	Massive sulphide mineralization with >10% inclusions of footwall rocks, angular to sub-round in shape. The inclusions are entirely surrounded by sulphides, which includes the typical Po–Pn–Cp assemblage. INMS transitions to other sulphide mineralization types both gradually and sharply.
Contorted schist inclusion sulphide (CSIS)	This is a high-sulphide content mineralization containing schistose fragments within a fine-grained sulphide matrix. The fragments are often rounded, crescent or s-shaped, and make up from less than 10% to more than 50% of the mineralization. The sulphide is finer grained than in other sulphide mineralization types and generally has a lower Cu/Ni ratio. CSIS may be transitional into MASU.
Interstitial sulphide (INSU)	Similar to disseminated sulphide mineralization, but a less common mineralization type characterized by sulphide filling interstices between cumulus crystals of pyroxene and/or plagioclase.

Figure 6-4: Schematic Section Showing Mineralization Types



Note: Figure prepared by Vale, 2020

Sulphide mineralogy is dominated by pyrrhotite and less abundant pentlandite and chalcopyrite. Copper to nickel ratios are approximately one, and PGM values are >2.5 g/t.

6.3.3.3 FOOTWALL-STYLE DEPOSITS

Footwall-style deposits are emplaced in dilatant fractures within or near thermally-metamorphosed Sudbury Breccia. A physical connection between Contact and Footwall-style mineralization is not always preserved or recognized. Footwall-style deposits host highly fractionated mineralization compared to the contact-style mineralization. Copper, nickel, platinum, palladium, silver and gold grades increase from the Contact-style mineralization into the Footwall-style mineralization, while cobalt, ruthenium, rubidium, iridium and osmium grades decrease.

Two types of Footwall deposits are identified in the North Range. These are massive sulphide copper–PGM deposits and low-sulphide high-PGM deposits:

- The massive sulphide copper–PGM Footwall mineralization has significant PGM content. It occurs as veins and stockwork systems. These deposits may occur up to 600 m into the Huronian footwall rocks in the North Range. Sulphide mineralization is primarily massive chalcopyrite or cubanite that varies from a few millimetres to >10 m wide. Veins that consist of massive intergrown bornite, chalcopyrite and millerite characterize the distal portions of these deposits;
- Low-sulphide high-PGM footwall mineralization occurs as disseminated sulphide and fracture fillings and quartz vein sulphide adjacent to the Footwall massive sulphide copper–PGM mineralization, and as large zones of fine-grained disseminations and narrow discontinuous fracture fillings in “footwall breccia” and Sudbury Breccia in the North and East ranges of the Basin. The low-sulphide high-PGE–gold footwall mineralization is dominated by chalcopyrite and minor millerite.

Low-sulphide–high-PGM, and to a lesser extent massive sulphide copper–PGM deposits occur in the South Range.

Most orebodies in the Sudbury area have experienced some degree of tectonic overprint. This has caused local remobilization of sulphides.

Deformation by the South Range Shear Zone tectonic overprinting has locally resulted in significant variations in the ore mineralogy by enhancement or depletion of nickel grades. Pyrite–marcasite has locally replaced pyrrhotite and pentlandite due to oxidation, and development of trace mineral assemblages, including cobaltite–gersdorffite, maucherite ($Ni_{11}As_8$), galena, and sphalerite.

Figure 6-5 and Figure 6-6 are generalized sections for the North Range and South Range respectively, showing the typical deposit types that can be found in each of these areas.

6.4 PROPERTY GEOLOGY

The deposits that have current mineral resource estimates are discussed in alphabetical order in the following sub-sections.

6.4.1 BLEZARD

The Blezard Contact-type deposit is in a primary trough at the base of the SIC, which is situated at the northeastern end of the South Range Breccia Belt between the Stobie and Garson complexes. The near-surface part of the deposit was mined from 1889–1893. The deeper part of the Blezard deposit is undeveloped within the Vale property holdings, and continues into the adjacent Lindsley contact and footwall deposits that were mined by Glencore from 1992–2009.

6.4.1.1 DEPOSIT DIMENSIONS

The Blezard Contact-type deposit is approximately 3,180 ft (969 m) long, ranges in width from 150–700 ft (46–213 m), averaging 450 ft (137 m), and ranges in thickness from 180–300 ft (55–91 m), averaging 200 ft (61 m). The deposit is currently delineated from surface to a depth of 2,200 ft (671 m), dips at about 45º, and plunges to the northeast at 45º.

6.4.1.2 LITHOLOGIES

The SIC in the Blezard area includes the Sublayer, South Range Norite and quartz gabbro. The Sublayer forms an irregular, discontinuous sheet at the base of the SIC. It can include fragments of norite, basalt, gabbro, granite and ultramafic rocks set in a fine-grained matrix. The Sublayer has a sharp contact with the underlying tholeiitic basalt, mafic tuff and gabbro units. The upper contact is gradational with the South Range Norite.

The major host rock types to the sulphide mineralization include metamorphosed gabbronorite, amphibolite and diorite. In all cases, primary minerals and textures have been subjected to greenschist facies metamorphism and locally, lower-temperature alteration.

All rock types are cut by late mafic and olivine diabase dykes that are associated with northwest-trending brittle deformation zones within the footwall and SIC units.

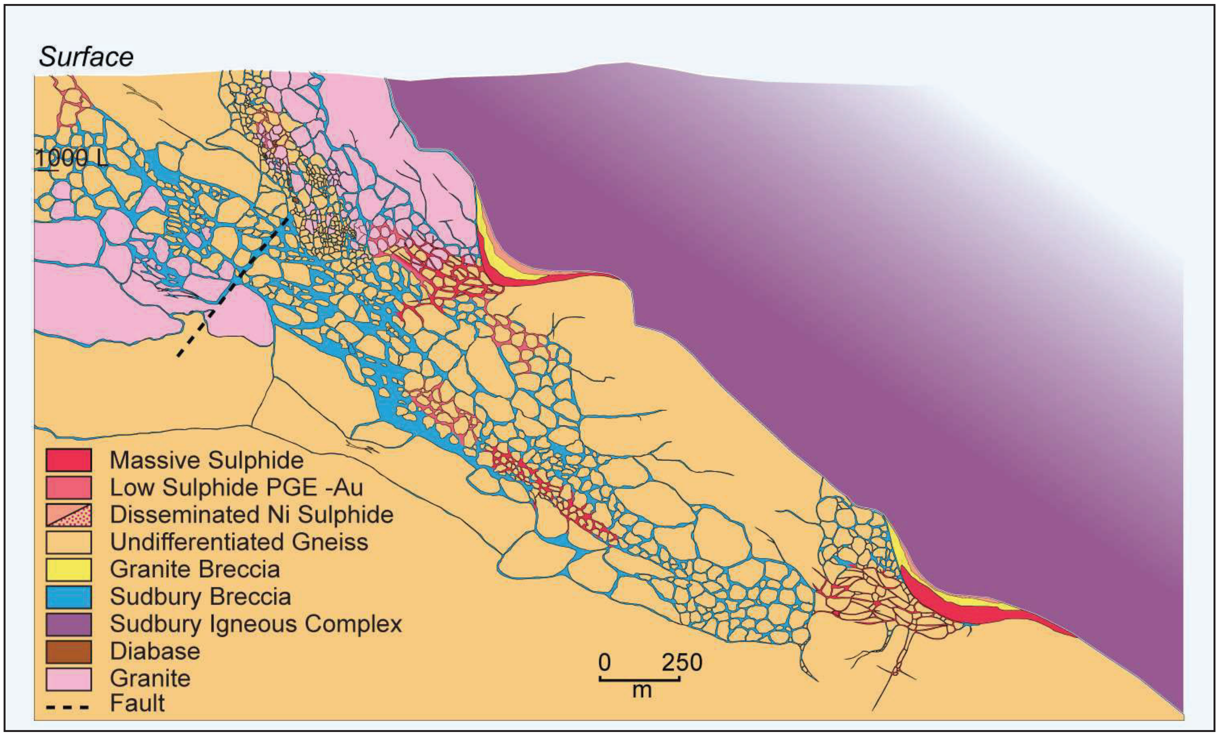
6.4.1.3 STRUCTURES

Shearing, interpreted as post-mineralization, has formed zones of biotite schist along the footwall/Sublayer contact.

6.4.1.4 MINERALIZATION

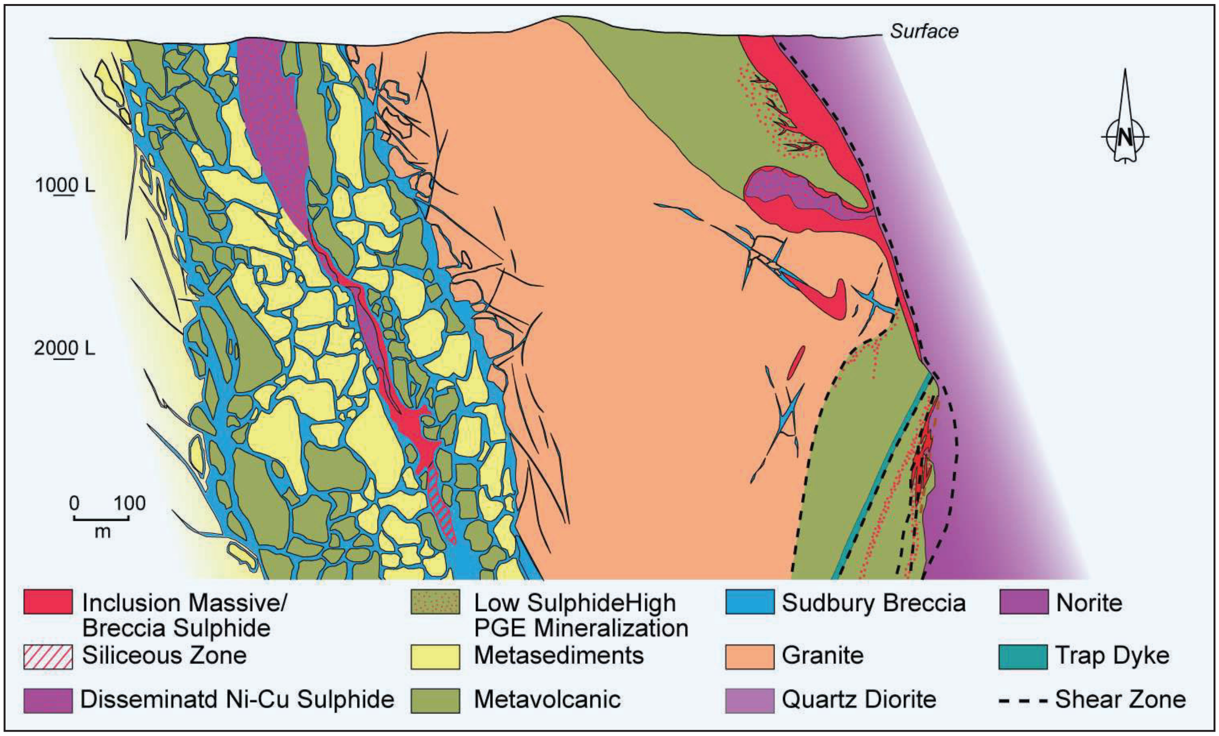
The Sublayer can contain 5–65% sulphides. The breccia matrix consists of pyrrhotite, chalcopyrite, pentlandite, minor quartz, and magnetite as disseminations, ragged masses and veins, within fine-grained norite. Pyrrhotite, chalcopyrite, and pentlandite are the major sulphides. Pyrite is only a minor constituent. Galena and sphalerite can occur in late north-trending cross-cutting veins, in association with calcite and marcasite. Platinum group elements include michenerite (PdBiTe) and sperrylite ($PtAs_2$).

Figure 6-5: Composite Cross-Section of North and East Range Deposit Types



Note: Figure prepared by Vale, 2016

Figure 6-6: Composite Cross-Section of South Range Deposit Types



Note: Figure prepared by Vale, 2016

A schematic geology section is provided in Figure 6-7. A representative drill section showing the orientation of the drilling to the mineralization, and examples of mineralization grades is provided as Figure 6-8.

6.4.2 COLEMAN

The Coleman Mine includes the original Coleman deposits, consisting of the Upper and Lower Coleman, and the High Shaft Copper deposit. No mining is currently conducted in these areas. It also includes the McCreedy East deposits, including the Main, West, 153 and 170 deposits where active mining is occurring. Other deposits include the inactive East and 7386/6166 Footwall Zone areas.

6.4.2.1 DEPOSIT DIMENSIONS

A summary of the deposit dimensions for the major zones in the Coleman Mine is provided in Table 6-5. Zones are classified as Footwall- or Contact-type.

6.4.2.2 LITHOLOGIES

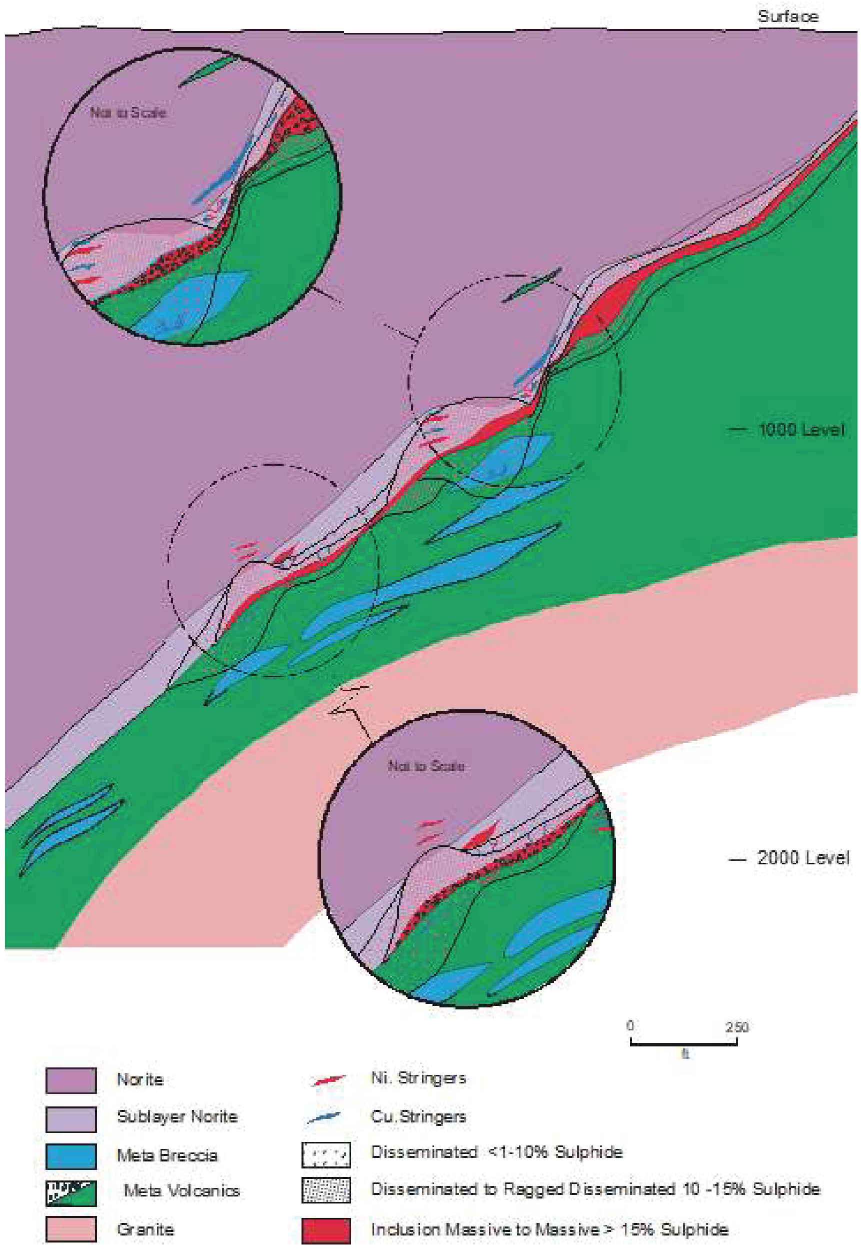
The Coleman Mine is situated at the central and eastern limits of an extensively mineralized, 9 km long portion of the North Range of the SIC known as the Levack Embayment.

The main lithological units of the Levack Embayment include:

- Main Mass of the SIC. Towards the base of the main SIC, overlying the embayment, the basal, mafic norite contain rare inclusions and sulphide disseminations;
- Sublayer norite, occurring discontinuously along the contact between the base- of mafic norite and the country rocks. Sublayer norite consists of 55–70% dominantly mafic, fine to medium-grained sub-rounded to rounded fragments within a mafic igneous matrix of noritic composition;
- Footwall/granite breccia, which is locally developed along the SIC-footwall rock interface as the basal unit of the Sublayer norite. The footwall/granite breccia is a matrix-supported heterolithic breccia with clast sizes ranging from 1 cm to hundreds of metres in diameter. The clasts are typically sub-angular to sub-rounded and represent approximately 70–80% of the rock mass. The composition of clasts ranges from gabbro, diabase, mafic gneiss to granitic gneiss and granite;
- Sudbury Breccia, occurring as veinlets and veins in fractured footwall rock to the SIC and form irregularly-shaped masses up to several hundreds of feet thick. The Sudbury Breccia is a matrix-supported fragmental rock with a black to light gray, aphanitic to fine-grained and variably re-crystallized matrix composed of feldspars, quartz, amphibole, biotite. Rounded and equant footwall clasts range to as much as 30 m in diameter and consist of gabbro, diabase, mafic gneiss, intermediate gneiss, granite gneiss and granite;
- Footwall rocks of the Levack Gneiss Complex, which is largely composed of granite and mafic gneiss. The granitic component of the complex is medium to coarse-grained and massive to incipiently foliated. Mafic gneiss is medium-grained, massive to incipiently foliated with 30–40% interstitial feldspar occurring as a mosaic laths interstitial to amphiboles. The gneissic banding can be regular or contorted and locally is continuous over tens of feet. Lenses of mafic gneiss commonly occur as boudins within granitic gneiss.

The basal contact of the SIC dips south-southeast at approximately 35º on the Coleman Mine property. Footwall/granite breccia thickness range from <1 m to >30 m in “plumes” that cross-cut the basal SIC stratigraphy up into the sublayer norite and mafic norite. The sublayer norite displays similar range of stratigraphic thicknesses. Both footwall/granite breccia and Sublayer norite host Contact-style nickel-rich mineralization which is typically developed in troughs and irregularities at or near the basal SIC contact with the footwall rocks of the Levack Gneiss Complex. Contact-style mineralization grades into Footwall-style mineralization within Sudbury Breccia. Footwall-style mineralization extends as much as 450 m below the SIC-footwall contact.

Figure 6-7: Schematic Geological Section, Blezard (17500 N)



Note: Figure prepared by Vale, 2018. Section looks east.

Figure 6-8: Example Cross-Section, Blezard

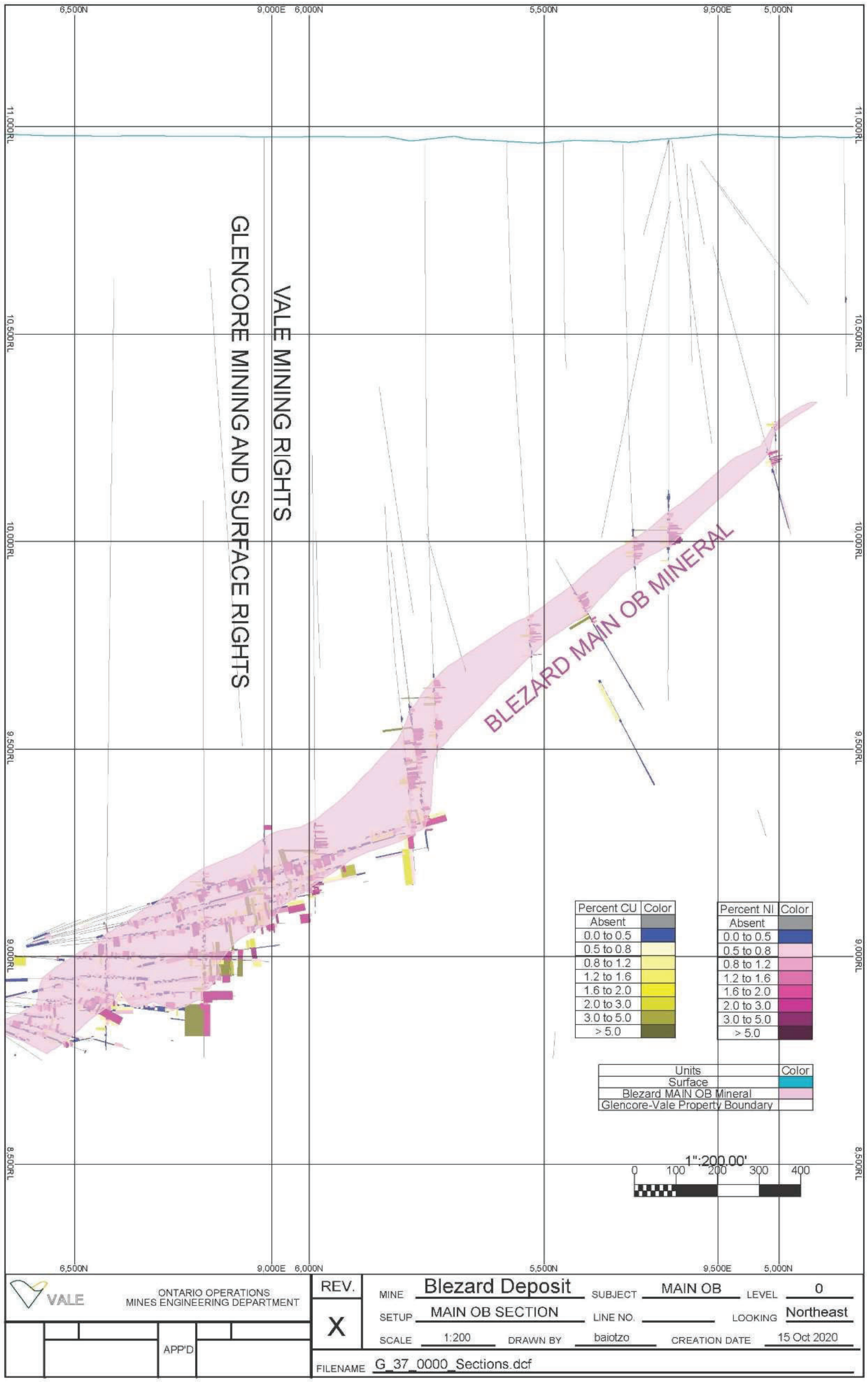


Table 6-5: Dimensions, Coleman Zones/Orebodies

Zone Designation	Type	Length (m)	Width/Strike (m)		Thickness (m)	
			Average	Range	Average	Range
148	Footwall Cu	455	30	3–60	10	0.5–10
153	Footwall Cu	305	30	5–60	20	0.5–25
170	Footwall Cu	275	90	5–185	10	0.5–20
Main (MOB)	Contact	580	60	5–175	50	10–150
6166	Footwall Cu	150	45	5–60	20	0.5–30
7386 CLM	Footwall Cu	335	65	5–65	30	0.5–45
East OB	Contact	220	15	2–35	10	2–30
W Chutes	Contact	220	15	5–45	10	3–45
West OB	Contact	215	30	5–50	30	2–30

Zone Designation	Depth (m)	Dip (º)	Plunge (º)
148	870–1205	30	5 W
153	1250–1585	50	80 E
170	1645–1830	40	55 N
Main (MOB)	1045–1330	40	40 SW
6166	1080–1310	45	45 S
7386 CLM	1310–1435	30	15 S
East OB	995–1125	50	40 E
W Chutes	1310–1345	50	35 E
West OB	1165–1335	64	40 SW

An olivine diabase dyke cuts through the northeastern portion of the deposit. A diabase dyke occurs in the footwall area. It is locally fragmented and has been linked to several large magnitude seismic events.

6.4.2.3 STRUCTURE

There are three major structural features encountered at the Coleman Mine:

- Fraser #2 Fault: also known as the #2 East Fault, strikes approximately north to south and is steeply dipping (60–80°). A splay of the Fraser #2 Fault has intersected the upper Main Orebody and has caused some localized difficult mining conditions;
- Lunchroom Fault: strikes roughly north to south, with a variable dip of 50–70° to the northeast along its length. Encountered on nearly every cut on the Main Orebody; locally associated with bad ground;
- Bob's Lake Fault: strikes roughly northwest, and dips to the east at approximately 70–90°; locally associated with bad ground.

6.4.2.4 MINERALIZATION

Contact-style mineralization forms high-grade nickel-rich pods or sulphide concentrations, that are surrounded by a low-grade halo in the host sublayer norite or footwall/granite breccia. The sulphide mineral assemblage consists of pyrrhotite, pentlandite, chalcopyrite and minor pyrite. Variations in style and orientation of mineralization occur abruptly over small distances, resulting in a complex mode of sulphide occurrence. The sulphide is mostly present as fine disseminations, blebs, and stingers in breccia matrix, locally as fracture fillings, or as semi-massive and massive ores. The Cu:Ni ratio for the Coleman contact nickel ores is approximately 0.7.

Footwall-style copper–nickel–PGE mineralization is hosted in Sudbury breccia. It is characterized by a sulphide mineral assemblage dominated by chalcopyrite, with lesser pentlandite, millerite, cubanite, bornite and pyrrhotite. The copper content in all footwall deposits is very high, with the Cu:Ni ratio typically exceeding 6.5, with correspondingly high PGE tenors (Pt + Pd + Au > 7.7 g/t).

A schematic cross-section showing the geology of the Coleman and McCreedy areas is included as Figure *6-9* and Figure *6-10* respectively. A representative drill section showing the orientation of the drilling to the mineralization, and examples of mineralization grades is provided as Figure *6-11*.

6.4.3 COPPER CLIFF

The Copper Cliff deposit consists of numerous mineralized zones. The major zones include the actively-mined 120, 100, 900, 880, 865, 860, 830, 810 orebodies, and the currently inactive 191, 178, 138, 890, 860, 850, 790, 740, 725, and 712 zones.

6.4.3.1 DEPOSIT DIMENSIONS

A summary of the deposit dimensions for the major zones in the Copper Cliff Mine is provided in Table *6-6*.

6.4.3.2 GEOLOGY

Copper Cliff is predominantly an Offset-style deposit with associated minor Contact- and Footwall-type mineralization styles. Mineralization is hosted in a quartz–diorite dyke, the Copper Cliff Offset, which strikes 15 km south into footwall rocks from the base of the SIC, is steeply dipping, and averages 40 m wide. The Copper Cliff Offset is cut by narrow aplitic, quartz diabase, and olivine diabase dykes, locally referred to as “trap dykes”.

Contact-style mineralization associated with Sublayer norite is present in the North Copper Cliff Mine area. Sudbury Breccia occurs in footwall rocks adjacent to the Copper Cliff Offset.

6.4.3.3 STRUCTURE

The Copper Cliff Offset is affected by post-impact displacement along the Creighton and Murray faults and several smaller splay faults.

The Copper Cliff Offset is folded about north easterly-trending open fold axes that have steeply-dipping axial planes. Folding of the quartz–diorite dyke is confined to part of the dyke south of the Creighton fault. West-trending diabase and northwest-trending olivine diabase dykes post-date the folding.

6.4.3.4 MINERALIZATION

The sulphide mineralization is mainly associated with coarser grained quartz diorite and rarely crosscuts footwall rocks. Mineralization consists of disseminated and ragged disseminated sulphides, interstitial sulphides, inclusion massive sulphides, gabbro peridotite inclusion sulphides, contorted schist inclusion sulphides and massive sulphides.

The major sulphides are pyrrhotite, chalcopyrite and pentlandite. Minor sulphides include pyrite, cobaltite, sphalerite, galena, and gersdorffite (NiAsS). The precious metal mineral assemblage includes sperrylite, froodite (PdBi2), michenerite, hollingworthite ((Rh, Pt, Pd) AsS), native gold, argentite (Ag2S) and hessite (Ag2Te).

Sulphide content increases towards the centre of the ore zones and also increases with depth. Typically, chalcopyrite content increases from the centre along strike and down-dip. The Copper Cliff Mine zones have variable copper to nickel and pyrrhotite to nickel ratios.

The local geology of the Copper Cliff deposit is shown in plan view in Figure *6-12*. A representative drill section showing the orientation of the drilling to the mineralization, and examples of mineralization grades is provided as Figure 6-18.

Figure 6-9: Coleman Mine 153 Orebody (schematic section looking east)

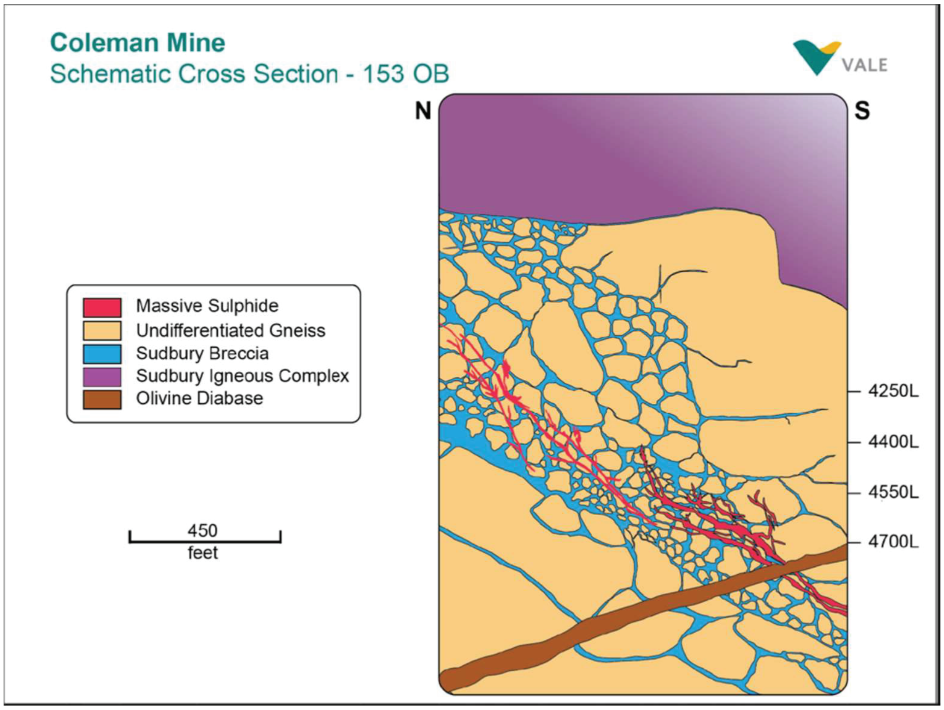


Figure prepared by Vale, 2016.

Figure 6-10: McCreedy East Section (north–south)

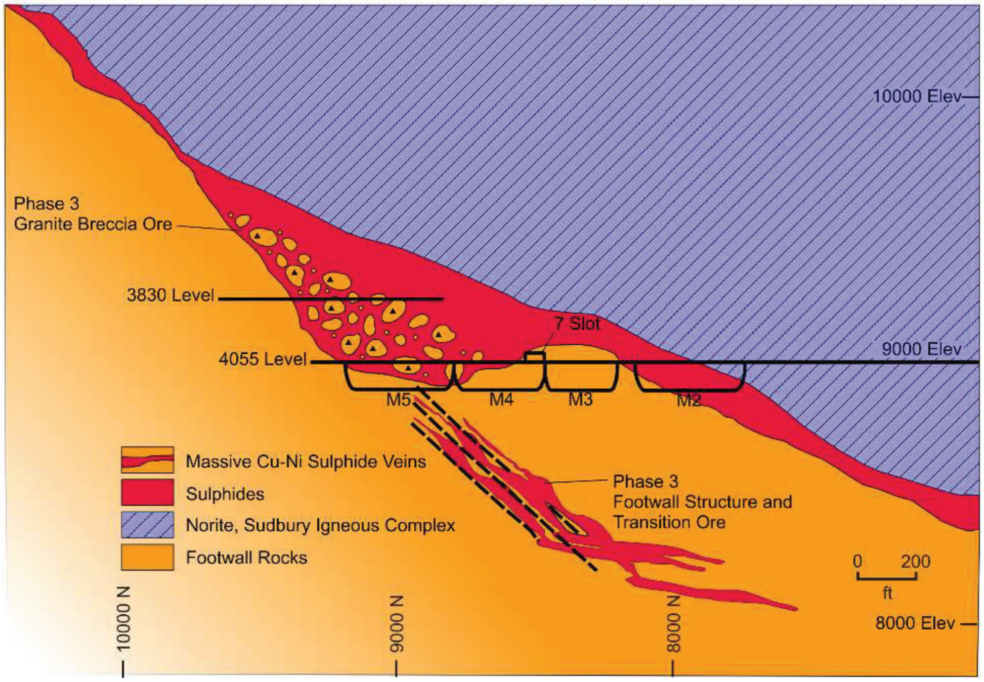


Figure prepared by Vale, 2016. M1–M5 denote mining divisions in the deposit.

Figure 6-11: Example Cross-Section, Coleman (Lower 70 east)

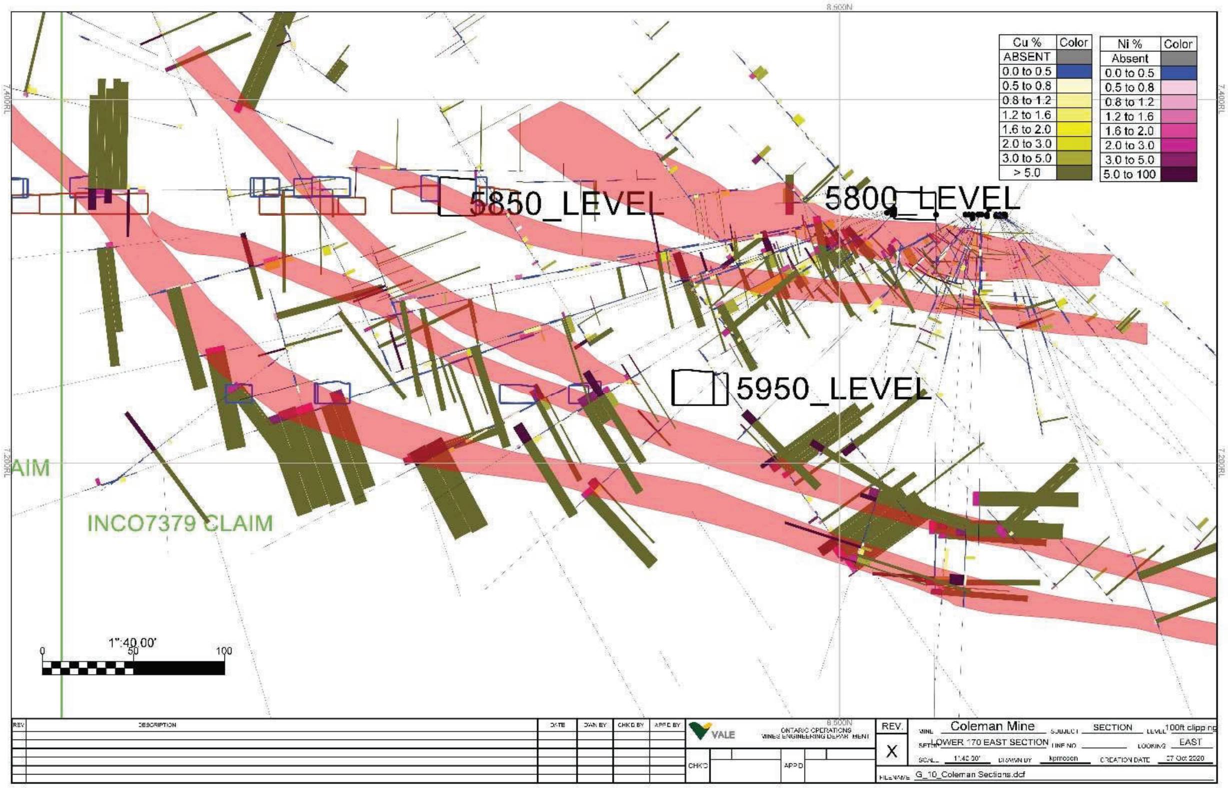


Table 6-6: Dimensions, Copper Cliff Zones/Orebodies

Zone Designation	Type	Length (m)	Width/Strike (m)		Thickness (m)	
			Average	Range	Average	Range
191	Offset	1160	730	90–975	50	15–75
178	Offset	425	395	35–580	30	10–45
138	Offset	335	60	25–105	20	5–25
120	Offset	1355	260	45–365	20	5–25
100	Offset	1890	105	30–120	20	10–45
900	Offset	1850	190	50–245	20	5–25
890	Offset	1190	245	120–305	20	10–30
880	Offset	995	320	245–365	20	3–25
865	Offset	1495	275	85–320	20	3–45
860	Offset	495	245	105–355	20	5–45
850	Offset	975, 425	305	45–455	20	5–30
830	Offset	1065	200	105–365	30	10–45
810 (805, 800)	Offset	455	365	50–505	20	5–35
712 (KL 710/720)	Offset	975	535	150–685	20	5–30
725 (KL)	Offset	520	200	25–380	10	5–15
740 (KL)	Offset	215	215	90–275	20	5–25

Zone Designation	Depth (m)	Dip (º)	Plunge (º)
191	490–1,575	70–90	—
178	1,220–1,630	50–70	—
138	305–1,340	90	90
120	1,160–1,675	70–90	90
100	0–1,890	90	90
900	120–1,850	80–85	90
890	1,035–2,180	90	90
880	120–1,280	70–75	90 (sub-vertical)
865	990–1,880	75–80	0 (sub-horizontal)
860	990–1,525	70	30 S
850	0–1,585	60–75, 40–70	90 (sub-vertical)
830	610–1,640	70	90 (sub-vertical)
810 (805, 800)	1,010–1,555	80	90 (sub-vertical)
712 (KL 710/720)	680–1,690	80–85	48 S
725 (KL)	110–640	90	30–40 S
740 (KL)	275–490	90	—

Figure 6-12: Local Geology of Copper Cliff Deposit

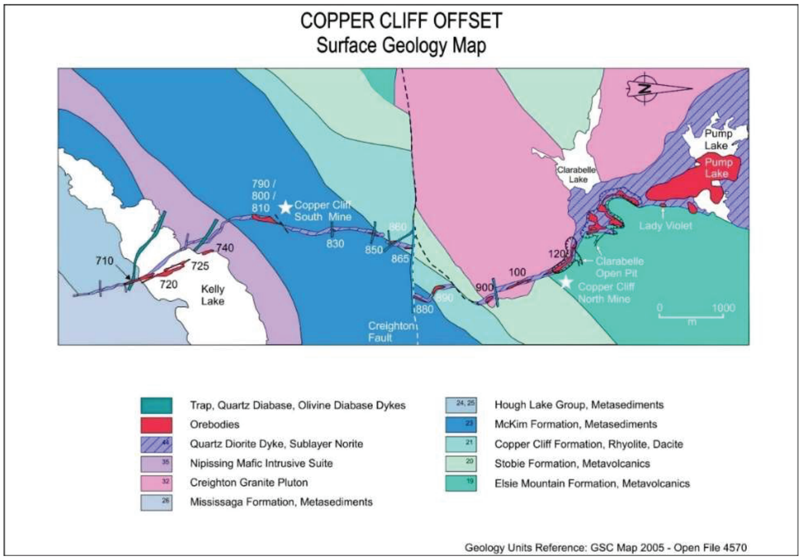
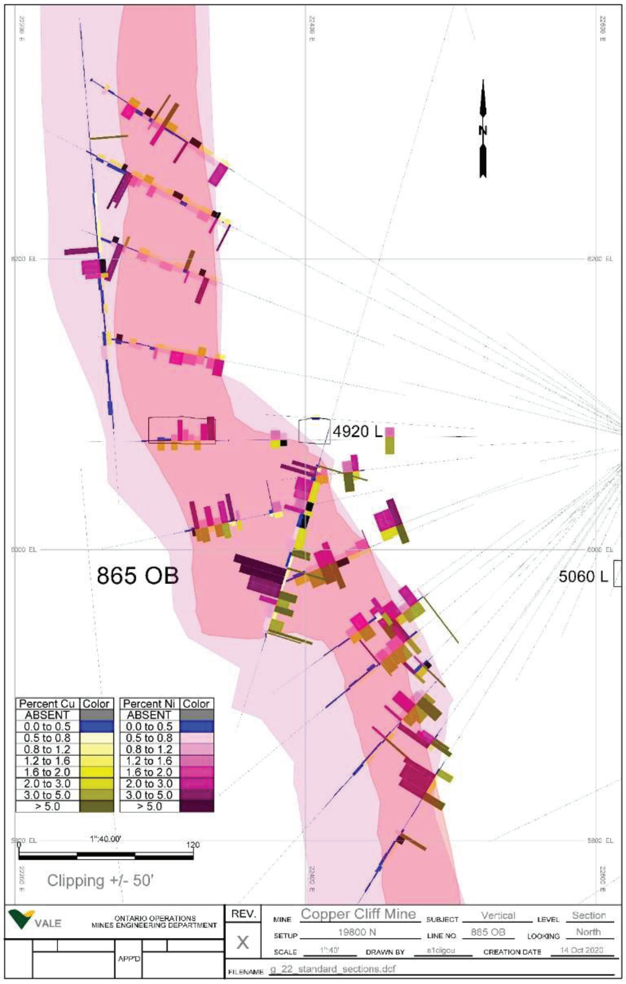


Figure prepared by Vale, 2016.

Figure 6-13: Example Cross-Section, Copper Cliff (865 orebody)



6.4.4 COPPER CLIFF PIT

6.4.4.1 DEPOSIT DIMENSIONS

The Copper Cliff Pit deposit is approximately 3,000 ft (914 m) long, ranges from 1,000–1,400 ft (305–427 m) in width, averaging 1,200 ft (366 m), and ranges in thickness from 50–250 ft (15–76 m), averaging 80 ft (24 m). The deposit is currently delineated from surface to a depth of 5,000 ft (1,524 m), dips at 40–50º, and plunges to the north at 40–60º.

6.4.4.2 GEOLOGY

Contact-style mineralization is hosted in Sublayer norite above Huronian metasedimentary rocks and the Murray granite pluton.

The Copper Cliff Pit sulphide mineralization occupies a lenticular embayment or trough in the footwall rocks on the south contact of the SIC. The Murray embayment/trough is 914 m wide at surface, decreasing to 610 m at the 1000 level, and 1,074 m wide at the 4000 level. It strikes northeast–southwest and dips variably at 40–60° towards the north. Towards the northeast, the embayment pinches, becoming a narrower zone of sulphide mineralization.

6.4.4.3 STRUCTURE

Many of the identified and modelled structures in the vicinity of the Copper Cliff Pit are considered to be preliminary interpretations and may not be an accurate representation of all the structural geology in the Copper Cliff Pit area. Most of the existing structural wireframes created are based on drill hole intersections and logs with some guidance from televiewer surveys. Most of the drill holes in the area are historic drill holes (>60 years old) and most of these drill holes do not have detailed logs/comments, and core photos are limited to the sampled zones.

The historic surface geological mapping indicates the presence of two post-mineralization olivine diabase dykes on the east side of the mineral model. Due to the sub-vertical, north–south orientation of the dykes, the rock units appear in a limited number of drill holes near surface above ~1500 Level. The 2014–2020 core drill programs intersected the dykes in variable locations. Only the eastern-most dyke, which is 150 ft (46m) thick, was used to deplete the block model. The additional dyke(s) are considered too narrow to be selectively segregated due the bulk open-pit mining process. However, the accuracy of the location, orientation and dip of these dykes is recognized as variable.

A major fault, the Main X-fault was mapped from surface to a depth of 3,000 ft. The fault crosscuts the entire deposit geology, strikes east–west and dips between 30–50° north. It is defined by a 10–30 ft wide zone of highly sheared rocks and up to 1 ft of fault gouge. The Main X-Fault corresponds to the South Range Shear Zone—a large, variably developed ductile shear zone at the contact between the SIC rocks and the metavolcanic and metasedimentary rocks of the Huronian Group.

All available information on the underground infrastructure in the Copper Cliff Pit area east of the Elsie orebody workings and down to about 750L was digitized and incorporated into 3D Datamine files. The cave volume was drilled from all sides. The cave is separated into two different wireframes:

- Cave material consisting of blasted blocks of rock and highly damaged areas;
- Cave rubble zone, a larger shape that represents the cave damage zone. It is assumed to consist of large blocks of material. The extent is based on subsidence cracks on surface, which were last updated in the 1970s, and on areas of low rock quality designation (RQD) in recently logged drill holes. The surface expression of this damage zone is slightly outside the last known extents of cracks due to the cave.

6.4.4.4 MINERALIZATION

Mineralization is typically zoned, the lowest zone consisting of inclusion massive sulphide containing variable amounts of irregular angular wall rock fragments with rare high-grade copper and nickel stringers of sulphide that project into the footwall rocks.

A geological composite section showing the geology in relation to the mineralization is provided in

Figure 6-14. A representative drill section through the deposit showing the orientation of the drilling to the mineralization, and examples of mineralization grades is provided in Figure *6-15*.

6.4.5 CREIGHTON

The Creighton deposit consists of the actively mined 310, 400, 461 orebodies and the inactive Creighton Deep 320, 330 and 6100 zones.

6.4.5.1 DEPOSIT DIMENSIONS

Deposit dimensions for the major zones that are currently being mined are provided in Table 6-7.

6.4.5.2 GEOLOGY

The Creighton deposit hosts Contact- and Footwall-style mineralization. Mineralization is hosted within the Creighton Embayment and is controlled by two troughs or indentations into the footwall region. Quartz diorite, quartz diabase and olivine diabase dykes occur. Footwall rocks consist of the Paleoproterozoic Creighton Granite/Gabbro that intrudes lower Huronian Metavolcanic rocks and metasediments. Sudbury Breccia occurs within the footwall rocks.

Figure 6-14: Geological Section, Copper Cliff Pit

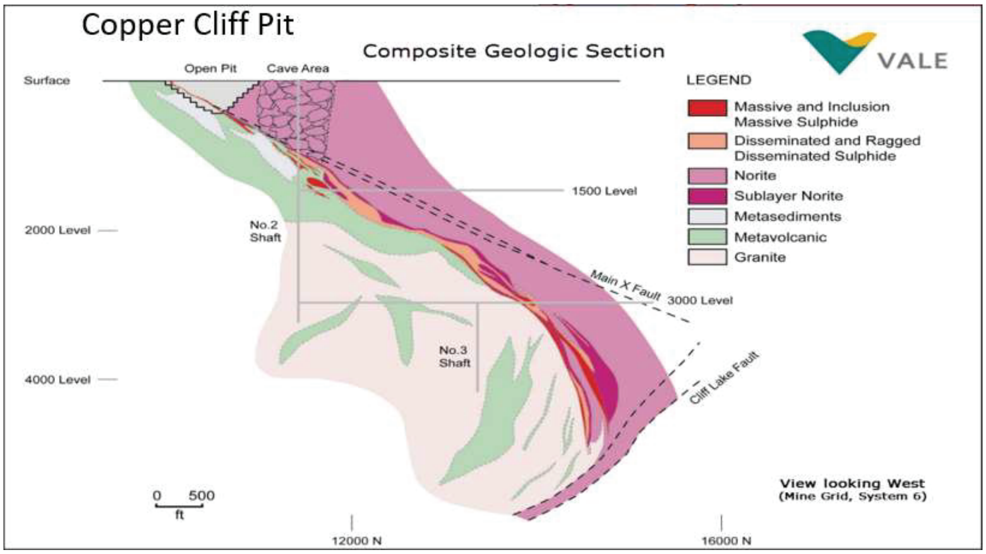


Figure 6-15: Example Cross Section, Copper Cliff Pit (13,300 m east)

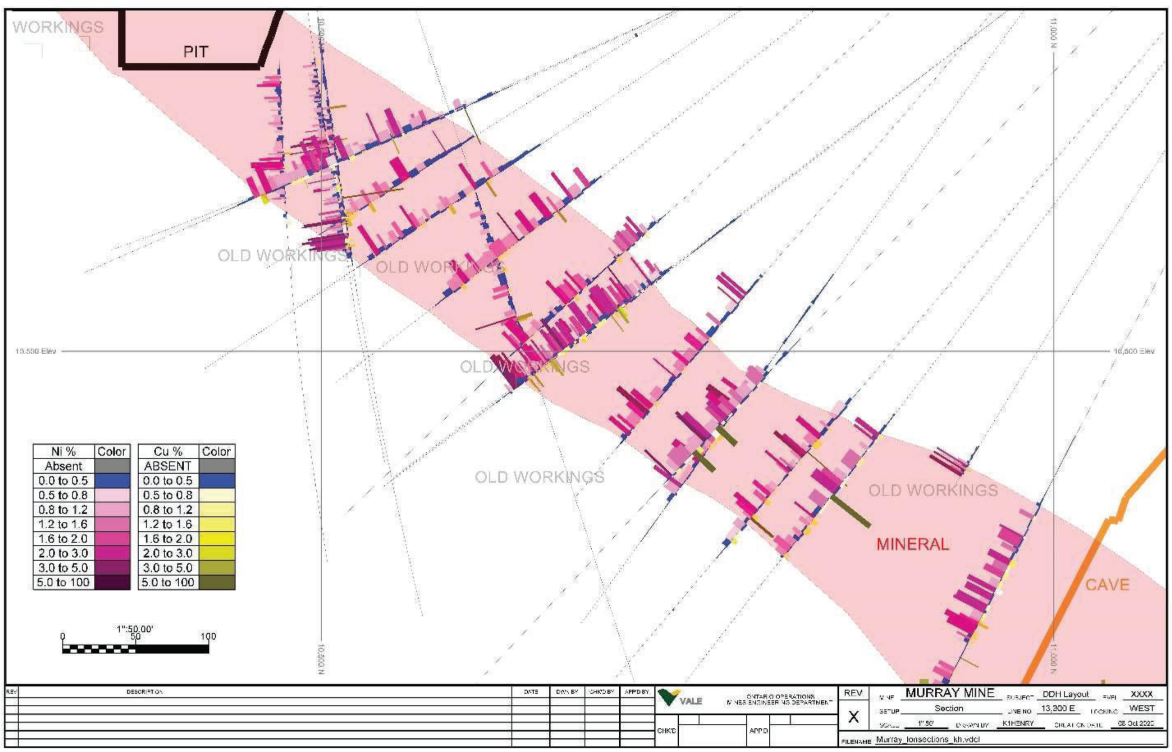


Table 6-7: Dimensions, Creighton Zones/Orebodies

Zone Designation	Type	Length (m)	Width/Strike (m)		Thickness (m)	
			Average	Range	Average	Range
300	Contact	1,065	250	55–300	30	3–155
310	Contact	520	210	55–270	10	3–70
320 (330)	Footwall	325	125	10–175	10	3–60
400	Contact/ Footwall	670	240	45–295	10	5–190
404	Footwall	250	50	10–80	10	3–35
461	Footwall	230	95	30–130	10	3–50
Zone Designation	**Depth From/To (m)**	**Dip (º)**	**Plunge (º)**			
300	2,135–3,200	70–90	90			
310	2,420–3,000	90	45 E			
320 (330)	2,650–2,980	70	90			
400	2,295–2,965	70	90			
404	2,460–2,695	90	90			
461	2,410–2,635	90	90			

6.4.5.3 STRUCTURE

The Creighton Fault cuts the Creighton embayment just south of the Creighton deposit. It is a steeply-dipping, east–west-trending fault system and has been interpreted as primarily dextral strike slip with a lesser normal component of displacement.

The Cliff Lake Fault is a major, shallow south–southeast dipping thrust structure related to the South Range Shear Zone. Drilling at Creighton Mine has intersected the Cliff Lake Fault at a depth of approximately 10,000 ft (approximately 3.1 km). Displacement has been interpreted up to 4 km.

Throughout the Creighton deposit, evidence of significant structural influence on footwall ore emplacement, geometry and sulphide fractionation is evident. Major shears include the 6 Shaft, 117, 118, 400 East, 1290 and 2000N shears. There are several other minor shears within the mine area.

6.4.5.4 MINERALIZATION

Contact-style mineralization has a generalized sequence of sulphide styles from hanging wall to footwall of disseminated sulphide, interstitial sulphide, ragged disseminated sulphide, gabbro peridotite inclusion sulphide, contorted schist inclusion sulphide, inclusion-bearing massive sulphide and massive sulphide.

The major sulphides are pyrrhotite, chalcopyrite and pentlandite. Minor sulphides include pyrite, cubanite ($CuFe_2S_3$), cobaltite, sphalerite, galena, and gersdorffite. The precious metal mineral assemblage includes michenerite, hollingworthite, irarsite ((Ir, Ru, Rh, Pt) AsS), froodite, Pd-melonite ($PdNiTe_2$), sperrylite and native gold. All of the zones contain low levels of arsenic, lead, and zinc. The Creighton zones have variable copper to nickel and pyrrhotite to nickel ratios.

Figure 6-16 shows a generalised geology plan and Figure 6-17 a composite cross-section of the Creighton deposit. A representative drill section showing the orientation of the drilling to the mineralization, and examples of mineralization grades is provided as Figure 6-18.

Figure 6-16: Geological Plan, Creighton Mine Area

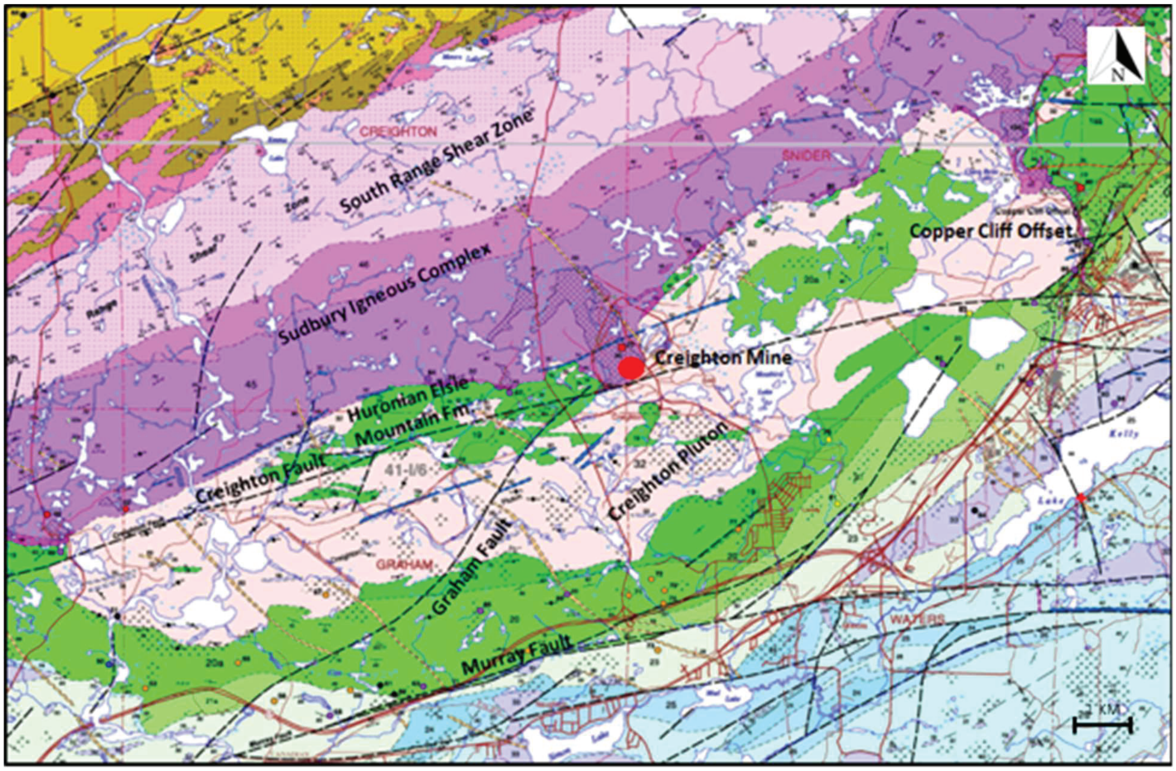


Figure prepared by Vale, 2016.

Figure 6-17: Composite Cross Section, Creighton Mine

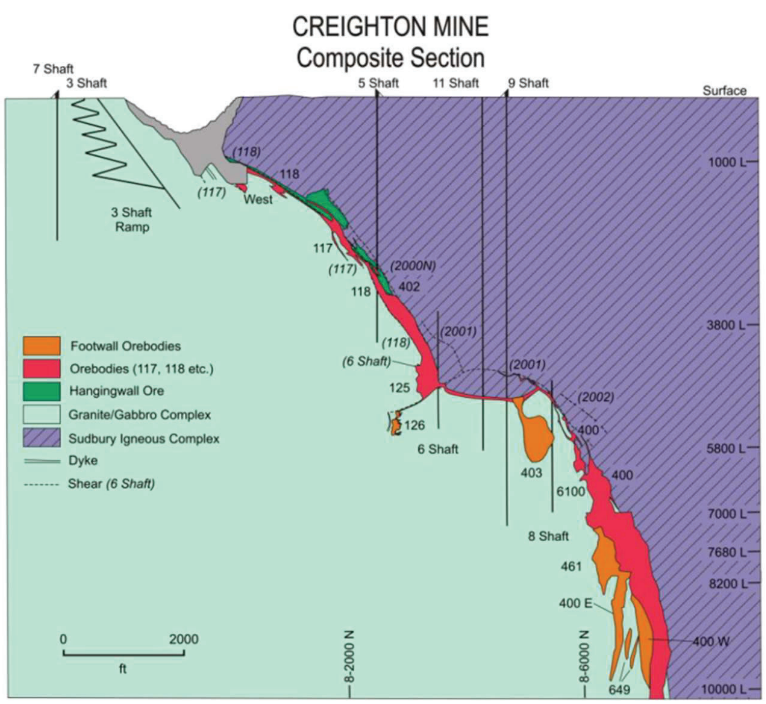
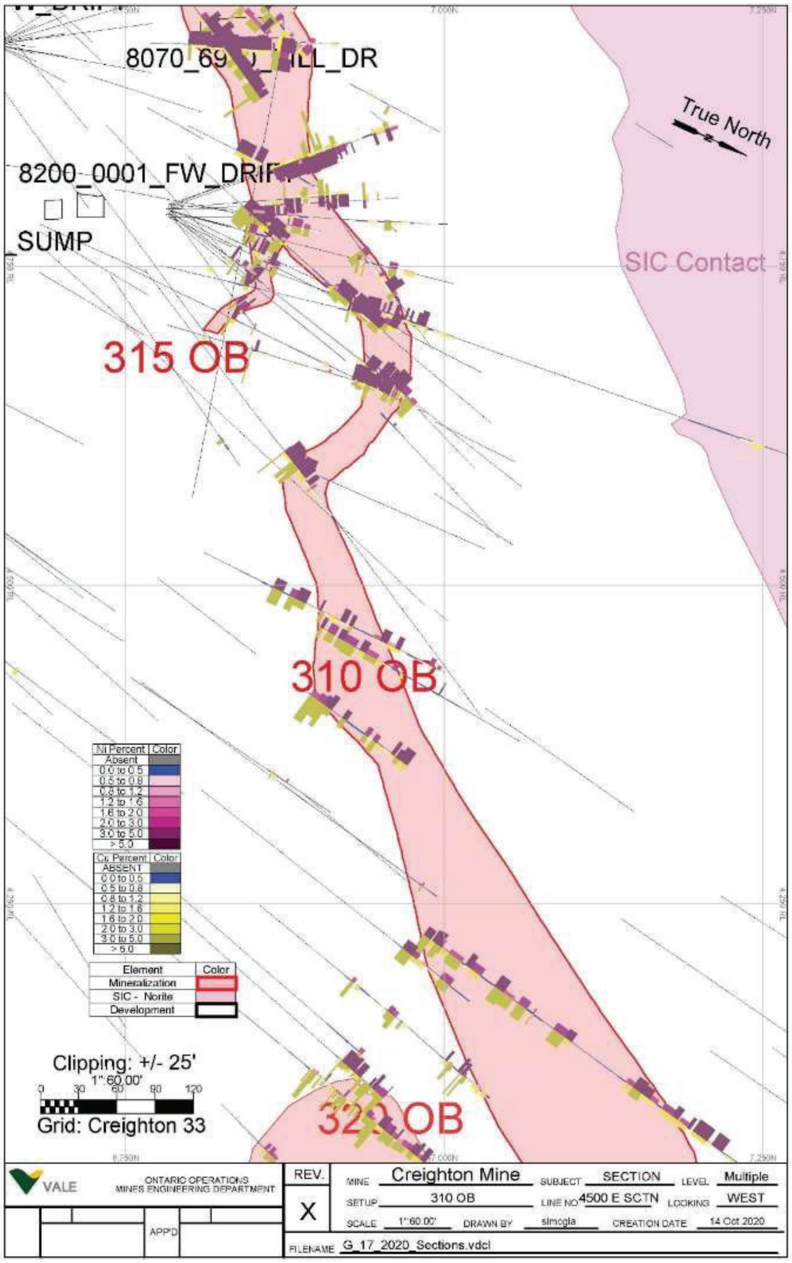


Figure prepared by Vale, 2016. Figure looks west.

Figure 6-18: Example Cross Section, Creighton (4,500 east)



6.4.6 STOBIE

None of the zones in the Frood–Stobie Mine are currently being mined. The zone of current interest is the Stobie 37 block.

6.4.6.1 DEPOSIT DIMENSIONS

The Stobie 37 block is approximately 2,310 ft (705 m) long, ranges in width from 530-1040 ft (162–317 m), averaging 855 ft (261 m), and ranges in thickness from 15–450 ft (5–137 m), averaging 170 ft (52 m).

6.4.6.2 GEOLOGY

The Frood and Stobie deposits have zones that have been classed as Contact, Footwall and Offset-style mineralization. The deposits lie within a breccia belt which is roughly parallel to the SIC Main Mass norite–footwall contact 1.5 km to the north. The breccia belt is composed of:

- Fragments and blocks of Proterozoic footwall rock;
- Anastomosing network of Sudbury Breccia;
- Discontinuous pods of quartz diorite.

The quartz diorite pods are assumed to be co-magmatic with the SIC and contain inclusions of country rock, exotic lithologies, and barren to weakly-mineralized quartz diorite. In addition to rock fragments, angular to rounded massive sulphide inclusions have been documented within the inclusion quartz diorite. Barren gabbro and peridotite inclusions to 45 m in diameter are found within the quartz diorite and Sudbury Breccia.

The breccia belt strikes northeast, and dips from 65–75º to the northwest. Two mineralized bodies are connected by a narrow bridge of disseminated sulphide mineralization that occurs above a “saddle” of unmineralized rock.

The 37 Block area of the Frood–Stobie deposit is hosted in an inclusion-bearing quartz diorite and consists of a low-grade, copper–nickel-bearing, disseminated-style mineralization.

6.4.6.3 STRUCTURE

Structure does not appear to play a significant part in the location of the mineralization at Stobie, but local shearing parallel to the walls of the structure sometimes create challenging ground conditions. Two main structures at Frood are as follows:

- The “Main Cross Fault”, which has been traced from the south nose of the mineralized zone above 1000 Level downwards towards 2600 Level. At 1000 Level, the fault strikes normal to the ore zone and dips north at slightly less than 30º northward. The fault intersects progressively lower levels and the strike rotates through 90º. At 2600 Level the strike of the fault is indistinguishable from other sub-parallel faults at the same horizon. An apparent offset of up to 50 ft (15 m) is observed locally but on other areas no offsetting by the fault is apparent;
- Frood Proper Footwall Shear. The footwall has been extensively sheared throughout the length of the orebody, but shearing is particularly heavily developed in the metasedimentary rocks above 1200 Level. Localized mining-related slippage of 10–20 ft (3–6 m) that occurred along the shear plane into the Footwall has resulted in local ground problems

There are two mining-related subsidence structures:

- The 60 and 19 Block Footwall Structure is a major crack in the footwall of the Frood North Extension pit first noted in mid-2007;
- Ore Zone Structure consists of an area of parallel fractures dipping 30–50º towards the footwall.

The Frood deposit is shaped like an elongated funnel, with a northeast to southwest strike axis, and a northwesterly dip of 70°. The mineralization is approximately 1,350 m in length and reaches a maximum width of nearly 300 m wide. The mineralization is continuous down-dip from surface to 2800 Level below which it splits in two along strike and progressively becomes narrower at depth until the orebody pinches out on the 3600 Level.

Chalcopyrite, pentlandite and pyrrhotite are found in discrete blebs in a silicate matrix in the upper zones of mineralization. Below the 2800 Level this disseminated mineralization merges with massive sulphides. Copper–nickel ratios are constant at 1:1, but locally change laterally and generally increase with depth in the brecciated zones. Copper content increases with depth.

Two pendants of precious metal-enriched “siliceous” mineralization occur at the base of the Frood orebody, beneath the massive sulphide mineralization.

Most of the Frood deposit was mined or is no longer accessible. The remaining blocks of mineral resources were assigned to the Stobie Mine, but were mined by the Frood Division. Currently no workings at the Frood Mine below the 1400 Level is accessible.

6.4.6.4 MINERALIZATION

The dominant mineralization styles at Frood–Stobie are disseminated and inclusion massive sulphide. Sulphide mineralization consists primarily of pyrrhotite, pentlandite and chalcopyrite. Secondary mineralization at Stobie consists of discontinuous veins of marcasite, galena, and carbonate, with minor occurrences of pyrite and violarite. At Frood, a cubanite-rich zone is present at the base of the massive and breccia sulphide, above the precious metal-enriched siliceous zone.

The continuity of the quartz diorite at Stobie is interrupted above the 1,000 Level by two large lobes of footwall rock extending downward into the disseminated mineralization. The mineralization to the north by this lobe of footwall averages 120 m in width, while in the south mineralization reaches a maximum width of 170 m at the 2000 Level. Below the 2200 Level, the mineralization gradually narrows and eventually bottoms above the 4100 Level.

Copper–nickel ratios are relatively constant throughout the Stobie deposit, averaging 0.92:1. There is no indication of copper enrichment at depth, but the copper content of the inclusion massive sulphide does increase at the extreme north end as mineralization narrows before pinching out completely.

Contacts with the surrounding footwall rocks are sharp, quite distinct, and generally regular.

The generalized geology is shown in plan view in Figure 6-19. Mineralized domains are shown in long section in Figure 6-20. A representative drill section showing the orientation of the drilling to the mineralization, and examples of mineralization grades for the 37 Block is provided as Figure 6-21.

6.4.7 GARSON

The Garson deposit includes the actively mined Garson Surface Ramp (13 and 360), and Garson Mine #1 Shear, #4 Shear deposits. Inactive deposits include the McConnell, and Garson Ramp (600) zones.

6.4.7.1 DEPOSIT DIMENSIONS

Dimensions of the major zones within the Garson deposit are provided in Table 6-8.

6.4.7.2 GEOLOGY

Garson is a deformed Contact-style deposit. Contact-style mineralized zones are remobilized into a series of near-parallel ductile shear zones. Shear-hosted copper–nickel sulphides are offset by later stage dykes and possible late-stage shearing. The 1 Shear and 4 Shear are the primary mineralized zones.

The 1 Shear extends from surface to below 6500 Level, a distance of approximately 1,980 m. It has a strike length of 120–600 m, with strike length decreasing with depth. Hanging wall to footwall widths along the orebody vary between 3–60 m, with an average width of 10 m.

The 4 Shear extends from the 2800 Level to a currently known limit of 6700 Level, a distance of approximately 1,200 m. It has a strike extent of 685 m and an average width of 7 m. It strikes east–west and generally dips 70° south. The 4 Shear orebody runs parallel to the 1 Shear orebody, lying approximately 45 m to 60 m to the northwest.

Figure 6-19: Frood–Stobie Generalized Geology Plan

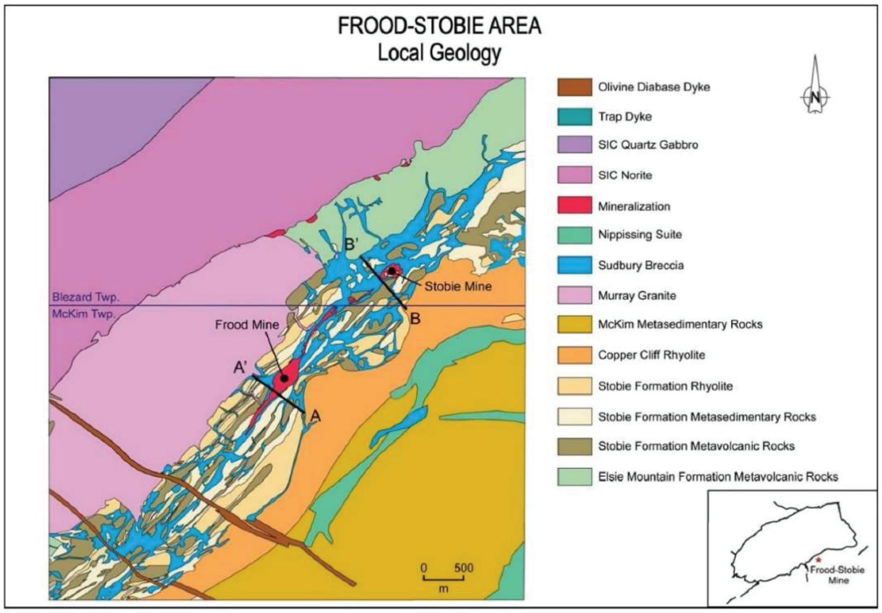


Figure prepared by Vale, 2016.

Figure 6-20: Frood–Stobie Mineralization Type Distribution (long section)

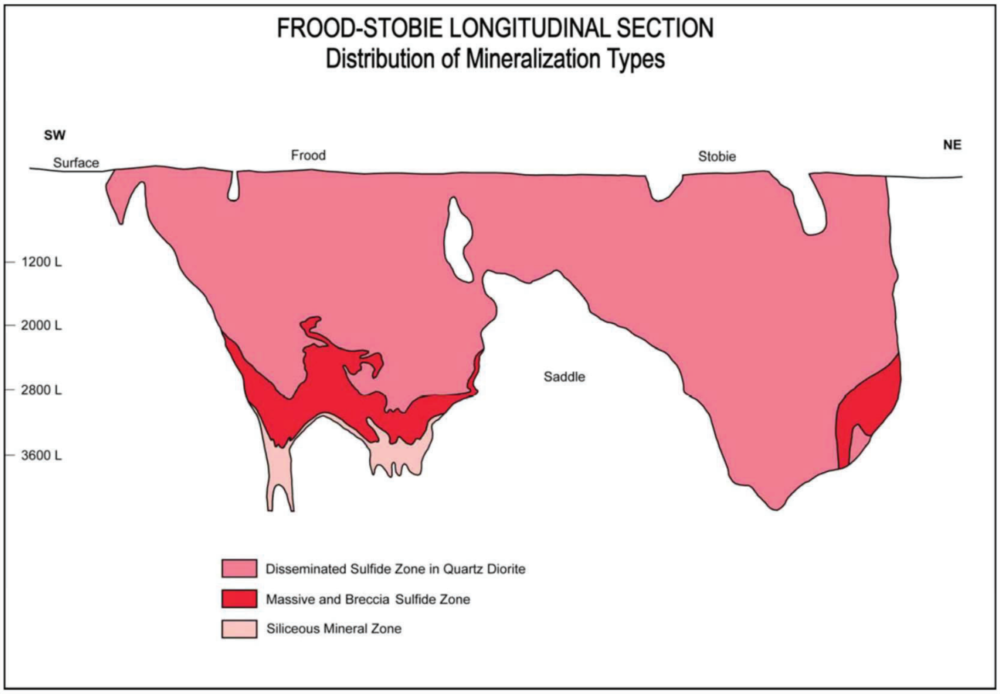


Figure prepared by Vale, 2016.

Figure 6-21: Example Cross-Section, Block 37 (3150 N)

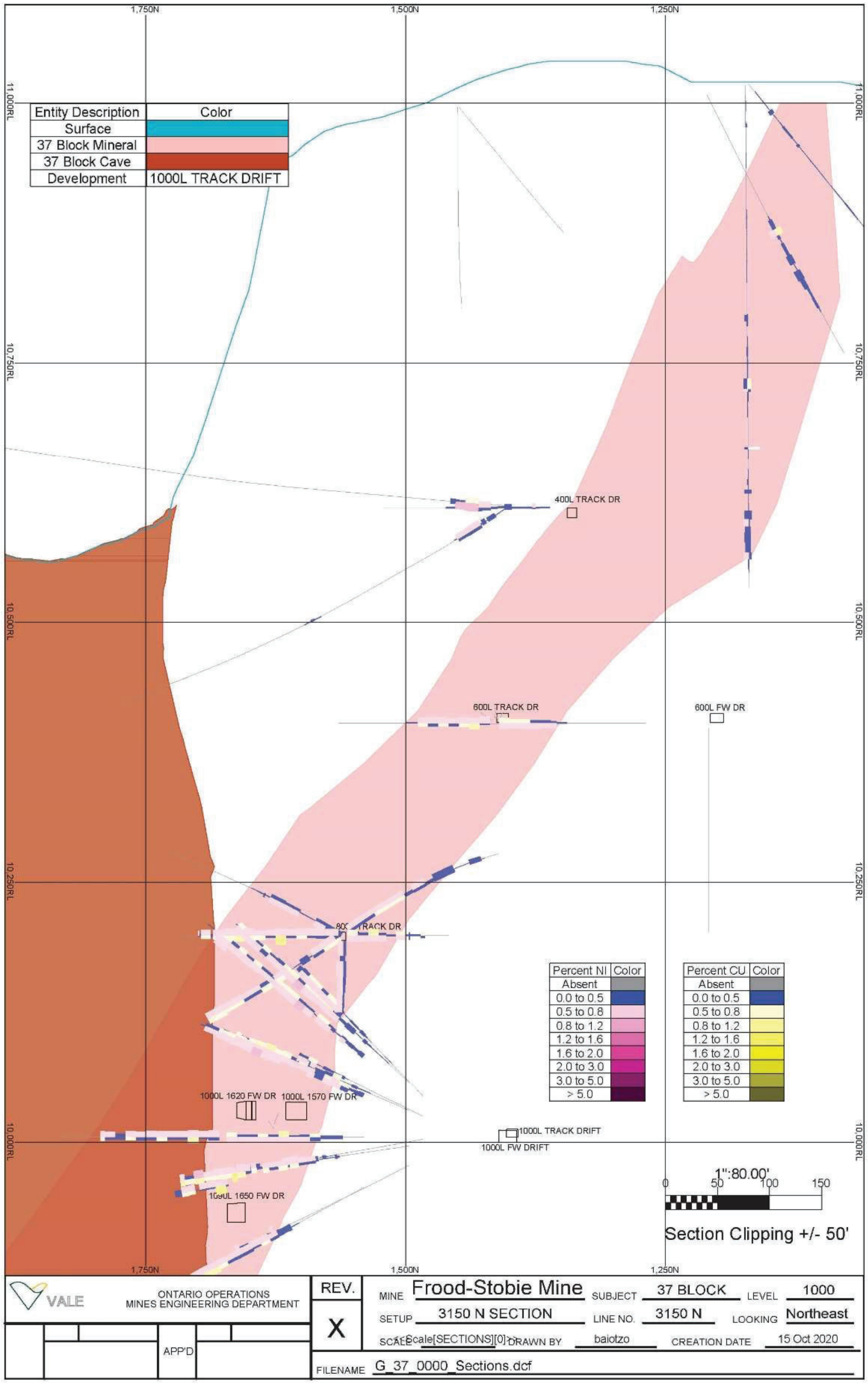


Table 6-8: Dimensions, Garson Zones/Orebodies

Zone Designation	Type	Length (m)	Width/Strike (m)		Thickness (m)	
			Average	Range	Average	Range
1 Shear	Contact	760	455	120–610	10	3–60
4 Shear	Contact	1130	855	700–1065	10	3–20
360	Contact	150	90	45–185	20	10–20
13 OB	Contact	245	305	150–365	10	3–20
Zone Designation	**Depth From/To (m)**	**Dip (º)**	**Plunge (º)**			
1 Shear	915–1,675	75 S	70 E			
4 Shear	1,220–1,980	60 S	50 E			
360	185–305	60 S	90			
13 OB	90–255	60 S	70 E			

Both shears dip at a slightly shallower angles than the SIC contact, which means that above the 4000 Level the shears are mostly hosted in the SIC with the dominant lithology being Sublayer Norite and below the 4000 Level the shears cut the metasedimentary and metavolcanic Huronian footwall rocks.

The deposit is crosscut by two separate olivine diabase dykes. These dykes are sub-parallel to each other and range in width from 15–60 m.

6.4.7.3 STRUCTURE

The Garson region was subjected to significantly more structural activity than the rest of the Sudbury Basin. This structural activity caused the Huronian footwall rocks to overturn and form the hanging wall. This overturning caused a significant amount of shearing sub-parallel to the strike of the Garson Contact-style deposits producing a series of near-parallel shears.

Major geological structures include the Garson Fault, the 2500 Shear, and the 3500 Shear. The 2500 shear and the 3500 structures and are roughly 12–23 m wide, strike north–northwest and dip steeply to the east. Fractures are commonly filled with calcite, galena, marcasite and sphalerite. Late-stage faults and fractures also deform the orebodies.

There are a number of “cross-over” sulphide zones that connect that the 1 Shear and 4 Shear Orebodies. These cross-over zones are near vertical and <3 m wide.

6.4.7.4 MINERALIZATION

The mineralization is dominated by inclusion massive sulphide and massive sulphide lenses and stringers, contorted schist inclusion sulphide, ragged disseminated and sulphide breccia. Pyrrhotite is the most common sulphide mineral. Pentlandite is the main nickel-bearing mineral. Chalcopyrite is the main copper-bearing mineral, and is locally associated with elevated precious metals. Trace to minor amounts of cobaltite–gersdorffite, niccolite (NiAs), nickeliferous pyrite, marcasite, sphalerite, galena and argentopentlandite ($Ag(Fe, Ni)_8S_8$) are distributed throughout the 4 Shear.

Platinum-group minerals include michenerite, hollingworthite, irarsite, froodite, Pd-melonite and sperrylite. The oxide mineral assemblage is composed of magnetite, with magnetite content varying from 0.5–2%. Rare and local clustering of lead and zinc mineralization occurs as veinlets associated with late fracture zones and within major structures. The hydrothermal alteration assemblage consists of marcasite (FeS_2) and violarite ($FeNi_2S_4$).

Arsenic-bearing mineral assemblages occur primarily along the strongly sheared hanging wall and footwall-sulphide contacts. Arsenic also occurs within the main sulphide zones associated with late-stage structural/schistose zones. Commonly, occurrences can be found associated with shear planes in the halo of the main mineral zone associated with low-grade disseminated and copper rich veinlets. The dominant As-bearing minerals are niccolite and cobaltite–gersdorffite. Maucherite ($Ni_{11}As_8$) has been reported but is relatively rare. Other arsenide and sulpharsenide minerals are present in trace amounts including sperrylite. Stockpiling and re-handling of high arsenic content ore is done to ensure processing requirements are achieved.

A schematic cross-section showing the locations of the mineralized zones is provided in Figure 6-22. Representative drill sections through the deposit showing the orientation of the drilling to the mineralization, and examples of mineralization grades are provided as Figure 6-23 and Figure 6-24.

6.4.8 GARSON–MCCONNELL

Although proximal to, and along strike from the Garson Mine orebodies, the McConnell deposit is in a different geological setting with different geological and mineralogical characteristics and is classified as an Offset-type deposit.

6.4.8.1 DEPOSIT DIMENSIONS

The McConnell deposit is approximately 1,425 ft (434 m) long, ranges from 200–570 ft (61–174 m) in width, averaging 430 ft (131 m), and ranges in thickness from 30–100 ft (9–30 m), averaging 60 ft (18 m). The deposit is currently delineated from surface to a depth of 1,350 ft (411 m), dips at about 70º, and plunges to the south at 70º.

6.4.8.2 GEOLOGY

Mineralization at the McConnell deposit is associated with a narrow, concentric, quartz–diorite dyke that has intruded into metasedimentary units within the Stobie Formation. The dyke strikes at 85º east and dips at 70º south. The immediate foot and hanging walls consist of quartz diorite acting as an envelope around the mineralization. Beyond this, the country rocks consist of embedded greenstone and quartzite with zones of Sudbury Breccia.

6.4.8.3 STRUCTURE

No significant cross-cutting dykes or structures have been identified or interpreted; however, the presence of shearing has been noted.

6.4.8.4 MINERALIZATION

The mineralization consists of massive sulphide and contorted schist inclusion sulphide with a high pyrrhotite/nickel ratio, above-average precious metals content and negligible arsenic content. The sulphides occur as 1–2 cm blebs within the quartz diorite, but mainly as disseminated sulphides in the surrounding breccia.

A representative drill section showing the orientation of the drilling to the mineralization, and examples of mineralization grades is provided in Figure 6-25.

Figure 6-22: Garson Mine Typical Cross-Section (looking east)

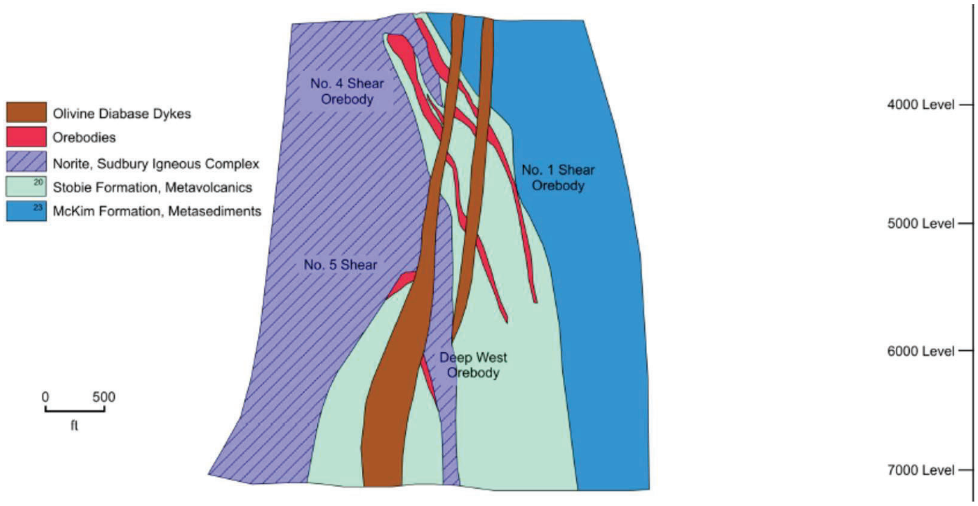


Figure prepared by Vale, 2016.

Figure 6-23: Example Cross-Section, Garson (level 3250 E)

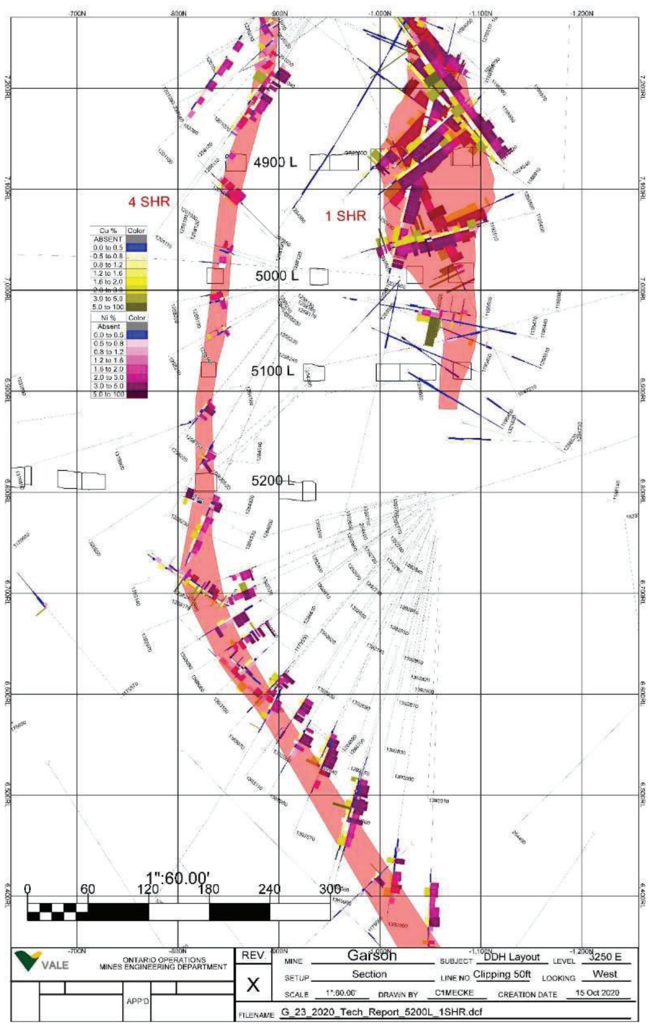


Figure 6-24: Example Cross-Section, Garson (level 3450 E)

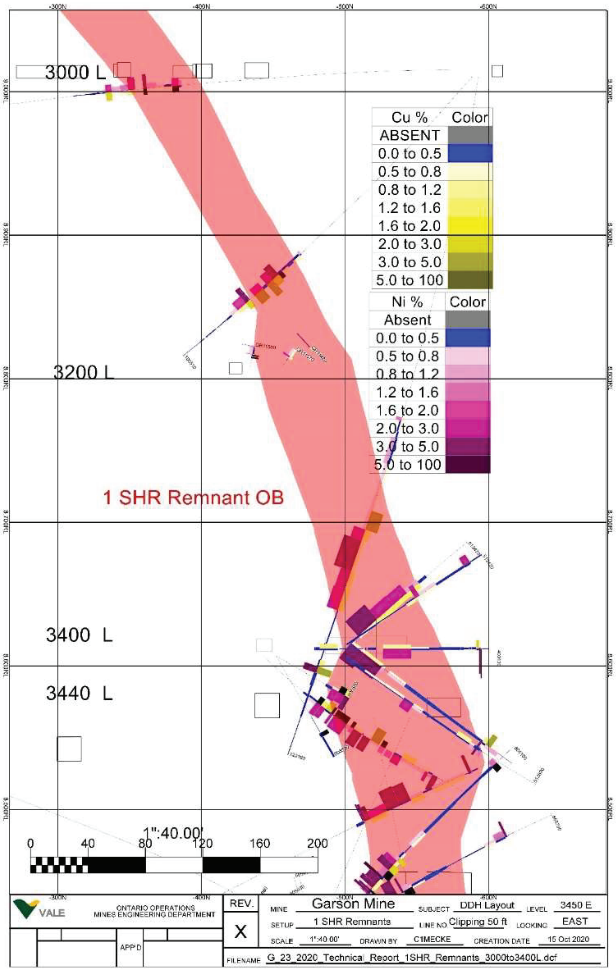
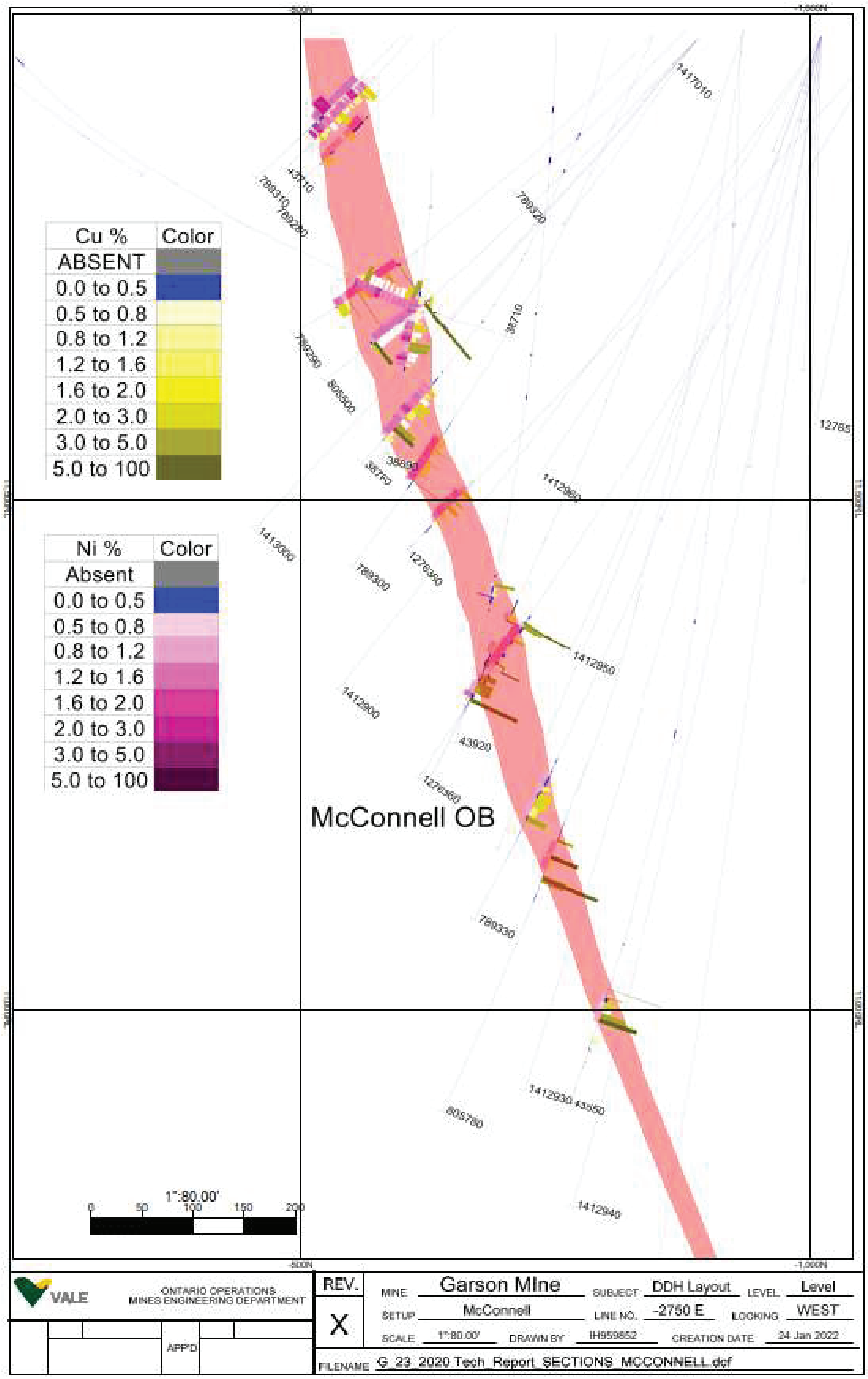


Figure 6-25: Example Cross Section, McConnell (level 2750 east)



6.4.9 TOTTEN

The Totten Mine deposits consists of the actively mined Totten Main (215), and other mineralized zones including the 230, 260, 242, 235, 238, 238 West, Howland, and McIntyre zones.

6.4.9.1 DEPOSIT DIMENSIONS

Dimensions of the major zones within the Totten deposit are provided in Table 6-9.

6.4.9.2 GEOLOGY

The Totten deposit is hosted within the Worthington Offset Dyke which extends 12 km south from the SIC. The dyke attains a thickness of 45 m in the Totten Mine area, strikes approximately 045°, and has steep variable dips.

Metasedimentary rocks and the Nipissing meta-gabbro sill underlie the Totten Mine area. The sill is 365 m thick, trends east–west and dips at approximately 65° to the southeast. The Worthington Offset cuts both the metasedimentary rocks and the gabbro sill. Late quartz diabase and olivine diabase dykes crosscut all lithologies.

The contact between meta-gabbro and Worthington Offset Dyke is characterized by a meta-gabbro breccia with fragments up to 10 m diameter. Locally the meta-gabbro is invaded by an inclusion quartz diorite stockwork and mineralized stringers. These breccia and stockwork features are not developed in metasedimentary rocks.

Two quartz diabase dykes occur in the immediate vicinity of the Totten Mine and bound the majority of the high-grade mineralization hosted in the Totten Main orebody. The quartz diabase dykes are steeply dipping and vary in thickness from <3–10 m. Quartz diabase dykes are generally fractured especially along the contacts resulting in local poor ground conditions. Several olivine diabase dykes of variable width occur to the north of the Totten Main orebody.

6.4.9.3 STRUCTURE

The Worthington Offset has been displaced by two major faults. The Creighton fault strikes east–west, is vertical to steeply dipping to the north, and dextrally displaces the Worthington Offset Dyke by approximately 1 km. The Murray fault also strikes east–west, is vertically dipping and dextrally displaces the Worthington Offset by approximately 1 km.

Between the Creighton and Murray faults the local rock mass has been subjected to northwest–southeast fracturing and weak faulting. Minor displacement occurred locally on some of the larger fractures.

6.4.9.4 MINERALIZATION

Copper–nickel–PGE–gold sulphides are hosted within an inclusion quartz diorite phase of the Worthington Offset. This sulphide zone consists of variable thicknesses of massive and semi-massive copper–nickel-bearing sulphides surrounded by a disseminated and blebby sulphide halo.

The massive sulphide varies in true thickness from 2–15 m and is dominantly pyrrhotite and pentlandite. The massive sulphide thins and splays into 2.5 cm to 1 m thick copper-rich stringer zones within the disseminated sulphide halo. Semi-massive sulphides are also typically pyrrhotite and pentlandite rich, but are spatially associated with chalcopyrite-rich patches. In areas where large meta-gabbro inclusions are present, metal grades tended to be higher than in portions of the dyke containing only amphibolite inclusions.

Thick, localized accumulations of ore are situated to the north and south of the quartz diabase dykes. Nickel and copper mineralization become progressively higher grade with depth and towards the core of the mineralization.

Table 6-9: Dimensions, Totten Zones/Orebodies

Zone Designation	Type	Length (m)	Width/Strike (m)		Thickness (m)	
			Average	Range	Average	Range
215 (Main)	Offset	1420	305	60–455	20	2–30
230	Offset	230	90	20–165	4	3–8
238	Offset	130	30	5–115	6	3–20
Zone Designation	**Depth From/To (m)**	**Dip (º)**	**Plunge (º)**			
215 (Main)	565–1,525	90	45 S			
230	1,205–1,290	90	30 N			
238	315–440	90	40 S			

PGE–gold minerals are spatially associated with more copper-rich sulphides. Platinum and palladium grades increase with depth but the gold grade does not. The highest PGE–gold grades are concentrated at depth around a portion of the southernmost quartz diabase dyke.

Mineral zone boundaries are locally characterized by arsenic-bearing minerals such as niccolite and gersdorffite. Niccolite stringers are also encountered in the quartz diabase dyke and sometimes in quartz diorite and inclusion quartz diorite proximal to the Worthington Offset.

Figure 6-26: shows the general geology along the Worthington Offset in the Totten Mine area. Drill sections through the deposit showing the orientation of the drilling to the mineralization, and examples of mineralization grades are provided as Figure 6-27: and Figure 6-28.

6.4.10 VICTOR–NRS EXTENSION

The Victor–NRS Extension deposit includes the Main, 14 N, 24 N, and 28 N zones. The NR14 and BL28 zones are currently divided by a Glencore/Vale claim boundary.

6.4.10.1 DEPOSIT DIMENSIONS

Dimensions of the major zones within the Victor deposit are provided in Table 6-10.

6.4.10.2 GEOLOGY

The deposit footwall consists of felsic, intermediate and mafic gneisses, diabase sills, and Sudbury breccia. The SIC lithologies include felsic norite, Sublayer norite (norite breccia), mafic norite (dark norite) and late granite breccia. The preferred host lithology for mineralization is the Sublayer. Late diabase dykes cut all earlier lithologies.

6.4.10.3 STRUCTURE

Five fault types are differentiated. Cataclasite faults range from a few centimetres in width to as much as 4 m, and have no significant displacement. They are post-SIC, competent structures that show sharp to variable contacts, and are often associated with quartz–carbonate veins and infilled joints. A second fault type, consisting of a low RQD fracture zone hosts numerous chlorite-coated fractures. The Victor Shear is characterized by pervasive epidote/chlorite alteration. The fourth major fault set consists of a set of 4–6 m thick parallel, brittle structures that do not appear to disrupt stratigraphy. Faults designated as “steep” are typically 10–30 cm wide, often associated with chlorite, and also do not show significant displacement.

Figure 6-26: Worthington Offset Regional Geology

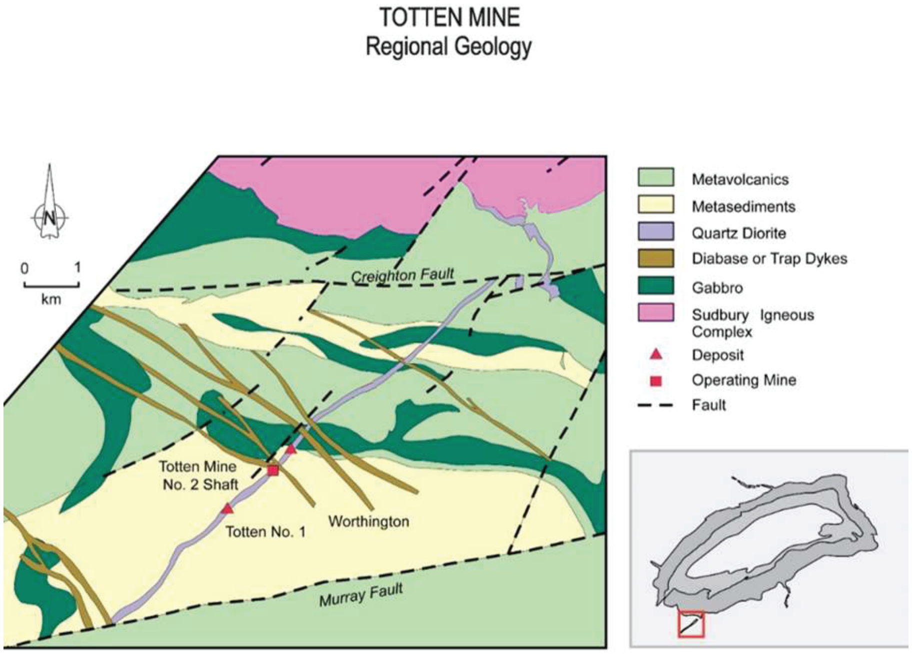


Figure prepared by Vale, 2021.

Figure 6-27: Example Cross Section, Totten (20,500 N)

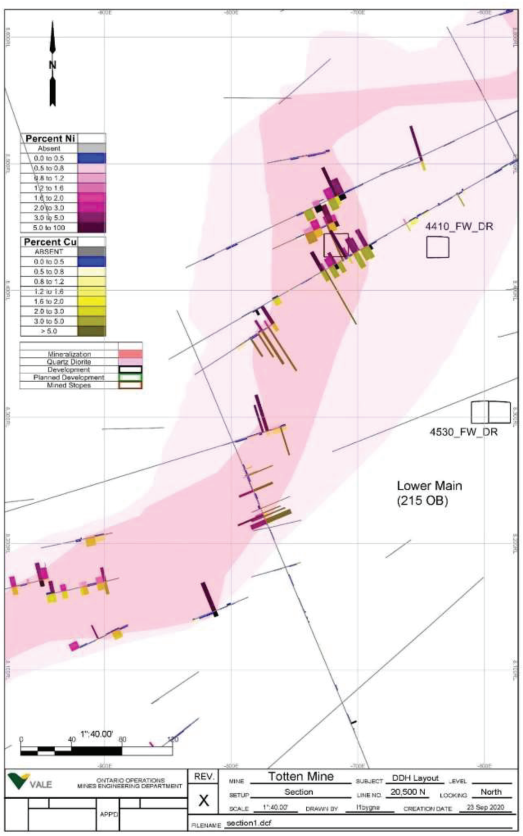


Figure 6-28: Example Cross-Section, Totten (21,700 N)

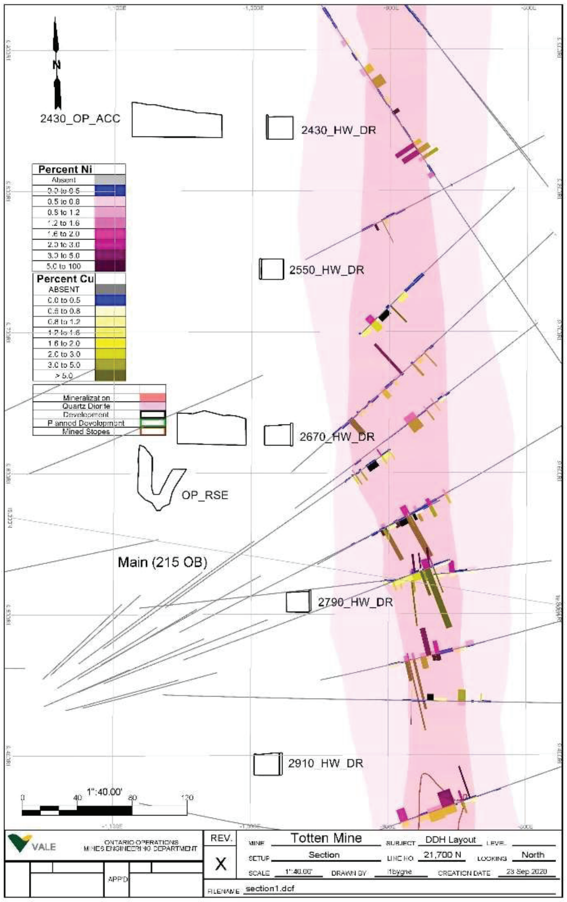


Table 6-10: Dimensions, Victor Orebodies

Zone/Orebody	Type	Length (m)	Width/Strike (m)		Thickness (m)	
			Average	Range	Average	Range
Victor Main	Contact	1035	120	30–150	20	2–45
Victor 14 N	Footwall	385	215	150–305	20	3–55
Victor 24 N	Footwall	70	120	30–185	10	1–30
Victor 28 N	Footwall	335	305	275–335	20	3–40

Zone/Orebody	Depth From/To (m)	Dip (º)	Plunge (º)
Victor Main	1,310–1,940	50–65	60–65 S
Victor 14 N	2,370–2,690	45–55	50–55 S
Victor 24 N	595–745	60–70	45–50 S
Victor 28 N	2,465–2,680	45–55	50–60 S

6.4.10.4 MINERALIZATION

Three copper–nickel sulphide mineralization types occur:

- Nickel-rich Contact mineralization occurs at the base of the SIC, predominantly hosted by late-granite breccia and lesser amounts of dark norite breccia;
- Fractionated Contact mineralization migrated to the gneissic footwall and Sudbury breccia, typically exploiting planes of structural or lithological weakness form copper-rich footwall deposits;
- Hanging-wall nickel mineralization occurs above the base of the SIC, hosted predominantly in norite breccia and upper portions of a late-granite breccia (Glencore/Vale – NRS Extension Project, 2020).

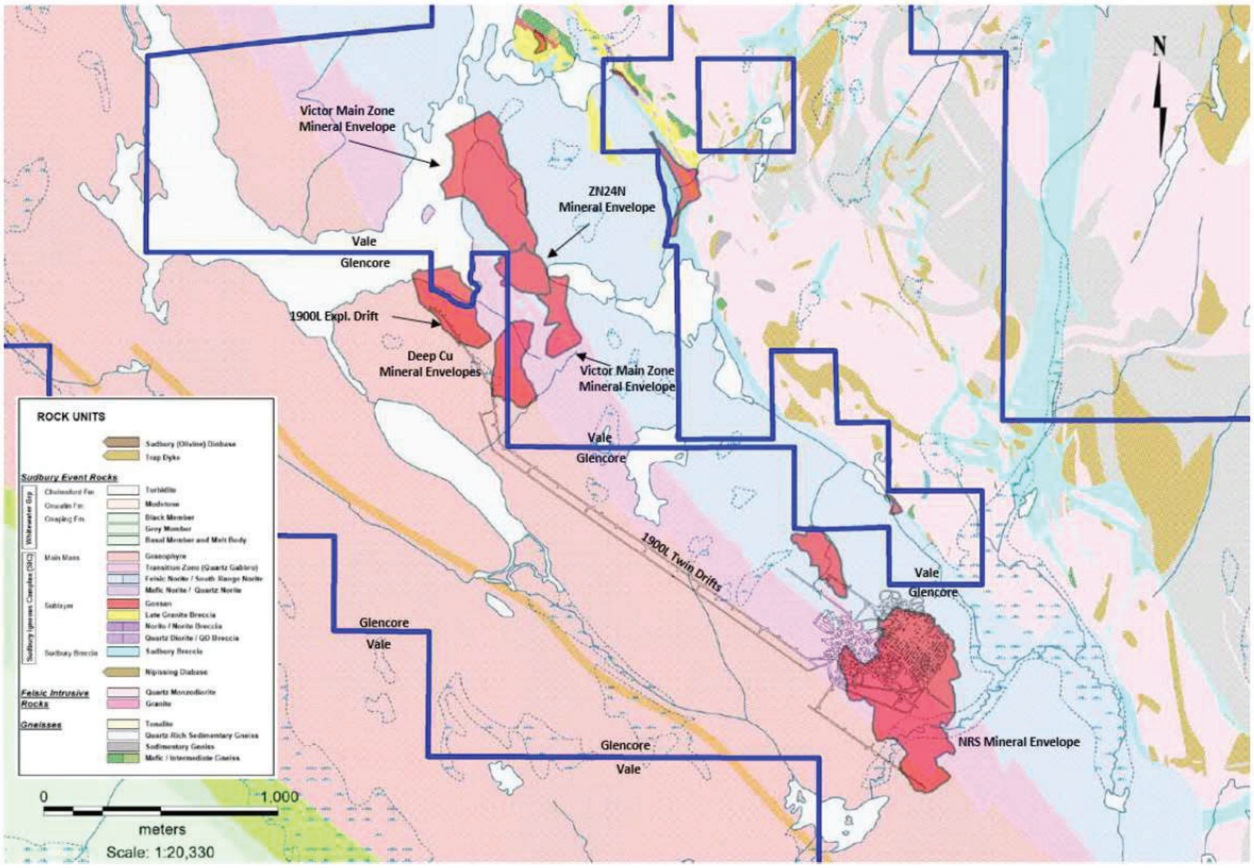
In the Main zone, mineralization consists of massive to disseminated sulphide textures composed predominantly of pyrrhotite with accessory pentlandite and chalcopyrite with trace to patchy pyrite.

The Footwall-style mineralization in the 24 N zone consists of a massive sulphide zone comprising massive chalcopyrite veins and accessory blebby pentlandite and streaks of millerite. The massive sulphide zone transitions into narrow (<10 m) zones of chalcopyrite stringer-stockwork style textures with occurrences of millerite and bornite.

Deep Copper Footwall-style mineralization occurs as variable width stringers / veins forming a stockwork with high rock inclusion content (50 to 70%). The mineralization consists of massive chalcopyrite-cubanite-bornite and chalcopyrite-millerite-pentlandite stringers and vein systems with a highly variable distribution and range in thickness from one inch to several meters.

A geological plan is included as Figure 6-29. Drill sections through the deposits showing the orientation of the drilling to the mineralization, and examples of mineralization grades are provided as Figure 6-30 and Figure 6-31.

Figure 6-29: Geological Plan, Victor–NRS Extension Area



Note: Figure prepared by Vale, 2020.

Figure 6-30: Example Cross Section, Victor (7,500 m east)

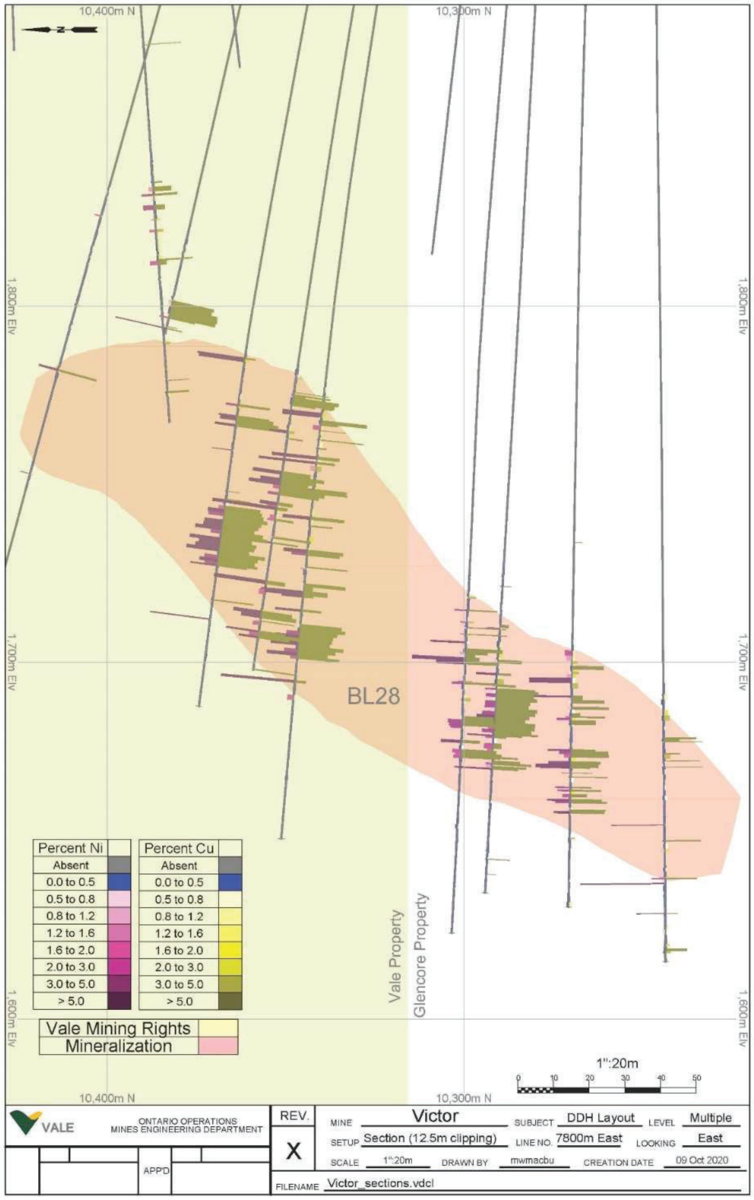
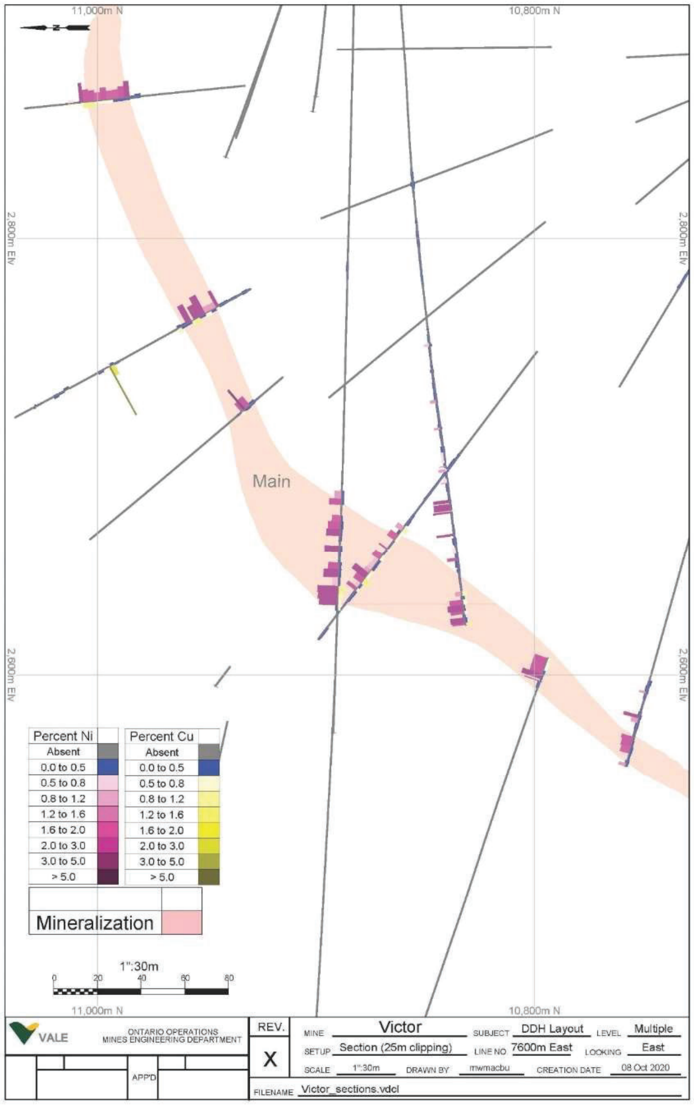


Figure 6-31: Example Cross Section, Victor (7,600 m east)



7 EXPLORATION

7.1 EXPLORATION

7.1.1 GRIDS AND SURVEYS

Each mine has its own mine grid. Survey information is generally collected in Imperial units.

7.1.2 GEOPHYSICS

The primary geophysical exploration methods applied include University of Toronto Electro Magnetometer (UTEM-4), televiewer, radio imaging method (RIM) and down-hole induced polarization (IP). These methods are used to identify areas of sulphide mineralization and to delineate targets for exploration drilling.

UTEM-4 is a geophysical tool that is good at defining massive sulphide conductors. Depending on the presence of conductive material, UTEM-4 can locate targets beyond and between boreholes. Imaging, modelling and inversion methods are applied to these data to generate estimates of the location and attitude of the boundaries of sulphide mineralization.

A televiewer is an in-the-hole device that records an optical image of the walls of the drill hole and provides true three-dimensional orientations of contacts and planar features.

The RIM system generates a cross-section profile of conductivity variation between two parallel drill holes of comparable lengths.

Down-hole IP methods are deployed in areas with mineralization occurring as disseminated, ragged disseminated or interstitial sulphides.

The application of cosmic-ray muon tomography, a new technique for the Sudbury Basin is planned. This newer technology uses detectors, imaging, inversion technologies, and artificial intelligence to map the intensity of cosmic-ray muons under the earth's surface. From this information three-dimensional shapes can be derived and used as exploration vectors.

7.1.3 QUALIFIED PERSON'S INTERPRETATION OF THE EXPLORATION INFORMATION

The Sudbury Basin has been extensively explored for over 100 years, and a considerable information database has developed as a result of both exploration and mining activities.

The primary exploration method is core drilling and assay collection. However, advancements in geophysics, in particular, borehole geophysical surveys, have improved the amount and quality of data that can be used for geological interpretations and geological modelling. The geophysical information is integrated with the drill hole database to improve deposit model interpretations.

7.1.4 EXPLORATION POTENTIAL

The Ontario Operations continue to actively explore within the current mining operations. Areas that are planned to be drill tested include:

- Coleman: two targets generated from machine-learning, including a copper target located below the 170 orebody, and a nickel target below the Main orebody. Other underground targets include the H2 zone, and the 160 orebody. The 148 orebody is planned to be drilled from surface.
- Copper Cliff: depth extents to the 815, 830, 850, 900, 120 orebodies, and mineralization extensions to the north of the 810 orebody and to the west of the Copper Cliff Pit;
- Creighton: mineralization extensions down dip and to the east of the 400, and to the west of the 310 and 300 orebodies;
- Garson: drilling below 5500 level, in 5 Shear East and West, and below 5600 level in 4 Shear West;

- Totten: continue to define the extents/cut offs of Totten main/deep and shelf areas, and the 230 and 238 orebodies.

Exploration is conducted underground from existing infrastructure and services with the aim of discovering and delineating additional mineralization that is within reach of the active mine infrastructure.

Brownfields exploration is focused on areas in the Sudbury basin within a reasonable radius of existing infrastructure. Greenfields exploration is conducted throughout the Ontario Operations area to identify new stand-alone nickel and copper deposits.

7.2 DRILLING

7.2.1 DRILLING ON PROPERTY

Drilling totals 76,778 core drill holes for 12,671,771 m of drilling.

The drilling for areas that have current mineral resource estimates are summarized in Table 7-1 to Table 7-3, by drill hole purpose. Drill collar location plans are provided in Figure 7-1 to Figure 7-10.

The QP notes that due to the historical nature of some of the data, there may be drill holes that have not been captured in the current drill databases. Geotechnical and geomechanical drill holes are included as part of the exploration/resource definition category.

7.2.2 DRILLING EXCLUDED FOR ESTIMATION PURPOSES

Drill data can be excluded if the data are considered questionable, see discussion in Chapter 11.3.

7.2.3 DRILL METHODS

The primary drill method is core drilling. Drill holes are spaced at intervals as required by the type of mineralization and the information required (i.e., exploration or resource definition drilling), with the typical spacing being >100 m for exploration and 10–50 m for resource definition drilling.

Current underground drill programs for exploration and operations purposes typically use a core size of BQ (36.4 mm diameter). Surface programs use NQ size (47.6 mm). AQTK (35 mm diameter) core was used historically.

7.2.4 LOGGING

Standardized logging procedures and software are used to record geological and geotechnical information including lithology, description of mineralization and percentage sulphide content, mineralogy, major structures, rock quality designation (RQD) and rock mass rating (RMR).

7.2.5 RECOVERY

Core recovery is generally good at all deposits. Areas of poor recovery are typically limited to fault and shear zones.

7.2.6 COLLAR SURVEYS

The required azimuth direction of the drill collar layout, for both surface and underground, are identified using front sight and back sights. On surface, global positioning system (GPS) coordinates are used for collar locations, while underground, drill collar locations are measured from survey control points.

7.2.7 DOWN HOLE SURVEYS

The deviation and deflection from changing rock properties and/or lithological units is considered when determining the starting dip angle of a proposed drill hole. As a result, the starting dip and azimuth can be modified based on historical, local drill hole responses to ensure target locations are accurately acquired.

Table 7-1: Drill Summary Table, Blezard, Coleman, Copper Cliff, Creighton

Drill Type	Blezard		Coleman		Copper Cliff		Creighton	
	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)
Exploration	217	85,919	975	409,308	2,531	1,140,222	1,062	421,200
Exploration and resource definition	—	—	3,805	319,100	9,447	1,117,229	5,081	437,632
Infrastructure	—	—	2,495	80,577	1,844	57,189	976	33,031
Unknown	—	—	2,491	341,201	4,873	708,987	8,478	830,466
Glencore/external third party	—	—	9,321	3,508,699	—	—	—	—
Totals	***217***	***85,919***	***19,087***	***4,658,885***	***18,695***	***3,023,628***	***15,597***	***1,722,329***

Table 7-2: Drill Summary Table, Garson, McConnell, Frood–Stobie, Copper Cliff Pit

Drill Type	Garson		McConnell		Stobie/ Stobie 37 Block		Copper Cliff Pit	
	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)
Exploration	570	114,156	137	37,387	376	56,438	103*	18,411
Exploration and resource definition	4,065	346,844	—	—	1,734	147,600	1,810	275,968
Infrastructure	905	25,324	—	—	447	12,777	—	—
Unknown	5,432	484,754	—	—	3,987	202,217	—	—
Glencore/external third party	—	—	—	—	—	—	—	—
Totals	***10,972***	***971,078***	***137***	***37,387***	***6,544***	***419,031***	***1,913***	***294,379***

Note: * exploration <1935 drill holes

Table 7-3: Drill Summary Table, Totten, Victor

Drill Type	Totten		NRS Extension (Victor)	
	Number of Drill Holes	Metres (m)	Number of Drill Holes	Metres (m)
Exploration	891	378,481	424	419,705
Exploration and resource definition	1,083	195,277	79	48,435
Infrastructure	195	11,058	—	—
Unknown	272	40,651	—	—
Glencore/external third party	—	—	—	—
Totals	***2,441***	***625,467***	***503***	***468,140***

Figure 7-1: Drill Collar Location Plan, Blezard

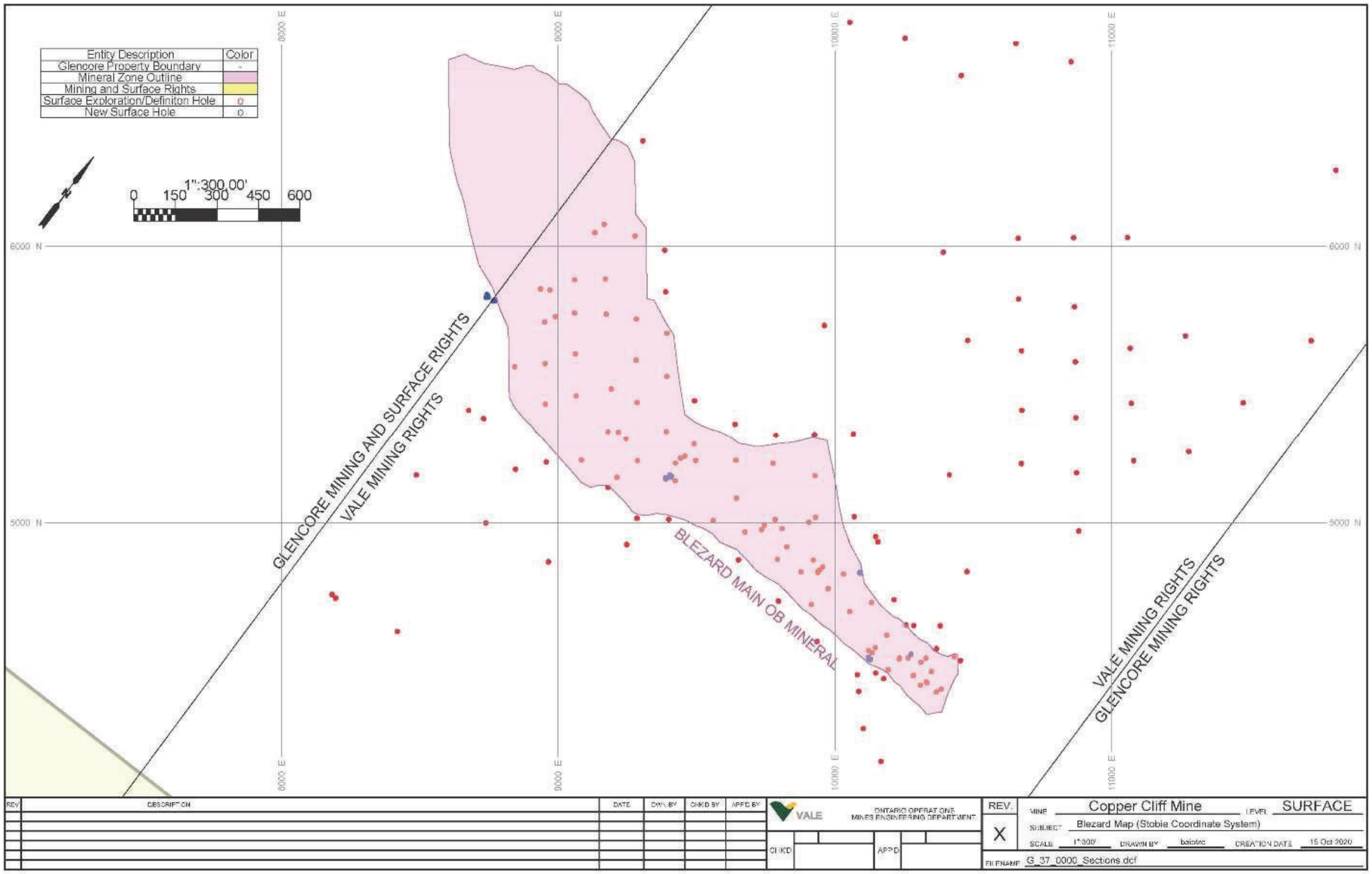


Figure 7-2: Drill Collar Location Plan, Coleman

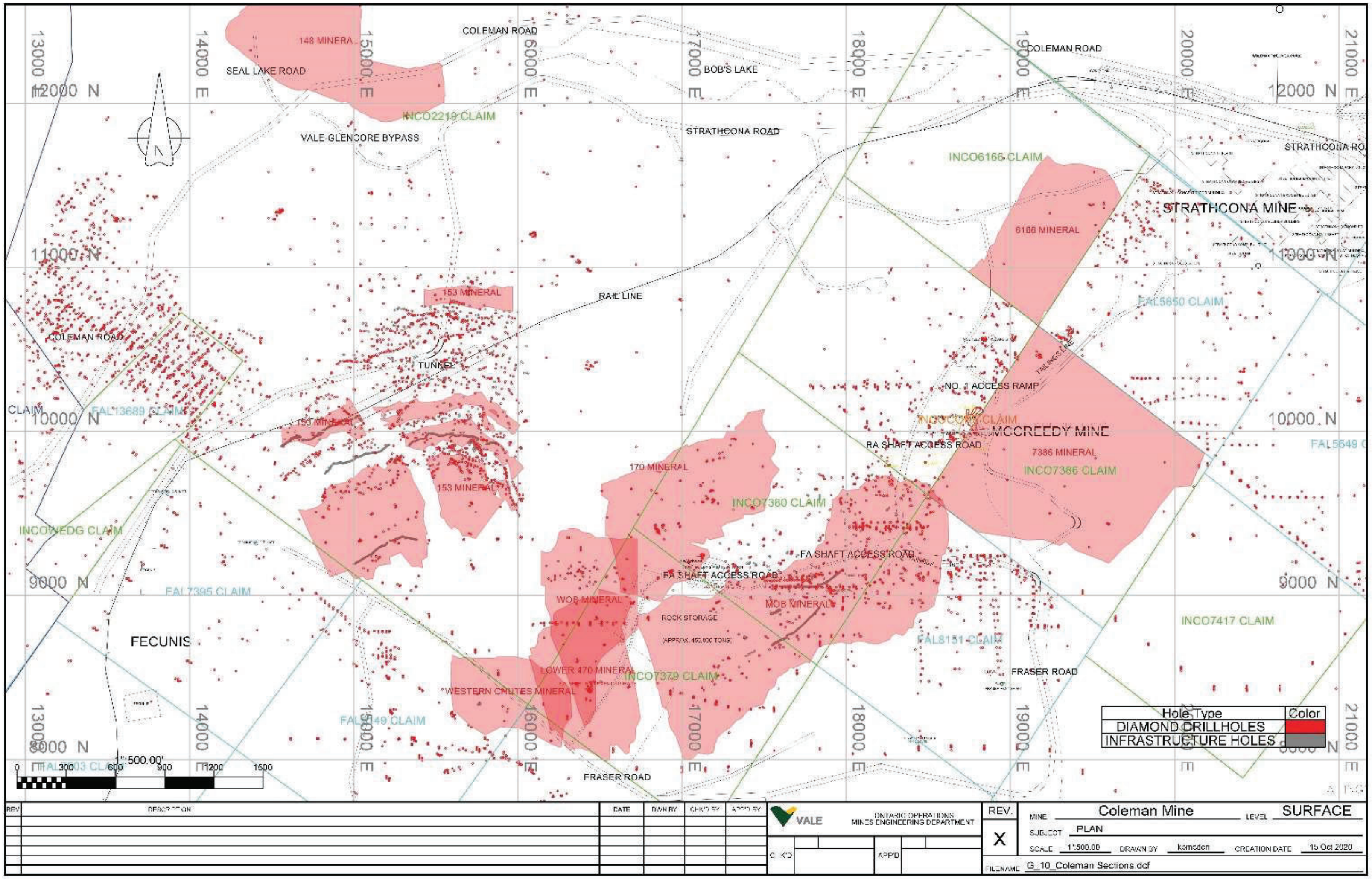


Figure 7-3: Drill Collar Location Plan, Copper Cliff

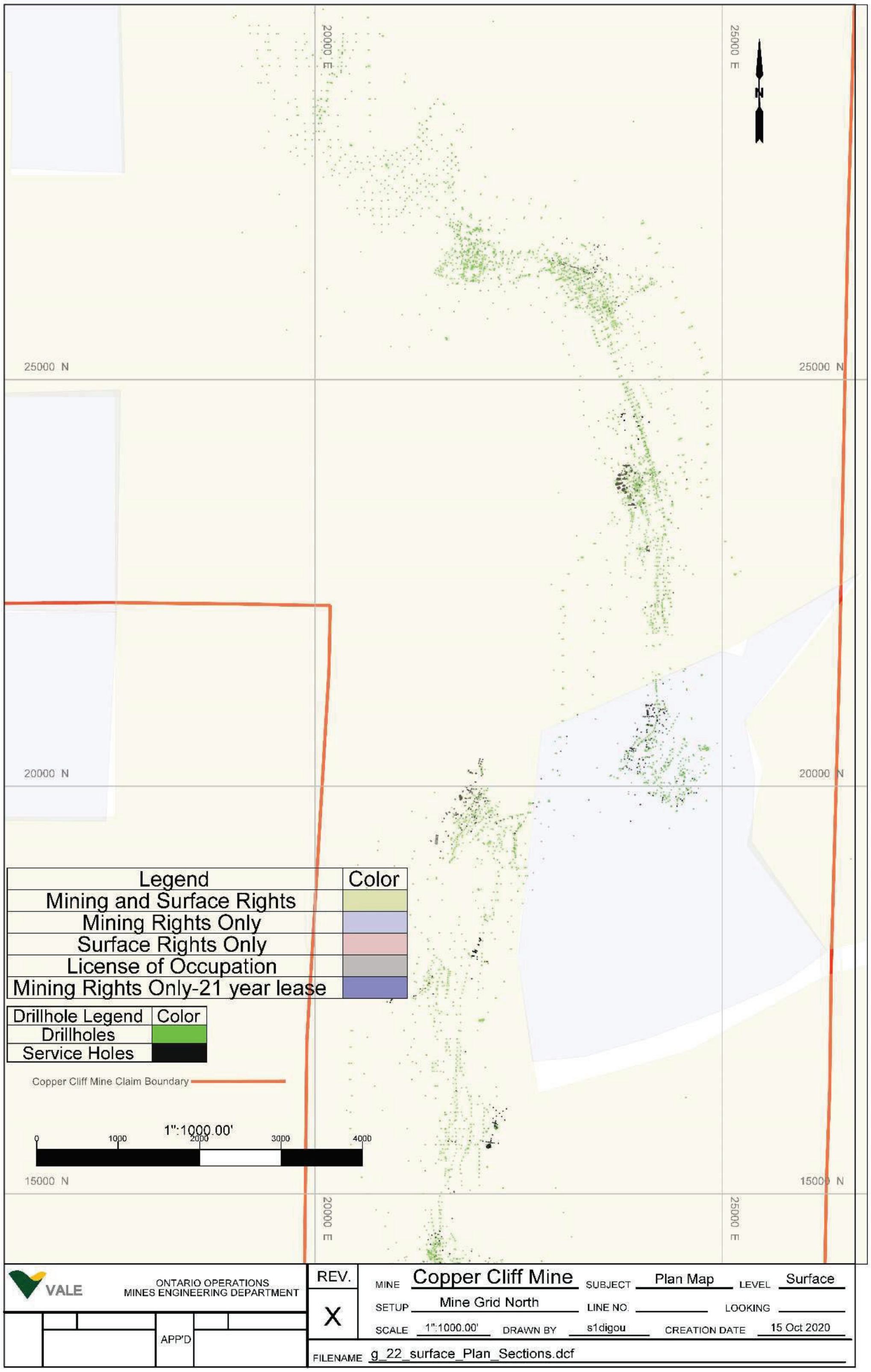


Figure 7-4: Drill Collar Location Plan, Creighton

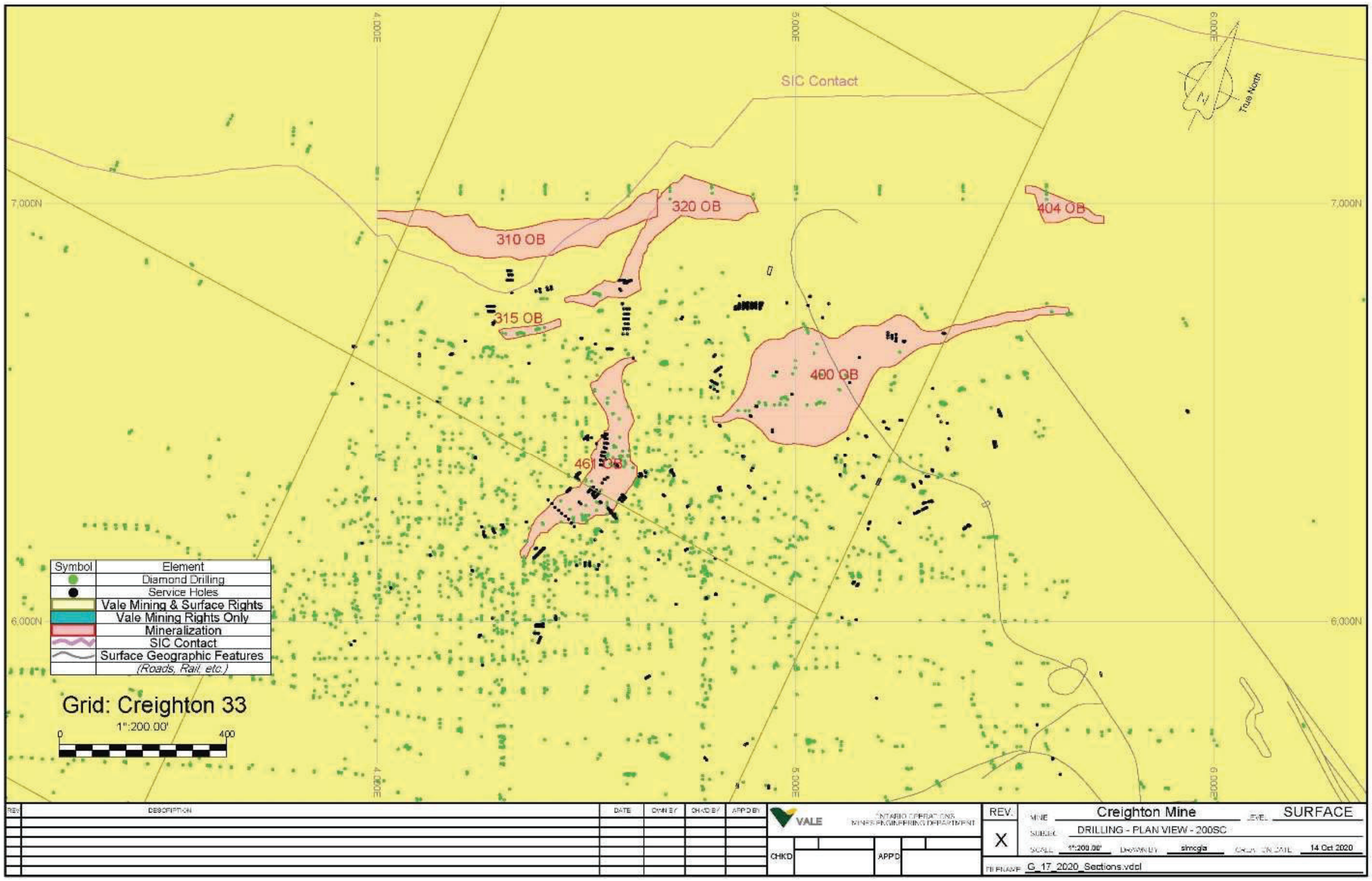


Figure 7-5: Drill Collar Location Plan, Frood–Stobie Block 37

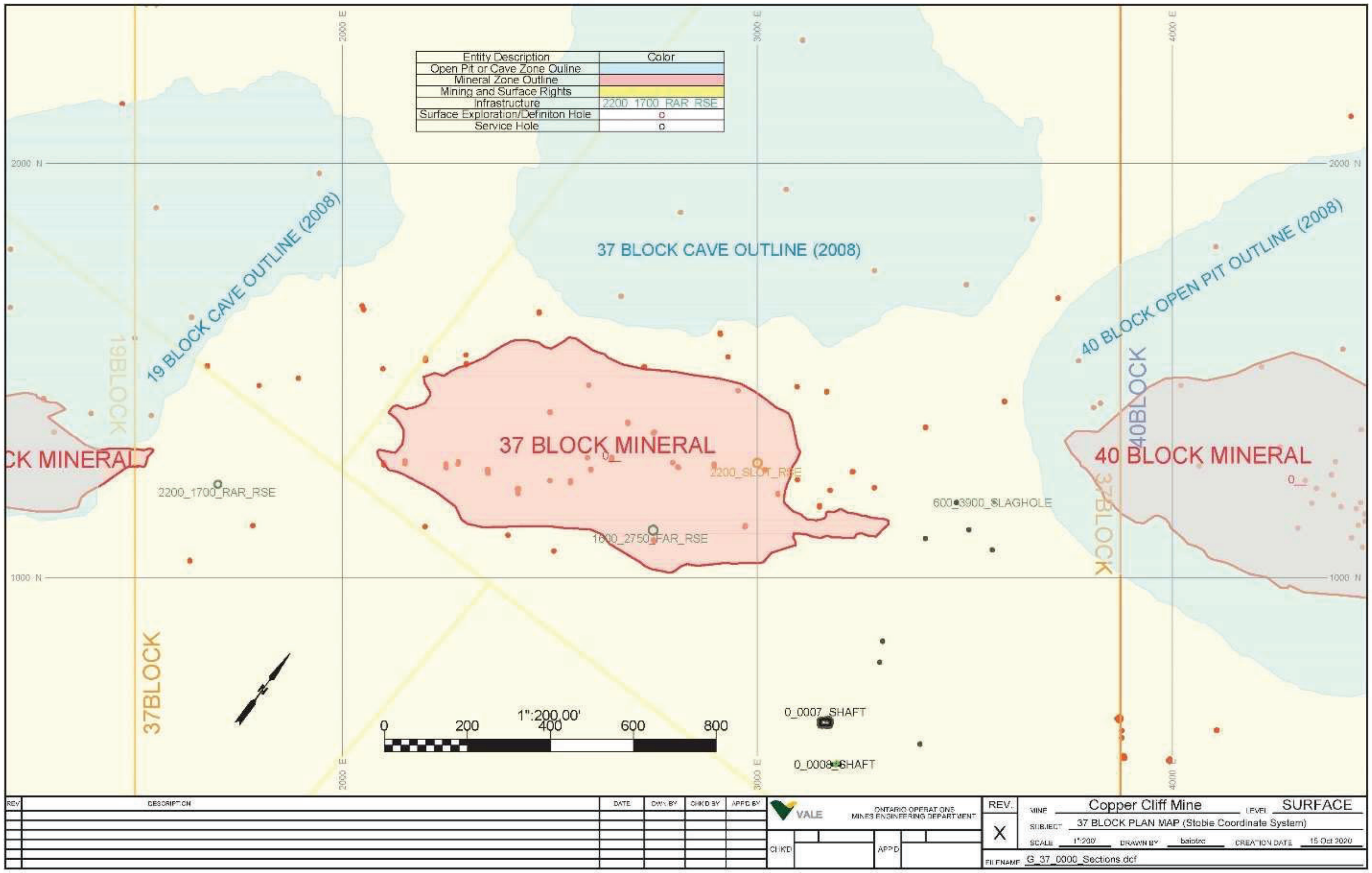


Figure 7-6: Drill Collar Location Plan, Garson

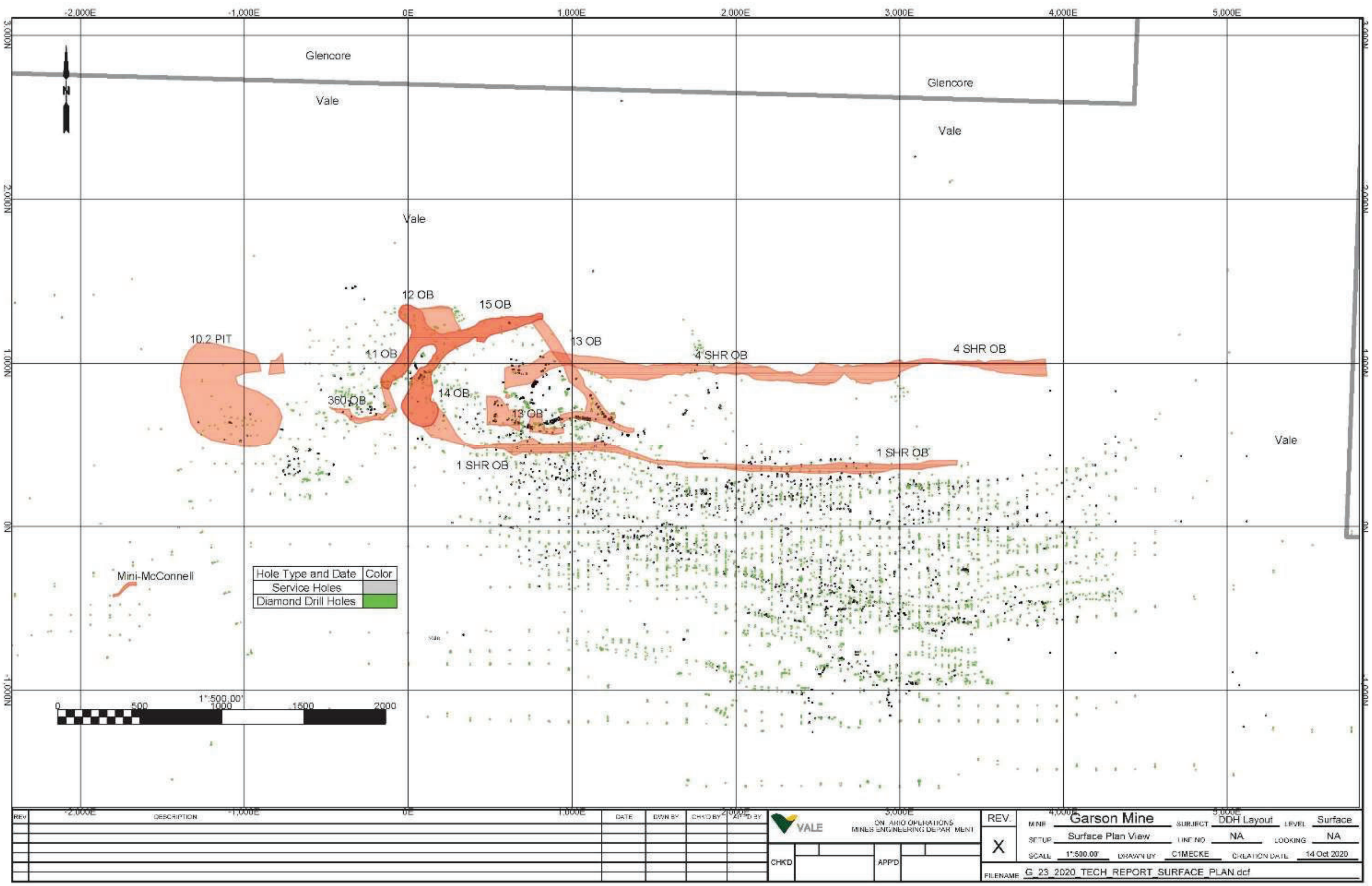


Figure 7-7: Drill Collar Location Plan, McConnell

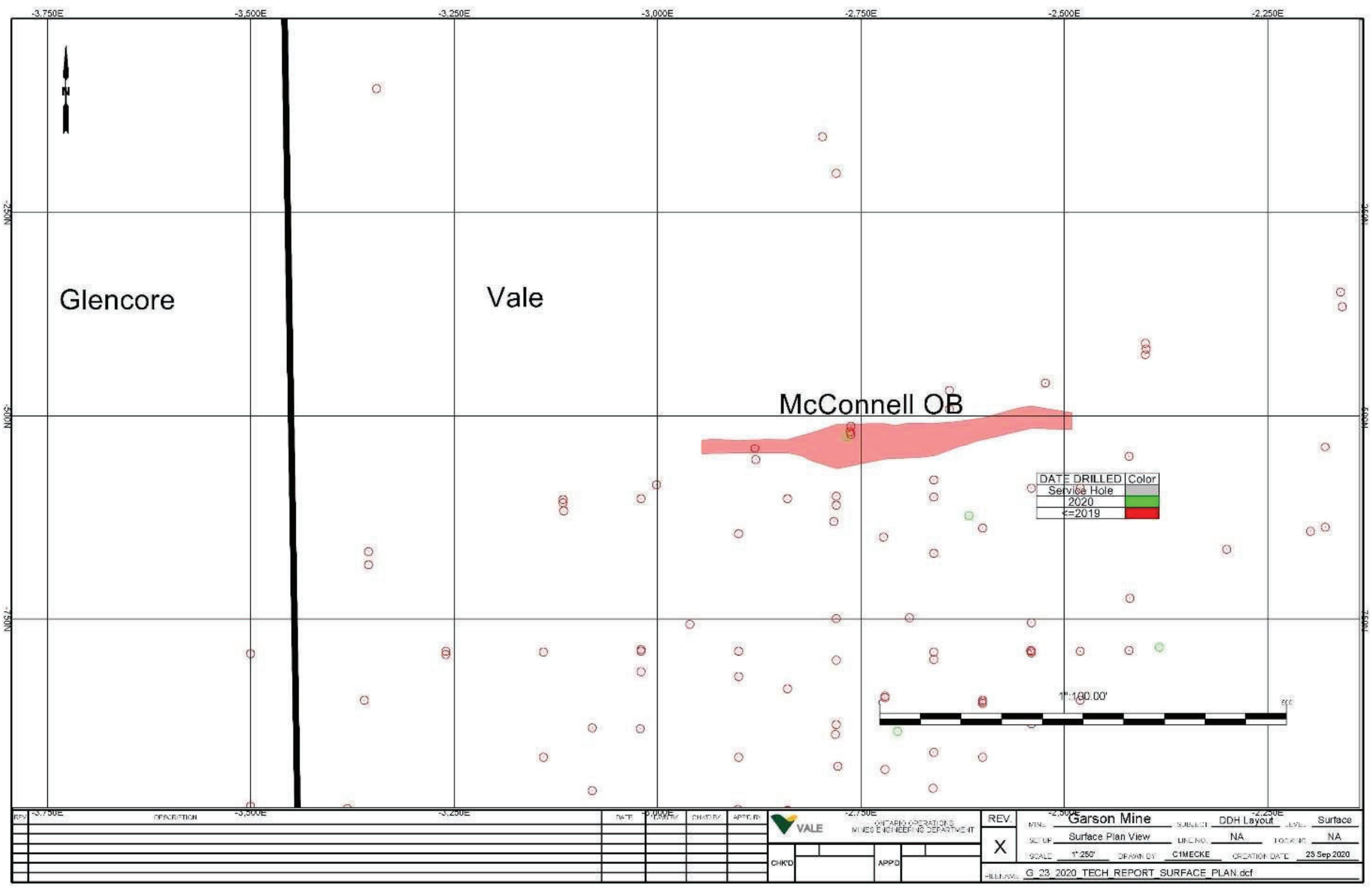


Figure 7-8: Drill Collar Location Plan, Copper Cliff Pit

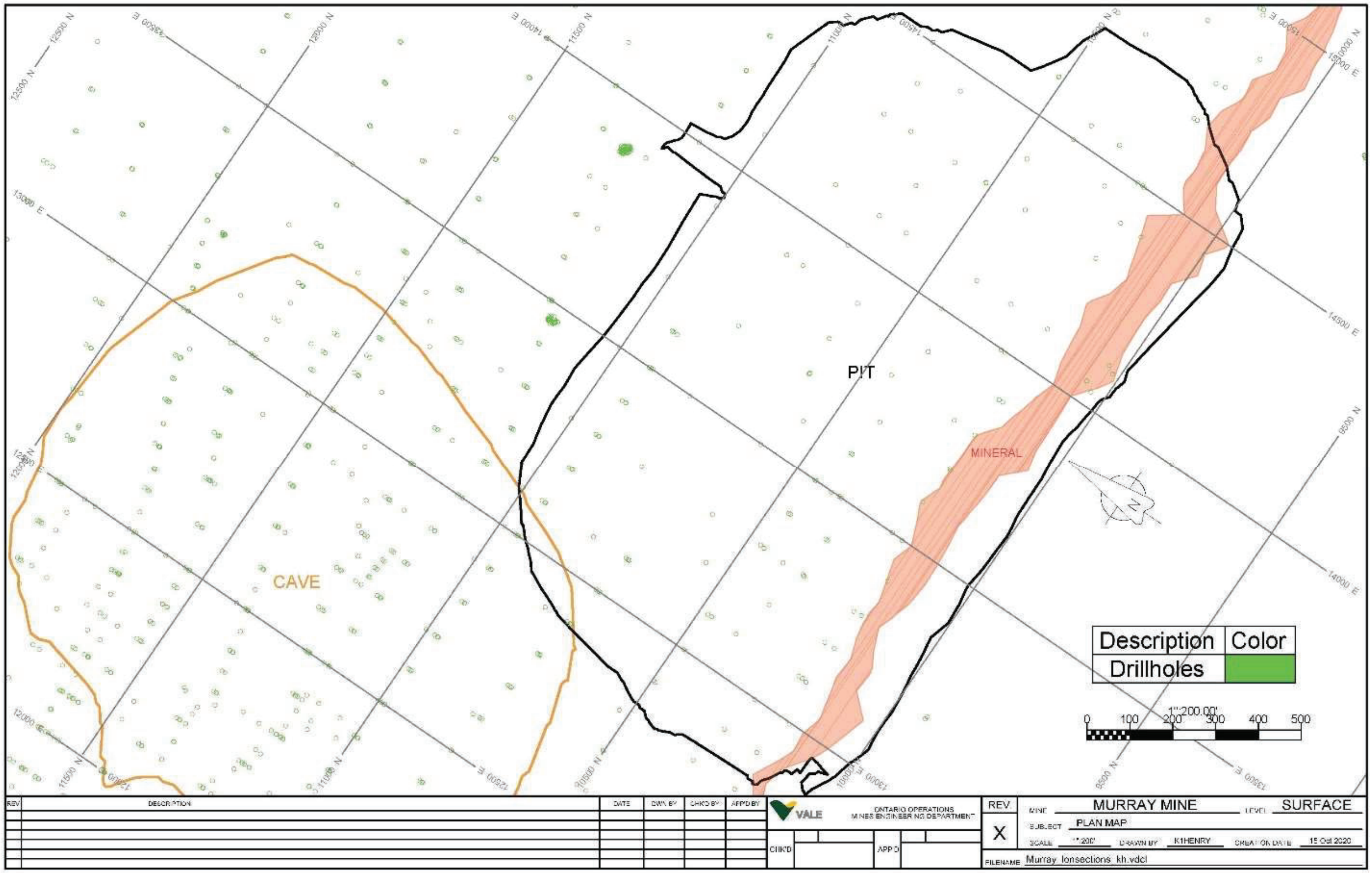


Figure 7-9: Drill Collar Location Plan, Totten

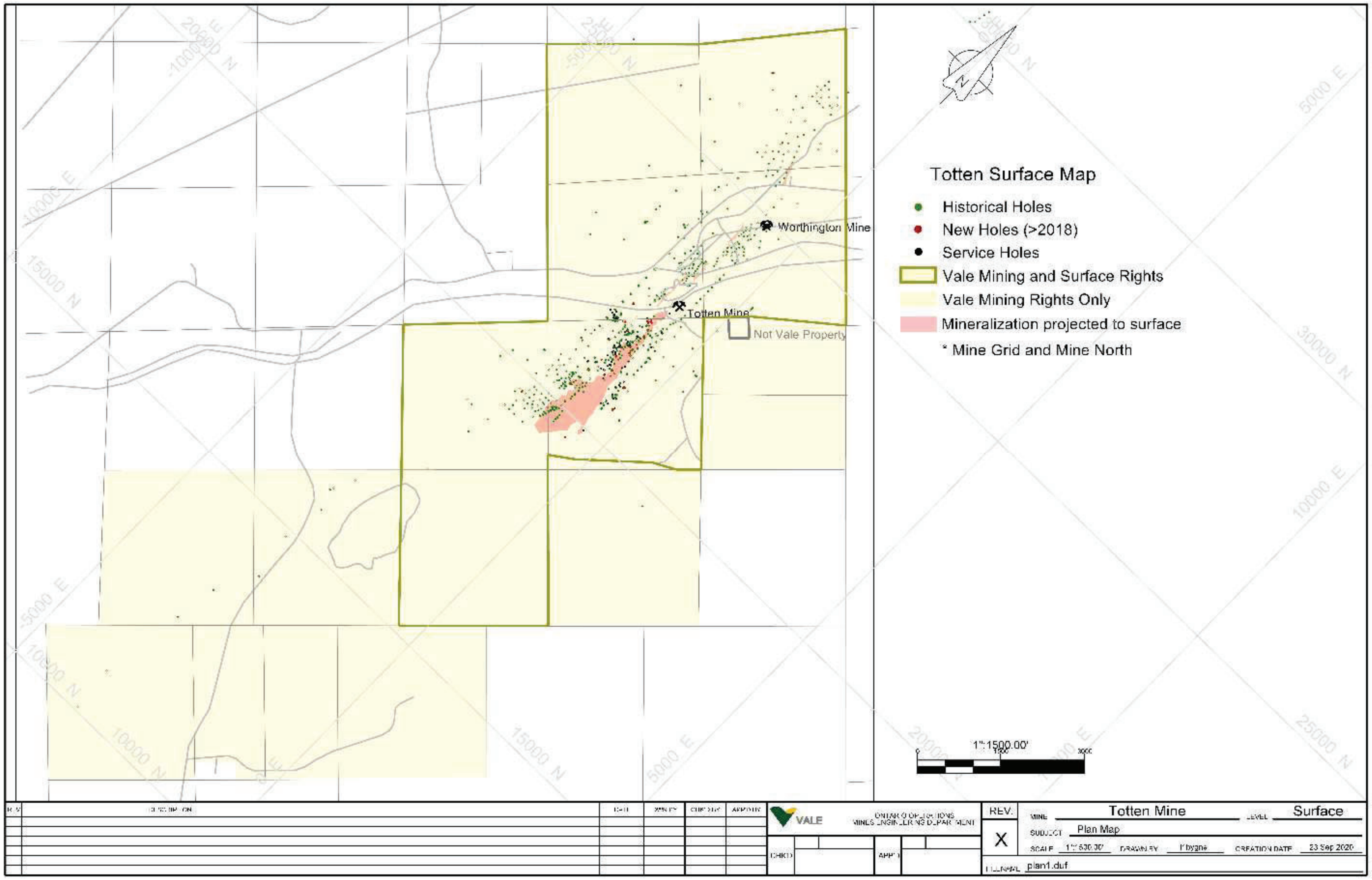
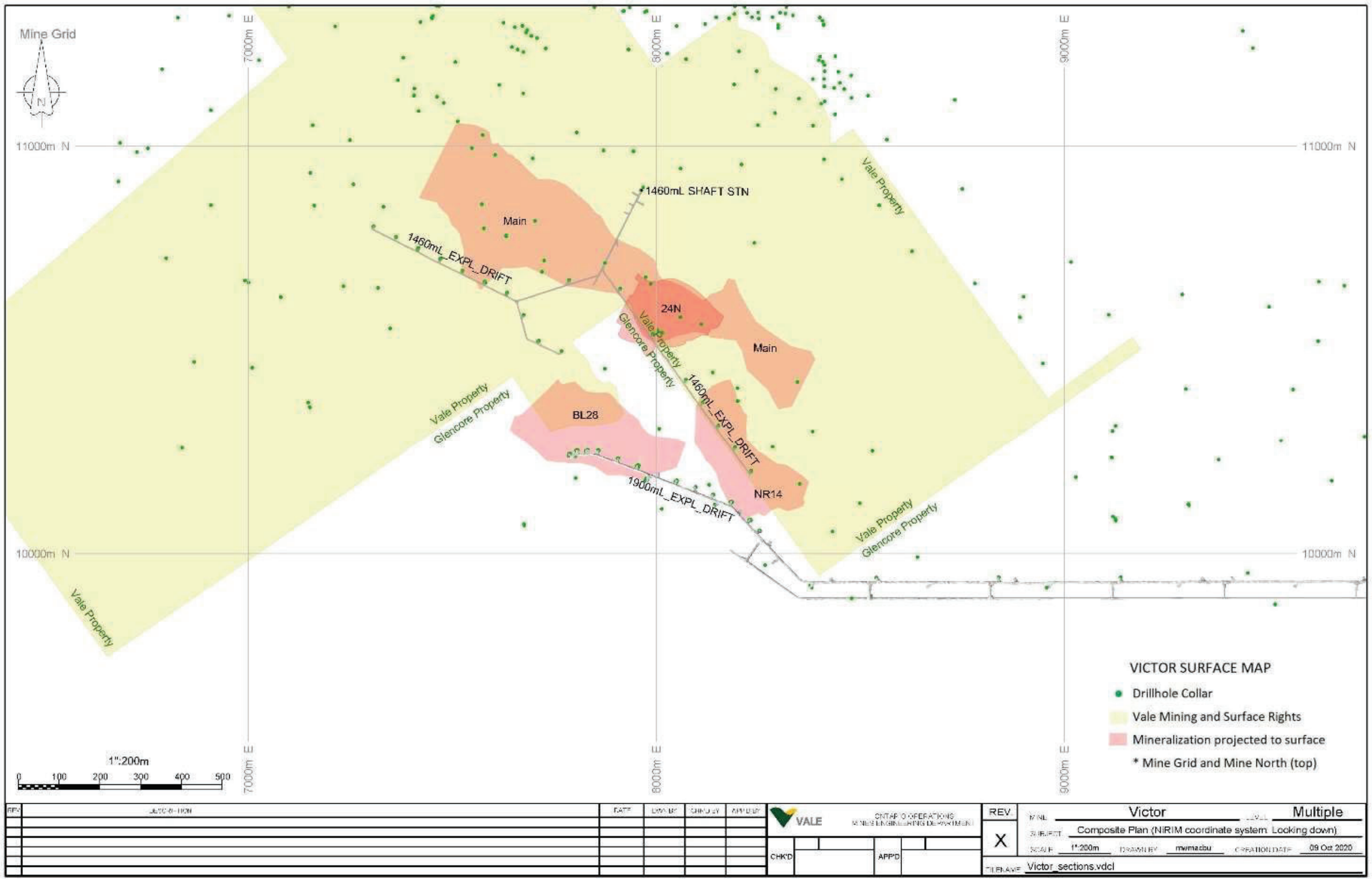


Figure 7-10: Drill Collar Location Plan, Victor



Currently, the trajectory of all surface holes and many of the underground holes are surveyed using multi-shot gyroscopic orientation tools. Non-magnetically susceptible instruments (e.g., north-seeking gyro) are conventional for exploration holes. Shorter definition holes typically use single shot and/or multi-shot surveys using tools such as FlexIt and VisionR. These tools are influenced by magnetic properties; therefore, azimuth data are calculated rather than measured.

Pre-2009 borehole dip measurements were taken using an acid tube test. Historical boreholes are occasionally resurveyed using a gyroscopic instrument for trajectory verification.

7.2.8 COMMENT ON MATERIAL RESULTS AND INTERPRETATION

Drilling and surveying were conducted in accordance with industry-standard practices at the time the drilling as performed and provide suitable coverage of the zones of copper–nickel 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.

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

7.3 HYDROGEOLOGY

7.3.1 INTRODUCTION

Information obtained during early-stage hydrological and hydrogeological evaluations is superseded by data obtained from many years of mining activities. Vale has undertaken regular water sampling since 1999, and initiated hydrological studies and water monitoring protocols to allow the provincial authorities to grant permits to take water.

Groundwater models were prepared using industry-standard water modelling software, such as Modflow, in support of permits to take water. The hilly topography in the Sudbury regional area creates numerous complex groundwater subsystems. Water entering a flow system in each recharge area may be discharged in the nearest topographic low or it may be transmitted to the regional discharge area in the bottom of a major valley. The dominant discharge is to the Vermilion River system in the central and northern portions of the Sudbury area, and to the Whitefish River system in the southern portion.

7.3.2 SAMPLING METHODS AND LABORATORY DETERMINATIONS

Monitoring is currently conducted at approximately 1,700 water wells and about 400 surface stations, located throughout the Ontario Operations area. Well and surface station numbers vary through time, because wells can be damaged or decommissioned, or new wells were installed. The well and surface station sampling schedule is seasonal, with sampling conducted by third-party consultants, BluMetric Environmental Inc. (BluMetric) in the spring and fall (ground and surface water), summer (surface water only). Field parameters such as water levels within the wells, pH, conductivity, temperature and oxidation–reduction potential (ORP) are measured by BluMetric. One field duplicate was collected for every 10 samples, and a blank was inserted for every 20 samples. Water samples are analysed by Testmark Laboratories, in Garson, Ontario (Testmark). Testmark is independent of Vale, and holds ISO170125 accreditation for selected analytical techniques. The following parameters are measured by Testmark: pH, conductivity, alkalinity, hardness, acidity, sulphate, nitrate, nitrite, ammonia, chlorite, dissolved metals (45-element suite), total dissolved solids, total suspended solids (surface water only), and turbidity (surface water only).

Hydrogeology data, including pore pressures and groundwater flow, can be collected during pre-construction studies and later from on-going data collection programs in operating mines. For rock types sensitive to moisture, tests may be conducted to evaluate moisture content and susceptibility to deterioration. Data collected during these programs are integrated into numerical simulations.

Dewatering measures can include advanced development (normally with drain holes) which may later be used for mining purposes, drain holes drilled from existing excavations, or development headings and sumps.

7.3.3 COMMENT ON RESULTS

Well and surface station sampling data are verified prior to upload and stored in a Vale database. The water sample blank and duplicate data are evaluated by Testmark, and results provided to Vale. Regular reports for defined monitoring periods are provided by BluMetric to Vale in which the groundwater quality is compared to Table 2 (potable water) and Table 3 (non-potable water) of the Site Condition Standards under Ontario Regulation 153/04. Vale documents the findings to the provincial government as required to meet monitoring and regulatory reporting obligations.

BluMetric observed that the impacts of dewatering around Vale mines in the Sudbury Basin are typically limited to within a few hundred metres of the actual mine workings.

The underground mines are relatively dry, with only small groundwater inflows. Most of the water that needs to be pumped from the mines enters as fresh process water, or as contained moisture in the backfill slurry.

Water entering the mines from precipitation is minimal, except for the Copper Cliff and Creighton Mines. These mines have open pits or cave areas that are connected to the underlying working areas. They have been in operation for many years, and have developed systems and procedures to handle inflows from these areas. The Stobie Mine, which is on care-and-maintenance, is being allowed to flood. While some short-term disruptions to production may occur from large precipitation events, as of the Report date these had not resulted in long-term disruptions.

7.4 GEOTECHNICAL

7.4.1 OVERVIEW

Geotechnical core logging and laboratory strength testing activities start during early-stage exploration and feasibility studies. Data collection continues once mines are operating in conjunction with definition drilling and expansion projects. This information is used as the basis for empirical, analytical, and numerical analyses to support mine design activities.

7.4.2 SAMPLING METHODS

Geotechnical core logging and geotechnical field mapping are the principal data collection methods. Currently, information is directly logged into databases at the core logging facilities. If surface access (e.g., open pit) or underground access (e.g., mine workings) is available, then the geotechnical core logging results may be confirmed or supplemented with field geotechnical mapping of broader exposures.

Typical data collected from core logging and mapping programs are intended to establish both the intact and the rockmass strengths of various lithological/geotechnical domains. Intact strength parameters are derived during geotechnical core logging using point load test machines and are validated with additional samples sent out for laboratory testing.

The rockmass quality is assessed using well established characterisation systems, primarily the Q system (Barton et al., 1974), RMR (Bieniawski, 1974 and Laubscher, 1990). Data collected may include parameters such as RQD (Deere, 1968), joint frequency, number of joint sets, joint roughness, joint alteration, joint in-filling, persistence, point load tests, rock mass fabric characterization and information on discrete structural features.

Typical structural characterization consists of documenting joint sets (including bedding, foliation), faults, shear zones, and dykes via non-oriented core, acoustic and optical televiewer surveys, and field mapping. Data collected can include observations such as dip, dip direction, spacing, and persistence.

In the deep mines, well-known indicators related to the field stresses are documented using observations such as core disking and borehole breakouts. Such observations are proven indicators that help to identify zones of high stress within the rock mass. Back analyses using microseismic data and numerical models can be undertaken to help establish confidence in forward looking stress models that are used to evaluate mine designs.

In active operations, data collection includes inspection of each active heading on at least a monthly basis, and one of the objectives of these inspections is to determine whether the support system installed is appropriate for the ground conditions. Underground site visit observations are recorded in a ground control logbook.

Microseismic arrays are deployed at all of the seismically active mines in Ontario to locate seismic events underground, and consist of a mix of uniaxial and triaxial sensors and geophones. In addition, a strong ground motion system is installed which picks up major seismic events.

Falls of ground, rockbursts, unusual seismicity, ground support failure, and significant changes in ground conditions are classified as ground control unusual occurrences, and data relating to the unusual occurrence are collected as a record.

Backfill materials are tested to measure the unconfined compressive strength of samples, which are taken at the discharge point and the preparation plant. Where appropriate, other data collected may include slump tests, the temperature of the prepared samples, and water content of the solid material.

Cemented rock fill or cemented aggregate fill is also tested to evaluate the UCS of samples taken at discharge point. Moisture contents, the particle size distributions of aggregates or waste rock are also evaluated.

A backfill quality control program was implemented at each of the operating mines using backfill.

A range of monitoring instrumentation including extensometers, either single-point or multi-point units, closure stations, and sloughmeters can be used to monitor displacements. A slope stability radar is also strategically deployed at one of the legacy open pits to monitor potential slope movements in real time. Loading devices, including stress cells, can be strategically installed to understand load/stress conditions of rock mass and/or ground support system. Drones can be used to assist with visual inspections and also allow for LiDAR surveys to be carried out in areas that were previously not accessible due to high worker exposure to hazardous areas.

7.4.3 LABORATORY DETERMINATIONS

Geotechnical testing, typically comprising Young's modulus (or Elastic Modulus), Poisson's ratio, and unconfined compressive strength tests, is currently performed at Golder's Burnaby, British Columbia rock mechanics laboratory (Golder Burnaby). The laboratory may be requested to perform point load index, triaxial compressive strength, Brazilian tensile tests or direct shear tests in specific instances. Golder Burnaby is independent of Vale. Historically, independent laboratories used for geotechnical work have included the Queen's University Rock Mechanics Laboratory (Kingston), Laurentian University (Sudbury) and Wood (Mississauga). The laboratories are not accredited for geotechnical testwork; this is typical for the industry.

Golder Burnaby uses the methodologies set out in ASTM D7012-14: Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures.

All laboratories, including laboratories currently used by Vale, and proposed to be used by Vale in the future, must meet ASTM testing standards.

7.4.4 QUALITY ASSURANCE AND QUALITY CONTROL

The quality assurance in place at Golder Burnaby includes regular equipment calibration, accredited by Cal-Check Canada Inc, a third-party calibration inspection facility. Depending on the testing type, the quality program undertaken at Golder Burnaby may include senior peer reviews or auditing of laboratory and office procedures, to ensure that all information and recommendations are consistent.

There is a formal Ground Support Quality Control Program, and local ground control personnel manage this program at the individual mine sites. The Ground Support Quality Control Program includes review of contractual agreements with suppliers regarding specifications of support products and how these specifications are checked and assured. It also incorporates actions to be taken if material test results do not conform to the required specifications, the quantity and types of tests for the various support systems installed, delivery and storage practice of support products, how these products are protected against damage, quality control programs for shotcrete and backfill including information on types of testing, testing frequency and correction measures if the results are not within the design range, and by whom and how often task observations and inspections are conducted, and whether records of these observations and inspections are kept on file.

In addition to regular testing of the backfill materials, system audits, instrument calibration and test data analysis are part of the backfill/cemented rock fill/cemented aggregate fill quality control program.

7.4.5 COMMENT ON RESULTS

A combination of historical and current data, together with mining experience, are used to establish ground support designs for different geotechnical conditions.

Analytical methods are used to evaluate structural behaviour of the rock mass. Classic static load factor-of-safety calculations (load demand versus support capacity) are employed in situations requiring site-specific discrete analysis.

Empirical designs use data collected on the past performance of the rockmass during mining activities. These data are also used in numerical model calibrations.

Numerical models are constructed to calculate the induced stress levels around mined-out openings. The models incorporate multi-disciplinary data including the mine’s geology, rock mass properties and production sequence. Through comparison of the model forecasts with the resultant stability performance and mine seismicity record, modelling input parameters are refined and used to provide future stress/instability forecasts. The models are routinely used as part of the economic evaluation cycle to evaluate the stability of a mine design option and help minimize risk, particularly in seismically-active mines.

These data and mining experience support the geotechnical recommendations that support the mine plans discussed in Chapter 13 of this Report.

8 SAMPLE PREPARATION, ANALYSES, AND SECURITY

8.1 OVERVIEW

Vale has corporate governance procedures in place in support of data collected that supports mineral resource and mineral reserve estimation.

Each operation has documented protocols and internal controls for drilling, sampling, sample preparation and assaying procedures that were approved by Vale's Resource Management Group. Documentation of the protocols is maintained as current, and personnel receive adequate training to apply them. All data are properly identified by unique reference numbers so that drill hole information can be reliably reconstituted from independent collar, survey, geology, physical properties and assay tables. All data are verified and checked prior to 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 contracted by the Ontario Operations are confirmed by periodic reviews and/or audits. The database contains all relevant information for use in mineral resource and mineral reserve estimation. The database used in estimation contains unbiased and representative data, and any major issues identified by QA/QC programs have appropriate corrective actions applied and disclosed.

Given the longevity of the Ontario Operations, sample preparation, analytical, QA/QC, database upload and verification, and sample security methods varied over time. The material procedures and protocols are presented in the following sub-sections by operator.

8.2 SAMPLING METHODS

Drill core is visually examined for mineralization distribution. High and low-grade intervals are identified as separate samples. Continuous samples are collected through the entire mineralized zone with barren samples taken to bracket the mineralized zone on either side. Non-mineralized inclusions within the zone are also sampled to allow proper statistical evaluations of mineral distribution to be performed. Care is taken to ensure that mineralization from the high-grade sample intervals is not included in the low-grade sample intervals.

The sampling interval is established by minimum or maximum sampling lengths and geological and/or structural criteria. The minimum sampling length is 15 cm while the maximum is 3 m. The typical sample length in the Contact-style massive sulphide zones is 1.5 m. In the Footwall-style copper zones, a 0.3 m sampling length is typical due to the presence of narrow, massive chalcopyrite veins. Samples of barren rock bracketing the mineralized zone are 1.5 m in length, regardless of zone they are bracketing.

The core from underground drilling is typically sampled in its entirety. Surface exploration programs split most mineralized intersections and store half of the core. Representative samples of each mineralized intersection are taken for future reference. One sample is taken for every 3 m of core or when the lithology changes. These "rep" samples are typically 10–15 cm in length and are not assayed. They are boxed in core trays, labelled, and shipped to the Copper Cliff Mine core farm area for storage. The remaining unsampled core is discarded.

8.3 SAMPLE SECURITY METHODS

Drill core is boxed and secured at the drill site with fibre tape. Core boxes are transported by Ontario Operations' employees to surface and then stored on site before transport by courier to the Copper Cliff core logging facility where they are stored until logged. Both storage areas are monitored by security cameras and personnel 24 hr/day.

Coarse and pulp reject material from the underground drill core samples is stored at the sample preparation laboratory in Sudbury until all required checks and the assay verification is complete (typically for a period of up to one year) after which it is discarded. Pulp reject material from surface exploration drill core samples is stored at the sample preparation laboratory in Sudbury for a period of one year after which the pulps are returned for permanent storage, while the corresponding coarse reject material is disposed of after the analytical data verification.

Skeletonized core from exploration drill holes is stored in core farms located at Copper Cliff Mine and at the former Little Stobie Mine.

8.4 DENSITY DETERMINATIONS

Density was estimated based on a multivariate regression of nickel, copper, and sulphur data which can be approximated using the following formula:

- Density = 100 ÷ (100 ÷ 2.88 + 0.0166 x Cu - 0.1077 x Ni - 0.328 x S).

Density data were reported using US customary tons per cubic foot (ton/ft^3). Values ranged from a minimum of 0.0874 ton/ft^3 to a maximum of 0.156 ton/ft^3, with averages ranging from 0.097–0.107 ton/ft^3.

Where sulphur data were not available, a nickel, copper, and cobalt regression was used.

Corrections to density values were also made if the data were collected prior to 1975, which assumed that of the nickel, cobalt and sulphur analytical data from that time period, the nickel data were the most likely to be accurate given the analytical methods and detection limits in place at the time. An example of a correction regression formula is:

- Density = (100 ÷ (100 ÷ 2.88 + 0.0166 x Cu - 0.1077 x Ni - 0.328 x S)) ÷ 32.05.

The estimated density values were periodically checked by comparing with water immersion specific gravity (SG) measurements collected during logging and sampling. The water immersion measurements were guided by a written procedure. A comparative analysis between the measured SG and estimated density for different lithological units and mineralization types was typically completed before block model creation at the exploratory data analysis stage.

8.5 ANALYTICAL AND TEST LABORATORIES

The analytical and test laboratories used for data that supports the mineral resource and mineral reserve estimates are summarized in Table 8-1. Except for the Inco Field Exploration laboratory, the Ontario Operations mine laboratory, and the Vale Technical Development (Canada) Limited laboratory, all laboratories that were used for sample preparation and analysis since 1999 were independent of Inco and Vale.

8.6 SAMPLE PREPARATION

8.6.1 INCO

Inco diamond drill core samples were crushed in their entirety with a combination of different size jaw crushers to 75% -10 mesh. In some instances, a cone crusher was used after a coarse crush on the jaw crusher. A sample of ~150 g was split for pulverization to obtain a pulp of 95% passing 200 mesh.

8.6.2 VALE

The sample preparation procedure is to crush to a minimum of 70% passing 10 mesh (2 mm), followed by pulverizing to 85% passing 200 mesh (0.074 mm).

Table 8-1: Analytical and Test Laboratories, Ontario Operations

Laboratory Name	Year	Accreditation	Purpose	Note
Ontario Operations mine laboratory (Central Process Technology laboratory), Copper Cliff, ON	Prior to 1999 (mostly pre 1970)	Not accredited	Sample preparation and analysis.	
Inco's Field Exploration (ITSL) Laboratory, Copper Cliff, ON	Prior to 1999 (mostly 1971-1998)	Not accredited	Sample preparation and analysis.	
ALS Geochemistry, Mississauga, ON/Vancouver, BC	1999–2005	ISO 9001: 2000	Primary sample preparation	
ALS Geochemistry, Sudbury, ON	2005 to date	ISO 9001: 2008 (until mid-2014) ISO/IEC 17025:2005/2017 (after mid-2014)	Primary sample preparation	The sample preparation procedures adhere to a protocol designed for all operating mines in the Ontario Operations.
ALS Geochemistry, Vancouver, BC	1999 to date	ISO 9001:2000 (until 2005) ISO/IEC 17025:2005/2017	Primary analytical laboratory	Used for assaying of all Ontario Operations samples.
Central Process Technology laboratory, Copper Cliff, ON	1999-2005	ISO/IEC 17025:2005	Secondary analytical laboratory	A representative portion of the samples analyzed by ALS Vancouver re-assayed.
SGS Lakefield Research, Lakefield, ON	2006-2015	ISO/IEC 17025:2005	Secondary analytical laboratory	A representative portion of the samples analyzed by ALS Vancouver re-assayed
Vale Technical Development Limited, Mississauga, ON	2016 to date	ISO/IEC 17025:2005/2017	Secondary analytical laboratory	A representative portion of the samples analyzed by ALS Vancouver re-assayed.

8.7 ANALYSIS

8.7.1 INCO

Beginning in 1971, all of the Inco drill core from Sudbury was analysed by the Inco Field Exploration Laboratory using a Philips 1270 simultaneous X-ray fusion (XRF) unit which was equipped with 14 channels (Si, Fe, Mg, Co, Ni, Al, S, Cu, Ca, Ti, Mo, K, Zn, As). The XRF unit was calibrated using 200 samples which represented the various ore deposits in the Sudbury district. Samples were pressed in aluminum cups with a binder for 12 seconds at 15 tons on a Herzog press. Results for the pressed pellets for diamond drill samples were reported for copper, nickel, cobalt, iron, and sulphur. The XRF program also calculated a specific gravity based on intensities from the 14 channels. Three control samples at various sulphide concentrations were routinely run to ensure that the calibration remained accurate.

Gold, platinum and palladium were primarily assayed at Inco's Central Process Technology laboratory by a combination of fire assay and a variety of analytical finishes, including the silver bead being arced on an ARL spark emission spectrometer, direct current plasma (DCP) and inductively-coupled plasma (ICP) analysis. In later years the laboratory also analysed for gold, platinum, palladium, rhodium and silver using an arrested cupellation of the lead button from a fire assay fusion.

During the 1980s, a portion of core samples was sent for assaying to the Inco Central Process Technology Laboratory. The method used a Na_2O_2 fusion followed by ICP analysis of a base metal suite. Some mine samples were despatched to ALS Geochemistry (formerly Chemex and ALS Chemex) using the same Inco procedure for base metals, and assayed for precious metals by fire assay/ICP.

Starting in late 1990s, all core drill samples were prepared and analysed at the ALS Geochemistry laboratory using the Na_2O_2 fusion/ICP procedure for base metals, iron and sulphur, whereas precious metals were analyzed by a fire assay/ICP method.

8.7.2 VALE

All samples were analyzed for copper, nickel, cobalt, iron, sulphur, arsenic, lead and zinc using a sodium peroxide fusion with inductively-coupled plasma (ICP) atomic emission spectroscopy (AES) finish (ALS method ME-ICP81). When requested, lime, magnesia and silica were also reported.

Platinum group element contents were determined by a lead collection fire assay fusion/ICP–AES technique (ALS methods PGM-ICP23 or PGM-ICP27) on a 30 g sample.

Arsenic and lead at the trace levels were reported from the aqua regia digestion followed by an ICP finish (ALS method ME-ICP41).

Any samples with concentrations exceeding the upper limits of the method were automatically re-assayed using ALS Vancouver's default over-limit methods.

Lower detection limits by ALS are summarized in Table 8-2.

The Vale Technical Development Limited laboratory uses analytical methods similar to those of ALS: sodium peroxide fusion with ICP–AES finish for base metals and lead fire-assay with an ICP mass spectrometry (MS) finish for precious metals.

8.8 QUALITY ASSURANCE AND QUALITY CONTROL

8.8.1 INCO

8.8.1.1 SURVEY

Periodic field calibrations and checks of the north-seeking gyro used during the later Inco campaigns were done by the supplier/contractor with repairs completed as required.

8.8.1.2 LOGGING

The geologist and technologist responsible for the drill program completed an error check of the drill log. Prior to being uploaded to a master drill hole database the logging software performed a check of each drill hole. These checks ensured that potential errors such as incorrect hole azimuths and dips, sample number sequences, rock codes, and hole depths were minimized. The drill log was also compared with adjacent verified and validated drill hole information.

8.8.1.3 ASSAYS

Inco's quality control samples were reported along with the check results and compiled to ensure that the Inco results met internal standards. The Inco laboratory automatically repeated any outliers. Check samples that fell outside the expected precision (along with the original surrounding samples), were reviewed by the contract laboratory to determine if the error was systematic for a group of samples or merely isolated cases. Upon reconciling the differences, corrections were issued by the laboratory. The Inco program checked both the sampling and assaying procedures of the contract laboratory and encouraged the laboratory to minimize systematic and random errors. Precision and accuracy of these checks were routinely examined to ensure assays were within acceptable error limits.

Occasional assay checks of the original pulps were undertaken at the Inco laboratory ensure that accuracy at the assaying stage was acceptable. However, care had to be taken to avoid selecting older, oxidised samples, to avoid introducing an additional error source.

Table 8-2: Lower Detection Limits (ALS Geochemistry)

ME-ICP81								ME-ICP41		PGM-ICP23		
Cu (%)	Ni (%)	Co (%)	Fe (%)	S (%)	As (%)	Pb (%)	Zn (%)	As (ppm)	Pb (ppm)	Au (opt)	Pt (opt)	Pd (opt)
0.002	0.002	0.002	0.05	0.01	0.01	0.01	0.002	2	2	0.00003	0.0001	0.00003

Prior to 1970, elements other than nickel and copper were estimated either from composite samples or factors. Composites were generally composed of from pulps of four to five sequential samples that were not necessarily characterized by the same type or degree of mineralization.

The sulphur and PGE–gold assay for the composite was then assigned to the individual samples that went to make up the composite. This practice tended to smooth values and prevented the full understanding of the distribution of PGE–gold minerals, particularly in a narrow seam environment.

The pre-1972 data for PGE–gold, sulphur, and cobalt are not used in resource modelling. The impact of these legacy data that have different sampling and analytical techniques is investigated primarily with regression analyses, and when required, a regression formula is applied.

8.8.2 VALE

8.8.2.1 GEOLOGICAL

There are three major quality control checks conducted during core logging, including:

- Weight check (estimated weight versus measured weight by laboratory);
- Assay check (visually-estimated nickel and copper grade versus nickel and copper assay values);
- Sulphide check (visually-estimated sulphide content versus calculated sulphide).

Should assay data correspond to geologists' estimates, a geologist sign-offs on the drill hole quality control. This sign-off process is linked to drill hole finalization, which cannot be completed without the quality control sign-off. All drill holes that are not finalized are considered incomplete. A quality control review of all assay data received in a month is carried out by QA/QC personnel from the North American Mines Technical Services department for all operating mines' data. The results of these assessments are communicated to mine personnel and reported monthly.

8.8.2.2 QA/QC

The QA/QC program includes insertions of standard reference material (SRMs) (2% insertion rate), blank samples (<1%) coarse reject duplicates (3%), field/split core duplicates (1–2%), and a check assay program using an external laboratory (2–3%). Insertion rates are in line with industry norms. The frequency of checks may be increased if it is determined that an extra control is required.

The sample preparation laboratory is audited annually, and the primary assay laboratory is audited on average every 2–3 years.

Until 2014, monitoring of ALS Vancouver's internal control sample results augmented the QA/QC protocol used at the Ontario Operations. However, the geological QA/QC protocols for Ontario Operations have proven capable of revealing issues with the analytical service provider, and the issuance of annual reports of the laboratory's internal QC was transferred to the ALS Vancouver analytical laboratory.

Vale's Resource Management Group conducts an annual review of the QC sample results and issues a summary report to the Mines Technical Services group.

8.9 DATABASES

The sample and analytical database typically includes data on geology, survey, geophysics, geochemistry, sample assays, rock quality, tonnage factors and may also include information on mineability, mineralogy, metallurgy and economics.

Data are stored and managed in the Mines Exploration Borehole System (MEBS). The database for mineral resource estimation is required to clearly identify interpreted data (e.g., calculated density) as such with respect to primary data (e.g., density measurements by the water displacement method).

Several steps are employed to validate data and ensure the integrity of the MEBS database, the majority of which are performed by software data-checking routines. It is the operation qualified person's (see definition in Chapter 9.1.2) responsibility to ensure that the database is validated and its integrity maintained by the direct supervision of one person (the database manager) who reports directly to the operation qualified person.

The database is subject to regular back-ups.

8.10 QUALIFIED PERSON'S OPINION ON SAMPLE PREPARATION, SECURITY, AND ANALYTICAL PROCEDURES

The sample preparation, analysis, quality control, and security procedures used by the Ontario Operations have changed over time to meet evolving industry practices. Practices at the time the information was collected were industry-standard, and frequently were industry-leading practices.

Vale currently uses a system of "layered responsibility" to ensure that only appropriately verified data are used for estimation purposes (see discussion in Chapter 12.1).

The Qualified Person is of the opinion 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.

9 DATA VERIFICATION

9.1 INTERNAL DATA VERIFICATION

9.1.1 DATA VALIDATION

The Mines Geology department within the Ontario Operations performed monthly assay data validation through three principal quality indicators:

- Weight checks;
- Assay checks;
- Sulphide checks.

The Mines Geology department used several steps of data validation. Most of these checks were performed by software data checking routines that rigorously verify data acceptance. All new assay data being added to the database were monitored daily and validated monthly for accuracy and consistency by comparing the data transferred to MEBS to the assay certificates received from ALS Vancouver.

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. In addition to these internal checks Vale contracted independent consultants to perform laboratory, database and mine study reviews. The process of active database quality control and internal and external audits generally resulted in quality data.

Prior to use in mineral resource estimation, the data were downloaded from MEBS into a project file and reviewed for improbable entries and high values. Any errors were flagged and corrected. Quality control graphs were plotted at a minimum for assayed Cu+Ni versus estimated grade, measured sample weight versus estimated weight, and calculated sulphide (from assayed sulphur) versus estimated sulphide. Discrepancies were investigated, with re-assays requested where required.

Vale staff also conducted regular laboratory reviews and audits. However, the scheduled 2020 and 2021 annual reviews were cancelled due to the COVID-19 pandemic.

9.1.2 MINERAL RESOURCE AND MINERAL RESERVE ESTIMATES

A system of “layered responsibility” was established within the Vale’s Base Metals Division for documenting the information supporting the mineral resource and mineral reserve estimates, describing the methods used, and ensuring the validity of the estimates. The concept of a system of “layered responsibility” is that individuals at each level within the organization assume responsibility, through a sign-off or certification process, for the work relating to preparation of mineral resource and mineral reserve estimates that they are most actively involved in.

Mineral reserve, mineral resource and exploration target estimates are prepared and certified by qualified persons at the mine site level, and are subsequently reviewed by qualified persons at the Vale Base Metals corporate level. Where there is more than one mine, the mine qualified persons prepare and sign on the estimates for their mine and provide them to the operations qualified persons, and then to the qualified persons at the Vale Base Metals corporate level.

Mineral reserves and mineral resources are estimated in accordance with the Vale Base Metals Guidelines and Standards for Mineral Resource Mineral Reserve Reporting protocols. Each year the corporate qualified persons update and revise these guidelines, which are then reviewed and approved annually by the Vale Base Metals Mineral Reserve and Mineral Resource Subcommittee. The guidelines may be subject to revisions as approved by the subcommittee any time throughout the year, based on certain circumstances such as external opinions, or amendments to external regulations.

Operations qualified persons have responsibility for ensuring that the mineral reserve, mineral resource, and exploration target estimates, technical documents and other scientific and technical information for their operation are consistent with the guidelines. These qualified persons also supervise the sample and analytical database manager; establish and maintain core drill hole and assay QA/QC programs for the operation; ensure that production reconciliation are tracked and reported quarterly; ensure that mining adherence results are tracked and reported monthly to the Corporate Technology and Engineering Group for compilation and reporting (if applicable) and ensure mitigation actions are in place to address deviations from tracked plans; and provide supporting documentation related to material additions or changes in estimates of mineral reserves, mineral resources, and exploration targets. Operations qualified persons are expected to co-ordinate with, and where applicable, assist mine qualified persons in co-ordinating with other subject matter experts to obtain all information necessary to support estimation. Other experts include individuals in marketing, legal, tax, corporate affairs, finance, strategic and business planning and sustainability (environment, social, governance). These experts are responsible for providing such information as may be required by the operation qualified persons to ensure that the reports supporting mineral resource and mineral reserve disclosure contain all pertinent information.

Mines qualified persons have similar responsibilities to those outlined for the operations qualified persons. Mines qualified persons 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 modelling, sampling and assaying procedures, core drilling, geotechnical, geomechanical, hydrogeology, hydrology, metallurgy, mineralogy, scheduling, cost estimation, lands administration, economic analysis, finance, law, and environment.

Corporate qualified persons are responsible for ensuring that the required governance is satisfied for the estimation, reporting, and disclosure of Vale Base Metals mineral resources and mineral reserves, including compliance with the internal guidelines. The corporate qualified persons are responsible for developing and maintaining mineral resource and mineral reserve estimation and reporting standards and ensuring that such standards and guidelines follow industry best practices, and meet Vale's corporate requirements as well as legal requirements.

Technical reviews of the mineral reserve and mineral resource estimates are performed by the Corporate Technology and Engineering Group annually (or as needed) for each operation and mine. The Corporate Technology and Engineering Group prepares and issues a technical review report to each mine and operation with risks identified and ranked. All identified risks require mitigation and addressing, consistent with the risk rating that has been assigned to them, to be consistent with the disclosure requirements of SK1300, and to be compliant with the Vale Base Metals corporate standards and guidelines for mineral resource and mineral reserve reporting, and the Vale Global Guidelines for Mineral Resources and Mineral Reserves Management.

9.1.3 STUDIES

Vale staff perform a number of internal studies and reports in support of mineral resource and mineral reserve estimation for the various Ontario Operations mines. These include reconciliation studies, mineability and dilution evaluations, investigations of grade discrepancies between model assumptions and probe data, drill hole density evaluations, long-range plan reviews, and mining studies to meet internal financing criteria for project advancement.

9.1.4 PEER REVIEW BY SUBJECT MATTER EXPERTS

The QPs requested that information, conclusions, and recommendations presented in the body of this Report be reviewed by Vale experts or experts retained by Vale in each discipline area as a further level of data verification.

Subject matter experts were requested to cross-check, where applicable, numerical data, flag any data omissions or errors they identified, review the manner in which the data were summarized and reported in the technical report summary, check the interpretations arising from the data as presented in the Report, and were asked to review that the QP's opinions stated as required in certain Report chapters were supported by the data and by Vale's future intentions and Project planning.

Feedback from the subject matter experts was incorporated into the Report as required.

9.2 EXTERNAL DATA VERIFICATION

Vale and its predecessor companies commissioned a number of audits and third-party reviews of block models, mineral resources and mineral reserves. External audit requirements follow the Vale Global Guidelines for Mineral Resources and Reserves Management. Recent external data verification programs are summarized in Table 9-1.

9.3 DATA VERIFICATION BY QUALIFIED PERSON

As part of data verification, Chris Gauld performs reviews of core drill activities, core logging data collection and chain of custody reports, QA/QC, grade control, geological mapping and production reconciliation processes during site visits.

Mr. Gauld also routinely reviews the following for the Ontario Operations: geological and resource estimation practices and peer review memos, QA/QC verification memos, currency of geological and structural support, core drill planning, production reconciliation results, budgeting and requirements for drill spacing for mineral classification, audits changes to mineral resource estimates, reviews the results of external and internal audits, and reviews the results of mineral resource and mineral reserve audits.

9.4 QUALIFIED PERSON'S OPINION ON DATA ADEQUACY

The QP is of the opinion that data that have been verified on upload to the database, and checked using applicable Vale protocols, are acceptable for use in mineral resource and mineral reserve estimation.

Table 9-1: External Data Verification, Ontario Operations

Company	Year	Verification Type
AMEC	2005	Audit of resource and reserve estimation methods, Creighton copper–nickel mine.
AMEC	2007	Technical audit of 153 and 170 deposits, McCreedy East mine.
SRK Consulting	2009	Garson Deep (5100 to 5600 Level) mineral resource and mineral reserve audit report.
Golder Associates (Golder)	2010	Mineral resource and mineral reserve audit
AMEC	2014	Mineral resource and mineral reserve audit, Copper Cliff Mine
Amec Foster Wheeler	2015	Review of mineral resources, mineral reserves, mine plans, and economic analysis supporting the mineral reserves
RPA-SLR	2020	Mineral resource audit of Copper Cliff 191, Creighton Deep, Victor Deep Cu deposits.
SRK	2021	Mineral reserve audit of Copper Cliff Mine. Mineral resource audit of Victor Main deposit.

10 MINERAL PROCESSING AND METALLURGICAL TESTING

10.1 INTRODUCTION

The mineralogy and metallurgical performance of the sulphide deposits at the Ontario Operations is generally well understood due to the extensive drill hole coverage, mill performance records and mineralogical and metallurgical studies conducted over the last 100 years. These metallurgical studies, ranging from bench-scale to multi-tonne pilot testing, have included academic and industrial research and development of mineral separation. Based on these studies, flowsheet evolution and optimization has continued.

Specific deposits and/or ore zones possess unique characteristics with respect to sulphide and gangue mineralogy. Geochemical domains are identified and documented by a mine or project geologist familiar with the deposit through assessment of:

- Geological (mineralogical) mapping (e.g., high-grade copper zones, alteration zones, structural-influenced zones);
- MEBS assay results (copper–nickel, pyrrhotite–nickel, high PGM–low sulphide zones);
- Elemental ratio plots, for example sulphur against copper, nickel and PGM, assessing for bi- or multi-modal distributions;
- Normative sulphide mineralogical calculations and plots using the "normative mineralogy" functions available through Datamine Studio scripts.

Documents from the geologists identifying the mineralogical domains are submitted to metallurgical specialists at Vale Technical Development (VTD), located in Mississauga, Ontario in conjunction with sample material for metallurgical testwork. These documents include a spatial and geological description, elemental scatter-plots, three-dimensional views of normative mineralogy and a reference to nearby samples previously analyzed.

Samples taken during exploration and strategic studies drilling are used for metallurgical testing during the scoping, prefeasibility and feasibility studies. For current orebodies where the ore types are well understood, drilling is performed to delineate the response from those particular areas. Where there is less geological information, definition-style drill holes, bulk or grab samples may be selected for additional metallurgical testing. The test samples typically consist of either drill core or sample rejects representative of a portion or complete deposit/zone.

10.2 TEST LABORATORIES

Metallurgical testing is primarily done at Vale's Sheridan Park testwork facility. This facility is not independent of Vale, or its predecessor company, Inco. There is no international standard of accreditation provided for metallurgical testing laboratories or metallurgical testing techniques.

Vale uses a standard procedure that is calibrated against the Clarabelle Mill.

10.3 METALLURGICAL TESTWORK

Metallurgical testing programs were implemented and continue for all primary production ore zones as well as any future ore zones prior to development. Ore evaluation and full circuit simulation flotation studies are performed as a joint effort between the Ontario Operations technical services staff, and the Sheridan Park facility.

Vale Base Metals has adopted standard test procedures to develop throughput and recovery models for the existing mine and future ore zones. These procedures are based on the existing processing flowsheet, operating conditions, and reagent suite, calibrated against Clarabelle Mill.

During 2005-2010 the Clarabelle Mill flowsheet was studied and modified to implement a simplified flowsheet, referred to as the "challenging ore recovery" (CORe) project. The main revisions to the flowsheet include the elimination of the magnetic pyrrhotite separation stage, new rougher–cleaner–scavenger circuits and the installation of an IsaMill for regrind purposes.

The metallurgical testwork procedure (FCS-full circuit simulation) after 2012 CORe implementation at Clarabelle Mill was modified to reflect the changes. The mineralogy and metallurgical recovery reports include the characteristics (i.e., mineral liberation, floatable silicates, hexagonal pyrrhotite, pyrite content, etc.) which is used to identify problematic ores and possibly mitigate negative effects.

Samples have been historically, and are currently, composited from ½ or ¼ contiguous drill core

The ore zones currently in production may be tested to investigate the following:

- The expected metallurgical performance for non-typical ores, such as low sulphide, copper-rich sulphides with elevated precious metals content, ore zones with high hexagonal pyrrhotite content, and lower nickel-tenor disseminated sulphide in norite;
- Reasons for local variations in recovery (liberation during grind and separation in the rougher scavenger circuit, differences in abundance of pyrrhotite polytype, PGM–sulphide–silicate intergrowth and grain size differences;
- The impact of deleterious elements (mineralogy and mode occurrence) on grade and recovery;

Some drill core samples are submitted for grindability testing (i.e., Bond work index).

Ore zones planned to be brought into production are subject to similar tests. The testwork is conducted sufficiently ahead of production scheduling to allow characterization of the material for inclusion in mine planning.

10.4 RECOVERY ESTIMATES

The Ontario Operations produce nickel–copper–PGM ores that are blended and treated in the Clarabelle Mill to produce sulphide concentrates containing the valuable metals. The Sudbury ores contain cobalt, gold, silver, platinum, palladium, ruthenium, rhodium and iridium that are typically associated with the valuable sulphides.

The forecast smelting and refining recovery factors are determined from the annual metals plan models, which incorporate current metallurgical factors, processing and unaccounted losses in smelting and refining processes.

The anticipated metal recoveries at the Clarabelle Mill are based on an empirical mill process model based on ore attributes (nickel:pyrrhotite ratio, nickel grade, etc.) which were developed internally by Vale personnel. The model rejects the same percentage of pyrrhotite from all the mineralization going to the mill at the same metal grades (annually adjusted to plan). Similarly, the rock tailings are rejected at the same metal grades (annually adjusted to plan) for all mineralization. The model contains assumptions as to the behavior of typical ores based on grade and pyrrhotite content. Maximum allowable values for recoveries are set for ores that may exceed the known expected recoveries.

The milling recovery for nickel is estimated based on the nickel head grade and the calculated amount of pyrrhotite. The forecast milling recoveries for cobalt are approximately 3% less than the nickel recovery and the forecast copper recoveries are estimated using the annual copper head grades in the feed. The milling recovery assumptions for platinum, palladium and gold are estimated based on historical actual recoveries and are driven by the head grade of each precious metal.

Table 10-1 shows a comparison of the actual recoveries to mill prediction for the period 2016–2021.

Table 10-1: Clarabelle Mill Recoveries, 2015–2021

Year	Status	Clarabelle Mill Actual Data					Model Predicted		Actual less Predicted	
		Cu (%)	Ni (%)	S (%)	Cu Rec (%)	Ni Rec (%)	Cu Rec (%)	Ni Rec (%)	Cu Rec (%)	Ni Rec (%)
2016	Actual	2.04	1.46	9.7	97.4	84.9	95.7	85.4	1.7	-0.5
2017	Actual	2.24	1.60	10.0	97.1	83.8	97.1	86.4	0.0	-2.5
2018	Actual	2.16	1.60	10.0	97.1	85.0	97.1	86.4	0.0	-1.4
2019	Actual	2.26	1.46	9.2	97.0	85.2	96.7	85.2	0.3	0.0
2020	Actual	1.88	1.27	7.9	96.4	84.3	96.1	84.2	0.3	0.1
2021	Actual	1.90	1.26	8.1	95.7	84.0	96.2	84.1	-0.5	-0.1

Note: Source of data is Clarabelle month end base-metal balances, model recoveries from mill budget model. 2020 and 2021 models include modelled for fresh hoist and March 2020 observed for Creighton stockpile material.

The Ontario Operations have experienced increased variations in predicted versus actual nickel recoveries in recent years. The increased nickel recovery variation can be attributed to deficiencies in the ability of the recovery model to distinguish between monoclinic and hexagonal pyrrhotite recoveries.

In 2017, modeled copper recovery expectations were increased to account for sustained improvements in copper recovery associated with the challenging ore recovery (CORe) project and following optimization work. Based on the past model recovery predictions performance, it is believed that the mill recovery model can continue to be used to accurately predict the actual annual copper and nickel mill recoveries from the Clarabelle Mill.

Smelter and refinery recoveries for all metals are calculated monthly. These recovery rates include all recoveries from processing the nickel–copper concentrate to finished nickel and other intermediate metals or finished metals to customers. The actual smelter and refinery recoveries for 2015–2021 are provided in Table 10-2.

With the change in the processing flowsheet that resulted from the clean atmospheric emissions reduction project (Clean AER project), a technical limit has not been found at the forecast blended arsenic grades in the life-of-mine (LOM) plan. Some operational and cost implications have been found in relation to As:Ni ratios. These implications require As:Ni grade control in blended feed to minimize variability in As:Ni ratios and corresponding impacts at the Copper Cliff Nickel Refinery and matte processing. Incremental plant trials are under way to move from the previously-understood arsenic limit to a As:Ni limit sufficient to process forecast arsenic grades for the five-year mine plan. Additional work was identified in downstream processes and is expected to be largely completed in 2022.

The slag cleaning converter, which is operated primarily to improve smelter cobalt recovery, was offline for the second half of 2019, but is expected to be reactivated in 2022.

Table 10-3 summarizes the predicted metallurgical recoveries for the LOM.

10.5 METALLURGICAL VARIABILITY

Tests were performed on samples that are considered to be representative for the different orebodies/zones and the mineralogy of the various orebodies and zones.

10.6 DELETERIOUS ELEMENTS

The deleterious elements for smelting are arsenic, lead, zinc, and chromium. With these typical deleterious element concentrations, the mill concentrate feed (nickel concentrate currently) for the smelter routinely meets smelter specifications. The element of the greatest concern is arsenic and the overall blended feed into the plant is kept below 0.008% As.

Table 10-2: Combined Smelter and Refining Recoveries, 2015–2021

Year	Cu Rec. (%)	Ni Rec. (%)	Co Rec. (%)	Pt Rec. (%)	Pd Rec. (%)	Au Rec. (%)
2015	94.2	93.9	36.0	95.6	95.7	94.5
2016	95.2	93.8	37.3	96.3	96.4	95.6
2017	94.7	92.3	38.1	94.7	94.6	93.9
2018	93.7	95.1	37.1	95.0	95.8	93.5
2019	93.2	94.3	36.7	95.7	96.0	93.9
2020	93.4	94.6	38.7	95.8	95.9	93.4
2021[1]	92.6	94.4	34.1	95.8	95.8	93.7

Note:

1. Full year 2021 recoveries for copper, nickel and cobalt. November 2021 year-to-date recoveries for platinum, palladium and gold.

Table 10-3: Long Term Average Processing Metal Recoveries

Metal	Mill Recovery to Bulk Concentrates (%)	Smelter and Refinery Recovery of Ni Concentrate (%)
Cu	94.6	93.3
Ni	84.6	94.0
Co	79.2	35.0
Pt	79.3	95.6
Pd	83.8	95.6
Au	74.4	94.0

Note: Data source is the 2021 Reserves financial model.

In the period from 2025–2026, Garson ores are forecast to be higher in arsenic (0.075–0.080%), and may pose challenges in controlling the arsenic to the correct levels so as to not impact smelter efficiency and operating cost. As an integrated operation, the Ontario Operations have some flexibility in the control of their feed through stockpiling and blending strategies. The mine is addressing the forecast arsenic head grade in mill feed over the LOM plan to alleviate any negative impact on planned production.

10.7 QUALIFIED PERSON'S OPINION ON DATA ADEQUACY

Industry-standard studies were performed as part of process development and initial mill design. Subsequent production experience and focused investigations guided mill alterations and process changes.

Testwork programs, both internal and external, continue to be performed to support current operations and potential improvements. From time to time, this may lead to requirements to adjust cut-off grades, modify the process flowsheet, or change reagent additions and plant parameters to meet concentrate quality, production, and economic targets.

Based on these checks, the metallurgical test work and reconciliation and production data support the estimation of mineral resources and mineral reserves, and the inputs to the economic analysis.

The plant will produce variations in recovery due to the day-to-day changes in ore type or combinations of ore type being processed. These variations are expected to trend to the forecast recovery value for monthly or longer reporting periods.

11 MINERAL RESOURCE ESTIMATES

11.1 INTRODUCTION

Mineral resources were estimated for selected zones within the Blezard, Coleman, Copper Cliff, Creighton, Stobie, Garson (McConnell is included with Garson), Copper Cliff Pit, Totten and Victor deposits.

Resource estimation follows a similar procedure for the Ontario Operations. Vale has a set of protocols, internal controls, 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/correlograms); understanding of the influence of outliers and variables with highly skewed distributions and selection of an appropriate handling strategy (capping, restricted neighborhood); selection of an appropriate selective mining unit (SMU) size for the geometry of mineralization, spatial distribution of borehole and sample data, potential 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., interpolation technique, interpolation or kriging plan, search strategy, variogram models to be used, post-processing methods, in particular for indicator estimation); 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 performed as a team effort involving several technical disciplines.

All mineralogical information, exploration boreholes and background information were provided to the estimators by the geological staff at the mines or by exploration staff. Commercially-available Datamine software was used for estimation.

The block size was based on the spacing of the core drill holes and the potential mining method. The block size generally represents the smallest possible SMU, and varies by deposit/zone, for example, the block sizes in the X, Y and Z directions include 3 x 2 x 3 m (10x5x10 ft) used at the Coleman Main zone, 6 x 3 x 6 m (20x10x20 ft) used at the Creighton 310 zone, and 3 x 6 x 6 m used at the Victor Main.

11.2 EXPLORATORY DATA ANALYSIS

A rigorous review of the deposit drill hole database was conducted prior to initiating modelling. A statistical query of the various elements in the drill hole database was independently performed for all geological and grade domains.

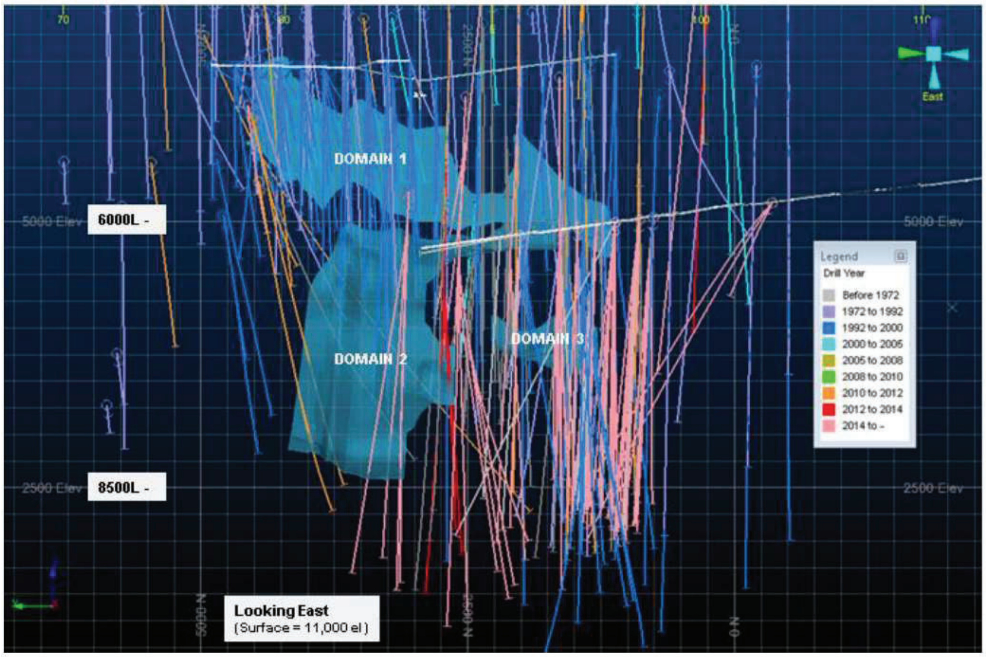
Bivariate and multivariate statistical and spatial data reviews were conducted on the data for each zone estimated. The reviews checked for elements such as outlier values that would require influence restrictions, mean values, spatial geochemical trends, evidence of fractionation, and correlation discrepancies such as discrepancies due to historical correlation estimation methods.

11.3 GEOLOGICAL MODELS

Domain wireframes were constructed using data from surface and underground drill holes that had different age periods, ranging from discovery-style drilling to exploration and infill drill programs. Wireframes were verified to ensure there were no modelling construct issues such as merge, boundary or crossover strings. The strings were checked to ensure they were snapped to relevant drill hole points and encompassed the interpreted mineralized system.

An example of a domain wireframe showing the drilling used to construct the domains is provided in Figure 11-1.

Figure 11-1: Example Wireframe Domains vs Drill Data, Victor Contact



Note: Figure prepared by Vale, 2016

A thorough review of the drill holes and samples captured within the wireframes was completed to identify any drill holes with questionable data such as poor selection of the drill hole orientation, inconsistent geological interpretations, poorly-constrained drill trajectories, poor logging and analytical methodologies, lost core intervals, and instances where the drill hole was never logged or assay data were pending. All drill holes considered inappropriate for use in resource modeling were removed from the estimation dataset, with the reasons for exclusion recorded in the dataset.

Intervals logged as “lost core” were assigned an absent value for all elements, unless such intervals were specifically identified as waste inclusions, in which case a value of 0.0 was assigned for all elements.

11.4 DENSITY ASSIGNMENT

As noted in Chapter 8.4, density data were calculated using a regression formula, and interpolated using the methods described in Chapter 11.9.

11.5 GRADE CAPPING/OUTLIER RESTRICTIONS

A number of approaches were used to evaluate whether grade caps were warranted; for example, X–Y scatter plots or evaluation using Excel could be used to check nickel and copper values prior to undertaking compositing to determine outlier values.

A similar approach was used where the deposit had cobalt, platinum, palladium or gold values that could be potentially economic. Vale typically reduced precious metal outliers to the 99.5 percentile; however, this may be modified if the individual deposit evaluation warrants that.

Vale’s estimation protocol was not to cap deleterious element grades.

11.6 COMPOSITES

Vale used a customary 5 ft (1.52 m) composite interval for all Sudbury nickel–copper–platinum group element resource models. However, in certain deposits, such as the Coleman Mine MOB4, a 3 ft (0.91 m) interval was selected.

All sample compositing was done using the Vale Ontario Operations Customization scripts "create sample composites".

A validation script was used to check database fields, such as CU, NI, CO, PT, PD, AU, SULP, DENSITY and LENGTH.

11.7 UNFOLDING

Unfolding was used for the majority of the Ontario Operations deposits to compensate for changes in strike and dip and/or pinch–swell geometry of a deposit, and to compensate for poor grade sample constraints within a mineralized wireframe. The unfolding process helped produce more realistic grade representations within the block model. A scripted process, "create unfold composites" was employed.

Unfold strings were created and the composited samples were unfolded using a standard modeling process. The starting locations of all strings were verified, and all the samples were unfolded properly with the total sample length in the unfolded system matching the original sample length. The top of the unfold strings was set to follow the trend of the mineralization. A schematic showing the unfolded strings in relation to drill composites for the Copper Cliff Pit deposit is included as Figure 11-2.

The text output from the script and a visual inspection of the unfold strings relative to the composited drill hole sample data were used to verify the unfolding process had worked properly.

11.8 VARIOGRAPHY

Experimental grade variograms were created using the "calculate grade variogram" process in Datamine. Typically, the model was a spherical, anisotropic two-structure model. If the variography indicated a clear plunge direction to the mineralization, the variograms were rotated to compensate for the plunge or the plunge was built into the unfold DTM and strings. Where relevant, the rotated variogram was used for the application of the variogram model and the search parameter directions.

11.9 ESTIMATION/INTERPOLATION METHODS

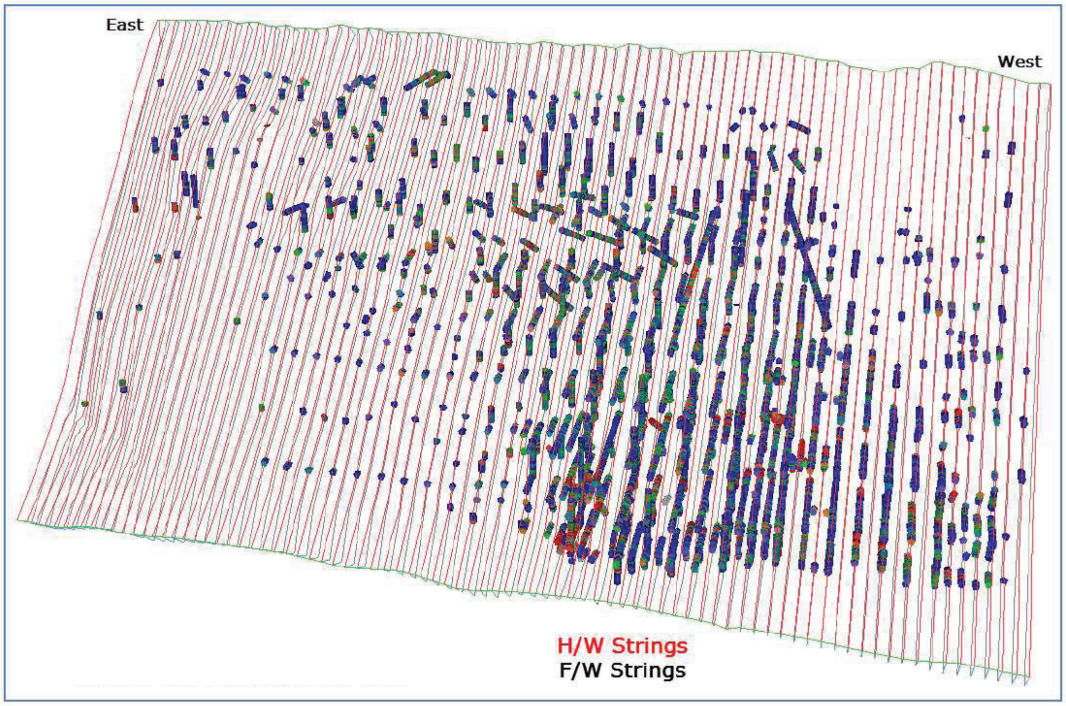
The long-range distance or second structure of the variogram model was used to help determine the radius of the search ellipsoid for grade interpolation. The across strike direction was decreased to half of the value in order to avoid excessive grade spreading in that direction, as per current Vale resource modelling practice. As is customary Vale practice, the base metals (Ni, Cu, Co) were grouped together with the sulphide content and bulk density, the precious metals (Pt, Pd, Au) were grouped together, and the deleterious elements (As, Pb) were also grouped together for search distance purposes.

Grade estimation was conducted using ordinary kriging (OK), with search distances based on variography. The OK estimation process followed the methodologies developed by Ontario Operations and used customized Datamine scripts.

Due to insufficient data, unfolding and variography were not performed for the Coleman Main zone; instead, this area was estimated using a dynamic anisotropy inverse distance weighting to the second power (DA–ID2) method. DA–ID2 was also used for a portion of the Garson 4 Shear Orebody.

The models were typically estimated in three successive passes, and a final, fourth pass was completed to estimate blocks that were not informed during the first three passes. Blocks estimated during the fourth pass were not included in the classified resources, as they were intended for use in defining drill targets.

Figure 11-2: Schematic Showing Unfolded Strings Relative to Composited Samples



Note: Figure prepared by Vale, 2020. Oblique view, looking southeast. Composites shown as coloured cylinders, unfolded strings as lines.

Nearest neighbor (NN) models were constructed, and used primarily to validate the OK global estimates, check the smoothing ratios, and apply a global variance correction to the final estimated models where necessary. A second NN model set, where the samples were composited to one sample grade per borehole (1CNN), was created to help identify any instances of poorly-oriented holes improperly influencing estimated block model grades by comparing the global mean grades to those of the regular NN model. The NN2 model was spatially reviewed in 3D against the informing drill holes.

11.10 VALIDATION

Validation was conducted according to the Vale Ontario Operations procedures. Validation steps included: checking block model volumes against the mineral wireframe volumes; checking of model grades against the drill hole grades; checking for over-smoothed grades and applying corrections where necessary; checking, if the model was unfolded, that all drill holes were appropriately captured; ensuring that all relevant samples were captured within the wireframes; checking that the OK and NN estimates were compared to the drill holes, that the block grades reasonably matched the drill hole grades, and, where applicable, the grade trends paralleled the footwall and hanging wall contacts.

Swath plots were used to review the distribution of the base, precious and deleterious metals along strike, through the vertical ranges, and from the footwall to hanging wall contact.

A DA–ID2 interpolation, created using Vale custom scripts, could also be used to check the OK estimates.

All resource estimates were subject to peer review by a review committee consisting of personnel from the relevant mine or exploration depending on deposit location, and representatives of the Mine Design and Evaluation and Resource Management departments.

11.11 CONFIDENCE CLASSIFICATION OF MINERAL RESOURCE ESTIMATES

11.11.1 MINERAL RESOURCE CONFIDENCE CLASSIFICATION

The mineral resource confidence categories were initially assigned based on a combination of factors, including geological understanding and confidence, drill hole support, grade estimation confidence relative to planned production rates, and identified risk factors (e.g. metallurgy). The initial assignments were reviewed to assess the impacts of factors such as metallurgical recoveries, geomechanical studies, mine design work, and representative mineability and recovery reconciliation analysis. An example of the resulting confidence classifications is provided in Figure 11-3 for the Garson Mine.

Where mining has occurred or is currently active, the mined-out volumes were wireframed, classified as either void or fill, and overprinted upon the resource model to account for mining depletion.

11.11.2 UNCERTAINTIES CONSIDERED DURING CONFIDENCE CLASSIFICATION

Uncertainties regarding sampling and drilling methods, data processing and handling, geological modelling, and estimation were incorporated into the classifications assigned. The areas with the most uncertainty were assigned to the inferred category, and the areas with fewest uncertainties were classified as measured.

11.12 REASONABLE PROSPECTS OF ECONOMIC EXTRACTION

11.12.1 INPUT ASSUMPTIONS

For each resource estimate, an initial assessment was undertaken that assessed likely infrastructure, mining, and process plant requirements; mining methods; process recoveries and throughputs; environmental, permitting and social considerations relating to the proposed mining and processing methods, and proposed waste disposal, and technical and economic considerations in support of an assessment of reasonable prospects of economic extraction. All material is assumed to be blended at the Clarabelle Mill, and milling throughput rates will depend on the blending strategy in place at the mill at the time the material is processed.

Key parameters used to constrain the resource estimates are summarized in Table 11-1.

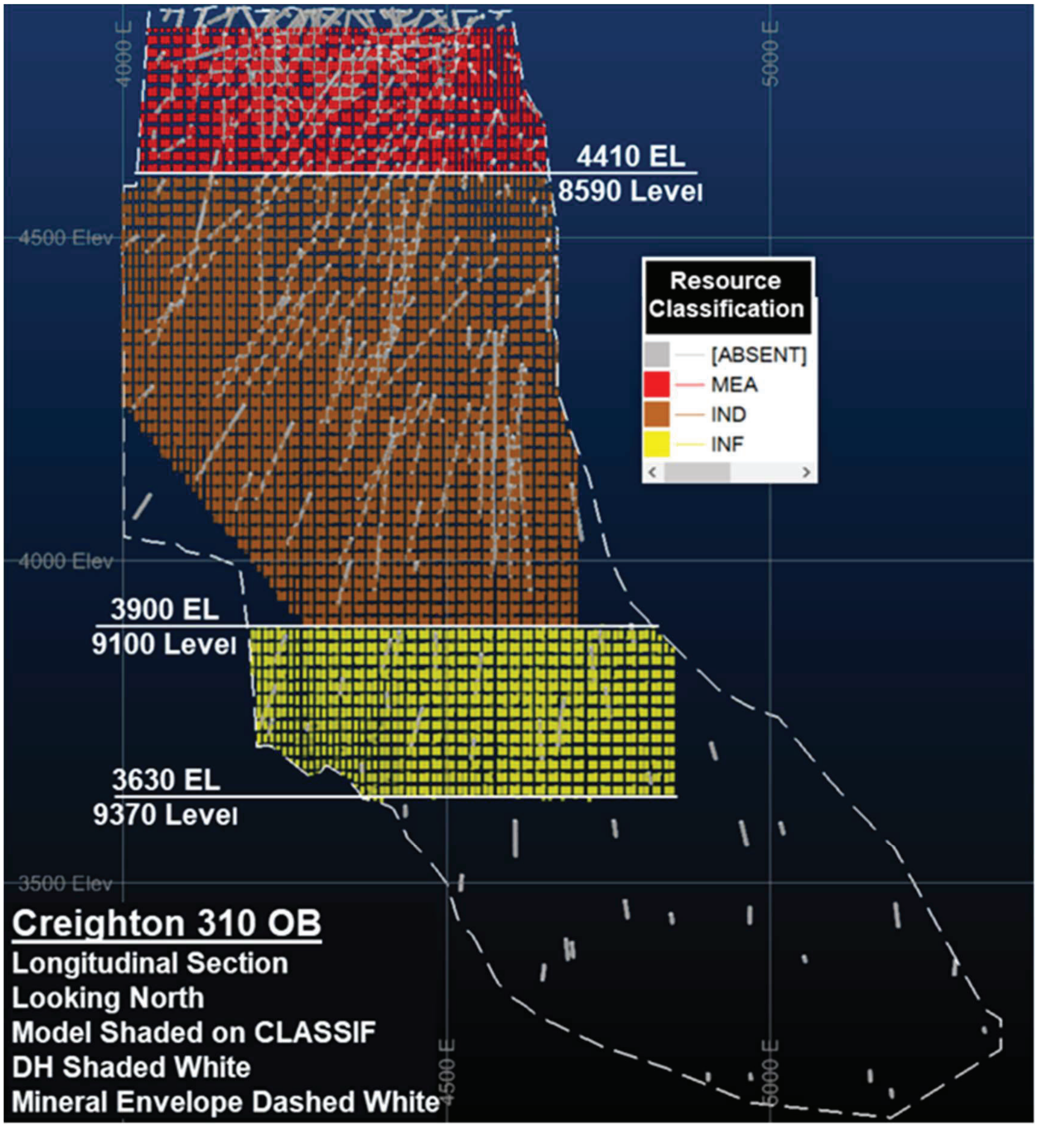
11.13 COMMODITY PRICE

The commodity pricing forecasts in Table 11-1 were established using a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. An explanation of the derivation of the commodity prices is provided in Chapter 16.

11.14 CUT-OFF

The resources are reported at varying cut-off values, which are based primarily on the mining method that will be used. Process and general and administrative (G&A) costs are based on the assumption that material will be sent to, and blended at, the Clarabelle Mill.

Figure 11-3: Example Assigned Confidence Classifications, Creighton 310 Deposit



Note: Figure prepared by Vale, 2021

Table 11-1: Input Parameters

Parameter	Unit	Value or Range
Cu sale price [1]	US$/tonne	5,250–7,000
Ni sale price [1]	US$/tonne	13,376–18,000
Co sale price [1]	US$/tonne	27,500-45,000
Pt sale price [1]	US$/oz	1,150–1,225
Pd sale price [1]	US$/oz	750–1,093
Au sale price [1]	US$/oz	1,200–1,373
Exchange rate [1]	USD/CAD	1.26–1.34
Mining method	—	Various, including: underground bulk stoping; underground narrow vein cut and fill and bulk stoping; underground bulk: slot/slash longitudinal stoping; underground blast hole (slot slash); top down; underground bulk longhole and underhand cut-and-fill cutter machine; and open pit
Assumed throughput rate	tonnes/day	150–9,085
Mining recovery [2]	%	81–100
Dilution [2]	%	5–20
Mine operating cost	US$/tonne mineralization mined	33-247
Process cost [3]	US$/tonne processed	15-112
G&A cost	US$/tonne processed	2-39
Cu recovery	%	79–94
Ni recovery	%	45–91
Co recovery	%	25–54
Pt recovery	%	39–85
Pd recovery	%	49–90
Au recovery	%	58–86
Cut-off	US$/tonne Metal Eq	3.40–231 0.50% NiEq; 3.25% CuEq
Pit slope angle 4	°	40–51

Notes:

1. Commodity prices used for reasonable prospects of economic extraction determination based on the assumptions from the year the reasonable prospects of economic extraction was evaluated.
2. Mining recovery and dilution are only a consideration for reasonable prospects of economic extraction determination but are not applied to the mineral resource estimates.
3. The overall process cost includes both operating cost and sustaining capital for all processing pants (mill/smelter/refineries) and varies considerably based on metal content of feed. Ranges shown are for consolidated rock. Shallower slope angles are used in zones of block caved (unconsolidated) material.
4. The differences between foreign exchange and commodity price assumptions for resource mine design and economic analysis are due to timing. As of December 31, 2021, the assumptions used for mine design continue to provide a reasonable basis for establishing the prospects of economic extraction for mineral resources.

11.14.1 QP STATEMENT

The QP is of the opinion that any issues that arise in relation to relevant technical and economic factors likely to influence the prospect of economic extraction can be resolved with further work. The mineral resource estimates are performed for deposits that are in a well-documented geological setting; the district has >100 years of active open pit and underground mining operations; Vale is very familiar with the economic parameters required for successful operations in the Sudbury area; and Vale has a long history of being able to obtain and maintain permits, social licence and meet environmental standards. There is sufficient time in the 22-year timeframe considered for the commodity price forecast for Vale to address any issues that may arise, or perform appropriate additional drilling, testwork and engineering studies to mitigate identified issues with the estimates.

11.15 MINERAL RESOURCE ESTIMATE

Mineral resources are reported as at 31 December, 2021, using the mineral resource definitions set out in SK1300, and are reported exclusive of those mineral resources converted to mineral reserves. The reference point for the estimate is in situ. The measured and indicated mineral resource estimates for the Ontario Operations are provided in Table 11-2. The inferred mineral resource estimates are included in Table 11-3. The Qualified Person for the estimate is Chris Gauld, P.Geo.

11.16 UNCERTAINTIES THAT MAY AFFECT THE MINERAL RESOURCE ESTIMATE

Areas of uncertainty that may materially impact all of the mineral resource estimates include:

- Changes to long-term metal price and exchange rate assumptions;
- Changes in local interpretations of mineralisation geometry such as pinch and swell morphology, extent of brecciation, presence of unrecognized mineralization off-shoots; faults, dykes and other structures; and continuity of mineralised zones;
- Changes to geological and grade shape, and geological and grade continuity assumptions;
- Changes to unfolding, variography and search ellipse ranges that were interpreted based on limited drill data, when closer-spaced drilling becomes available;
- Changes to metallurgical recovery assumptions;
- Changes to the input assumptions used to derive the potentially-mineable shapes applicable to the assumed underground and open pit mining methods used to constrain the estimates;
- Changes to the forecast dilution and mining recovery assumptions;
- Changes to the cut-off values applied to the estimates;
- Variations in geotechnical (including seismicity), hydrogeological and mining method assumptions;
- Changes to environmental, permitting and social license assumptions.

Table 11-2: Ontario Operations, Measured and Indicated Mineral Resource Statement

Mine/Area	Category	Tonnage (kt)	Grade					
			Cu (%)	Ni (%)	Co (%)	Pt (g/t)	Pd (g/t)	Au (g/t)
Blezard	Measured	—	—	—	—	—	—	—
	Indicated	7,887	0.68	0.99	0.04	0.26	0.27	0.08
	Sub-total measured + indicated	7,887	0.68	0.99	0.04	0.26	0.27	0.08
Coleman	Measured	234	1.08	2.12	0.07	0.43	0.57	0.04
	Indicated	2,290	4.33	1.57	0.04	3.62	4.83	1.77
	Sub-total measured + indicated	2,524	4.03	1.62	0.04	3.33	4.44	1.61
Copper Cliff	Measured	2,065	1.70	1.35	0.05	1.12	1.35	0.52
	Indicated	4,207	1.07	1.32	0.04	1.04	1.42	0.35
	Sub-total measured + indicated	6,273	1.28	1.33	0.04	1.07	1.40	0.41
Creighton	Measured	—	—	—	—	—	—	—
	Indicated	6,213	3.29	4.52	0.09	0.98	1.16	0.33
	Sub-total measured + indicated	6,213	3.29	4.52	0.09	0.98	1.16	0.33
Garson	Measured	230	1.24	1.79	0.11	0.64	1.60	0.44
	Indicated	2,598	1.49	1.35	0.06	0.98	1.87	0.50
	Sub-total measured + indicated	2,828	1.47	1.39	0.06	0.95	1.85	0.49
Copper Cliff Pit	Measured	4,340	0.50	1.13	0.06	0.12	0.21	0.02
	Indicated	3,177	0.44	0.78	0.04	0.11	0.15	0.05
	Sub-total measured + indicated	7,517	0.47	0.98	0.05	0.12	0.18	0.03
Stobie	Measured	—	—	—	—	—	—	—
	Indicated	10,035	0.42	0.47	0.02	0.20	0.22	0.09
	Sub-total measured + indicated	10,035	0.42	0.47	0.02	0.20	0.22	0.09
Totten	Measured	441	1.33	1.13	0.03	1.53	0.67	0.48
	Indicated	278	1.18	0.66	0.01	1.53	0.79	0.51
	Sub-total measured + indicated	719	1.27	0.95	0.02	1.53	0.72	0.49
Victor	Measured	—	—	—	—	—	—	—
	Indicated	13,859	4.39	1.75	0.03	1.48	1.82	0.60
	Sub-total measured + indicated	13,859	4.39	1.75	0.03	1.48	1.82	0.60
Total	***Measured***	***7,311***	***0.93***	***1.24***	***0.05***	***0.51***	***0.61***	***0.20***
	Indicated	***50,546***	***2.19***	***1.59***	***0.04***	***0.92***	***1.17***	***0.38***
	Total measured + indicated	***57,857***	***2.04***	***1.54***	***0.04***	***0.87***	***1.10***	***0.35***

Table 11-3: Ontario Operations, Inferred Mineral Resource Statement

Mine/Area	Category	Tonnage (kt)	Grade					
			Cu (%)	Ni (%)	Co (%)	Pt (g/t)	Pd (g/t)	Au (g/t)
Blezard	Inferred	—	—	—	—	—	—	—
Coleman	Inferred	877	3.3	0.5	0.01	2.4	3.2	1.1
Copper Cliff	Inferred	2,535	1.6	1.0	0.03	1.6	1.5	0.6
Creighton	Inferred	3,302	3.2	4.0	0.08	1.6	2.2	0.5
Garson	Inferred	916	1.9	1.4	0.05	0.6	0.9	0.3
Copper Cliff Pit	Inferred	—	—	—	—	—	—	—
Stobie	Inferred	—	—	—	—	—	—	—
Totten	Inferred	398	1.9	1.2	0.03	1.2	1.3	0.3
Victor	Inferred	537	3.4	0.7	0.01	0.5	0.8	0.3
Total	***Inferred***	***8,564***	***2.5***	***2.1***	***0.05***	***1.5***	***1.8***	***0.6***

Notes to accompany mineral resources tables:

1. Mineral resources are reported using the mineral resource definitions set out in SK1300. The reference point for the mineral resource estimate is in situ. The estimate is current as at 31 December, 2021. The Qualified Person for the estimate is Chris Gauld, P.Geo., a Vale employee.
2. Mineral resources are reported exclusive of those mineral resources converted to mineral reserves. Mineral resources that are not mineral reserves do not have demonstrated economic viability.
3. The estimate uses the following key input parameters: open pit mining methods or underground bulk stoping or narrow vein cut-and-fill mining methods; copper sale price of US$5,250-7,000/t, nickel sale price of US$13,376-18,000/t, cobalt sale price of US$27,500-45,000/t, platinum sale price of US$1,150-1,225/oz, palladium sale price of US$750-1,093/oz, gold sale price of US$1,200-1,373/oz; variable copper recovery ranging from 79–95%, variable nickel recovery ranging from 45–91%; mine operating costs ranging from US$33–US$247/t mined, process costs ranging from US$15–112/t milled; general and administrative (G&A) costs ranging from US$2–$39/t milled; mining recovery ranging from 81–100%, and mining dilution of 5–20%. Costs, metallurgical recovery, pricing data is shown as ranges, due to the variability in specific deposit requirements and timing of the associated estimate.
4. Numbers have been rounded.

Specific factors that may affect individual estimates include:

- Blezard: although recent drilling has decreased the weight of historical drilling there remains a significant volume (approximately 33%) defined by older (pre-1974) drillholes. Results of the 2020 core drilling campaign from surface confirmed the general lithological, spatial and grade distribution of the historical drillholes and previous estimates. The newer data reduce the risk associated with the older data, which may have over- or under-represent the grades locally within the zone;
- Coleman: wireframing based on discrete veins may be excluding mineralization above cut-off that occurs between the modelled veins; conversely, exclusion of this material may result in overestimation of grade within the wireframes;
- Copper Cliff: the quartz diorite dyke in the 860 zone is treated as a single domain for estimation purposes. Additional drilling may support sub-domaining within the dyke to differentiate lower-grade mineralization. There is a risk that the tonnage estimate in this area may be locally overstated;
- Creighton: detailed geological mapping from underground stations indicates the existence of local internal rock inclusions and/or embayments caused by the pinch and swell morphology that are not captured by wider-spaced drilling. There is a risk that the local geological interpretations do not adequately reflect these, and that resource models may be locally over or under estimating the tonnage and grade;
- Garson: the deposit can have elevated arsenic levels, averaging 0.03–0.5% globally, but with spot highs that may reach as much as 30% As. These arsenic values are well above those for a typical Sudbury deposit, and may lead to exceedance of the mill limit (1,000*As/Ni). Mineral resource block estimates may not precisely reflect local variances in arsenic values. Similarly, elevated lead levels in the 2500 Structure domain may not be locally precise, which may exceed accepted thresholds for the mill. Historically, mine production and mill feed are blended to reduce the impact and mitigate the risk associated with deleterious mineralogy to downstream processes;
- Copper Cliff Pit: historical geological and mining reports have documented the presence of “talc” boulders. The expression “talc” was historically used to refer to variably-altered ultramafic inclusions consisting of silicates (actinolite, orthopyroxene, chlorite, micas, etc.) which negatively impact the metallurgical recovery process from slimes during mineral processing and by interfering with sulphide recovery during the flotation process. There is a risk that the metallurgical recovery used in assessing reasonable prospects of economic extraction may be overstated. However, magnetic sorters may be able to be used to selectively reject and reduce the amount of “talc” sent to the mill;
- Victor: some areas of the Contact zone model have lower data density, which affects wireframe interpretations especially in the extremities of the domains. The resource models may be over or under estimating the tonnage and grade due to the geological and structural controls on the mineralized system. The domains have pinch–swell–termination occurrences that could affect drill hole continuity interpretations and there is a risk that the geometry may change considerably over very short distances along strike and down dip.

To the extent known to the QP, there are no other known environmental, permitting, legal, title-related, taxation, socio-political or marketing issues that could materially affect the mineral resource estimate that are not discussed in this Report.

12 MINERAL RESERVE ESTIMATES

12.1 INTRODUCTION

Mineral reserves are reported for the Coleman, Copper Cliff, Creighton, Garson and Totten deposits.

To publicly report a mineral reserve estimate, Vale Base Metals must have a current intention to mine the mineralization as demonstrated by the inclusion of the mineral reserves in an operation or project's "Mineral Reserves only" life-of-mine (LOM) plan. Typically the mineral reserve estimate is supported by a mine plan, an annual technical report, and supporting files (including and not limited to: safety plan, driving layouts, execution schedules, production schedules, cost reports, capital outlay/procurement schedule and asset integrity system) for mineralization that is to be exploited from existing mine infrastructure (generally funded with operating costs or limited sustaining capital).

Mineral reserves were estimated using underground mining methods. For each mine and mineral zone with mineral resources to be mined, a mining plan was developed that included selection of mining method, stope production sequencing, consideration of development, equipment and infrastructure requirements, and estimation of capital and operating costs. Mining plans and engineering studies were completed for all mineral reserve estimates. All engineering studies were at a minimum prefeasibility-level studies.

Based on the selected mining method, and using the mineral resource block model, a mine design was prepared for each individual stope. Only measured and indicated mineral resources were converted in the stope design to estimate proven and probable mineral reserves. In the Coleman Mine's 170 area only, measured mineral resources were converted to probable mineral reserves based on the uncertainty of the planned mining method.

Economic cut-off grades were estimated for each mine and mining area and used to determine the design of each stope. Following stope design, the mineral resources contained within the stope outline were interrogated. Internal (planned) dilution within the stope was included in the mineral resource estimates.

Mining recovery (mineability) and external dilution factors were applied. These factors were estimated based on historical data and experience with the various mining methods at each of the mines, and were applied to each stope on stope-by-stope basis after consideration of both the mining method and any local considerations at each mine that could impact mining.

The resulting mineral reserves in each stope for each mine were scheduled in the mine operations life-of-mine production plan. The LOM plan included capital, operating and corporate costs estimates, and was assessed for economic viability. All mineable units or stopes that were scheduled for mining were included in the mineral reserves, and were tested in the overall Ontario Operations production plan. Material that did not meet economic criteria following the financial analysis of the production plan were not converted to mineral reserves.

12.2 DEVELOPMENT OF MINING CASE

The Ontario Operations currently have a total of five major operating underground mines. With the exception of Totten, which has an eight-year mining history, the mines have been in operation for decades and, consequently, there is significant history and data available on the geological setting, mining methods, mining conditions, mining recoveries and dilution, production capacity and mining costs. These historical data are used extensively in the mineral reserve estimation process.

The mining methods used in the Ontario Operations are a combination of bulk stoping and cut-and-fill approaches (refer to discussion in Chapter 13.4).

The throughput rate for each mine is based on a detailed mining plan that includes consideration of current and planned mining methods, geotechnical constraints and risks, materials handling system, mining equipment fleet, labour resourcing, infrastructure such as power supply and reticulation, dewatering, backfilling and ventilation. Life-of-mine plans, as well as more detailed five-year plans, are developed for each mine.

There are standard designs for stopes; however, there can be considerable variation in stope sizing from mine to mine and within each mine, depending on geology, geometry, logistical and geotechnical considerations, and historical data. Stopes can range from about 5,000 to >55,000 t.

Mine plans are adjusted by mine planners to minimize the risk of ground failures and seismicity through the establishment of an optimal mining block size and shape, and mine sequencing. All of the underground mines are relatively dry, with only small groundwater inflows.

12.3 DILUTION AND MINE RECOVERY

Dilution and mining recovery for each stope are estimated after consideration of the planned mining method and stope design, and are applied as a modifying factor in the form of a percentage allowance of the in-situ estimated tonnage of the stope.

Estimates of external mining dilution are based on historical data and stoping experience at the mines, which is tracked through a reconciliation procedure of planned versus actual production for each stope mined. The allowance also includes provision for external dilution by backfill material from adjacent backfilled stopes that is broken during blasting or sloughs during production, and cannot be separated from ore during mucking. The estimate of external dilution can be reduced by a further allowance, again based on experience, for waste rock separated from the broken mineralized rock in the stope by mucking under geological control.

Mineability factors include an allowance, based on local experience, for ore broken but not recovered during final mucking using remote-controlled load–haul–dump (LHD) vehicles. Oxidation of blasted ore frequently occurs where ore has been left in the stope for an extended period of time before removal. This leads to the ore consolidating as the sulphide content oxidizes, and makes it difficult to muck with LHDs, causing the loss of recovery. Mineral reserves within the design limits of the stope that are not recovered due to drilling and blasting limitations (e.g. stope shoulders) can also contribute to mineability losses.

After mining is complete, the resulting dilution and mineability for each stope is assessed using excavation volumes from laser cavity monitor scans, and from detailed mineral grade distributions from blasthole conductivity probing when available. Mineability and dilution modifying factors are developed at each mine for each of the mining areas and mining methods through historical data based on the ongoing program of stope reconciliation. As new data are made available for stopes, these factors are regularly reviewed and updated for each mining method and mineral zone to reflect changing operating practices, and prevailing geological and geotechnical conditions.

12.4 CUT-OFF GRADES

The Ontario Operations have a cut-off grade policy and procedures for mine design, production scheduling and day-to-day ore/waste determination. The mineralized zones contain multiple recoverable metals, each with different metal prices, resulting in a net processing return (NPR) formula being used to assign a dollar value grade descriptor to mineralization. The full mining operating cash cost per short ton is compared to the NPR value per short ton to determine if a given amount of material is ore or waste.

The NPR formula calculates the net in-situ value of the mineralized material before it is extracted, then the processing costs and certain direct corporate costs are subtracted from the anticipated revenue of the recoverable metal using the appropriate long-term sale price and exchange rate assumptions.

Input parameters to the NPR formula used in the LOM plans are provided in

Table 12-1. These inputs were used for all cut-off applications, including day-to-day grade control, short-range planning and longer-range mine design.

Vale uses a combination of contract pricing, knowledge of its key markets from a long production record, short term versus long term price forecasting, public documents and analyst forecasts when considering long term commodity price forecasts. Some of the forecast prices are adjusted locally by the individual mines to reflect the time at which the mine plans are updated, cashflows are conducted, and the local cut-off grade employed to suit each individual operation based on hoisting capacity, mining method, and geotechnical considerations. The estimated timeframe used for the price forecasts is the 23-year LOM that supports the mineral reserve estimates.

Table 12-1: LOM Plan NPR Formula Input Parameters

Parameter	Unit	Value/Range
Nickel sale price [1]	US$/t	13,376
Copper sale price	US$/t	6,100
Cobalt sale price	US$/t	45,000
Platinum sale price	US$/oz	1,225
Palladium sale price	US$/oz	925
Gold sale price	US$/oz	1,300
Exchange rate	US$/C$	1.30
Overall processing Ni recovery	%	69–86
Overall processing Cu recovery [2]	%	85–95
Cut-off grade/design cost	US$/t ore	69-235
Mine full operating cost [5]	US$/t ore	66-220
Mine period cost [3]	US$/t ore	1-6
Mine sustaining capital cost [3]	US$/t ore	8-48
Overall processing cost [5]	US$/t ore	51-187
Primary mining method	variable	Bulk stoping; narrow vein cut-and-fill
Mining recovery	%	75–99
Unplanned dilution	%	6–20

Notes:

1. The nickel sale price includes a premium of US$626/t, based on quality of product and established sales contracts.
2. The overall process copper recovery is for copper that is processed through the Copper Cliff Smelter Complex.
3. The mine maintenance shutdown costs and the mine sustaining capital costs presented are the average of recent historic costs.
4. The overall process cost includes both operating cost and sustaining capital for all processing pants (mill / smelter / refineries) and varies based on the metal content of feed.
5. Mine designs for individual deposits were prepared using a break even cut off and the selected metal prices and foreign exchange rate above. Evaluation to demonstrate the economic viability of the mineral reserve were made as of December 31, 2021, based on the assumptions described in Section 19.

12.5 ORE/WASTE DETERMINATIONS

Stope design boundaries are based on a combination of the mineral zone interpreted outline and the NPR value in the mineral resource block model. After deduction of the full mine operating cash cost from the NPR value in each block, an outline is created around all the mineral resource model blocks which have a positive value, and then this outline is used as the basis for the creation of a practical stope outline. Once the stope has been designed, modifying external dilution and mineability factors are applied to the interrogated tonnage and grade of the material in the stope.

A stope is considered for inclusion in the mine plan if its value is equal to or greater than the forecast mining cost. Uneconomic stopes are reviewed to determine if the value can be increased through improved design, but once confirmed as uneconomic, these stopes are removed from the mine plan. The cut-off value is a proxy for the cut-off grade.

12.6 MINERAL RESERVE ESTIMATE

Mineral reserves are reported using the mineral reserve definitions set out in SK1300. The reference point for the mineral reserve estimate is the point of delivery to the process plant. Mineral reserves that are reported in

Table 12-2 are current as at 31 December, 2021. The Qualified Person for the estimate is Nick Gardner, P.Eng., a Vale employee.

Table 12-2: Proven and Probable Mineral Reserve Statement

Deposit	Category	Tonnage (kt)	Grade					
			Cu (%)	Ni (%)	Co (%)	Pt (g/t)	Pd (g/t)	Au (g/t)
Coleman	Proven	3,157	3.58	1.43	0.04	1.72	2.77	0.93
	Probable	2,065	2.77	1.12	0.02	2.19	2.92	0.76
	Sub-total Proven + Probable	5,222	3.26	1.31	0.03	1.90	2.83	0.86
Copper Cliff	Proven	6,797	1.42	1.06	0.03	1.22	1.03	0.51
	Probable	29,059	1.28	1.16	0.03	1.08	1.48	0.39
	Sub-total Proven + Probable	35,856	1.30	1.14	0.03	1.11	1.39	0.41
Creighton	Proven	2,245	2.53	3.05	0.06	0.85	1.01	0.32
	Probable	1,474	2.27	3.07	0.059	0.93	0.99	0.18
	Sub-total Proven + Probable	3,719	2.43	3.06	0.06	0.88	1.00	0.27
Garson	Proven	3,470	1.24	1.55	0.05	0.64	0.55	0.25
	Probable	1,966	1.03	1.34	0.05	0.60	0.52	0.16
	Sub-total Proven + Probable	5,436	1.17	1.48	0.05	0.63	0.54	0.22
Totten	Proven	3,213	1.74	1.39	0.03	1.64	0.80	0.52
	Probable	390	1.65	0.86	0.02	1.89	1.32	0.86
	Sub-total Proven + Probable	3,603	1.73	1.33	0.03	1.67	0.86	0.56
Total Ontario Operations	***Proven***	***18,882***	***1.94***	***1.51***	***0.04***	***1.22***	***1.19***	***0.51***
	Probable	***34,954***	***1.40***	***1.24***	***0.03***	***1.12***	***1.49***	***0.39***
	Sub-total Proven + Probable	***53,835***	***1.59***	***1.33***	***0.04***	***1.16***	***1.38***	***0.43***

Notes to accompany mineral reserves table:

1. Mineral reserves are reported using the mineral reserve definitions set out in SK1300. The reference point for the mineral reserve estimate is the point of delivery to the process plant. The estimate is current as at December 31, 2020. The Qualified Person for the estimate is Nick Gardner, P.Eng., a Vale employee.
2. The estimates use the following key input parameters: bulk stoping or narrow vein cut-and-fill mining methods; copper sale price of US$6,100/t, nickel sale price of US$13,376/t, cobalt sale price of US$45,000/t, platinum sale price of US$1,225/oz, palladium sale price of US$925/oz, gold sale price of US$1,300/oz; variable copper recoveries ranging from 85–95%, variable nickel recoveries ranging from 69–86%; mine operating costs ranging from US$66–220/t mined, process costs ranging from US$51–187/t milled; mining recovery ranging from 75–99%, and unplanned dilution of 6–20%.
3. Numbers have been rounded.

12.7 UNCERTAINTIES THAT MAY AFFECT THE MINERAL RESERVE ESTIMATE

Factors that may affect the mineral reserve estimates include:

- Long-term commodity price assumptions;
- Long-term exchange rate assumptions;
- Long-term consumables price assumptions.

Other factors that can affect the estimates include changes to:

- Mineral resource input parameters;
- Constraining stope designs;
- Cut-off grade and NPR assumptions;
- Geotechnical (including seismicity) and hydrogeological factors;
- Supply of back fill material (e.g. rock tailings from concentrator);
- Metallurgical and mining recovery assumptions;
- Ability to control unplanned dilution;
- Ability to access the site, retain mineral, surface rights and water rights titles;
- Ability to maintain environmental and other regulatory permits, and maintain the social license to operate.

Specific factors that may affect individual estimates include:

- Coleman: increases in unplanned dilution as a result of overbreak of bulk stope shoulders; ability to manage any impact of historical onsite waste rock to surface and groundwater; impact of any potential mining-induced seismicity that would require discontinuing in-person entry mining methods and using bulk mining methods as the alternative; ability to use infrastructure from Glencore Canada's Fraser mine post closure of that mine in 2025, such that the Coleman Mine could no longer use Fraser #2 Shaft as a means of secondary egress, maintain/increase ventilation from the Fraser Mine fresh air raise, and underground dewatering;;
- Copper Cliff: impact of any geotechnical issues such as rockbursts; ability to manage any impact of historical onsite waste rock to surface and groundwater; potential metals leaching/acid rock drainage issues arising from historical stockpile areas;
- Creighton: ability to manage any impact of onsite waste rock to surface and groundwater; potential metals leaching/acid rock drainage issues arising from historical stockpile areas;
- Garson: impact of seismicity on operations; addressing the forecast arsenic head grade in mill feed over the LOM plan to alleviate any negative impact on planned production; impact of future mine closure on groundwater; ability to manage any impact of historical onsite waste rock to surface and groundwater; potential metals leaching/acid rock drainage issues arising from historical stockpile areas; geological and grade interpretations, mine designs, and mine recovery assumptions due to the structurally complex mine setting;
- Totten: ability to manage any impact of historical onsite waste rock to surface and groundwater.

To the extent known to the QP, there are no other known environmental, permitting, legal, title related, taxation, socio-political or marketing issues that could materially affect the mineral reserve estimates that are not discussed in this Report.

13 MINING METHODS

13.1 INTRODUCTION

The Ontario Operations use conventional bulk stoping or narrow vein cut-and-fill mining methods, depending on the mine and geological setting. Mines are Owner-operated, and use conventional equipment.

13.2 GEOTECHNICAL CONSIDERATIONS

13.2.1 GUIDANCE DOCUMENTS

Vale has technical guidelines and procedures in place to ensure that valid geotechnical data are collected and interpreted using appropriate methods, and that existing or planned risk mitigation measures which support mine designs are based on those data and interpretations. Documentation meets the requirements of Section 6 of the Regulation 854 for Mines and Mining Plants, under the Occupational Health and Safety Act of Ontario, R.R.O. 1990.

All underground mines must have an effective Ground Control Management Plan, also referred to as the “Mine Design Package”, which is a single coherent document that must be developed through application of sound geotechnical engineering practices, conform to local mining regulations, and be aligned with Vale’s safety standards. The document covers a wide range of technical topics, including geology; geotechnical information, mine arrangement, mining methods, ground control methods and support standards, ground control procedures, ground support quality control program, ground monitoring program, geomechanical evaluation, record keeping and communications, ground control training, mining-induced seismicity, geotechnical considerations in mine design and risk assessment and management. The Ground Control Management Plan is updated annually by a ground control engineer and annually reviewed and signed off on by the mine manager. This provides a robust basis for geotechnical evaluation, modelling and mitigation measures.

The Ontario Operations maintain a Seismic Risk Management Plan, which is designed to identify, assess and manage seismic hazards. All five operating mines were considered to be seismically active at the Report effective date, consisting of Coleman, Creighton, Copper Cliff, Garson and Totten. A Seismicity Review Board was established in 2017 with a five-year mandate to assess these operations. The Review Board assesses the effectiveness of controls in place at the mine to manage seismicity with external understanding of leading seismic management practices and procedures in the industry. Additional support can be provided when requested; for example, Vale could request the Review Board to examine causes and propose mitigations from large, high-risk seismic events if they occurred.

13.2.2 GEOTECHNICAL DESIGNS AND SUPPORT

Geotechnical data collection and rock mass characterization are used to define domains. For each domain, a simplified set of ground support requirements is specified for each categorized ground condition through the iterative process of support element selection, consideration of support system coherence, application of different design methods and local regulations. These ground support requirements also take into consideration, excavation size and shape, required life of excavation, stress conditions, proximity to present and future openings, personnel exposure, and local historical experiences.

Geotechnical assessments are completed to:

- Identify high stress zones;
- Evaluate the stability of major infrastructure;
- Assess the influence of major geological structures;
- Evaluate the stability of permanent pillars and other long-term excavations;

- Design optimal ground support systems to ensure the safety and stability of the excavations for the intended service life.

The results of geotechnical assessments are recommendations for vertical development, lateral development, and mining stopes, as well as the mine plan, which may have specific sequences of stope extraction. Old workings or natural voids are also considered where present.

For each mine, the mine's Ground Control Management Plan (see discussion in Chapter 13.2.1) sets out the considerations for the selection of ground support elements for various ground conditions including mine and service life, seismicity, corrosion potential and product characteristics. If shotcrete is applied at a mine, information on the types of material used (wet-mix, dry-mix, plain or reinforced) and the required thickness of application in different circumstances is incorporated into the document. The plan provides the justification process for the mine support standards and provides information on the selected pattern for each support category. It documents the scaling techniques used in each mine and related procedures. Standard development drilling and blasting patterns and their application with respect to various conditions and controlled perimeter blasting techniques are provided. The dewatering/depressurization requirements and methods are noted. Areas that routinely receive exceptionally high levels of ground support are recorded.

A complete ground support system for each mine consists of a series of activities and techniques such as scaling, local reinforcement (bolting), loose retention (meshing or strapping), shotcreting and cable-bolting. Primary support can include resin grouted rebar, friction and swellex bolts, and shotcrete. Secondary support is typically used for openings with a span of >7 m, and can consist of different elements such as cable bolts, Super-swellex bolts, strand-lok resin cables, and shotcrete arches and posts. Dynamic ground support systems (i.e., Par-1 dynamic bolts & #0 Gauge Mesh Straps) are installed in rockburst-prone and/or high seismic hazard areas.

13.2.3 BACKFILL

Either sand or mill rock tailings are used as a hydraulic backfill, with the type of fill materials dependent on the proximity of a mine to the Clarabelle Mill and the availability of proximal alluvial sand sources. The Copper Cliff and Creighton Mines use mill rock tailings, the Garson and Totten Mines use alluvial sands, and the Coleman Mine uses a mix of mill rock tailings and alluvial sands.

High-density (paste) backfill is only used at the Main area of the Garson Mine. Alluvial sand and silt from the Garson sand pit used in paste production, and the binder is 90/10 (slag/Portland cement). The stope plugs and body are poured at 26:1 (sand to binder) ratio, achieving a UCS of approximately 130 psi in 28 days.

13.3 HYDROGEOLOGICAL CONSIDERATIONS

Hydrological planning relies on historical norms and information. Most of the water that reports to the underground operations is from three sources: pumped in, surface runoff and ground water. A large percentage of a mine's process water is pumped in (approximately 50–70%); about 30–50% is derived from surface depending on the season, and only minor amounts are contributed from ground water. The exception is at the Garson Mine, where approximately 80% of pumped water is believed to be from groundwater ingress.

Water entering the mines from precipitation is minimal except for the Copper Cliff and Creighton Mines that have open pits/cave areas that are connected to the underlying working areas. Both mines have been in operation for many years, and have systems and procedures in place to handle these inflows.

Water management strategies for the mines are summarized in Table 13-1.

Table 13-1: Hydrological Considerations

Operation	Note	Comment
Coleman	Minor groundwater inflows. Primary water sources are process water from mining operations, water flow from seams intersected with core drilling, decant water from hydraulic fill and drainage from Levack Mine as per an agreement with Glencore.	Levack water is collected in a dam on 3600 level and piped across to the Coleman main sumps. Clear water is pumped through multi-stage pumps to surface and to Glencore's waste water treatment facilities. There is a risk to the LOMP if Glencore were to shut down their operations, and an alternative plan would have to be adopted in order to meet government guidelines.
Copper Cliff	Moderate groundwater inflows due to the direct connection of underground mine workings to the non-operational open pits on surface. Significant inflows during spring runoff as the ice and snow in the pits melt and travel underground. There is risk of exceeding the storage and pumping capacity of the mine during spring runoff and flooding operational areas of the mine. Deeper parts of Copper Cliff Mine have minor water inflow, with the majority of dewatering due to process water and backfill.	The north side of the mine's dewatering system includes a pump station on the 4,000 Level, a booster station on the 3,000 Level and the main pump station on the 2,200 Level. All mine water below the 2,000 Level is collected on the 4,000 Level and pumped to the 2,000 Level and collected in the 114 water stope. All water above the 2,000 Level is directed to the 114 water stope, which serves as a reservoir. Water from this water stope is pumped to surface via the main pump station. At the south side of the mine, water is collected in sumps at the 2,300, 3,250 and 4,000 Levels. Water from the lower levels is pumped to the sump on the 2,300 Level. From the 2,300 Level, water is pumped to surface. On surface, water from both sides of the mine is treated at the Copper Cliff Waste Water Treatment Plant prior to being released to the environment.
Creighton	Creighton is relatively dry, but can see influxes of water through the open pit during heavy rainfall or spring runoff. Most of the water is generated from backfill and drilling equipment.	Mine water is collected in main dirty water sumps located on the 1,900, 3,800, 5,400 and 7,000 Levels. Water below the 7,000 Level is collected on the 7,400, 7,940 and 8,200 Levels before being pumped to the 7,000 Level main sump. Solids are allowed to settle, and clear water is pumped to surface in stages. All mine effluent is captured and treated at a centralized area near the town of Copper Cliff before being released to the environment.
Garson	The Main part of the mine accessed via the shaft from surface receives minor to moderate amounts of groundwater throughout the year. A high density hydraulic backfill is used which introduces much less water into the Main mine than typical hydraulic backfill. The groundwater inflows in the Garson Ramp area of the mine are more significant due to it's proximity to surface.	The area below shaft bottom (4,000 Level) is dewatered by a series of intermediate sumps and pumping stations located on the 4,270, 4,600, 4,900 and 5,100 Levels. These pumps feed the main pump station located on the 4,000 Level at the shaft. Waste water is pumped from the 4,000 Level to the 3,000 and 1,000 Levels, and ultimately to surface. Approximately 750–1,000 k gallons of water are pumped out daily. Water is treated before being released into the environment.
Totten	The largest contributor to the water inflows is the hydraulic backfill. Drilling equipment is another key contributor. Groundwater inflows are minor and not impacted by seasonal changes.	The dewatering system design at Totten consists of two main sump stations and level settling sumps. The main sump stations are located on the 2,000 and 4,000 Levels; settling sumps are located on all main production levels. The main pumping station on the 2,000 Level discharges to surface at a rate of 800 gallons/minute. Water is pumped via the shaft up to the 2,000 Level and then from the 2,000 Level sump station up through boreholes to the 1,850 Level and then to surface.

13.4 MINE ACCESSES

13.4.1 COLEMAN

The primary access to the Coleman Mine is by the #1 Shaft and a series of internal ramps. In 1987, the #1 Shaft was deepened from the 2210 Level to the current shaft bottom at the 3450 Level. The Lower Coleman Mine is situated approximately 914 m south of the Upper Coleman Mine, at a depth of approximately 1 km. Ramp access is provided from 3370 Level to all active regions of the Coleman Mine via a 5 km ramp system stretching west from the Coleman #1 Shaft at the 3370 Level.

The main access drift and the conveyor drift are connected to the #1 Shaft at the 3370 Level and 3090 Level, respectively. The service ramp extends from 3370 Level to the 3575, 3770 and 3860 Levels. In parallel, the Kiruna haulage ramp extends from 3370 Level to the 3575 and 3770 Levels, and then splits into two branches below 3770 Level: the lower main haulage ramp which extends to the 4055 and 4215 Levels, and the 153 OB Kiruna haulage ramp.

There is also an emergency escape way from the 3575 Level via Glencore Canada's Fraser Mine 3600 Level track drift (the Fecunis escape way). This escape route was established in 2006, from the 3511 Level to Fraser Mine 3600 Level. The Fraser Mine is currently planned for closure in 2025. As a result, negotiations are underway to obtain use of the infrastructure upon Fraser Mine closure. This is envisaged as use of the Fraser #2 Shaft as a second egress, maintaining/increasing ventilation from the Fraser Mine fresh air raise, and underground dewatering.

13.4.2 COPPER CLIFF

The main mine is accessed via the #1 Shaft on the north side of the mine and via the main ramp on south side. The #1 Shaft has a level access approximately every 61 m (200 ft) at vertical intervals; however, only a few levels are connected to other parts of the mine via internal ramp systems. The main ramp system on south side is currently connected to north side workings on the 2050, 2400/2490 and 3400 Levels. The 114 orebody is accessed via the 114 orebody portal and ramp system from surface, and is not connected to either the #1 shaft or the main ramp system.

The current main egress for the south side is via the south portal and ramp systems, with egress raises constructed where required. The south shaft will become the main egress for the south side by mid-2022 when the conveyances are commissioned and transferred to the operations.

13.4.3 CREIGHTON

The main mine is accessed via the #9 Shaft with the shaft bottom being extended to about 37 m below the 7000 Level. There is a ramp system from surface to the 2600 Level at the #3 Shaft. As part of the escapeway, some connections were established between #9 Shaft and #3 Shaft ramp.

The #9 Shaft has level openings at approximately 61 m (200 ft) vertical intervals. Two internal ramp systems are available from the #9 Shaft. The upper ramp system is located between 3310 and 5400 Levels, while the lower ramp system is located between the 6600 Level and extends beyond the 8400 Level. The bottom of the lower ramp system is currently approaching 8460 Level. Vale is evaluating either deepening the #9 Shaft to reach the 10,000 Level, or developing an internal winze that would extend from the 7000 Level to the 10,000 Level.

13.4.4 GARSON

The Garson Main Mine is accessed via the 1,293 m (4,240 ft) deep Garson #2 Shaft while the Surface Ramp is accessed through a portal from surface, situated about 400 m west of the shaft collar. The main Level accesses from #2 Shaft are 3800 and 4000. The secondary means of egress for the Main Mine is through is a ladder system in the power raise from surface to 3400 Level. Access. Primary and secondary egresses from the bottom of the Main Mine on 5200 Level to 3400 Level are a combination of haulage declines and relatively short ladderway systems.

The Garson Main Mine and Garson Surface Ramp operations are physically connected on the 200, 400 and 600 Levels. The 200 Level has an escapeway to surface and serves as a secondary means of egress for the Surface Ramp operation. On the 400 Level of the Surface Ramp, access to the

Main Mine is via the 400 Level Track Drift. The 400 Level has a escapeway to the 200 Level. This level also serves as a secondary means of egress for the Surface Ramp. A third location as secondary means of egress between the Surface Ramp and the Main Mine is 660L and 790L escapeway drift. The 790 Escapeway drift is accessed from the 660 Level access drift on the Surface Ramp side and connects to the 600 Level main sill drift on the Main Mine side.

13.4.5 TOTTEN

The 1,260 m (4130 ft) deep #2 Shaft is the primary entry and exit point into the mine for personnel, materials and ore/waste.

The secondary means of egress is a ladder system from surface down to the 4530 Level. A ramp has been connected to shaft access levels on the 3850 and 3150 Levels and it serves as second egress for the workings between the 3150 and 3800 Levels. Apart from the shaft, ramp access now exists from the 4650 to 2330 Levels. When ramp development is completed, mine will have ramp access from the 1850 to 4630 Levels.

13.5 MINING METHODS

A number of mining methods are used across the Ontario Operations (Table 13-2). The Ontario Operations Mines each have a substantial history for which mining methods work best under various geological and geotechnical conditions. This experience combined with analysis was used to select the mining methods and stope sizes for the individual zones within each mine.

13.5.1 OPEN STOPING

This method is also referred to as blast-hole stoping, slot–slash stoping or sub-level open stoping. The stoping is done in a transverse or longitudinal orientation and is a bulk mining method.

The mining cycle begins with the development of a haulage drift parallel to the orebody strike or a sill drift through the ore. If required, crosscuts are then developed through the ore to the ore contact. Pillar widths are dependent on crosscut spacing and stope dimensions. Generally, stopes are divided in panels if the ore is >30 m thick, and are mined from hanging wall to footwall or vice-versa depending on the level configuration. Typically, bottom sill long wall slashes are required to create a void for blasting.

Slots are excavated in the form of drop raises. Production blast holes are drilled around the raise, and across the width of the entire panel in the slot drift. After the slot and production holes are drilled, they are blasted, usually in two to three blasts, to excavate the entire stope. Blasts are designed individually, based on the amount of void, and the location of the stope. Mucking is carried out with an 8 yd^3 load–haul–dump (LHD) vehicle equipped with remote-control capabilities. Following mining, the stope void is measured with a cavity monitoring system laser-based surveying tool.

Following surveying, the stope void is filled with backfill, typically consisting of a 10:1 cemented hydraulic sand fill plug at the bottom of the stope, followed by a cemented hydraulic sand fill body. Unconsolidated waste rock can be added to the body of the stope if permitted.

13.5.2 LONGITUDINAL STOPING

Longitudinal stoping is used in narrow portions of orebodies and in stopes adjacent to trap dykes. At the Totten Mine to avoid cross cuts through trap dykes, a footwall drift is developed through the trap dyke without any transverse cross cuts. The longitudinal sill is developed from the first cross cut after crossing the trap dyke within ore. In some cases, where the mineralization is very wide, two parallel sills can be developed to extract the entire width of the orebody. Stopes are very narrow, so that longwall slashes may or may not be needed in the bottom sill. Typically, stoping starts in the orebody extremity and retreats towards the main access.

Table 13-2: Mining Methods by Mine

Mine	Mining Method
Coleman	Slot–slash
	Mechanized post-pillar cut-and-fill
	Narrow vein cut-and-fill
	Uppers retreat
Copper Cliff	Vertical retreat mining/slot slash
	Uppers retreat
	Mechanized cut-and-fill Post-pillar Drift-and-fill
Creighton	Slot–slash
Garson	Slot–slash
	Uppers retreat
Totten	Slot–slash
	Mechanized cut-and-fill

13.5.3 TRANSVERSE STOPING

Most of the main ore body at the Totten Mine is mined using transverse primary–secondary stoping. Transverse stoping is also common at the Coleman, Creighton and CC Mines using a primary–primary sequence. A footwall drift is initially developed parallel to the strike of the ore body. Cross cuts or ore sills at 12–15 m intervals are developed normal to the footwall drift and cross cuts extend up to the hanging wall contact of the orebody. Bottom sill longwall slashes are required to completely recover the ore in the bottom sills. All of the production drilling is done from the top sills. Generally, where the orebody width is >30 m, the panel is divided into two stopes, one on the hanging wall side and one on the footwall side.

13.5.4 SLOT–SLASH MINING

Slot–slash mining is a bulk mining method that entails blasting vertical slices of ore to a free face, which initially will be a blasted inverse raise, or a bored raise. The amount of ore that can be blasted at any given time is limited to the existing void space and the available free face. Blastholes are loaded with staggered decks to break anywhere from 6 m to the entire length of the hole. The blocks are slashed out to the stope boundaries and up to a crown. The final crown is taken in one blast.

This method concentrates loading and blasting operations, and, once a slot has been established, stopes of 25,000–40,000 t of ore can be completely broken in 3–5 separate blasts, while smaller stopes can be blasted in one blast.

Blastholes are drilled using in-the-hole (ITH) drills. Prior to blasting, long blastholes are surveyed in order to determine their location and all holes are probed with a conductivity probe to confirm ore limits. If required, new holes are drilled to reduce burdens created by drilling inaccuracy and to blast additional ore found during the conductivity tests.

Slot–slash mining maximizes the availability of broken ore and increases the efficiency of stope service operations without compromising muck (waste) fragmentation. The walls of the stope are also supported for a greater period of time through the blasting and mucking cycle, improving stope stability and minimizing issues related to ground control.

The method is used in both transverse and longitudinal orientations. Following the removal of blasted ore by remote-controlled LHDs, the stope is filled with consolidated backfill.

13.5.5 VERTICAL RETREAT MINING

With vertical retreat mining, a bulk mining method, stopes approximately 15.2 x 15.2 m in plan by 36.6 x 61 m in vertical extent are blasted in 3 m horizontal slices up to a crown. The final, typically 9 m, crown is taken in one blast.

Holes are drilled using ITH drills. Prior to blasting, long blastholes are surveyed in order to determine their location and all holes are probed with a conductivity probe to confirm ore limits. If required, new holes are drilled to reduce burdens created by drilling inaccuracy and to blast additional ore found during the conductivity tests.

Inverse-crater blasting is employed. Detonation of up to 25–30 similarly-loaded blastholes in a timed sequence generates approximately 1,500 t of broken ore per blast.

Holes are typically initiated using non-electric (NONEL-type) detonators; however, electronic detonators are also used to minimize blast vibrations in areas that are close to surface and/or in large crown pillar blasts.

The method is used in both transverse and longitudinal orientations. Following the removal of blasted ore by remote-controlled LHDs, the stope is filled with consolidated backfill.

13.5.6 UPPERS RETREAT MINING

With the uppers retreat mining method, a bulk mining method, uppers blastholes (blastholes drilled upwards at typically between 60–90º) are drilled to recover ore where top-sill access is not available, or where the height of ore is insufficient to warrant ITH drilling for slot–slash or vertical retreat mining. This method is also useful for removing ‘ore-skins’ (thin layers of ore left remaining below previously-mined stopes).

Drill rings are established by fanning up-holes from the sill back, dipping towards the slot void, which is typically established by standard raising or raise boring or in the absence of a raise the rings are “wagon wheeled” such that they progressively steepened to create the initial down break or void.

Following the removal of blasted ore by remote-controlled LHDs, the stope is filled with consolidated backfill.

13.5.7 MECHANIZED CUT-AND-FILL

Mechanized cut-and-fill is used for flat-lying and narrow-vein deposits that are not suitable for bulk blasthole mining. Two distinctive types of mechanized cut-and-fill mining methods are used. The first is a narrow-vein approach whereby a set of sequential cuts 2.7–3.7 m high are mined with small equipment (i.e., one-boom drill jumbos, 3 yd^3 LHDs and rock bolting using hand-held drills such as jacklegs and stopers). Depending on the width of the vein, it is mined in one pass (narrow vein) or with multiple passes (drift-and-fill). With these methods, over-hand mining is the most common approach, but under-hand mining is also used. For larger flat-lying zones post-pillar cut-and-fill is used, with the cuts at approximately 6 m high and varying from 6–9.8 m in width. Regularly sized and spaced pillars are left to support the openings. The pillars are either post- or rib-type and generally are not recoverable. Both approaches extract the ore in horizontal slices over the entire deposit strike length then are backfilled before the next slice is mined. Production drilling is done with Jumbo drills.

Backfill is a combination of unconsolidated rock fill placed by the LHD into the empty cut as tight to the back as possible, and/or sand fill.

13.5.8 POST PILLAR CUT-AND-FILL

A post pillar cut-and-fill method is used for wide ore zones, with great vertical extent. Access ramps are driven from the main ramps and footwall drifts to the ore zones, initially at a negative grade and the ore is mined upwards on successive cuts. There can be as many as five cuts from the same access. For each successive mining cut within the ore, the back of the access ramp is slashed to grade. The ore is extracted by advancing development rounds, to mine a series of horizontal slices or cuts of ore, using the down-breasting technique. Some ore is left behind to form ribs and/or post pillars to control back stability. Each heading is mined in a drill–blast–muck-support mining cycle. Rock fill from waste development and sand fill from surface are used for backfilling; cemented sand fill is placed as required to form the floor for the next cut. The headings are developed using two-boom electric hydraulic jumbo drills, and rock bolters are employed for the ground support cycle.

13.5.9 NARROW VEIN CUT-AND-FILL

A narrow vein cut-and-fill method is used in zones that host complex ore veins and stringers, with irregular widths and dips. Ore is extracted by mining a series of horizontal slices or cuts, and each heading is mined in a drill-blast-muck-support mining cycle. Rock fill from waste development and cemented sand fill from surface are used for backfill. Mining blocks are divided into 33 m vertical intervals and connected by ramps and raises. Levels are divided into mining blocks for mining flexibility. Accesses are driven from the main ramps and footwall drifts to the ore zones and the ore is mined upwards in successive cuts. The access ramps and other development headings are driven using two-boom jumbos and Maclean bolters. In the narrow ore vein headings, single-boom jumbos are used for development in the ore, while stopers and jacklegs are used to install ground support. Fletcher bolters are used to bolt narrow vein headings. Some narrow veins are being mined with fully mechanized equipment due to the high stress conditions in the sill pillars and to help with mining flexibility.

Where veins are >8 m wide, they are mined using multiple passes, using a drift-and-fill sequence or are extracted using shotcrete posts. The drift-and-fill method entails advancing simultaneously in a direction parallel to the strike of the orebody, several (i.e., typically three) parallel primary headings that are separated by rib pillars. Once the primary headings are mined and backfilled, the rib pillars separating these headings are mined as secondary headings. Mining follows the narrow veins up dip and is done towards the east and west, from each access drift. The narrow vein cut-and-fill production headings are normally mined to the width of the ore vein.

13.6 BLASTING AND EXPLOSIVES

The types of explosives used, and blasting procedures vary depending on the mining method.

For blast-hole stoping, 7.6–15 cm diameter blastholes are charged with a combination of ANFO/gel products and/or emulsion while NONEL-type detonators with boosters are used to initiate the blasts. The use of digital electronic initiation systems (Orica–IKON) is also increasingly used to reduce vibration, and thus minimize wall damage that can cause dilution.

For mechanized cut-and-fill mining, blastholes typically 4.3 cm diameter by 3.7 m long are pneumatically loaded with ANFO, primed with NONEL-type detonators, hooked up with blasting cord, and initiated with electric caps.

13.7 ORE CONTROL

Ore control procedures include geological mapping, production blasthole conductivity probing, stope grade calculations or post-probe block modelling and stope grade calculations, and stope block laser scan (cavity monitor surveys) reconciliations. Vale has established standard operating procedures for grade control that are used at all of the mines.

13.8 ORE AND WASTE HANDLING

Ore and waste handling varies by operation.

13.8.1 COLEMAN

Ore is transported by LHD equipment and diesel haulage trucks from the primary locations or storages to internal ore passes. From these ore passes, ore is hauled to the muck circuit by 45 t (50 ton) capacity Kiruna electric haulage trucks.

Crushed ore is conveyed from the underground crusher to the Coleman #1 Shaft, where it is hoisted to surface by two 17.2 t (19 ton) skips operating in balance. The shaft has a rated hoisting capacity of 502 tons/hr.

On surface, ore is transported by 36 t (40 ton) highway trucks to a load-out at the rail head, for stockpile and rail transportation to the Clarabelle Mill.

Waste rock is used as rock fill in mined-out areas. Rock is therefore re-handled underground and not hoisted to surface, although waste rock hoisting will be required in the future due to increased waste development activity and fewer cut and fill areas available for disposal of waste fill.

13.8.2 COPPER CLIFF

Ore and waste rock are mucked using LHDs and handled at the North Shaft as follows:

- Muck is initially dumped in central loading areas, where it is subsequently loaded into 27 t trucks;
- Ore is trammed to the 2639 ore pass (on the 2,600 and 3,400 Levels) or dumped directly into the crusher (on the 3,935 Level);
- Crushed ore is hoisted to surface through #1 Shaft in 13.6 t skips that have a capacity of 270 t/hr;
- Ore is then trucked to surface stockpiles for blending with other ore sources to meet milling requirements.

The majority of waste rock is used underground as fill, while some is projected to be hoisted to surface. Currently the two main production constraints are trucking capacity and ventilation requirements.

The following system is being commissioned at the South Shaft and will be operational in 2022:

- Muck will be loaded by LHD into 27 t and 36 t trucks and hauled to the 3930 Level;
- On 3930L there will be a truck dump with rock breaker and grizzly that will feed a 180 t coarse ore bin, and two storages with 907 t capacity each. A LHD will feed the truck dump between truck loads and operate between shifts (automated from surface) to maintain inventory in the bin. The coarse ore bin will feed a crusher on the 4000 Level;
- Crushed ore will be hoisted to surface through the South Shaft in 16.3 t skips that are rated for 390 t/hr;
- On surface there will be a 1362 t load out bin and 317 t rock bin.

13.8.3 CREIGHTON

Division 6 ore is mucked by LHD to internal ore bins or re-muck storage on each of the main production levels. The ore is then trucked up a ramp from the ore bins or storage areas, using a mixed fleet of electric and diesel trucks, to the truck dump at the 6,970 Level. Material is then fed through the 7,000 Level crusher, and to the 6,680 Level loading pocket, via a conveyor.

All ore is hoisted up #9 Shaft, using a 7,000 HP double drum hoist and two 14.5 t (16 ton) aluminum skips. The skipping rate from the 5,280 Level loading pocket is about 336 t/hr (370 tons/hr), while the deeper 6,680 Level loading pocket can be skipped at 279 t/hr (308 tons/hr). All personnel and materials access the mine via the #9 Shaft cage.

Waste rock brought to surface via the hoist is handled through the ore system (i.e. crusher, bins, belts etc.). However on surface it is directed into a different chute than the ore.

13.8.4 GARSON

Ore and waste rock is mucked using LHDs to re-muck storages on each level and loaded into 45 t (50 ton; common) or 27 t (30 ton; less common) diesel trucks. Ore is hauled up the ramp and dumped into a storage bin from where it is loaded through a chute into rail cars. The ore is then trammed by rail along the 4,000 Level and into another chute feeding a crusher. Crushed ore is hoisted to surface via No. 2 Shaft in 10 t (11 ton) skips that have a capacity of 231 t/hr (255 tons/hr).

The majority of waste rock is used underground as fill, though some hoisting of rock does take place. Waste rock is loaded into 45 t (50 ton) diesel trucks by LHD and hauled up the ramp for hoisting to surface through the #2 Shaft in 9 t (10 ton) skips or disposed as fill into nearby open stopes

The Garson Ramp mining zone hauls ore and waste from underground in 36 t (40 ton) trucks via ramp to surface for shipment to the mill or disposal. Production capacity is approximately 454 t/day (500 tons/day).

13.8.5 TOTTEN

The main haulage level is the 3,800 Level. An ore pass links the 1,850 Level down to the 3,800 Level. The ore circuit also involves the trucking of material from below the 3,950 Level for dumping into an ore pass on the 3,800 Level. The crusher is located below the 3,850 Level and is ramp-accessible. The rock breaker is equipped for remote control operation, and the crusher is automated. Crushed ore is hoisted to surface via 16.3 t (18 ton) skips (over cage arrangement) with a capacity of 272 t/hr (300 tons/hr).

The waste rock circuit is equipped with truck-loading chutes to transport the waste rock from mining above. The waste pass extends from the 3,150 Level down to the 3,800 Level. Waste rock is also hoisted via the skip through the rock handling system.

13.9 UNDERGROUND INFRASTRUCTURE FACILITIES

13.9.1 MINE MOBILE EQUIPMENT MAINTENANCE

The underground mines use a combination of underground maintenance facilities of varying sizes and capacities. These shop areas are equipped with the necessary tools and equipment to service large industrial rock moving and drilling equipment. Most of the mobile equipment repairs are completed at these permanent facilities while smaller repairs can be done in the field by trained mechanics.

13.9.2 COMMUNICATIONS

The underground mines are equipped with leaky feeder communication in most underground work areas, with all employees being equipped with two-way radios. The surface buildings and underground refuge stations have wired telephones. Underground communications are linked to surface through fibre optic broadband systems. Totten Mine is equipped with Wi-Fi in most underground workings.

13.9.3 LOGISTICS AND SUPPLIES HANDLING

All mine supplies and personnel are transported underground via the mine hoisting shafts (with the exception of the Garson Ramp and Copper Cliff portals). This would include everything from employees to ground support products, fuel, safety supplies and explosives. The materials can either be loaded on a timber rail car or be handled with a mobile forklift. Once the material has arrived at the underground destination Level it is unloaded from the cage, and eventually brought to underground supplies storage locations with a boom truck or forklift.

13.9.4 VENTILATION

The mine ventilation systems are summarized in Table 13-3.

13.9.5 COMPRESSED AIR AND PROCESS WATER

Each of the mines uses compressed air and process water for numerous mining related activities such as drilling, dust suppression, and fire sprinklers and to operate some equipment such as pumps, ore-pass gates, and mining equipment. Each plant is structured in a similar fashion to provide compressed air and water services to the mining areas.

Table 13-3: Ventilation Systems

Mine	Ventilation Capacity (kcfm)	Ventilation System	Comment
Coleman	1,600	Two fresh air and two return air systems	As part of the Bowtie agreement with Glencore, an additional 400 kcfm of fresh air is supplied to Coleman from the Fraser Mine infrastructure. In return, the Ontario Operations accommodates 200 kcfm of the exhaust air from Fraser.
Copper Cliff	3,200	North-side and south-side ventilation supply each consisting of three separate fresh air and return sub-systems	
Creighton	1,700	Three parallel fresh air systems; one return air system	
Garson	1,050	One major fresh air system; four return air systems	The Garson Ramp circulates 300 kcfm.
Totten	685	One major fresh air system; one main return air system	

Large compressors situated on surface create the necessary air volumes at required working pressures (~80–120 psi). Varying diameter pipes are hooked up to the compressors and are directed underground through a shaft. A series of pipes then direct the compressed air to all active working areas. In areas where the permanent feed is insufficient or cannot be accessed, free-air compressors are used.

Process water is sourced from a suitable surface supply as well as from recycled process water from the underground workings. Similar to compressed air, the process water supply originates from a location on surface and is delivered underground through a network of pipes that are directed throughout the underground work areas.

13.10 PRODUCTION SCHEDULES

Each mine developed a production schedule that contained production and cost information for every producing area within the mine, based on mineral reserve estimates. Production schedules were limited by process and infrastructure constraints such as ventilation, drift development, blasthole drilling, LHD/haulage, backfilling, and muck circuit/storage. The assemblage of mining process activities are used to derive costs based on historical and budgeted rates.

These plans were collated into an overall production schedule for the Ontario Operations Based on this schedule, the forecast mine life is 22 years (2022–2043).

13.11 EQUIPMENT

Vale has a large fleet of mobile equipment consisting of approximately 650 units distributed between the operating mines depending on each mine’s operational requirements. The number of units for each mine changes over the LOM as development and production rates and haulage distances vary on an ongoing basis.

The total production and development fleet consists of over 200 units, consisting of production drill jumbos, development jumbos, LHDs, haulage trucks, and specialty vehicles to load explosives.

Drilling equipment is selected to suit the mining methods with bulk mining; down-hole drill units being the most predominant blasthole drilling equipment. The ITH drills use booster compressors to provide high pressure compressed air for higher penetration speeds and typically drill production blastholes of either 11.4 cm or 15 cm diameter. For up-hole blastholes, electric hydraulic top-hammer drill rigs are used typically drilling 8.9 cm (3.5 inch) diameter blastholes. For mechanized post-pillar cut-and-fill mining, two-boom electric hydraulic drill jumbos are used, and for narrow-vein cut-and-fill, one-boom jumbos are used. Specialized vehicles are used to load either ANFO or emulsion-type explosives.

Loading equipment includes both 7.2 t and 9 t (eight ton and 10 ton) capacity LHDs, although Totten has some 5.4 t (six ton) units. Smaller 2.3–3.2 t (2.5–3.5 ton) LHDs are used as utility vehicles in all the mines.

Haulage equipment includes 27 t, 36 t, and 45 t (30, 40 and 50 ton) capacity haulage trucks. Coleman Mine has six 45 t (50 ton) capacity electric trolley trucks working on a truck-priority haulage ramp.

The support equipment fleet consists of over 430 units including rockbolters, scissor lifts, shotcrete sprayers, shotcrete and cement transporters, mobile rock breakers, utility trucks with hydraulic lifting booms, graders, rail locomotives and rail ore cars, backhoes, personnel vehicles including small tractors, jeeps and personnel carriers, and other trucks used for transporting materials such as fuel trucks.

13.12 PERSONNEL

A total of 2,190 personnel support the mining operations.

14 PROCESSING AND RECOVERY METHODS

14.1 PROCESS METHOD SELECTION

The process plant design was based on a combination of metallurgical testwork and familiarity gained during historical processing. The Clarabelle Mill was originally built in 1971 and subsequently underwent a number of major modifications. The hourly design throughput of the plant was based on a yearly throughput of approximately 8 M tons. The utilization calculation was that the plant would operate 350 days per year, with an availability of 92%, for a net utilization of 88.2%. In 2017, the crushing plant and rod mill circuit was put on care and maintenance and the Clarabelle Mill became a SAG-only operating plant. The yearly throughput based on SAG-only operation is approximately 6.0 Mt.

At the concentrator, the ore is crushed and ground and fed to the froth-flotation cells. The multi-staged froth flotation separates the sulphide minerals into a nickel concentrate and a copper concentrate. The tailings are disposed of in tailings ponds. The nickel concentrate typically averages 11% Ni and 4% Cu . The copper concentrate typically averages 31.5% Cu and 0.4% Ni. The plant is operated in such a way to place as much copper into the saleable copper concentrate as possible, then recover remaining copper and maximum possible nickel into a high-grade nickel–copper bulk concentrate to maximize the product NSR values.

The copper concentrate is dewatered by two pressure filters and shipped to market buyers. The nickel–copper bulk concentrate is dewatered at the smelter, and upgraded to Bessemer matte by processing through fluid-bed dryers, flash furnace, and Pierce–Smith converters. The magnetic metallics (containing nickel, copper, and precious metals) are sent to the Copper Cliff Nickel Refinery. The nickel sulphides are roasted in a fluid-bed roaster to produce nickel oxides which are then sent to the Copper Cliff Nickel Refinery or the Clydach Nickel Refinery in Wales.

The Copper Cliff Nickel Refinery complex includes three areas: nickel refinery converter (NRC), Inco pressure carbonyl (IPC) and electrowinning (EW). Nickel sulphides and oxides from the smelter complex and other feeds are blended and fed to top blown rotary converters, which produce a high-grade nickel matte. This matte is granulated, dried, and fed into one of three carbonylation reactors in the IPC, where nickel and trace iron are extracted by reaction with carbon monoxide. The mixture is separated into a pure nickel carbonyl stream and an iron/nickel carbonyl stream. Material from both streams is decomposed at high temperature to produce pure nickel pellets, pure nickel powders and ferro-nickel pellets, which are sold directly to market. The residue left in the reactor, high in copper, cobalt and precious metals, is ground and pumped to the EW plant as a slurry.

In the EW process, copper is removed from IPC residue. Copper cathodes are plated from solution and sold to market. Three other products are made at EW: a nickel–cobalt carbonate slurry, a slurry-rich in precious metals containing platinum-group metals, silver and gold and a slurry enriched in platinum-group metals and selenium–tellurium. These are sent to Port Colborne for further processing.

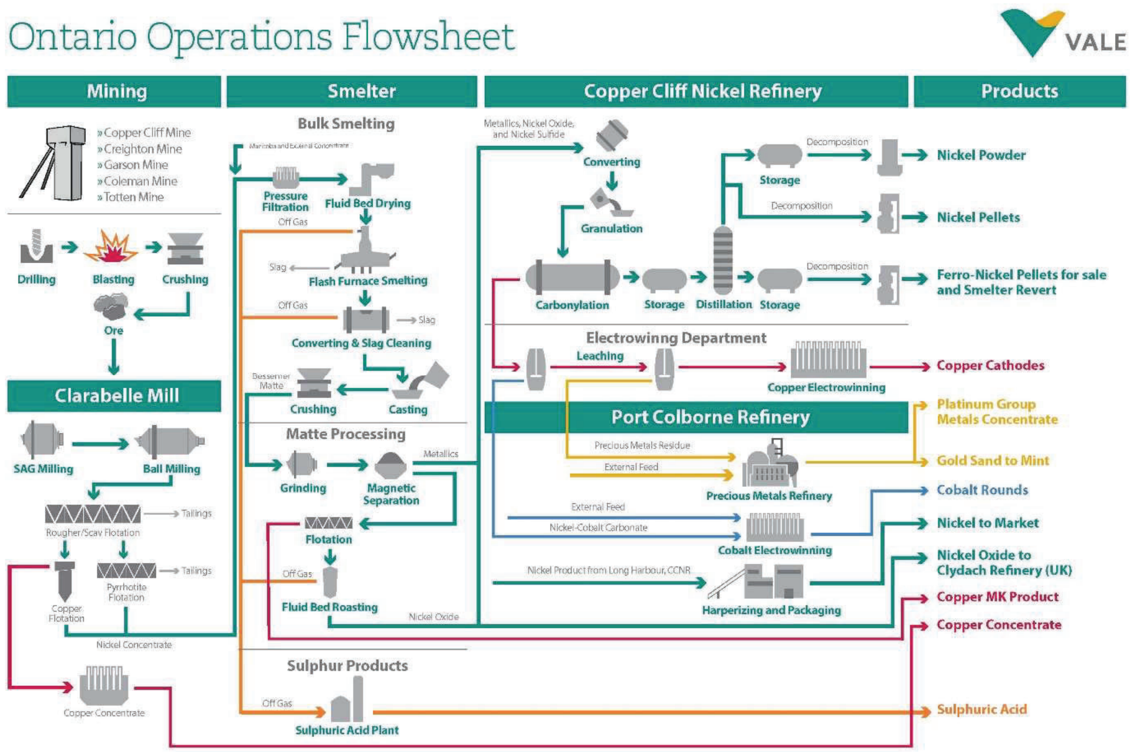
An overview of the process flowsheet from the mill to smelter and refinery is provided in Figure 14-1.

14.2 PROCESS PLANT

14.2.1 FLOWSHEET

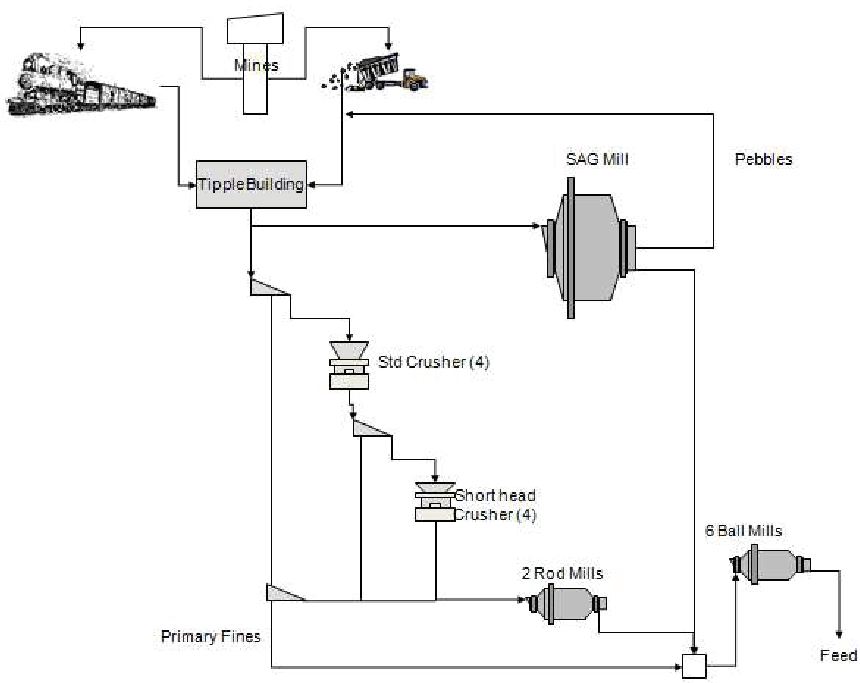
A simplified process flowsheet is included as Figure 14-2 and Figure 14-3.

Figure 14-1: Process Overview Flowsheet



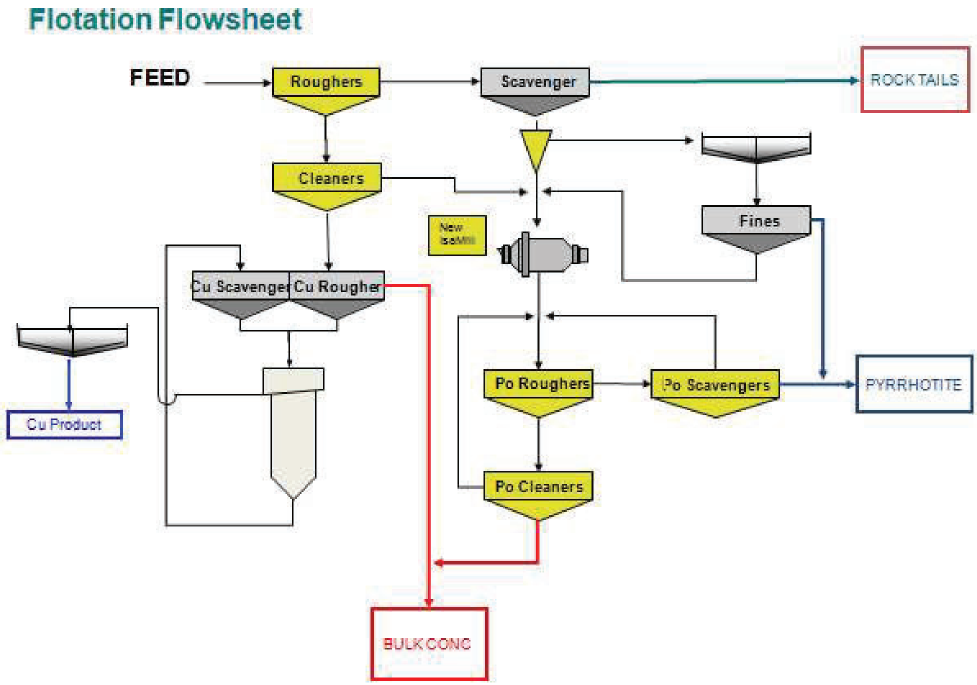
Note: Figure prepared by Vale, 2020.

Figure 14-2: Simplified Comminution Flowsheet



Note: Figure prepared by Vale, 2015.

Figure 14-3: Simplified Flotation Flowsheet



Note: Figure prepared by Vale, 2015.

14.2.2 PLANT DESIGN

Ore is transported from the Ontario Operations mines and third-party feed suppliers by rail and/or truck to the Clarabelle Mill where the material is blended. From the tipple building, feeders send the material along one of two comminution paths:

- Circuit 1: Most of the ore feeds the semi-autogenous grind (SAG) mill where ore is ground with added water. Discharge passes through a trommel; coarse trommel oversize material is transferred back to the tipple building by conveyor, while the trommel undersize is pumped to vibrating screens located near the feed of the SAG mill. Screen oversize is fed back into the SAG mill while the screen undersize is pumped to the ball mill feed distribution pumping system;
- Circuit 2: Material from the tipple building is fed into a fine crushing circuit. This circuit consists of primary screening, four secondary (in closed circuit with screens) and four tertiary crushers. Product from this circuit feeds two rod mills.

Product from both primary grinding circuits (SAG and rod mills) feeds the ball mill feed distribution system, which can send slurry to the cyclone feed pumpboxes of six ball mills. Each ball mill in combination with its own cyclone system grinds the material to a target of 80% passing 106 µm. Once the material is ground to the correct size, the slurry is sent to flotation.

Material entering flotation passes through the rougher circuit which recovers most of the copper and a high proportion of the nickel to a mixed bulk concentrate. This concentrate is sent to the rougher cleaners. Rougher tails material is sent to the pyrrhotite separation circuit via the pyrrhotite regrind circuit. Cleaner concentrate is sent to the copper roughers which in turn provide a concentrate to the copper cleaners. The copper cleaners produce a saleable copper concentrate while the tails from the copper cleaners return to the copper roughers. The copper rougher tails are a mixed high-grade nickel–copper concentrate which is sent to the Sudbury smelter complex for further processing.

The rougher tails contain both nickel and pyrrhotite minerals. This material is processed in the scavengers which produces a scavenger concentrate and a final rock tailings which can either be sent to the paste backfill plant or to the tailings storage facility (TSF). The scavenger concentrate is sent to cyclones which separate out a coarse fraction and a fine fraction.

The fine fraction is thickened and then flotation is performed to create a fines concentrate. This fines concentrate is combined with the rougher cleaner tails and combined with the rougher coarse fraction and sent through a regrind circuit. The product of the regrind is sent to the pyrrhotite roughers and scavengers. The pyrrhotite rougher concentrate is cleaned through cleaning columns and joins the high-grade nickel–copper concentrate being sent for processing in the smelter complex. The pyrrhotite scavenger concentrate is recirculated to the head of the pyrrhotite feed. The pyrrhotite tails are sent to the TSF for disposal.

In total, two concentrate products and two tailings streams are produced. The two different concentrates reporting for sale or to the smelter are:

- A high-grade copper concentrate grading approximately 31.5% Cu and 0.4% Ni;
- A nickel–copper concentrate grading approximately 4.0% Cu and 11% Ni.

The tailings (rock and pyrrhotite) contain most of the gangue minerals, and report to either the backfill paste plant or the TSF.

The copper concentrate is sold to market while the nickel–copper concentrate is dewatered, mixed with custom concentrate feed and high-grade silica flux and conveyed to the smelter.

14.2.3 EQUIPMENT SIZING

The key equipment in the Clarabelle Mill is summarized in Table 14-1.

14.2.4 POWER AND CONSUMABLES

The power consumption for the Ontario Operations is described in Chapter 15.9.

Consumables in the process plant include grinding media, frother, sodium cyanide, flocculant, lime, xanthate, electrical materials, lubricants, and maintenance supplies.

Water for process and potable needs is sourced from the Vermilion River, or is recycled from the plant. Average water consumption is approximately 327,000 m^3. This level of water consumption is projected to remain approximately the same for the duration of the LOM.

14.2.5 PERSONNEL

A total of 120 persons are employed at the Clarabelle Mill.

14.3 REFINERY/SMELTER

14.3.1 FLOWSHEET

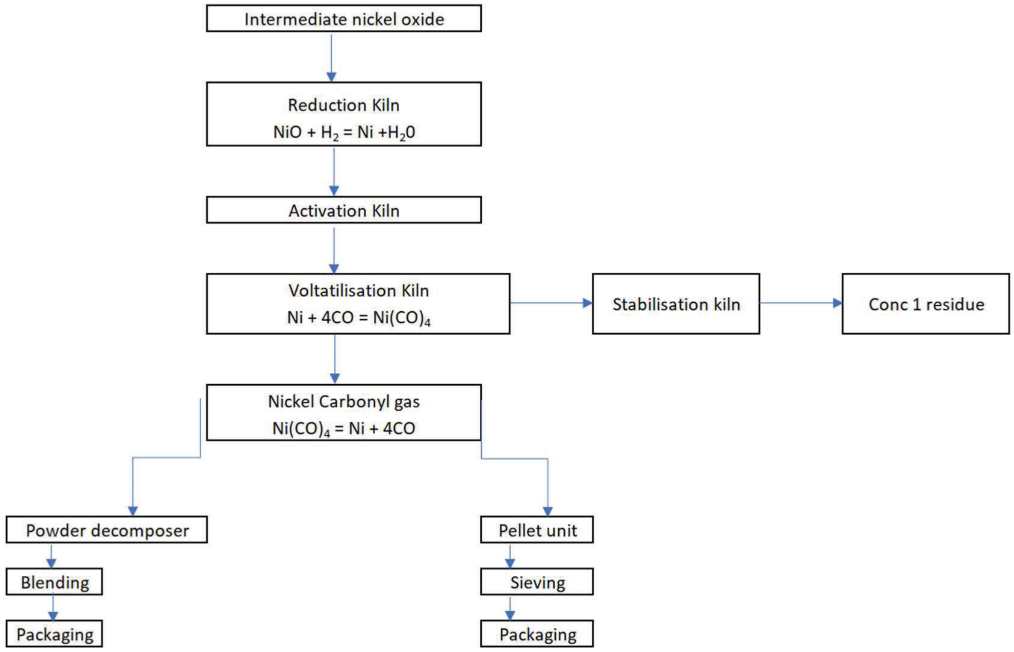
A simplified process flowsheet for the Ontario Operations was included as Figure 14-1. Figure 14-4 is a simplified flowsheet for the Clydach Refinery. An illustrated schematic of the flowsheet for the Copper Cliff Nickel Refinery is included as Figure 14-5.

Table 14-1: Key Equipment, Clarabelle Mill

Area	Equipment	Number	Note	Comment
Ore discharge	Holding bin	1	25,000 tons (22,700 t)	Ore is received at -6 inch (-152 mm)
	Conveyor belts	2	48 in. x 1,900 ft (1.22 x by 579 m)	
	Coarse ore bin	1	2,500 tons (2,270 t)	
SAG circuit	SAG feed bin	1	8,800 tons (8,000 t)	
	SAG mill	1	32 ft dia. by 13.5 ft long (9.75 m by 4.11 m)	The SAG mill processes 785 st/hr (700 t/hr) ore on average, net of pebble production. Control of the SAG mill is through a Foxboro DCS. The mill employs a SAG Expert system for process control.
	Ball size		5 in (127 mm)	
	Mill speed		8.2–10.8 rpm	
	Critical speed		79% max	
	AC drive motor	2	5,500 hp (4,100 kW) variable speed	
	Shell liners		3 x 13 inch (76 mm by 330 mm) with integrated lifters.	
	Discharge grates		2 inch (51 mm) slots with an open area of 256 sq. inch (0.16 m^2)	
	Rubber panels		0.75 in. wide by 2 in. (16 mm by 51 mm) slots.	
	Pebble bin		400 tons (363 t)	Approximately 12% of the SAG mill feed is removed as pebbles.
	Tramp metal magnetic separator	2		
	Double-deck, vibrating screens	2	8 ft by 24 ft (2.43 m by 7.31 m)	The upper polyurethane deck has 0.25 inch (6 mm) wide slots while the lower deck has 0.125 inch (3 mm) wide slots.
Ball mill grinding circuit	Ball mill	5	13 ft 6 inch dia. by 18 ft (4.11 m by 5.49 m)	SAG feed is distributed to any one of five ball mills via a six-way pressurized distributor. Targets P80 of 150 µm. Particle size is analyzed by an on-stream, particle size monitor
	Ball size		2.5 in (63 mm)	
	Mill speed		17.3 rpm	
	Critical speed		83%	
	Motor		2,000 hp (1,492 kW)	
	Cyclones	5	20 in. (0.0.51 m)	Operated in closed circuit.
Primary flotation circuit	Rougher flotation cells	2 parallel banks of 5	100 m^3 tank cell volume	Total 1,000 m^3
	Scavenger flotation cells	6 parallel banks of 8	1,350 cu. ft. (38 m^3)	Total 228 m^3

Area	Equipment	Number	Note	Comment
	Rougher cleaner	2 banks of 7 cells	20 m^3 tank cell volume	Total 280 m^3
Copper circuit	Conditioning tanks			
	Copper rougher	Nine 20 m^3 flotation cells		
	Copper cleaner	Four columns		The number of columns in operation at any given time is driven by the amount of copper concentrate recovery required to obtain the desired Cu:Ni ratio in final nickel concentrate based on the smelter needs.
Copper concentrate dewatering and storage	Thickener	94 ft. dia. (28.2 m)		
	Filter presses	Two	Larox vertical filter presses	
Pyrrhotite regrind circuit	Regrind mills	Two	Two 13 ft 6 in. dia. by 18 ft. long (4.11 m x 5.49 m) ball mills. 2,000 hp (1,492 kW) motor. Operate at 83% of critical speed.	Closed circuit. Product grind target of P80 of 60 µm
		Cyclones	One ball mill has a nest of seven 5-inch (0.13 m) cyclones and the other has 16 10-inch (0.25 m) cyclones	
		One	Isamill	Open circuit
		Cyclones	Nest of six 15 inch (0.38 m) cyclones	
Pyrrhotite rejection circuit	Rougher flotation tank cells	2 rows	Each with three 100 m^3 cells	
	Scavenger flotation tank cells	2 rows	Each with two 100 m^3 cells	
	Cleaner columns	3	4.5 m diameter	
Concentrate dewatering & storage	Thickeners	4	110 ft dia. (33.5 m)	
	Concentrate storage tanks	4		Provide concentrate surge capacity between the mill and the smelter when there is an imbalance between what the mill produces and what the smelter can take in as feed
Water treatment plant	Clarifloculators	2	135 ft dia. (41.1 m)	

Figure 14-4: Simplified Flowsheet, Clydach Refinery



Note: Figure prepared by Vale, 2021

Figure 14-5: Schematic Flowsheet, Copper Cliff Nickel Refinery

Note: Figure prepared by Vale, 2020.

14.3.2 DESIGN

14.3.2.1 COPPER CLIFF SMELTER

Bulk concentrate is sent from the Clarabelle Mill to the Copper Cliff Smelter. The concentrate is dewatered in a filter plant. The 20 wt% Cu–Ni–Co concentrate is fed to an INCO flash furnace, and is blown with oxygen burners located on opposite end walls of the vessel. Silica is added as a flux to ensure immiscibility of nickel sulphide-rich matte and iron oxide-based slag. Once the target matte level is reached the matte is tapped and sent to converters. The furnace slag is removed, and sent to a slag storage facility. Sulphur dioxide from the flash furnaces, converters, and fluid bed roasters is fixed and sold as sulphuric acid.

Removal of the remaining iron in the matte is accomplished by the use of Peirce-Smith converters. Charging of the converter occurs when matte is poured into the vessel through an opening in the top. The molten matte is blown with oxygen-enriched air to remove the remaining iron and silica flux is added to produce a slag. Sulphur dioxide is generated during the process. The converter slag is skimmed and returned to the flash furnace to recover oxidized cobalt and nickel prior to disposal. The Bessemer matte produced in the converter is subsequently cast into moulds and slow-cooled to produce a coarse crystal structure. The Bessemer matte is crushed, ground, and separated into metallic, nickel sulphide and copper sulphide materials by magnetic separation and flotation in a matte separation plant.

All of the precious metal-bearing metallic material is sent to the Copper Cliff Nickel Refinery. The nickel sulphide is roasted in fluid bed roasters. The resulting nickel oxide is processed in the Copper Cliff Nickel Refinery and the Clydach Nickel Refinery. Sulphur dioxide from the roasters is fixed as sulphuric acid.

Copper sulphide from matte separation is filtered and sold to market.

14.3.2.2 COPPER CLIFF NICKEL REFINERY

There are three main facilities at the Nickel Refinery: the nickel refinery converter plant, the Inco pressure carbonyl plant and an electrowinning building.

At the nickel refinery converter plant, feed input (nickel sulphide crudes, nickel–copper metallics, nickel oxides, precious metal-bearing intermediates and refinery intermediates, and fluxing agents) are charged into two top blown rotary converters, and melted using natural gas-oxygen lance burners. Once the temperature of the bath has reached approximately 1,600ºC, petroleum coke is added to reduce the oxygen content. High-pressure oxygen is occasionally blown into the bath to desulphurize it if the sulphur content is too high. The melted product is transferred to a teeming ladle and poured through high velocity water jets to granulate the product. The resultant granules are dewatered, dried in a gas-fired kiln, and conveyed to the Inco pressure carbonyl plant.

At the Inco pressure carbonyl plant, the granules are batch-reacted with carbon monoxide in three 150-t rotating reactors. Nickel and iron are extracted as carbonyl vapours, while copper, cobalt, precious metals and other impurities are retained in the residue. This residue is milled and pumped to the electrowinning plant. The nickel and iron carbonyl vapor is distilled in two parallel vertical distillation columns; nickel carbonyl separate and rises to the top of each column while iron carbonyl settles at the bottom of each column.

At the electrowinning building, the Inco pressure carbonyl residue is treated in a first stage metathetic acid leach circuit to remove nickel, cobalt, iron, arsenic and other minor element contaminants. A second stage oxidative leaching circuit is used to dissolve copper, selenium and tellurium from the first leach solid residue. The second stage slurry is filtered and the residue is sent to Port Colborne to extract the precious metals. The filtrate is pumped into tanks and an electrical current is applied through titanium cathodes and lead anodes. The copper plates onto the cathode over a two-week period. The copper sheets are removed from the cathodes and sent to market. The first stage leach solution is fed to the iron/arsenic removal circuit and then through a copper clean-up circuit. The nickel and cobalt are precipitated from the solution with soda ash. The resultant carbonate stream is thickened and sent to Port Colborne.

14.3.2.3 CLYDACH NICKEL REFINERY

Nickel oxide feedstock is continuously fed into a reduction kiln where it is tumbled in a stream of hydrogen, the reduced feed is then fed to the activation kiln. The activated nickel matte is sent to a volatilisation kiln, where the nickel reacts with carbon monoxide to form nickel carbonyl gas. The nickel carbonyl gas is piped to an adjacent plant for thermal decomposition into pure nickel pellet or powder.

To produce powder, the nickel carbonyl gas is injected at a metered rate into the top of eight decomposer towers, each 10 m high and 2 m in diameter. The walls of the towers are heated. The gas decomposes instantly to form nickel powder which settles at the bottom of the unit. The nickel powder is collected, blended for uniformity, screened, and packaged for sale.

When nickel carbonyl gas is heated in a pellet unit, it decomposes to form nickel metal and CO gas; this occurs when the gas comes into contact with hot nickel pellets. Nickel pellets grow in size each time they pass through a reactor (approx. once every 30 minutes). Once they reach saleable size, they are collected via a make screen. The nickel pellet is collected, sieved and packaged for sale.

14.3.2.4 PORT COLBORNE REFINERY

The Port Colborne Refinery is an electro-cobalt refinery and precious metals upgrading facility.

In the precious metals upgrading facility, slurry feed shipments of residues or process intermediates are received from the Sudbury Operations. The facility also processes toll materials from third-parties. The refinery is a hydrometallurgical process that uses several oxidative and reductive reaction steps along with acidic and basic leach steps to selectively remove impurities and purify targeted metals in each step. Base metals are precipitated and recycled back to Sudbury. Fiberglass and stainless-steel tanks are typically used as reaction vessels along with settlers and filters for liquid solids separation. The process produces gold, silver, and platinum group metal concentrate products for external customers. In addition, tellurium dioxide, selenium, bismuth, and lead carbonate are produced as by-products that are sold to market.

In the electro-cobalt refinery, slurry feed is received from the Copper Cliff Nickel Refinery that contains nickel, cobalt carbonates, and other impurities. This slurry is dissolved with sulphuric acid and then pH adjusted with soda ash. The mixture is filtered to remove calcium and iron along with other metals. The solid phase is rejected and liquid phase is sent through several other purification steps including copper ion exchange, and zinc ion exchange. The remaining liquid containing purified cobalt and nickel is treated with sodium hypochlorite to separate the cobalt from the nickel. The remaining nickel solution is treated with soda ash producing a nickel carbonate precipitate which is sent in slurry form to the fluid bed roasters at the Copper Cliff Smelter. Cobalt hydrate is precipitated, filtered, and sent to the electro-cobalt refinery building.

In the electro-cobalt refinery, the cobalt hydrate feed is subjected to additional purification through ion exchange, settling and filtering. Soluble cobalt contained in acidic liquor is pumped into plating cells containing cathodes and a sacrificial lead anode. Metallic cobalt is electrolytically deposited onto mandrels. Several hundred cobalt disks form on each mandrel to a size of about three centimetres in diameter. Once removed from the mandrel, the rounds are polished, degassed in an electrically heated kiln and packaged for market in 250 kg drums.

Nickel products are received from Vale operations, including the Ontario Operations. Nickel rounds go through a sulphuric acid dip for cleaning followed by screening, a water rinse and polishing. Nickel pellets, disc, and rounds are also received in bulk containers for repackaging. The products are packaged into 10 kg bags, 250 kg drums or tonne bulk bags for shipment to market.

14.3.3 EQUIPMENT SIZING

Key equipment sizes for the Copper Cliff Smelter are provided in Table 14-2, for the Copper Cliff Refinery in Table 14-3, for the Port Colborne Refinery in Table 14-4, and for the Clydach Refinery in Table 14-5.

14.3.4 POWER AND CONSUMABLES

The power consumption for the Ontario Operations is described in Chapter 15.9.

Consumables include:

- Copper Cliff Smelter: spare parts, electrical materials, maintenance supplies, refractories, quartz, sand, lime, coke, natural gas;
- Copper Cliff Nickel Refinery: refractories, lime, coke, MgO, dolime, sulphuric acid, soda ash, maintenance supplies;
- Port Colborne Refinery: soda ash, sodium hydroxide, sodium hypochlorite, sulfur dioxide, acid, chlorine, lime, maintenance supplies;
- Clydach Refinery: refractories, nickel sulphate, liquid ammonia, diethanolamine (DEA), potassium hydroxide (Benfield solution), sulphur dioxide, sodium hydroxide, sulphuric acid, maintenance supplies.

Table 14-2: Equipment List, Copper Cliff Smelter

Item	Number	Size/Model	Manufacturer/Make
Pressure filters	4		FL Smidth
Flash furnace	1		Hatch Eng. - Inco type
Pierce–Smith converters	2	13' x 45'	Anmar – Peirce–Smith converter
Slag cleaner	1		Howden Parsons (Howden Buffalo). Currently not in use
Main aisle overhead cranes	3	Two x 65/20 ton; one by 65/15 ton	Virgina Crane 65/20 ton; Dominion Engineering
Casting building overhead crane	2	65/15 ton	Dominion Bridge
Casting building crushers	3	Traylor crusher, 48" x 66" jaw; GG crusher, 48" x 15" jaw; Symons crusher	Gatex Fuller; B & D Manufacturing; Nordberg (Metso Minerals)
Rod mill	2		Metso Minerals
Ball mill	5		Metso Minerals
Recleaner column	2		Eriez
Flotation cell	16 cells in 4 banks		Denver
Fluid bed roaster	2		
Acid plant blowers	2		AC compressor
Plant compressor	19	air, oxygen, nitrogen	Ingersoll Rand; York; Delaval; Joy Electrical Company; Sulzer Ltd.
Plant separator	1	Oxygen	Peerless Pump Company
Plant regenerator	1	Nitrogen	

Table 14-3: Equipment List, Copper Cliff Refinery

Area	Item	Number	Size/Model	Manufacturer/Make
Converter		2	50 Ton Kaldo	Davy Ashmores
Granulation	Dewatering bin	2	15'-6" I.D. Cone x 15'-3" High	ASH Fluid Transport
	Granulation rotary dryer	1	Model: 502-32 / Size: 5'-1 1/4" I.D. x 31'-1 1/2" LG	FMC Technologies
	Granulation sluice	3	22'-7 1/8" LG x 3'-0" Wide	Div Shops
	Thickener	1	Model: 3900	Parson Corporation
	Granulation cooling tower	1	Series 15 #457-202	Marley Canadian Limited
Nickel refinery converter	Top blown rotary converter baghouse	2		
	Stack	1		
Inco pressure carbonyl	Inco pressure carbonyl reactors	3		
	Distillation column	1		
Overhead cranes	75 ton main aisle crane	1	6754/ 75T main hoist /15T aux hoist, 4 girder hot metal crane, 55ft span ; Rerated to 75T from 65T in 1974	Alliance Machine Company

Area	Item	Number	Size/Model	Manufacturer/Make
	EW 8T Crane	1	8T Crane, Class D Rerated to 8T from 6T in 2009	Provincial Crane Division
	IPC 20T Pellet Crane	1	DL-DMR-3, 55ft span, 65ft lift	Shawbox
	MGC 10T Crane	1	DL-DMR-2, 52'-6" span, 35ft lift	Shawbox
Main gas compressors	CO reciprocating Compressors	3	5HHE 5MGC, 5083	Ingersoll Rand
Pellet and powder decomposer	Pellet Decomposer units	18	43500,Rex ChainBelt Shop Code: 682	Rex Chainbelt Canada Limited
	Powder decomposer	10	28'-0" ft long x 6'-6" I.D.	Shell unknown, heating: EW Playford Company Limited
Electrowin cells, rectifiers	Concrete T and L sections	48T, 2L	Precast 'T' and 'L' concrete panels	Fisher Wavy Inc.
	Composite liners	49	FRP Cell Liners	Chemposite INC
	Tankhouse rectifier	1	45KA 150VDC	ABB

Table 14-4: Equipment List, Port Colborne Refinery

Area	Item	Number	Size/Model	Manufacturer/Make
Cobalt hydrate	North feed receiving tank	1	H: 30', dia: 13'6"; capacity 121,576 L	Troy
	South feed receiving tank	1	H: 30', dia: 13'6"; capacity 121,576 L	Troy
	Slurry leach tank	3	H: 10, dia: 8'; capacity 12,800 L	Mak Enterprises
	Leach–polish feed tank		H: 28', dia:12'; capacity 72,000 L	Ceilcote Canada Ltd
	Nickel solution tank 1	1	H: 30', dia: 12'; capacity 72,000 L	Precisioneering Ltd
	Nickel solution tank 2	1	H: 28', dia: 12'; capacity 60,000 L	Precisioneering Ltd
	Cobalt precipitation tank	2		
	Cobalt hydrate settling tank	3	approx 30' x12'	Precisioneering Ltd
	Nickel sol surge tank	2	H: 30'; dia: 8',	Precisioneering Ltd
Cobalt ECR	Cob hydrate surge tank	3	H: 20', dia: 16'; capacity 98,410 L	Protective plastics ltd
	Leach Tank A	1	H: 15', dia: 13'; capacity 52,333 L	Scepter Manufacturing
	Leach tank B	1	H: 15', dia: 13'; capacity 52,333 L	Scepter Manufacturing
	Leach tank C	1	H: 15', dia: 13'; capacity 52,333 L	Scepter Manufacturing
Precious metals recovery	Screw conveyor	1	AGCL/SiO_2 Fltr Dchrg, 40-9	Perrin
		1	SIO_2 FltrDchrg, 70-20, 2Fl,	
	Scrubber	1	Process vacuum circuit, 90-1-CT	
	Scrubber	1	Process SO_2 ventilation circuit, 90-2-CT	
	Tank	1	OPM Tank, 20-9.1-TK, 2Fl	
		1	Copper surge, 20-20-TK	
		1	Cu/Ni precipitation, 20-12.2-TK	

Area	Item	Number	Size/Model	Manufacturer/Make
Nickel processing	Conveyor	1	East speed belt,10 KBP	
	10KPB line conveyor	1	Palletizer infeed, 10 KBP	
	10KPB line conveyor	1	Palletizer eject, 10 KBP	
	10KPB line conveyor	1	East incline, 10 KBP	
	10KPB line conveyor	1	Magnetic,10 KBP	
	10KPB line compressor	1	Air, 10 KBP, Gardner Denver,	
	250KPB line conveyor	1	Escalator, #2, 250 KP	
	250KPB line conveyor	1	Reject &test weigh, 250 KP	
	250KPB line conveyor	1	Reversing, 250 KP	
	250KPB line conveyor	1	South squares, 250 KP	
	Tank	1	Acid dip tank, Ni processing	

Table 14-5: Equipment List, Clydach Refinery

Area	Item	Number	Size/Model	Manufacturer/Make
Process gas plant	Recycle hydrogen compressor	3	Capacity 45 m^3/hr: motor 4 kW	The Bryan Donkin Company Ltd.
	Start-up circulating compressor	1	Capacity 120 m^3/hr: Power 37.1 HP	Reavell & Co. Ltd.
	Vaporiser	2	External dimensions 2.4 x 2.4 m mounted on 2.5 m legs. Topped with a 3.8 m cone tapering to a 25 m long 70 mm flue.	Unknown
	Desulphuriser	2	14 m high x 1.5 m diameter. Stainless steel clad.	Old Park Engineering Ltd.
	Reforming furnace	2	4 x 4 x 10m. 10 reforming tubes	Power-Gas Corporation Ltd.
	Benfield solution absorber	1	33 m high x 660 mm ID	Danks Of Netherton Ltd.
	Benfield regenerator	1	36 m high x 1.4 m ID	Wefco (Gainsborough) Ltd.
	DEA Absorber	1	16.3 m high x 1 m ID	Wefco (Gainsborough) Ltd.
	DEA Regenerator	1	11.3 m high x 1.2 m ID	Wefco (Gainsborough) Ltd.
	Copper liquor absorber	1	32 m high x 1.1 m	Wefco (Gainsborough) Ltd.
	Copper liquor absorber wash tower	1	50 m x 400 mm	Power-Gas Corporation Ltd.
	Copper liquor regenerator	1	18.5 x 1.4 m	Wefco (Gainsborough) Ltd.
	Hydrogen gas holders	2	19 m high x 15.5 m	
	CO_2 holder	1	10 m high x 10.5 m	GW Walker
	CO holder	1	10 m high x 10.5 m	GW Walker

Area	Item	Number	Size/Model	Manufacturer/Make
Kiln plant	Reduction kiln	2	38 m long x 3.9 m	F.L. Smidth-Fuller Ltd.
	Hydrogen blower	2	Capacity 6000 m^3/hr with outlet pressure of 3 psi: power 165 HP	George Waller & Son Ltd.
	Primary scrubber	2	5.3 m high x 1 m	Projex Solutions Ltd
	Activation kiln	2	20 m long x 2 m	F.L. Smidth-Fuller Ltd.
	Volatilisation kiln	2	55 m long x 4.6 m	F.L. Smidth-Fuller Ltd.
	Stabilisation kiln	2	16 m long x 1.5 m	Unknown
Pellet plant	Carbonyl blower	6	355 mm x 890 mm, Mark 2 Roots type,	Waller
	Pellet units (standard)	17	Contains 30 t Ni	International Nickel (MOND) Ltd.
	Pellet units (double capacity)	2	Contains 45/60 t Ni	International Nickel (MOND) Ltd.
Powder plant	Powder decomposers	6	10 m long x 2 m	Caper Neil/Mortec
	Powder Blower	2	355 mm x 890 mm, Mark 2 Roots type,	Waller

Water requirements and water sources vary by smelter/refinery location.

The Copper Cliff Smelter and Copper Cliff Nickel Refinery source freshwater from the Vermilion River, and recycle process water from the plant operations. In the period 2017–2020, freshwater requirements ranged from 1,267,000–3,358,000 m^3, and process (recycle) requirements ranged from 473,000–540,000 m^3.

The Port Colborne Refinery sources its freshwater and process water needs from the Welland Canal. Annual water usage for the period 2017–2020 ranged from 3,006,000–3,769,000 m^3.

Fresh water is sourced from the municipal water supply system for the Clydach Refinery at a rate of 130,686 m^3 for 2021. This water is primarily for domestic usage, but a portion is also used for process water. Process water was abstracted from the Swansea Canal at a rate of 225,486 m^3 for 2021 and recycled water at a rate of 1,576,800 m^3 for 2021. There was no water abstraction from the Tawe River in 2021, and none planned in 2022. Further reduction in abstracted water is planned for 2022 from the Swansea Canal with no abstraction planned after 2023. The Clydach Refinery undertook in 2017 to install a complex recycled, closed-loop, cooling water circuit. Once completed in 2022, water will no longer be sourced from either the river or the canal.

The LOM plan assumes similar water usage patterns to those documented for the 2017–2020 period.

14.3.5 PERSONNEL

The personnel counts for the refining and smelting operations in 2021 included:

- Copper Cliff Smelter: 400 persons;
- Copper Cliff Nickel Refinery: 275 persons;
- Port Colborne Refinery: 150 persons;
- Clydach Nickel Refinery: 185 persons.

15 INFRASTRUCTURE

15.1 INTRODUCTION

Major infrastructure for the mine sites is summarized in Table 15-1.

The processing facilities in Sudbury include a concentrator, a combined nickel and copper smelter, matte processing facilities, a carbonyl nickel refinery, a copper anode casting plant, a sulphuric acid plant and a sulphur dioxide liquefaction plant. The copper refinery was closed in 2006.

Ontario Operations infrastructure also includes a tailings impoundment area, a slag disposal area and an oxygen plant.

All underground mines use a combination of several underground maintenance facilities of varying sizes and capacities. These shop areas are equipped with the necessary tools and equipment to service large industrial rock moving and drilling equipment. Most of the mobile equipment repairs are completed at these permanent facilities while smaller repairs can be done in the field by trained mechanics.

15.2 ROADS AND LOGISTICS

Road access is described in Chapter 4.2.

15.3 WASTE ROCK STORAGE FACILITIES

Waste rock is primarily stored underground. One active permanent waste rock disposal location used by the Garson and Copper Cliff mines is a non-producing open pit on the north side of the Copper Cliff mine property.

15.4 TAILINGS STORAGE FACILITIES

The Copper Cliff tailings impoundment or Central Tailings Area became operational in 1936 and has become the primary management site for tailings generated from the Ontario Operations. The facility encompasses some 2,430 ha, and divided into several areas according to eras of tailings disposal: A-Area, M-Area, CD-Area, P-Area, Q-Area, R-Area and the Upper Pond Area (UPA). A general location plan is provided in Figure 15-1 and a more detailed inset plan in Figure 15-2.

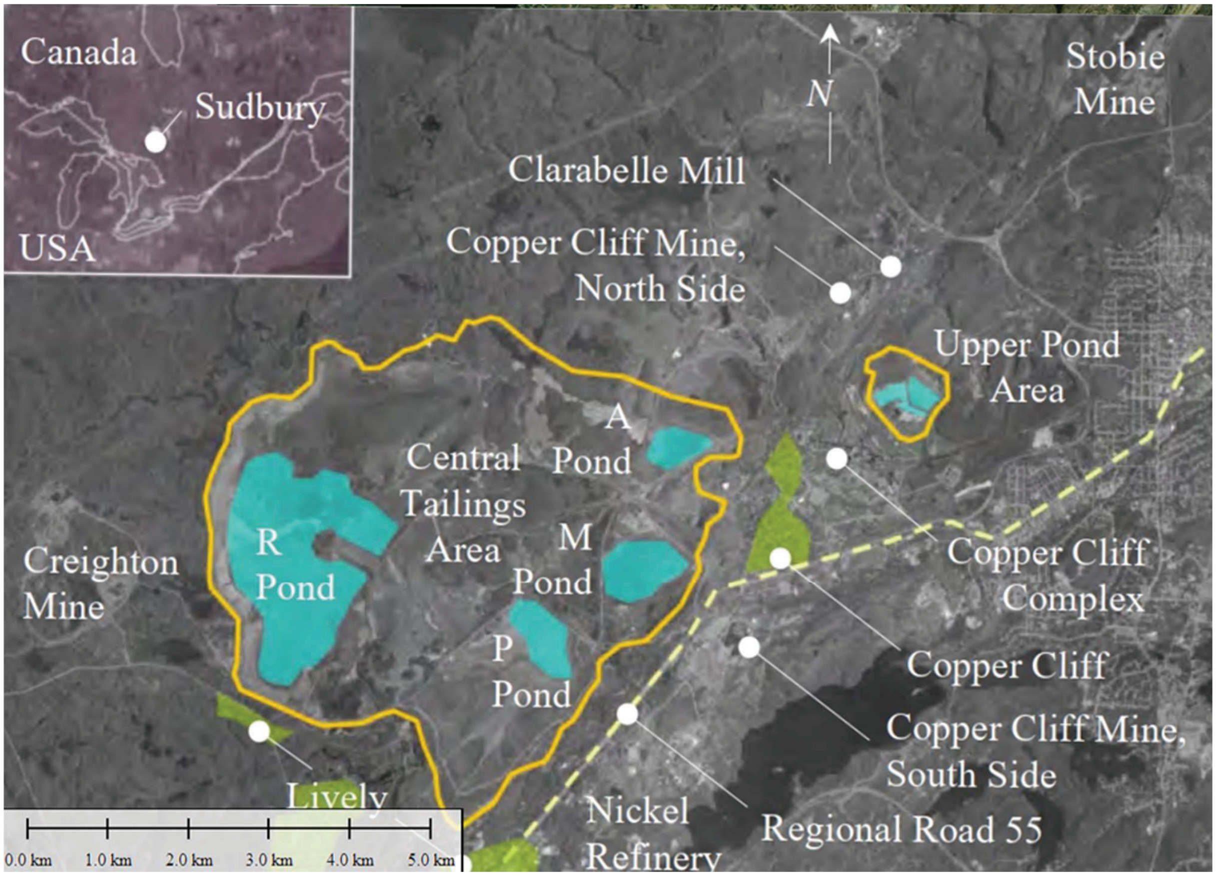
The UPA is the oldest area, dates to the 1930s, and is inactive in tailings disposal terms but is used as a process water supply for Clarabelle Mill. The A-Area followed in the late 1930's and covers about 421 ha. The A-Area Dam lies in the southeast corner. The A-Area collects seepage from other parts of the Central Tailings Area as well as runoff from a large watershed. Hill Station sump overflows also report to A-Area. When sump overflows exceed the flow capacity to A-Pond, excess flow reports to the Hill Station Emergency Overflow pond.

The M-Area usage start date is uncertain, but may have been the 1950s. It is currently inactive in tailings disposal terms, covers about 121 ha, and includes a storage pond. The M-Area is bounded to the southeast and northeast by the M-Area South and M-Area North Dams. The remaining portions of the M-Area are connected to other tailings areas. The dams are currently being buttressed to allow future deposition of dredged tailings in the M-Area.

Table 15-1: Mine Site Infrastructure

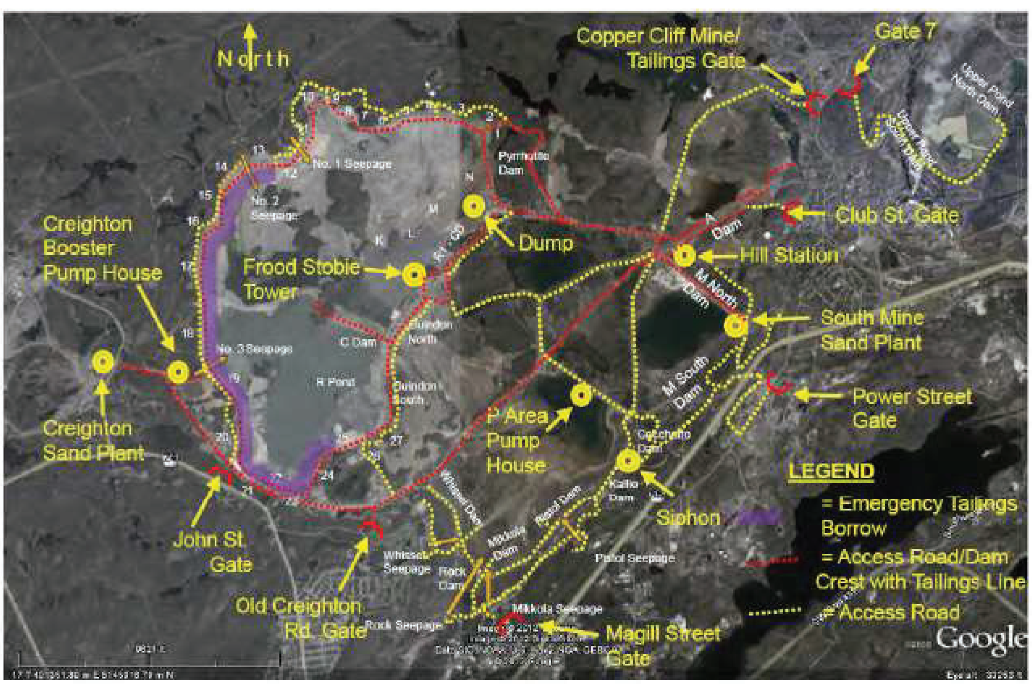
Mine	Key Surface Infrastructure	Comment
Coleman	Warehouses, mechanical and electrical shops, hoist room buildings, a sand plant, a first aid/security station, training rooms, offices and change/shower facilities.	The Levack water system, owned by Coleman Mine, provides industrial water.
Copper Cliff	Two head frames, open, cold, and heated warehouses, mechanical and electrical shops, hoist room buildings, fan houses, sand plant, a first aid/security station, training rooms, offices and change/shower facilities.	Water is sourced from the Vermillion water treatment plant located at the Creighton Mine. The South Headframe is currently not in operation but will be refurbished for start-up in 2017.
Creighton	Warehouses, mechanical and electrical shops, hoist room buildings, a sand plant, a first aid/security station, training rooms, offices and change/shower facilities.	Creighton Mine owns the Vermillion Water Treatment Plant that provides industrial water. Creighton Mine is also home to a government operated research facility, the Sudbury Neutrino Observatory.
Garson	Head frame, warehouses, mechanical and electrical shops, hoist room buildings, a first aid/security station, training rooms, management and technical services offices, paste fill plant, Aran sand plant, fan houses and a change house.	Water sourced from No 2. Well.
Stobie	Main office and change/shower facilities, warehousing, surface lay down, a maintenance shop and a diamond drillhole core logging and sampling facility.	Former producing underground mine that was shut down in 2017. Buildings and warehouse are used by central mine service departments.
Totten	Headframe, collar house, hoist house and compressor room, dry/office building, sewage treatment plant, process water storage tank and pump house, fuel storage facility, mine water treatment system, surface repair facilities, slick line system, dewatering pipeline, backfill plant, fresh and return air ventilation systems.	

Figure 15-1: Central Tailings Impoundment



Note: Figure prepared by Vale, 2019.

Figure 15-2: Tailings Impoundment Detail Plan



Note: Figure prepared by Vale, 2019.

The P-Area began being used in the 1960s and is currently inactive in tailings disposal terms; however, it remains an important attenuating element for water management. A total of six perimeter dams make up the impoundment: Whissel Dam, Rock Dam, Mikkola Dam, Pistol Dam, Kallio Dam, and Cecchetto Dam. The P-Area Pond is the final storage pond for process water prior to discharge from the Central Tailings Area, receiving water from the combined flow from the R-Areas pond, CD-Area, Q-Area and M-Area.

The Q-Area and CD-Area are both inactive in terms of tailings storage, and are bounded on all sides by other tailings storage areas.

The R-Area was originally split into four separate areas (R1, R2, R3 and R4), and are currently combined into one as the elevation of the R4 pond has risen to form a common pond with the R1, R2, and R3 Areas.

The original R1-Area was approximately 162 ha in size and bounded to the southwest by an internal dam, Dam C, and to the northeast by the Pyrrhotite Dam that separates the R1 Area from A-Area. The R2 Area lies to the northwest and is separated by a series of internal dykes known as Dams K, L, M, and N. The R1 Area is separated from CD-Area and Q-Area by the R1-CD and Guindon North Dams. Seepage from the Pyrrhotite Dam flows into A-Area. The R1 Area also receives seepage from the R2-Area flowing through the internal dykes.

The former R2-Area encompasses some 263 ha and makes up the northern region of the Central Tailings Area. It is bounded by 12 perimeter dams along the western and northern ends and the R1-Area on the southern end. A series of four separator dykes separate the R1- and R2-Areas. Seepage from Dams R-1 through R-9 flows to the A-Area drainage system. Seepage from Dams R-10, R-11, and R-12 is collected in a downstream seepage pond and pumped back to the R2 Area via the #1 Seepage Pumping Station. Two seepage containment dams downstream are used to prevent seepage escaping to the local environment.

The former R3-Area is approximately 202 ha in size and lies in the northwest region of the Central Tailings Area. It is bounded by five perimeter dams (Dams R-13 to R-17) on the western side. Seepage from the perimeter dams is captured by a series of ponds and channels, conveyed to a collection pond, and pumped back to the R3 Area via the #2 Seepage Pumping Station. Downstream seepage containment dams prevent seepage from escaping to the downstream environment.

The former R4-Area covers about 344 ha, and forms the southwestern portion of the Central Tailings Area. There are 10 perimeter dams (Dams R-18 through R-27) and one internal dam (Guindon Dam). Seepage from the majority of the perimeter dams is contained within a large collection pond and pumped back to the R4 Area via the #3 Seepage Pump Station. A series of seepage recovery dams was built in the late 1980s to divert water back to the seepage pump back stations at the downstream side of R3 between Dams R-10 and R-16.

In addition to tailings deposition, the Central Tailings Area receives an assorted stream of wastes including non-hazardous solid waste, water and process treatment plant sludges, and asbestos.

A site-wide seismic hazard assessment for the tailings areas was completed in 2001. Vale addressed the findings based on the assigned risk rating. Hazard assessments are ongoing.

Vale meets the requirements of the Ontario Ministry of Natural Resources (MNR), Lakes and Rivers Improvement Act, uses safety guidance provided by the Canadian Dam Association, and internal risk management frameworks to ensure dam safety. Vale has undertaken numerous studies on the Central Tailings Area to update various aspects of the facility to meet current dam engineering practices.

A detailed Operations Manual was developed that includes water management procedures, tailings delivery procedures, dam construction and safety procedures, instrumentation and monitoring procedures, environmental control procedures, management and control procedures, and the emergency preparedness and response plan. This manual is regularly updated.

As part of Vale's commitment to risk management for the Central Tailings Area and the UPA, Vale established a Technical Review Board in the 1990s. Board members are specialists in tailings and water management and dam safety with many years of experience. The Technical Review Board meetings typically involve presentations from Vale and their engineering consultants and discussion on the key issues related to the Central Tailings Area. The Technical Review Board work with Vale to address these issues and bring them to the attention of senior management. Vale developed a recommendations-tracking database to monitor the recommendations from the Technical Review Board and their status.

15.5 SLAG DISPOSAL FACILITY

The smelter operation generates approximately 1 Mt of slag annually.

Furnace slag is tapped and poured into a series of slag pot rail cars. The slag pots are taken to one of three locations on the Copper Cliff Smelter Complex property, emptied, and the slag is allowed to cool. The main slag facilities are continuously managed to provide storage of additional molten slag by active cleaning with bulldozers, excavators and other mobile equipment.

There are two main storage areas in the central and northeastern areas of the smelter that were designated for storage of cooled slag. Haulage trucks transport the slag from the main facilities to these storage areas.

15.6 WATER MANAGEMENT

15.6.1 WATER MANAGEMENT STRATEGY

The general water management strategy for several facilities peripheral to the Central Tailings Area involves collecting and treating impacted runoff. The strategy is common to the Copper Cliff and Creighton Mines, the Stobie property, Clarabelle Mill, the Central Tailings Area, UPA, Copper Cliff Smelter Complex, Copper Cliff Nickel Refinery, and the Copper Cliff and Nolin Creek waste water treatment plants.

The Ontario Operations monitor levels, flows and water balances on a weekly basis. Raw field data (flow, pond level, snow pack and precipitation) are incorporated into water balance and storage calculations. These data are reviewed by Vale's internal Water Management Committee, which includes representatives from the process plant, water treatment plants and environmental department. Once a review is complete, the Water Management Committee issues minutes to the individual operations and internal stakeholders. The individual operations are responsible for implementing recommendations.

15.6.2 WATER TREATMENT

15.6.2.1 COPPER CLIFF MINE, CREIGHTON MINE, CLARABELLE MILL, COPPER CLIFF SMELTER COMPLEX AND COPPER CLIFF NICKEL REFINERY

Surface water over areas potentially affected by acid rock drainage is managed using two systems; the Copper Cliff and Nolin Creek water management systems. The Copper Cliff water management system consists of seven sub-watersheds covering approximately 5,300 ha and has 22 reservoirs. Flows are either treated at the Copper Cliff waste water treatment plant or recycled for mill process water. There are a number of creeks within the Town of Copper Cliff that also convey water to the Copper Cliff waste water treatment plant. The Nolin Creek water management system consists of a separate watershed, comprising a single, three-reservoir catchment covering approximately 890 ha. Associated flows are treated at the Nolin Creek waste water treatment plant. There are two large storage reservoirs in front of the Nolin Creek waste water treatment plant to help provide attenuated water during peak flow events.

15.6.2.2 TOTTEN MINE

All mine water and surface contact waters are directed to the west surge pond, including mine dewatering, surface run-off and water pumped from the Worthington cave zone and through the dewatering wells installed around the return and fresh air raises. Water is pumped from the west surge pond to a high density sludge treatment plant, where metals and solids are removed through hydroxide precipitation, settling and filtration. The treated water is released to the polishing pond. Water from the polishing pond is primarily used as process water at the mine, with discharge to the environment required only when inputs exceed mine demand (typically seasonally). Domestic sewage is treated at the onsite sewage treatment plant with effluent discharged to the west surge pond within the larger Totten Mine waste water treatment system.

15.6.2.3 GARSON MINE

Waste water at the Garson mine is managed through a waste water treatment plant that is supported by a series of upstream reservoirs and downstream settling ponds. Mine dewatering is pumped directly to a surge pond at the intake of the waste water treatment plant, though can also be directed to R2 reservoir if needed. Surface contact waters are collected in the north pond, and the R1 and R2 reservoirs and are pumped to a surge tank for treatment. The waste water treatment plant uses a metal hydroxide precipitation process. Water discharged from the waste water treatment plant reports to the settling pond, flowing then to the polishing Pond and is pH adjusted using CO_2 prior to discharge to the environment.

15.6.2.4 COLEMAN

The Coleman mine operates within an integrated waste water management system, tying in inputs from Vale's operations as well as those from KGHM International Ltd's (KGHM) and Glencore's operations in the area. Mine dewatering from the Coleman and Levack mines, as well as domestic sewage treated in a small sewage treatment plant, report to the process water sump in the sewage treatment plant, which equalizes with Strathcona Lake. Strathcona Lake also receives inputs from the gravel pit pond, which receives runoff from the former tailings area, inputs from the Grassy Creek and Pike Lake interceptor wells, and water collected in the Levack Runoff Containment Area The Stratchcona pumphouse then moves the water from the lake for subsequent treatment within Glencore's Moose water treatment system.

15.6.3 WATER SOURCES

Process water for the Clarabelle Mill is sourced from the UPA. The Upper Pond consists of a water reservoir, two pumphouses that pump process water to Clarabelle Mill, and a gravity overflow structure that provides process water to the filter plant. Ancillary infrastructure that supports the Upper Pond includes the process water supply pipeline, two containment dams (north and south), roads, and power systems. Secondary uses for the Upper Pond include providing process water for the concentrate storage domes, dust suppression in the active slag facility, and providing gland water to the booster station. The Upper Pond also serves as a settling pond to settle out precipitated solids from the lime treated process water.

Fresh and drinking water is sourced primarily from the Vermilion River catchment. The Vermilion River water intake is owned and operated by Vale. The intake pumps raw water from the river to Creighton to be treated at the Vermilion water treatment plant. After treatment, water is supplied to the mines in the Sudbury area, the Clarabelle Mill, Copper Cliff Smelter, and the Copper Cliff Nickel Refinery The treatment plant also provides water to the City of Sudbury.

The primary water source for Port Colborne is the Welland Canal.

During 2022, water for the Clydach Refinery will be partially supplied by the Swansea Canal. The Clydach Refinery undertook in 2017 to install a recycled, closed-loop, cooling water circuit. Once completed in 2022, water will no longer be sourced from either the Tawe River or the canal.

15.7 BUILT INFRASTRUCTURE

All major infrastructure to support the Ontario Operations mining activities envisaged in the LOM is in place.

15.8 CAMPS AND ACCOMMODATION

No accommodations camps are operated. Personnel live either in Sudbury or in surrounding settlements.

15.9 POWER AND ELECTRICAL

Electrical power for the Ontario Operations is primarily sourced from the Ontario provincial supply (approximately 80%). Power is transmitted on the Hydro One transmission system and is connected to two locations in Sudbury and one in Port Colborne. In Sudbury, all incoming grid-connected power and hydroelectric generation is distributed to mines and processing plants through Vale's electrical distribution network, consisting of 69 kV distribution power lines, substations, transformers, breakers, disconnects and other electrical equipment. This distribution system is owned, operated, and maintained by Vale.

A portion of the demand (about 20%) is met by Vale's hydroelectric power facilities. Vale consumes 100% of its self-produced hydro generation behind-the-meter, i.e., Vale does not inject power onto the Ontario grid. The hydroelectric facilities have a nameplate capacity of 55 MW.

The Clydach nickel refinery obtains all of its power from a local utility.

The average annual usage by major area, based on 2020 data is summarized in

Table 15-2. These usage levels are forecast to remain approximately the same for the LOM.

Table 15-2: Annual Power Usage

Facility	Power (MWh)
Mining operations	515,000
Clarabelle Mill	251,000
Copper Cliff Smelter	356,000
Copper Cliff Refinery	162,000
Port Colborne Refinery	25,000
Clydach	35,000
Total power usage	***1,344,000***

Note: Numbers have been rounded.

16 MARKET STUDIES

16.1 PRODUCTS

Mining at Vale's Sudbury operations takes place at multiple mine sites. The Sudbury refinery produces high-purity carbonyl nickel chips, pellets, and nickel powders. Alongside nickel, this ore also contains copper, cobalt, PGMs, gold and silver. A portion of the gold production in Ontario is sold under a multi-year streaming agreement with Wheaton (See 3.8.1).

16.2 MARKETS

16.2.1 NICKEL

16.2.1.1 DEMAND

As a first use, nickel is consumed in plating, alloy steel, non-ferrous alloys, foundry, batteries and stainless steel. These are then used in several applications in varying industries including aerospace, automotive (including electric vehicles), appliances, electronics and energy production and consumption.

The largest demand segment is stainless steel accounting for roughly 70% of total nickel demand. Uses in aerospace, automotive and energy production and consumption make up roughly 20% with the battery market (lithium-ion and primary batteries) filling the remaining demand. This dynamic is expected to change as demand for batteries in electric vehicles grows with the expectation that the battery market will increase its share of total demand to 24% in 2030.

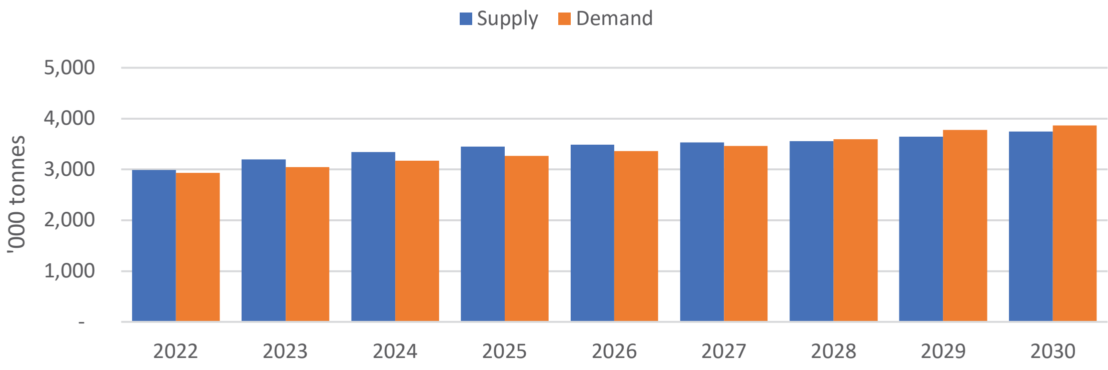
Nickel demand is expected to increase at a Compound Annual Growth Rate (CAGR) of 5% from 2020 to 2030 led by growth in the battery market. Total consumption, net of recycled material, is expected to grow from 2.4 million tonnes in 2020 to 3.9 million tonnes in 2030.

16.2.1.2 SUPPLY

Nickel production is broken out into two distinct streams: (1) class 1 consisting of high purity nickel products such as briquettes and cathodes, and (2) class 2 consisting of lower purity nickel such as nickel pig iron (NPI) and ferronickel (FeNi). Class 2 nickel is the primary feedstock for the stainless-steel industry while the remaining end uses prefer class 1.

Primary nickel supply is expected to increase at a CAGR of 4% from 2020 to 2030 led by growth in Indonesia NPI production. Primary nickel supply is expected to grow from 2.6 million tonnes in 2020 to 3.7 million tonnes in 2030. As growth is led by class 2, conversion to a suitable battery-grade class 1 material is essential to meet growing demand in the electric vehicle market. Market balances will be dependent on this conversion, with varying technologies requiring significant investment and prone to delays. See Figure 16-1

Figure 16-1: Nickel Market Forecast, 2022–2030



Source 3rd Party

16.2.2 COPPER

16.2.2.1 DEMAND

Copper consumption can be divided into product groups, such as copper wire rod, copper products and copper alloy products. In general, these products are consumed in broad sectors of the global economy, such as: civil and building construction, machinery, transportation, consumer and general products and utilities. Additionally, these copper products are vital to the rapidly growing green economy, such as renewable energy generation and storage.

Construction is the largest copper consuming sector, accounting for nearly 28% of total copper consumption. The main wire and cable and copper products consumed in the construction industry include building wire, power cable, copper plumbing and air conditioning tube, copper sheet and alloy products. Consumer and General and the Utility sector rank second and third, with both sectors accounting for just over 20% of copper demand.

Copper demand is diverse, which is why it is often describes as an “economic bellwether” for the global economy. Stable demand growth is expected from all the sectors described above. The long-term growth forecasts have been revised higher as global policy sets ambitious decarbonization targets, cost of renewable energy decreases and investments in the green economy increases. This acceleration will lead to a pivot towards more copper-intensive uses in renewable energy and transportation projects related to electric vehicles.

After significant impacts in 2020, due to the COVID-19 outbreak, copper demand is expected to grow at a CAGR of 2% between 2020 and 2030. Copper demand, net of recycled material, is predicted to grow from 23.5 Mt in 2020 to 29.3 Mt by 2030.

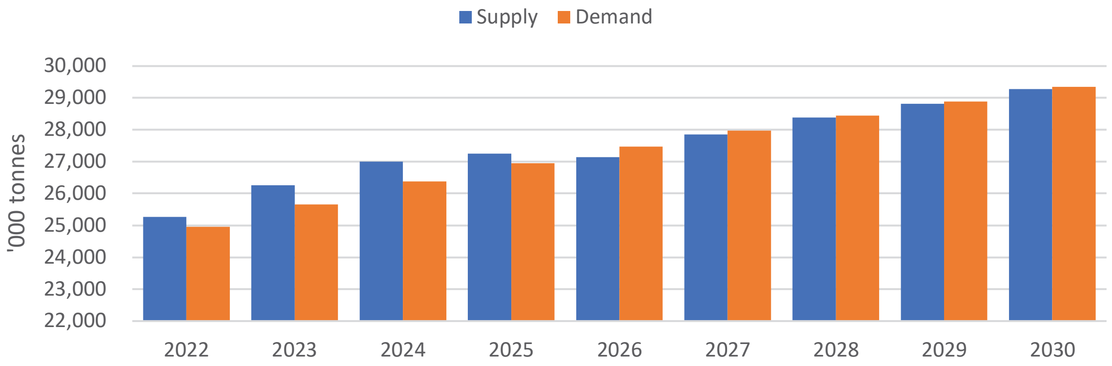
16.2.2.2 SUPPLY

Several mines were impacted during the initial COVID-19 outbreak in 2020, however, most were able to quickly reopen, and successfully manage the virus as time passed. In the short term, the overarching view is that there are enough quality assets being developed to meet demand. Longer term, growth is expected to struggle given declining ore grades and the lack of new major discoveries. More quality assets will be required in the medium to long term to replace existing operations ramping down or closing. Additionally, proposed increases to taxes and royalties in major producing regions could defer future investment, and risk longer-dated supply growth from key greenfield projects.

Refined copper supply is expected to increase at a CAGR of 2% between 2020 and 2030. Total refined supply is expected to reach 29.3 Mt by 2030, from 23.9 Mt in 2020. See

Figure 16-2.

Figure 16-2: Copper Market Forecast, 2022–2030



Source 3rd Party

16.2.3 COBALT

16.2.3.1 DEMAND

Cobalt is used in a wide variety of applications. Cobalt can be magnetized and is used to make magnets, including particularly powerful magnets when alloyed with aluminum and nickel. Other alloys of cobalt are used in jet turbines and gas turbine generators, where high-temperature strength is important. Cobalt salts have been used for centuries to produce blue colors in paint, porcelain, glass, pottery and enamels. The main end use markets include batteries for electric vehicles, tablet and smartphones, superalloys for use in aerospace, land-based turbines and medical prosthetics, and tool materials for use in mining and drilling.

The largest demand segment is battery chemicals accounting for roughly 56% of total cobalt demand. Uses in superalloys and tool materials make up roughly 22% with the other markets such as catalysts, pigments and magnets filling the remaining demand. The market share of battery chemicals is expected to change as demand for batteries in electric vehicles grows with the expectation that this market will increase its share of total demand to 70% in 2030.

Cobalt demand is expected to increase at a CAGR of 8% from 2020 to 2030 led by growth in the battery market. Total consumption is expected to grow from 135 thousand tonnes in 2020 to 282 thousand tonnes in 2030.

16.2.3.2 SUPPLY

Cobalt is mined across the world and the vast majority is produced as a by-product from large scale copper and nickel mines. Cobalt is only extracted alone in Morocco and some Canadian arsenide ores. Over 50% of the global cobalt reserves are found in Democratic Republic of Congo (DRC) and Zambia. Refined cobalt production is concentrated in China, accounting for 70% of global refined output in 2020.

Mined cobalt production is expected to increase at a CAGR of 7% from 2020 to 2030 led by growth in DRC with refined cobalt supply, including recycled material, expected to increase at a CAGR of 7% from 2020 to 2030 led by China. Total supply, including recycled material, is expected to grow from 132 thousand tonnes in 2020 to 256 thousand tonnes in 2030. See

Figure 16-3.

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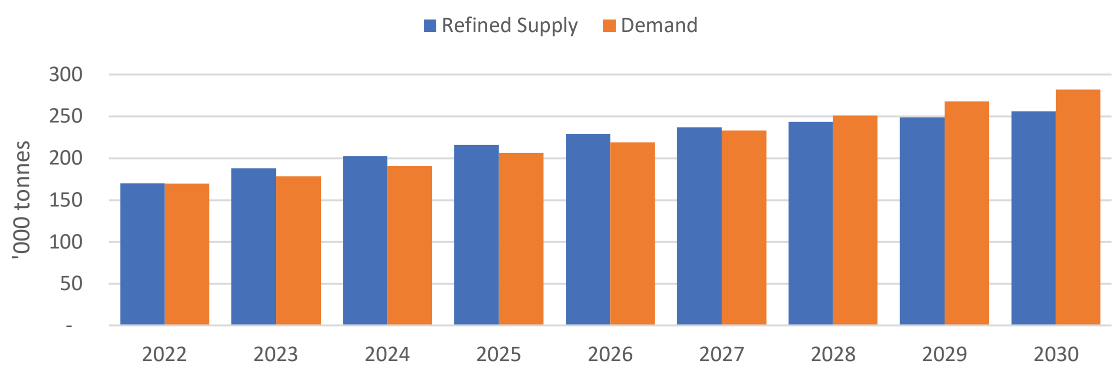
Figure 16-3: Cobalt Market Forecast, 2022–2030



Source 3rd Party

16.2.4 PLATINUM

16.2.4.1 DEMAND

The PGMs, or platinum-group metals, are a group of metals comprising platinum, palladium, rhodium, iridium, ruthenium and osmium. These metals have similar physical and chemical properties and tend to occur together in the same mineral deposit. The usefulness of PGMs is determined by their particular chemical and physical properties. The main uses of platinum are as a catalyst for automotive emissions control, in a wide range of jewellery pieces and in industrial catalytic and fabrication applications.

Certain of these properties are shared by other materials, but it is the unique combination of properties that makes the PGMs so valuable in their end-markets. The PGMs have high and specific catalytic activity, high thermal resistance, are chemically inert, biocompatible and are hard but malleable for forming into shapes. Platinum, palladium and rhodium are used in higher-volume industrial applications, while iridium and ruthenium have niche high-technology applications. Alongside their established applications, PGMs' attractive properties make them all the subject of intensive research and development into novel end-uses.

Automotive production is recovering with 13% YoY growth expected in 2021 to 85 million vehicles. Tightening regulation is expected to support platinum demand as OEMs are forced to increase loadings to meet stricter emission standards.

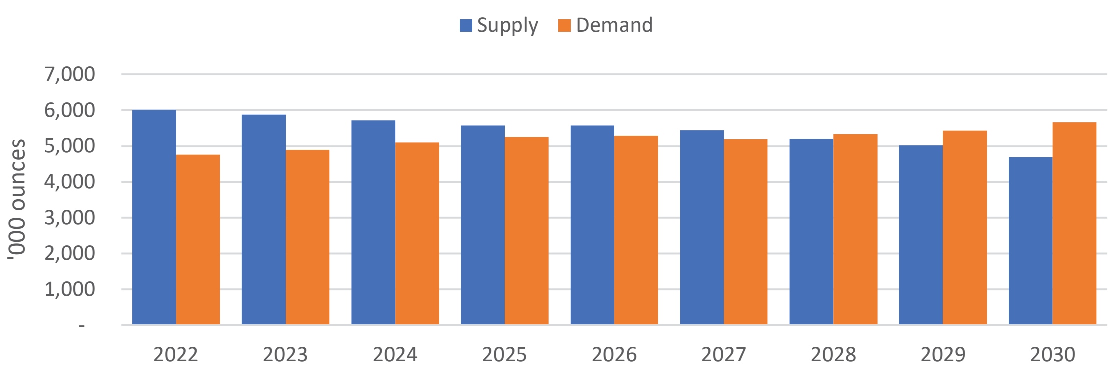
Platinum Jewelry demand was down 25% YoY in 2020 to an estimated 1,575 koz. Jewelry industry is heavily reliant on pent-up wedding demand to boost sales recovery, particularly in the West. Global platinum demand unlikely to reach 2 Moz p.a. (2019 levels) by 2024 due to challenging jewelry retail environment and unlikely reversal of years of decline in China.

Net platinum requirements for industrial demand is forecasted to recover (+19%) to 2.01 Moz in 2021, owing to rebounds in petroleum, chemical and other end-uses.

16.2.4.2 SUPPLY

The majority of PGM resources are located in Southern Africa. In South Africa, PGMs occur within a large, layered igneous intrusion called the Bushveld Igneous Complex (BIC) in which more than 70% of the world's known platinum resources exist. The BIC is a basin-shaped intrusion of some 370 km across, with only its rim exposed. The intrusion contains numerous distinct segregated layers formed during repeated fractionation cycles, three of which contain economic concentrations of PGMs. The main PGM-bearing layers, often referred to as 'reefs', are called the Merensky Reef, the UG2 Reef and the Platreef. Zimbabwe and North America are also important primary sources of PGM. PGMs are also found in high concentrations in Russia and Canada as a by-product to Nickel mining. See Figure 16-4.

Figure 16-4: Platinum Market Forecast, 2022–2030



Source 3rd Party

16.2.5 PALLADIUM

16.2.5.1 DEMAND

The PGMs, or platinum-group metals, are a group of metals comprising platinum, palladium, rhodium, iridium, ruthenium and osmium. These metals have similar physical and chemical properties and tend to occur together in the same mineral deposit. The usefulness of PGMs is determined by their particular chemical and physical properties. The main uses of platinum are as a catalyst for automotive emissions control, in a wide range of jewellery pieces and in industrial catalytic and fabrication applications. Palladium is primarily used as a catalyst in the automotive sector, mainly in gasoline-powered on-road vehicles, and has displaced platinum in some parts of on-road diesel engine autocatalysts. The second main use of palladium is in electrical components, specifically in multi-layer ceramic capacitors (MLCCs), as conductive pastes and in electrical plating.

Certain of these properties are shared by other materials, but it is the unique combination of properties that makes the PGMs so valuable in their end-markets. The PGMs have high and specific catalytic activity, high thermal resistance, are chemically inert, biocompatible and are hard but malleable for forming into shapes. Platinum, palladium and rhodium are used in higher-volume industrial applications, while iridium and ruthenium have niche high-technology applications. Alongside their established applications, PGMs' attractive properties make them all the subject of intensive research and development into novel end-uses.

Palladium loadings (usage per vehicle) and rising car sales in China lifts global demand. In 2021, a strong recovery in the US car market lifts demand in North America but falls short of 2019 levels. Higher loadings offsets the impact of substitution over the forecast period but removes upside for palladium over the longer term.

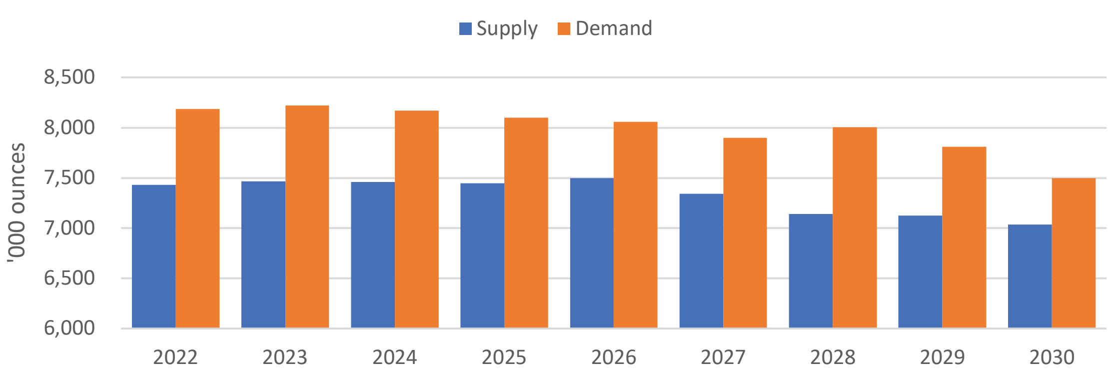
The prevalent trend of cosmetic-based and price-induced substitution away from metallic alloys to cheaper, non-PGM alternatives.

Further downsizing (thrifting) and potentially some substitution in palladium-utilizing components in microelectronics are also anticipated.

16.2.5.2 SUPPLY

The majority of PGM resources are located in Southern Africa. In South Africa, PGMs occur within a large, layered igneous intrusion called the Bushveld Igneous Complex (BIC) in which more than 70% of the world's known platinum resources exist. The BIC is a basin-shaped intrusion of some 370 km across, with only its rim exposed. The intrusion contains numerous distinct segregated layers formed during repeated fractionation cycles, three of which contain economic concentrations of PGMs. The main PGM-bearing layers, often referred to as 'reefs', are called the Merensky Reef, the UG2 Reef and the Platreef. Zimbabwe and North America are also important primary sources of PGM. PGMs are also found in high concentrations in Russia and Canada as a by-product to nickel mining. See Figure 16-5.

Figure 16-5: Palladium Market Forecast, 2022–2030



Source 3rd Party

16.2.6 GOLD

16.2.6.1 DEMAND

Gold is used in jewellery, as an investment instrument, in technology, and to manage central banks' reserves.

Gold jewelry is the largest demand sector, accounting for over 50% of total demand. Central bank demand has shifted since the financial crisis of 2008 with emerging markets increasing purchases and European banks halting sales of the metal, now accounting for roughly 6% of total market demand. Volatile markets sustain demand for gold in investment portfolios to protect purchasing power and minimize losses during market shocks, with this sector accounting for approximately 30% of total market demand. The unique properties of gold are driving technological uses in medicine, engineering and environmental management, with a total market share of approximately 10%.

The demand for gold has moved East in the past decade to the emerging economies of China and India. India is one of the largest consumers of gold and it plays a central role in the country's culture as a symbol of status.

16.2.6.2 SUPPLY

The geographical diversity of mined gold, mined on every continent except Antarctica, allows for stability in the market. Mine production of gold accounts for roughly 70% of total market supply annually with recycled material making up the balance.

16.2.7 COMMENTS ON MARKET STUDIES

There are no agency relationships relevant to the marketing strategies used by Vale Operations.

Product valuation is included in the economic analysis in Chapter 19 and is based on a combination of the metallurgical recovery, commodity pricing, consideration of processing charges, and allocations, where applicable for premiums paid on the products from the operations.

Since gold is a by-product of our operations, there is no technical specification for end-users to be saleable.

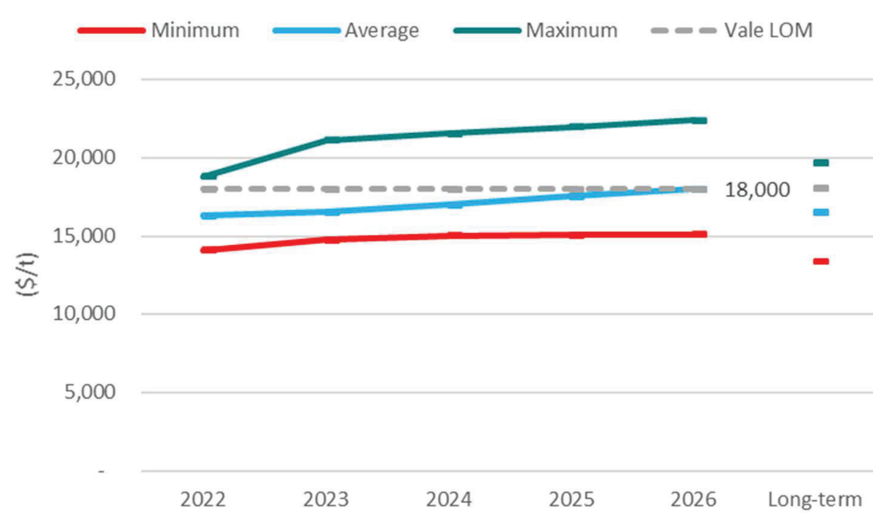
16.3 PRICE OUTLOOK

The intent is to demonstrate that the mineral reserves are economically viable, and the sensitivity analysis shows the potential upside or risks of the economics to factors such as price.

16.3.1 NICKEL

The LOM pricing (US$18,000) forecast uses a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2021–2025, reverting to a long-term fixed forecast from 2026 for the remaining mine life Figure 16-6).

Figure 16-6: LOM Nickel Price Forecasts

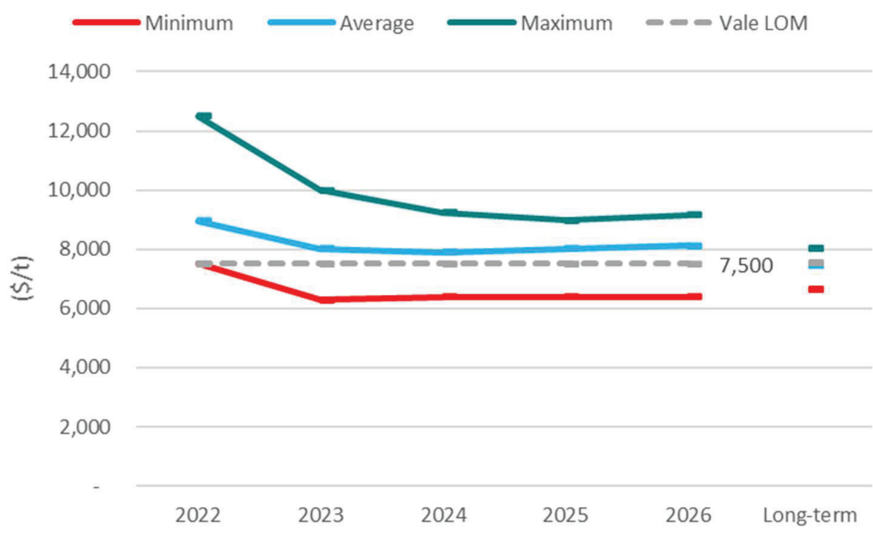


Source: Bank reports published from August 2021

16.3.2 COPPER

The LOM pricing (US$7,500) forecast uses a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2021–2025, reverting to a long-term fixed forecast from 2026 for the remaining mine life (Figure 16-7)

Figure 16-7: LOM Copper Price Forecasts

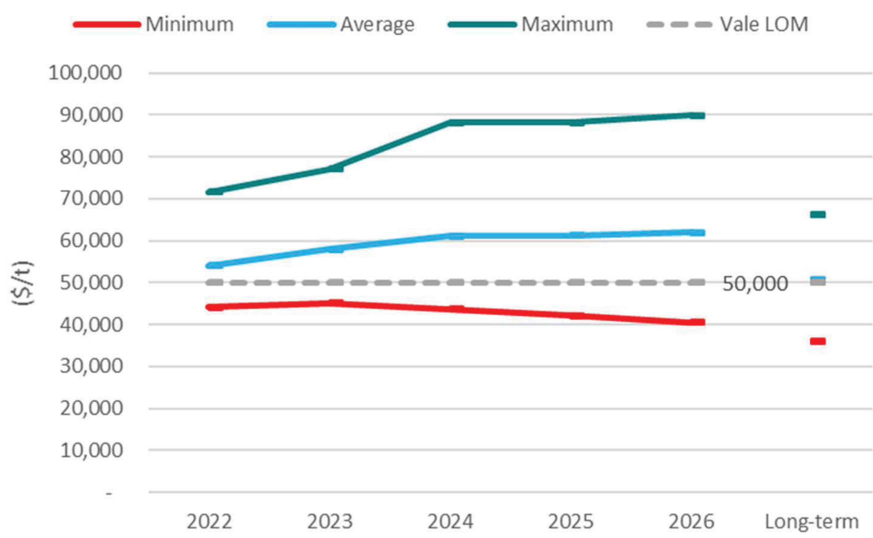


Source: Bank reports published from August 2021

16.3.3 COBALT

The LOM pricing (US$50,000) forecast uses a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2021–2025, reverting to a long-term fixed forecast from 2026 for the remaining mine life (Figure 16-8)

Figure 16-8: LOM Cobalt Price Forecasts

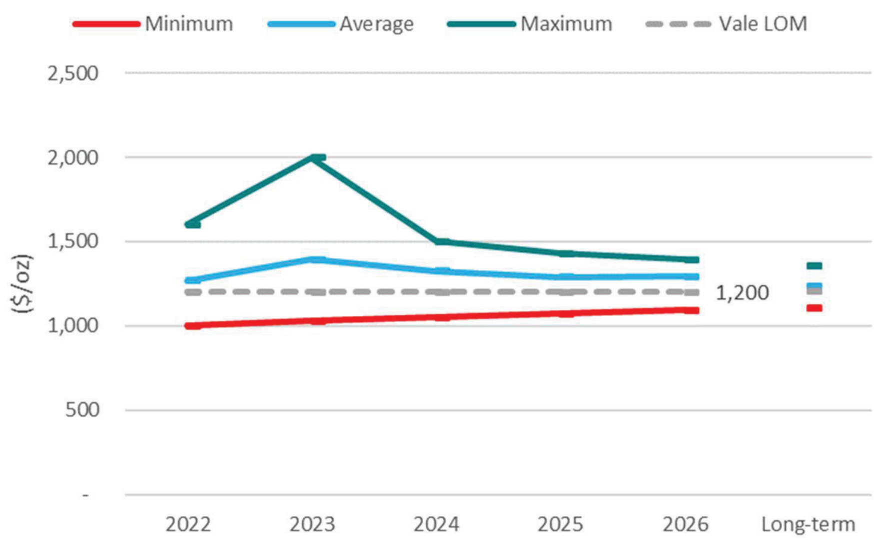


Source: Bank reports published from August 2021

16.3.4 PLATINUM

The LOM pricing (US$1,200) forecast uses a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2021–2025, reverting to a long-term fixed forecast from 2026 for the remaining mine life (Figure 16-9).

Figure 16-9: LOM Platinum Price Forecasts

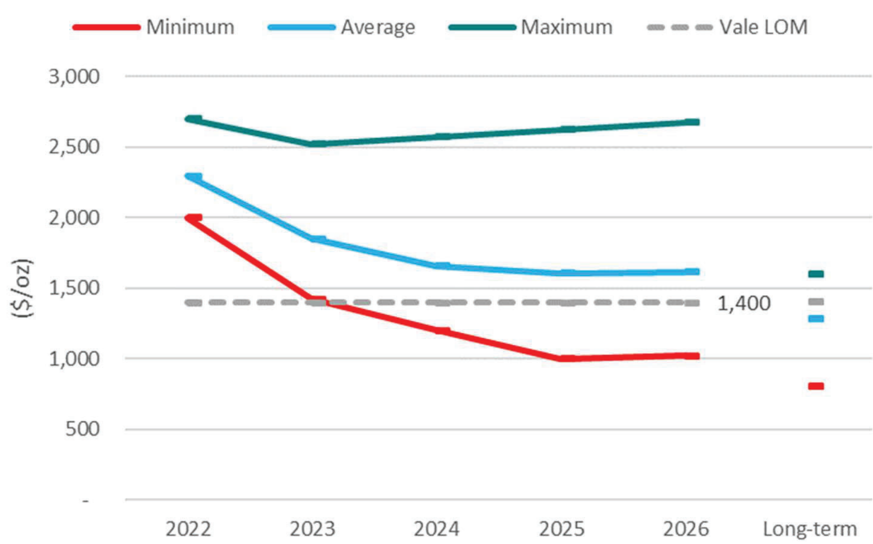


Source: Bank reports published from August 2021

16.3.5 PALLADIUM

The LOM pricing (US$1,400) forecast uses a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2021–2025, reverting to a long-term fixed forecast from 2026 for the remaining mine life (Figure 16-10).

Figure 16-10: LOM Palladium Price Forecasts

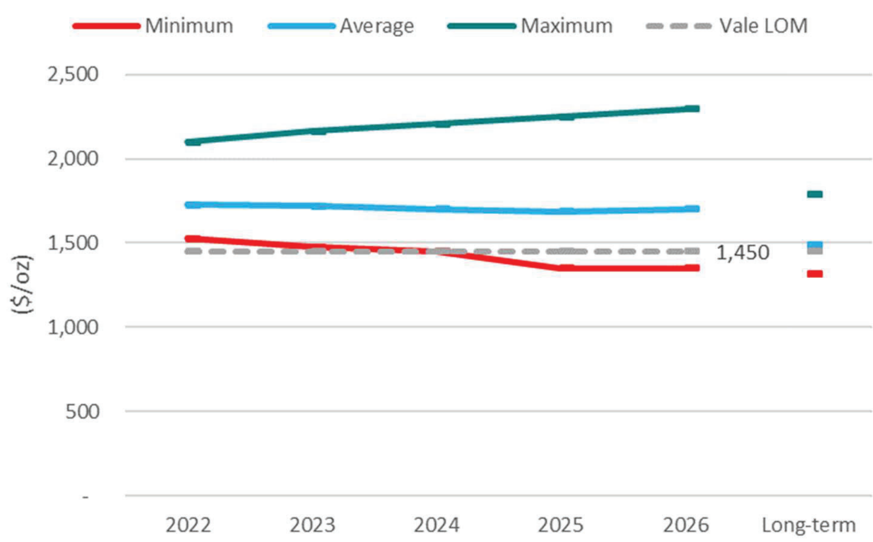


Source: Bank reports published from August 2021

16.3.6 GOLD

The LOM pricing (US$1,450) forecast uses a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2021–2025, reverting to a long-term fixed forecast from 2026 for the remaining mine life (Figure 16-11).

Figure 16-11: LOM Gold Price Forecasts



Source: Bank reports published from August 2021

16.3.7 CONTRACTS

Vale has agreements at typical copper concentrate industry benchmark terms for metal payables, treatment charges and refining charges for concentrates produced. Treatment costs and refining costs vary depending on the concentrate type and the destination smelter.

The terms contained within the concentrate sales contracts are typical and consistent with standard industry practice and are similar to contracts for the supply of copper concentrate throughout the world. Depending on the specific contract, the terms for the copper concentrate sale are either annually negotiated, benchmark-based treatment and refining charges, or in the case of spot agreements are based on fixed treatment and refining charges based on market terms negotiated at the time of sale. The differences between the individual contracts are generally in relative quantity of concentrates that are covered under annually negotiated treatment and refining charges.

As metals contained in copper products, the terms for gold are determined through a payable mechanism on metal content based on typical market terms. As typical for concentrates, the product is generally contracted under a medium-term contract.

The majority of cobalt production is sold under annual or multi-year contracts. These contracts are based on market pricing using a negotiated formula based on the Fastmarkets cobalt price plus a premium or discount. The remaining production is sold on a spot basis. These sales are based on the current market pricing at the time of sale, using similar pricing methodology as described previous, or at a spot or fixed current market price. Any finished cobalt sales to affiliated parties are sold at market pricing similar to external parties.

Gold sands are typically sold using spot pricing terms with end-users based on prevailing market conditions. A portion of Ontario gold production is sold under a multi-year streaming agreement.

Contracts may be entered into for goods and services required to operate underground mining operations. On occasions, mining contractors may be employed for specific mine development projects. The largest in-place contracts include transportation, purchase of fuel, reagents and other process consumables, ground support and mining equipment leases. The terms contained within the contracts are typical of, and consistent with, standard industry practices.

Intercompany agreements between Vale affiliates are negotiated at arm's length based on market terms and rates that would be achieved had the contract been negotiated with an unaffiliated third party.

As metals contained in copper products, the terms for gold and PGM's are determined through a payable mechanism on metal content based on typical market terms. As typical for concentrates, the product is generally contracted under a medium-term contract.

PGM concentrate and gold sands are typically sold using spot pricing terms with end-users based on prevailing market conditions. A portion of Sudbury gold production is sold under a multi-year streaming agreement.

17 ENVIRONMENTAL STUDIES, PERMITTING, AND PLANS, NEGOTIATIONS, OR AGREEMENTS WITH LOCAL INDIVIDUALS OR GROUPS

17.1 BASELINE AND SUPPORTING STUDIES

17.1.1 HISTORY

Vale's Ontario Operations are one of the largest integrated mining complexes in the world, including both mines and processing operations, some dating back to the early and mid-1900s. Environmental regulations and awareness has progressed significantly from the beginning of our operations in Ontario and the company has engaged in baseline studies, various improvement and legacy reclamation initiatives and other activities to ensure compliance as the regulatory regime changes.

All pertinent baseline information as per standard of the day is available in the Closure Plans for the mine sites and surface plants, including: land use, topography, regional geology, local geology and mineralogy, soil, climate and hydrology, hydrogeology, terrestrial plant and animal life and aquatic plant and animal life, with relevant updates provided in the subsequent Closure Plan amendments.

As the mines and plant sites have continued to expand, supporting environmental studies have been completed to assess site environmental conditions, and to support permit applications and decision-making processes.

17.1.2 CURRENT ACTIVITIES

At all mines, baseline and supporting environmental studies are completed to assess both pre-existing and ongoing site environmental conditions, as well as to support decision-making processes, and if applicable, permit applications for new projects as these are brought on stream. Characterization studies were completed for all environmental media including soil, water, waste, air, noise and closure.

Plans were developed and implemented for all Ontario Operation mine sites to address waste management, spill prevention and contingency planning, water management and fugitive dust management. Noise levels generally meet the required guidelines.

17.2 ENVIRONMENTAL CONSIDERATIONS/MONITORING PROGRAMS

17.2.1 WASTE ROCK

In general, the presence of comparatively large quantities of waste rock onsite presents a significant environmental liability. Waste rock is present throughout the Ontario Operations areas, and is both confined to specific piles or storage areas and distributed throughout the sites. Surface and groundwater monitoring has shown water quality to generally be acidic with elevated concentrations of metals. Specific areas requiring remedial work were identified and prioritized using the Water Quality Management Plan (see Chapter 17.2.3).

17.2.2 TAILINGS

The Copper Cliff tailings impoundment became operational in 1936 and was the primary management site for tailings generated from the Sudbury milling operations. The tailings area footprint is approximately 3,000 ha and currently contains approximately 534 Mt of tailings within seven internal cells. The perimeter was developed using upstream construction. In 1985, deposition commenced in the last cell, called the "R" area, and deposition will continue in this area over the next 25 years and reach an elevation of 335 m. Since tailings deposition could resume over "A" Area and given tailings will continue to be used for backfill underground, it is expected that there will be sufficient tailings storage until approximately 2050.

Historically, Frood Mine tailings were piped to the Vale's Central Tailing Area (CTA); however, tailings were occasionally discharged within the closure area within the Frood Emergency Tailings

Area (FETA) when they could not be accepted offsite. Runoff that is captured in the FETA is pumped back to Frood Pond.

Tailings were historically impounded onsite in the Levack Tailings Area. During operation most of the tailings produced by the Levack Mill were stored onsite for permanent disposal. The tailings are no longer actively deposited into the Levack Tailings Area and are currently dry. Tailings impacted surface and groundwater seepage is collected by a series of interception wells. The overall environmental impact of the tailings is reduced due to minimal water infiltration and the interception well system. A receiving water study showed that the perimeter seepage management systems are effective in preventing contaminant migration to surrounding natural water bodies.

In 2021, Vale concluded a tailings closure study for the closed facilities at the Frood Emergency Tailings Area (FETA), Levack Tailings Area (LTA), and the Shebandowan Tailings area. The objectives of the study were to provide detailed tailings characterization, anticipated extraction rates and schedules, equipment requirements and associated costs.

17.2.3 WATER QUALITY

Treated mine effluent and receiving water quality monitoring is ongoing as per permit and regulatory requirements. Acid mine drainage is the main water quality issue at all the sites. Routine sampling, in accordance with the stated requirements, is conducted on an ongoing basis at Totten Mine, Garson Mine, Crean Hill (Ellen Pit), and the Whistle Mine, as well as at the Copper Cliff Complex. The Copper Cliff Complex, serviced by the Copper Cliff and Nolin Creek waste water treatment plants, encompasses effluent and surface drainage from the Creighton and Gertrude Mines, Copper Cliff Mine, Stobie Mine and surface milling/smelting and refining facilities.

A summary of the major water treatment facilities is provided in

Table 17-1.

In 2009, Vale initiated a comprehensive Water Quality Management Plan, involving the consolidation of all surface and groundwater monitoring data for all sites, dating back to approximately 2001 (and earlier for some stations/data), into one web-based database (see also discussion on water sampling in Chapter 7.3). The Water Quality Management Plan is designed to be a proactive plan, involving hazard screening and a risk evaluation process, to guide Vale with the identification, prioritization and execution of remedial activities to address water impacts from seepages and discharges connected to historical operations.

The management of water quality impacts, and the associated regulatory implications, resulting from past practices when environmental protection programs and regulations were less robust remains a significant risk.

Regulatory limits associated with treated effluent water quality are consistently met. Work is ongoing to assess and continually improve effluent treatment processes and spill prevention.

17.2.4 AIR QUALITY AND SULPHUR DIOXIDE EMISSIONS

Ontario Regulation 419/05 requires all Ontario Operations mines and metallurgical plants to meet ambient air quality standards by both measurement and air dispersion modeling. Dispersion modeling is the tool used to predict offsite concentrations based on a reasonable worst-case production scenario and local meteorological data.

All Ontario Operations currently meet Ontario Regulation 419/05 standards, except the Copper Cliff Smelter which operates under a site-specific standard for annual nickel impact. A new site-specific standard was approved in December 2021, following submission in September 2020, and replaced the former site-specific standard that expired on December 31, 2021. The site-specific standard recognizes that, while nickel impact from the site has decreased over time, the site still does not comply with the Ontario Regulation 419/05 standard. The new site-specific standard will require the implementation of an Action Plan and will be effective until December 2031. Fifteen months prior to that date, a new application will need to be submitted if the site still does not show compliance with the nickel standard.

Table 17-1: Key Water Treatment Infrastructure

Plant	Comments
Copper Cliff waste water treatment plant	Manages water from the Central Tailings Area and other site sources of contact water, including from the Clarabelle Mill, smelter complex and refinery sites and the Creighton, Copper Cliff and Stobie Mine sites. The Copper Cliff waste water treatment plant also treats municipal runoff and domestic sewage effluent from the Copper Cliff sewage treatment plant. Capacity of up to 227,000 m^3/day
Nolin Creek wastewater treatment plant	Treats contact waters from the smelter complex, Stobie Mine, slag pile areas, the Clarabelle Mill property, as well as excess Clarabelle Mill reclaim thickener water. Capacity of up to 26,450 m^3/day
Garson Mine waste water treatment system	Treats effluent and site surface runoff
Totten Mine waste water treatment system	Treats effluent and site surface runoff
Whistle Mine Wastewater Treatment Plant	Treats effluent and site surface runoff
Crean Hill (Ellen Pit) Wastewater Treatment plant	Treats effluent and site surface runoff
Coleman Mine	Mine water and surface drainage are collected and transferred to the Glencore operations for treatment in their wastewater facilities

The Ontario Regulation 419/05 standards for SO_2 are decreasing as of July 2023. The Copper Cliff Smelter, Copper Cliff Nickel Refinery and Port Colborne Refinery currently do not meet the upcoming 1 hr SO_2 standard. The Ministry has proposed a separate Regulation specifically for the Copper Cliff Smelter, Copper Cliff Nickel Refinery and Glencore's Sudbury Smelter. It will replace the requirement to comply with the new SO_2 standards with specific requirements for SO_2 control and continuous improvement and will not have an expiry date.

The Port Colborne Refinery has investigated process changes to enable compliance to the new SO_2 standard. Based on the early investigation work, the refinery will be able to meet compliance for the new SO_2 standard.

17.3 CLOSURE AND RECLAMATION CONSIDERATIONS

17.3.1 CLOSURE PLANNING

Vale has 16 closure plans for aspects of the Ontario Operations, covering the Central Tailings Facility, Clarabelle Mill, the Copper Refinery, Crean Hill Mine, Creighton Mine, Frood–Stobie Mine, Garson Mine, Levack–Onaping-Coleman Mine, the nickel refinery, Copper Cliff North Mine, Port Colborne Refinery, Shebandowan Mine and mill, Copper Cliff Smelter complex, Copper Cliff South Mine, Whistle Mine and Totten Mine.

Closure plans for all operating sites were submitted to the relevant regulatory authorities in 2001, and there are plans in place for three closed sites (Whistle Mine, Shebandowan Mine and mill site, and Crean Hill Mine) in accordance with Part VII of the Ontario Mining Act. As required by regulation and internal guidelines, these documents are updated in five-yearly intervals to ensure they accurately depict onsite liabilities. Vale updated all 16 Closure Plans in 2018 and formally submitted to regulators in 2019. At the request of the regulator, the closure plans were submitted on a staggered basis to allow the Ministry of Northern Development Mines, Natural Resources and Forestry to better manage their internal review and approval process. Vale has received comments on these documents, and is working with the regulator to incorporate feedback.

While Ontario Operations uses "self-assurance" as its form of financial assurance for surface facilities, a performance bond of C$206 million, in the form of letters of credit, was provided for 10 properties. Such bonding is a requirement in Ontario when the half-life of a mine is exceeded or where a facility has formally ceased operations.

17.3.2 CLOSURE COSTS

Vale developed closure cost estimates associated with the chosen rehabilitation strategy for each property. The estimate also includes an expected schedule for closure-related expenditures.

Closure costs are included in the mine site financial models as cash costs, on an annual basis for all sites. The largest closure costs are associated with the process plant and mining infrastructure.

The escalated closure cost estimate for the Ontario Operations, as at year-end 2021, is US$2,060 million.

17.4 PERMITTING

All known and anticipated permits and approvals are in place to support operations. These include permits for air quality, noise emissions, taking and discharging water, and tailings, waste rock and waste disposal.

Where permits have specific terms, renewal applications are made of the relevant regulatory authority as required, prior to the end of the permit term.

For new mining projects that may be incorporated into future mine plans, assuming mineral resources can be converted to mineral reserves with the appropriate supporting studies, the expectation is that environmental/impact assessments (if required) will be near completion, and the permits required for mine development will be understood and advancing, where possible, with baseline and supporting studies completed to facilitate application submissions and detailed design.

17.5 SOCIAL CONSIDERATIONS, PLANS, NEGOTIATIONS AND AGREEMENTS

Indigenous Peoples may have Aboriginal & Treaty Rights and traditional territory where Vale operates as well as within lands in which Vale has mineral rights. In Canada, the Crown has an obligation to consult with Indigenous communities to address possible infringement of their rights. This obligation may need to be satisfied by the Crown in connection with development on Vale's lands, which may affect those rights. The Crown also frequently delegates the procedural aspects of this duty to consult to proponents such as Vale. Increasingly, Vale is being requested to consult with Indigenous communities on some provincial and federal environmental permit applications.

In accordance with revisions made to O. Reg. 240/00 (under the *Ontario Mining Act*), Vale is also required to consult with Indigenous communities, as directed by the Director of Mine Rehabilitation, before filing a certified Closure Plan or a certified amendment to a Closure Plan.

Vale routinely engages with four Indigenous communities in the Sudbury Basin including Atikameksheng Anishnawbek First Nation (AAFN), Wahnapitae First Nation (WFN), Sagamok Anishnawbek First Nation (SAFN), Whitefish River First Nation (WRFN) and the Métis Nation of Ontario (MNO) – Region 5. Vale has signed agreements with AAFN, WFN, SAFN and the MNO – Region 5. There are currently no known consultation obligations which would materially impact the mineral reserve estimates. However, consultation obligations may need to be satisfied before new areas that currently only have mineral resource estimates can be developed.

Due to the proximity of Vale's Ontario Operations to local communities, the company continues to engage the local communities of interest that may be impacted by future development. There are a variety of communication channels for community engagement including Annual Reports to the Community, annual Open Houses, a Community Liaison Committee, a company website, local media relations and advertising. Vale has also established a grievance mechanism known as the Community Concerns Line to receive community concerns, complaints, and other matters; there are also a number of email communication channels to register grievances. These grievances are recorded in a grievance database and tracked for mitigation and conclusion.

17.6 QUALIFIED PERSON'S OPINION ON ADEQUACY OF CURRENT PLANS TO ADDRESS ISSUES

Regulatory limits associated with treated effluent water quality are consistently met and managing collected runoff and seepage quantities is key to achieving environmental compliance

Remediation of potential water impacts from historical operations, which has often involved capturing additional site surface runoff and seepages, will need to be balanced with clean water diversion and/or appropriate management to ensure that the waste water treatment plant capacities are not exceeded.

It is possible that future changes in water quality discharge limits could result in the need for additional or more efficient water treatment facilities. More specifically, amendments to the *Fisheries Act* (including the possible addition of new parameters and/or lower effluent criteria into the Metal and Diamond Mine Effluent Regulations (MDMER)) have been proposed by the Federal Government, which could affect the operations of many mine sites across Canada with respect to water management and effluent treatment. All collected site waters are treated in existing treatment plants. Based on the current knowledge of potential changes to future discharge limits, it is reasonable to assume that future treatment requirements could be accommodated within the existing facilities, but with some upgrades/modifications to the treatment plants potentially required.

In 2009, Vale initiated a comprehensive Water Quality Management Plan, involving the consolidation of all surface and groundwater monitoring data for all sites, dating back to approximately 2001 (and earlier for some stations/data), into one web-based database (see also discussion on water sampling in Chapter 7.3). The Water Quality Management Plan is designed to be a proactive plan, involving hazard screening and a risk evaluation process, to guide Vale with the identification, prioritization and execution of remedial activities to address potential water impacts from historical operations. The management of water quality impacts resulting from past practices when environmental protection programs and regulations were less robust remains a significant risk.

18 CAPITAL AND OPERATING COSTS

18.1 INTRODUCTION

All capital and operating cost estimates are at a minimum at a pre-feasibility level of confidence, having an 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.

18.2 CAPITAL COST ESTIMATES

18.2.1 BASIS OF ESTIMATE

Capital costs are based on recent prices or operating data. Unit costs for in-house mine development are based on historical actual costs. Mobile equipment that is leased is included in operating costs. Lease periods typically range from two to five years. Lease costs are charged to capital while the equipment is doing capital work. Purchased equipment is allocated for in the capital plan. Mobile equipment and fixed asset costs are based on supplier quotations and/or current examples. Sustaining capital cost forecasts are based on forecast mine development and construction needs, mobile equipment re-build/replacement schedules and fixed asset replacement and refurbishment schedules.

18.2.2 CAPITAL COST FORECASTS

Across the Ontario Operations, sustaining capital cost forecasts are prepared considering three main categories:

- Annual capital development: sustaining capital investments required to open up new mine production areas. This category includes underground tunneling and infrastructure construction that will be in use for more than two years (e.g., ramps, ventilation raises, ore passes, switch rooms, backfill stations);
- Stoping and development (S&D): mobile equipment acquisitions, replacements, and rebuilds;
- Asset integrity: capital investments required to maintain existing main infrastructure, and rebuild and replace fixed assets (e.g., shafts, main fresh air fans, material handling systems, mill equipment, smelting equipment).

In addition, where the scope of a sustaining investment exceeds US$100 M estimated capital cost, the project is developed following a Front-End Loading (FEL) methodology and subject to an internal process of technical review and stage gate approval.

Vale is investing dedicated project capital at Copper Cliff Mine to increase production by re-establishing hoisting through its south shaft infrastructure. Pre-feasibility studies support the future development of the 191, 178, and 712 deposits to sustain production in the north and south shafts. Investments related to the Copper Cliff Mine Expansion is listed as dedicated Project Capital.

18.2.3 CAPITAL COST ESTIMATE SUMMARY

The overall capital cost estimate for the LOM is US$5,429 M as shown in Table 18-1. 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.

Table 18-1: LOM Capital Cost Estimate

Area	Capital Cost Type	Unit	Value
Mining	Annual capital development	US$ M	1,288
	S&D	US$ M	642
	Asset integrity	US$ M	515
Copper Cliff Mine Project	Project	US$ M	1,269
Milling	Sustaining	US$ M	256
Smelting and Refining	Sustaining	US$ M	942
Other[1]	Sustaining	US$ M	516
Total		***US$ M***	***5,429***

Note:
All numbers have been rounded.
[1]Other costs include provision for elements such as the power department (electrical power generation and distribution), the divisional shops (custom parts repair and manufacturing), the transportation department, the environment department and the central engineering department

18.3 OPERATING COST ESTIMATES

18.3.1 BASIS OF ESTIMATE

Operating costs are based on actual costs seen during operations and are projected through the LOM plan.

Historical costs are used as the basis for operating cost forecasts for supplies and services unless there are new contract terms for these items.

Labour and energy costs are based on budgeted rates applied to headcounts and energy consumption estimates.

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 long-term mine operating cost model accounts for the impact of varying production rates on the direct variable costs. As a mine approaches the end of mine life, indirect and distributed costs are reduced in line with the projected lower production rates. The processing operating cost estimates are the budget year cash costs applied to the mineral reserves mined throughout the LOM plan. These processing costs include both variable and fixed plant components. Since the throughput for the processing plants decreases over the LOM plan, the fixed cash cost component of these processing plants is stepped down in a logical progression as the feed decreases.

18.3.2 OPERATING COST ESTIMATE SUMMARY

Operating costs total US$13,781 M over the LOM (Table 18-2).

Table 18-2: Operating costs and expenses

Area	Unit	Value
Mining	US$ M	6,095
Milling	US$ M	756
Smelting and Refining	US$ M	3,224
G&A and Corporate Overhead	US$ M	2,649
Site Services and Other	US$ M	682
R&D	US$ M	156
Logistics and Distribution Costs	US$ M	218
Total	***US$ M***	***13,781***

Note: All numbers have been rounded.

19 ECONOMIC ANALYSIS

19.1 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 Vale publishes 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 METHODOLOGY

The financial model that supports the mineral reserve declaration is a standalone model that calculates annual cash flows based on scheduled ore production, assumed processing recoveries, metal sale prices and C$/US$ exchange rate, projected operating and capital costs and estimated taxes.

The financial analysis is based on an after-tax discount rate of 7.5% following a mid-year convention and an exchange rate CAD$/US$ 1.26. All costs and prices are in unescalated “real” dollars. The currency used to document the cash flow is US$.

All costs are based on the five-year plan approved budget. Post 2026, costs were estimated based on the 2022–2026 period.

Revenue is calculated from the recoverable metal and the long-term forecast of metal prices and exchange rate.

All inputs to the economic analysis are at a minimum of a pre-feasibility level of confidence.

19.3 INPUT PARAMETERS

The mineral reserves estimate was summarized in Chapter 12.6. The projected mine life was provided in Chapter 13.10.

The Ontario Operations also receives revenue from the sale of mined material by Glencore from the 6166 and 7386 claims at Coleman Mine, known as the “Bowtie” material. In this arrangement, Glencore mines and processes material that is located within VCL claims but adjacent to the Fraser Mine property. Vale then receives a Gross Metal Value type payment for the material mined. The “Bowtie” production began in April 2012 and has been progressing since then, with actual revenues being received by Vale.

The metallurgical recovery forecast was provided in Chapter 10.4.

Revenue is calculated from the recoverable metal and the long-term forecast of metal prices and exchange rates. Revenue from the sale of a copper concentrate is included, based on the contained metal, accountability factors and the long-term forecast for metals prices and exchange rates.

Commodity prices were discussed in Chapter 16.3.

Capital costs were summarized in Chapter 18.2.3. Operating costs were summarized in Chapter 18.3.2. Capital and operating costs were reported using Q4 2021 US$.

Royalties were summarized in Chapter 3.8.

Closure and reclamation costs were discussed in Chapter 17.3.

The economic analysis is based on 100% equity financing and is reported on a 100% project ownership basis.

19.4 TAXATION CONSIDERATIONS

Vale Canada Limited is subject to income and mining taxes, which are both profit-based taxes.

The financial estimates are based on a combined federal and provincial income statutory tax rate of 25% and a provincial mining statutory tax rate of 10%, before processing allowance. Depreciation rates for corporate income tax purposes have been applied, on a declining balance basis, at the base rates of 25% for depreciable tangible capital property and 30% for mine development. For mining tax purposes, depreciation has been approximated on a declining balance basis for mining (30%) and processing property (15%). Provincial mining processing allowance is further deducted as applicable. The mining tax paid is deductible for corporate income tax purposes.

19.5 RESULTS OF ECONOMIC ANALYSIS

The cashflow for Ontario operations is used to confirm the mineral reserve economic viability, which is the sole purpose of the presented figures and therefore it can differ from other information Vale publishes. The results of the reserve only cashflow should not be considered as a guidance.

Absent from the reserve only cashflow are the Ontario resources which may be converted into reserve over time to continue to extend our production plan, external feeds acquired by Vale from other mining companies and Manitoba concentrate treated by our Sudbury processing assets. Also, the contractual gold price conditions stated in the Wheaton streaming agreement are not reflected in the cashflow evaluation. Further details on the terms of the Wheaton agreement are discussed in Chapter 3.8.1.

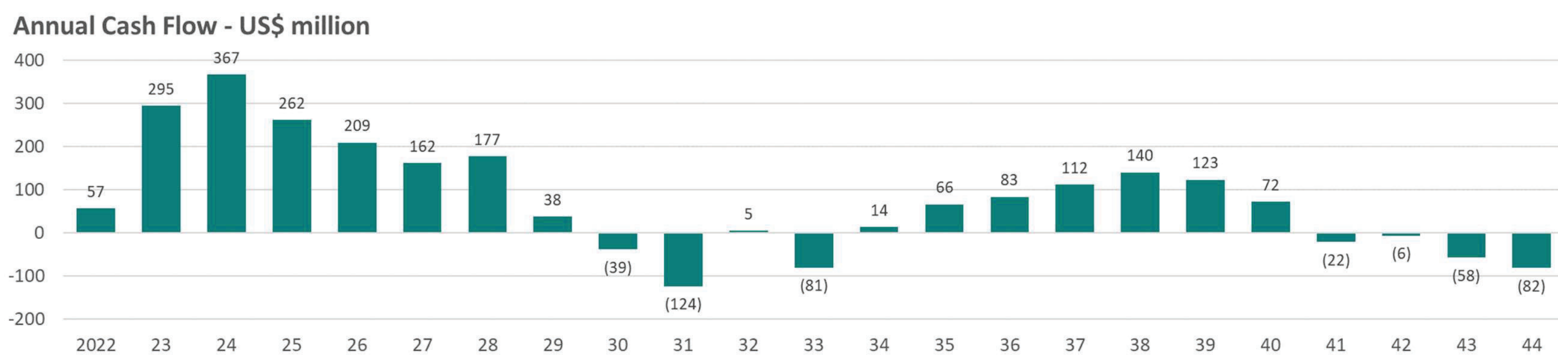
The annual cashflow is presented with the inputs as averages grouped for the first 2 years, followed by 3 years, and subsequently 5-year groups. For the end of the production period (LoMP) we have a specific group of 3 years. The average costs related to closure are summarized as a long-term group (2045-2148) and indicated in the cashflow footnote (3) of Table 19-1.

As the cashflows are based on existing operations where all costs are considered sunk to 1 January 2022, considerations of payback and internal rate of return are not relevant.

The post-tax $NPV_{7.5\%}$ is US$1,177 M and a cashflow summary is provided in Table 19-1.

Table 19-1: Ontario Average Cashflows[1,2,3,4] 2022-2148

Cash Flow	Unit	2022-23	2024-26	2027-31	2032-36	2037-41	2042-44	2045-2148
Ore Processed	Mt	4	3	3	2	2	1	
Nickel Recovered	kTonnes	45	43	26	19	19	7	
Copper Recovered	kTonnes	72	58	44	27	20	7	
Cobalt Recovered	kTonnes	0.4	0.4	0.3	0.2	0.2	0.1	
Platinum Recovered	kOz	114	107	76	62	52	11	
Paladium Recovered	kOz	129	114	90	88	77	15	
Gold Recovered	kOz	47	40	25	22	17	4	
Total Revenue	US$ million	1,722	1,535	1,041	755	674	218	
Operating costs, expenses, royalties, and closure costs	US$ million	(1,113)	(897)	(676)	(529)	(464)	(239)	(18)
Tax and Working Capital Change	US$ million	6	(10)	2	6	8	23	0
Total CAPEX	US$ million	(440)	(348)	(323)	(214)	(133)	(52)	



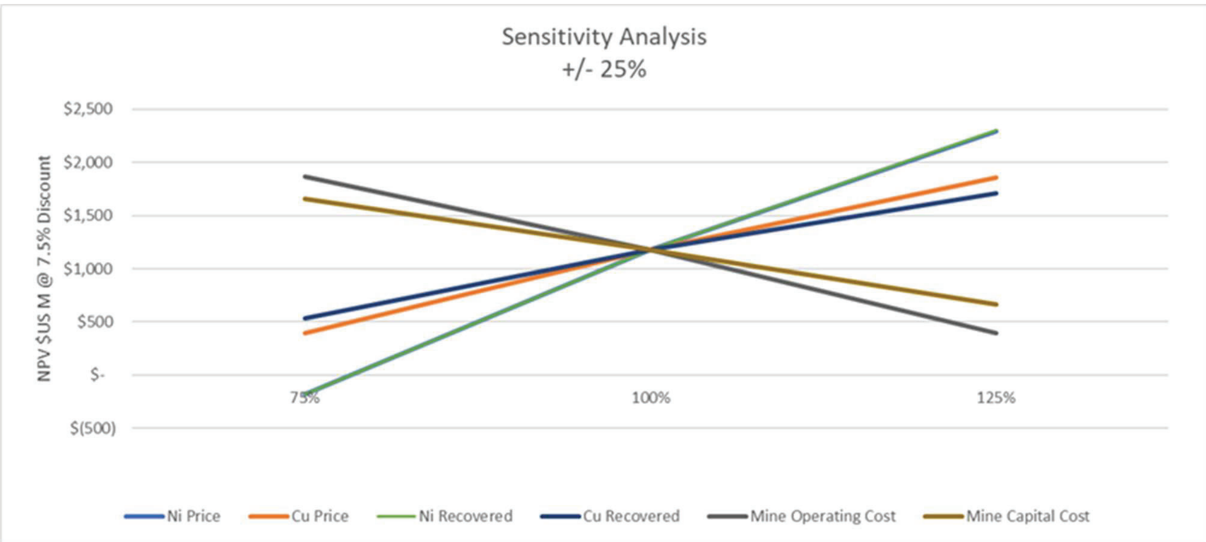
[1] Sale price of copper US$7,500/tonne, nickel US$18,000/tonne, cobalt US$50,000/tonne, gold US$1,450/oz, platinum US$1,200/oz, palladium US$1,400/oz
[2] Figures shown do not deduct the stream amounts. For a description of our streaming arrangement with Wheaton, see Chapter 3.8.1
[3] The closure costs from 2045-2148 totals US$1.9B. US$18M represents the annual average cost of closure in the period.
[4] 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

19.6 SENSITIVITY ANALYSIS

A sensitivity analysis was performed on metal prices, metal recovered, capital costs and operating costs. Ontario Operations are most sensitive to the following, arranged in order from most to least sensitive:

- Nickel price
- Nickel recovered
- Copper price
- Operating cost
- Copper recovered
- Capital costs

Figure 19-1: Sensitivity Analysis



20 ADJACENT PROPERTIES

This chapter is not relevant to this Report.

21 OTHER RELEVANT DATA AND INFORMATION

This chapter is not relevant to this Report.

22 INTERPRETATION AND CONCLUSIONS

22.1 INTRODUCTION

The QPs note the following interpretations and conclusions in their respective areas of expertise, based on the review of data available for this Report.

22.2 PROPERTY SETTING

The Ontario Operations are located in an area that has more than a hundred years of mining activity. As a result, local and regional infrastructure and the supply of goods available to support mining operations is well-established. Personnel with experience in mining-related activities are available in the Sudbury district. There are excellent transportation routes that access the Sudbury area.

There are no significant topographic or physiographic issues that would affect the Sudbury Operations. The dominant vegetation type is temperate boreal forest.

Mining operations are conducted year-round.

22.3 OWNERSHIP

The Ontario Operations are wholly-owned by Vale Canada Limited, a Vale subsidiary.

22.4 MINERAL TENURE, SURFACE RIGHTS, WATER RIGHTS, ROYALTIES AND AGREEMENTS

Information obtained from Vale experts supports that the mineral tenure held is valid and is sufficient to support a declaration of mineral resources and mineral reserves.

In each township, Vale is the registered owner of mining rights and surface rights or a combination of both shown as fee simple lands, mining leased lands, mining license of occupation lands and unpatented mining claims. Vale holds applicable water take permits to support operations.

There are no royalties or other similar payments made on the Ontario Operations mine properties within the Sudbury Basin other than that payable to Wheaton Precious Metals. Wheaton Precious Metals has the right to an amount of gold equal to 70% of the gold production from certain of Vale's Sudbury mines, including the Coleman, Copper Cliff, Garson, Stobie, Creighton, Totten Mines and the Victor project for a period of 20 years. Wheaton Precious Metals will make ongoing payments of the lesser of US$400/oz Au or the prevailing market price per ounce of gold delivered. There are no known encumbrances.

Vale has agreements in place, including: multiple road and property easements with various mining companies; various corridor agreements with Glencore permitting development of underground corridors; an exploration joint venture agreement with Glencore; ventilation agreements with Glencore, and OIC that allow Vale to export nickel, copper and PGM products outside of Canada for further refinement.

22.5 GEOLOGY AND MINERALIZATION

Deposits within the SIC are type examples of nickel–copper mineralization arising from a meteorite impact.

The geological understanding of the settings, lithologies, and structural and alteration controls on mineralization in the different zones is sufficient to support estimation of mineral resources and mineral reserves. The geological knowledge of the area is also considered sufficiently acceptable to reliably inform mine planning.

The mineralization style and setting are well understood and can support declaration of mineral resources and mineral reserves.

The Ontario Operations continue to actively explore within the current mining operations, and the majority of deposits remain open at depth. Exploration is conducted underground from existing infrastructure and services with the aim of discovering and delineating additional mineralization that is within reach of the active mine infrastructure.

Brownfield exploration is focused on areas in the Sudbury basin within a reasonable radius of existing infrastructure. Greenfields exploration is conducted throughout the Ontario Operations area to identify new stand-alone nickel and copper deposits.

22.6 HISTORY

The Ontario Operations have over 100 years of active mining history, and exploration activities date back to 1856 when nickel was first discovered.

22.7 EXPLORATION, DRILLING, AND SAMPLING

The exploration programs completed to date are appropriate for the style of the deposits within the Sudbury basin and Ontario Operations area.

Most drill holes are oriented to intersect mineralised zones at an angle, and the drill hole intercept widths reported for those drill holes are typically greater than the true widths of the mineralisation at the drill intercept point.

Sampling methods, sample preparation, analysis and security conducted prior to Vale's interest in the operations were in accordance with exploration practices and industry standards at the time the information was collected. Current Vale sampling methods are acceptable for mineral resource and mineral reserve estimation. Sample preparation, analysis and security for the Vale programs are currently performed in accordance with exploration best practices and industry standards.

The quantity and quality of the lithological, geotechnical, collar and down-hole survey data collected during the exploration and delineation drilling programs are sufficient to support mineral resource and mineral reserve estimation. The collected sample data adequately reflect deposit dimensions, true widths of mineralization, and the style of the deposits. Sampling is representative of the nickel, copper, and PGM grades in the deposits, reflecting areas of higher and lower grades.

Density is estimated using a formula, based on a multivariate regression of nickel, copper, and sulphur data. This formula has been in use since the late 1990s and is considered to provide acceptable density values for use in mineral resource and mineral reserve estimation.

The sample preparation, analysis, quality control, and security procedures used by the Ontario Operations have changed over time to meet evolving industry practices. Practices at the time the information was collected were industry-standard, and frequently were industry-leading practices. Vale currently uses a system of "layered responsibility" to ensure that only appropriately verified data are used for estimation purposes. The sample preparation, analysis, quality control, and security procedures are sufficient to provide reliable data to support estimation of mineral resources and mineral reserves.

The QA/QC programs adequately address issues of precision, accuracy and contamination. Modern drilling programs typically included blanks, duplicates and standard samples. QA/QC submission rates meet industry-accepted standards.

22.8 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. In addition to these internal checks Vale contracted independent consultants to perform laboratory, database and mine study reviews. The process of active database quality control and internal and external audits generally resulted in quality data.

The data verification programs concluded that the data collected from the Ontario Operations area 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.

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.

22.9 METALLURGICAL TESTWORK

Industry-standard studies were performed as part of process development and initial mill design. Subsequent production experience and focused investigations guided mill alterations and process changes. Testwork programs, both internal and external, continue to be performed to support current operations and potential improvements. From time to time, this may lead to requirements to adjust cut-off grades, modify the process flowsheet, or change reagent additions and plant parameters to meet concentrate quality, production, and economic targets.

Samples selected for testing were representative of the various types and styles of mineralization. Samples were selected from a range of depths within the deposits. Sufficient samples were taken so that tests were performed on sufficient sample mass.

Recovery factors estimated are based on appropriate metallurgical testwork, and are appropriate to the mineralization types and the selected process routes. The milling recovery for nickel is estimated based on the nickel head grade and the calculated amount of pyrrhotite. The milling recovery for cobalt is estimated as 1% less than the nickel recovery. The copper recovery is estimated based on the copper head grade. The plant will produce variations in recovery due to the day-to-day changes in ore type or combinations of ore type being processed. These variations are expected to trend to the forecast recovery value for monthly or longer reporting periods.

The deleterious elements for smelting are arsenic, lead, zinc, and chromium. With these typical deleterious element concentrations, the mill concentrate feed (nickel concentrate currently) for the smelter routinely meets smelter specifications. The element of the greatest concern is arsenic and the overall blended feed into the plant is kept below 0.008% As.

In the period from 2025–2026, Garson ores are forecast to be higher in arsenic (0.075–0.080%), and may pose challenges in controlling the arsenic to the correct levels so as to not impact smelter efficiency and operating cost. As an integrated operation, the Ontario Operations have some flexibility in the control of their feed through stockpiling and blending strategies. The mine is addressing the forecast arsenic head grade in mill feed over the LOM plan to alleviate any negative impact on planned production.

22.10 MINERAL RESOURCE ESTIMATES

Mineral resources are reported for the Blezard, Coleman, Copper Cliff, Creighton, Garson, Copper Cliff Pit, Stobie, Totten and Victor deposits.

Resource estimation follows a similar procedure for the Ontario Operations. Vale has a set of protocols, internal controls, and guidelines in place to support the estimation process, which the estimators must follow.

Estimation was performed as a team effort involving several technical disciplines. All mineralogical information, exploration boreholes and background information were provided to the estimators by the geological staff at the mines or by exploration staff. Commercially-available Datamine software was used for estimation.

Mineral resources are reported using the mineral resource definitions set out in SK1300, and are reported exclusive of those mineral resources converted to mineral reserves. The reference point for the estimate is insitu.

Areas of uncertainty that may materially impact all of the mineral resource estimates include: changes to long-term metal price and exchange rate assumptions; changes in local interpretations of mineralisation geometry such as pinch and swell morphology, extent of brecciation, presence of unrecognized mineralization off-shoots; faults, dykes and other structures; and continuity of mineralised zones; changes to geological and grade shape, and geological and grade continuity assumptions; changes to unfolding, variographical interpretations and search ellipse ranges that were interpreted based on limited drill data, when closer-spaced drilling becomes available; changes to metallurgical recovery assumptions; changes to the input assumptions used to derive the potentially-mineable shapes applicable to the assumed underground and open pit mining methods used to constrain the estimates; changes to the forecast dilution and mining recovery assumptions; changes to the cut-off values applied to the estimates; variations in geotechnical (including seismicity), hydrogeological and mining method assumptions; and changes to environmental, permitting and social license assumptions.

22.11 MINERAL RESERVE ESTIMATES

Mineral reserves are reported for the Coleman, Copper Cliff, Creighton, Garson and Totten deposits.

Mineral reserves were converted from measured and indicated mineral resources.

All current mineral reserves will be exploited using underground mining methods. Economic cut-off grades were estimated for each mine and mining area and used to optimize the design of each stope. Mining recovery (mineability) and external dilution factors were applied.

The Ontario Operations have a cut-off grade policy for mine design, production scheduling and day-to-day ore/waste determination. A stope is considered for inclusion in the mine plan if its value is equal to or greater than the forecast mining cost. Uneconomic stopes are reviewed to determine if the value can be increased through improved design, but once confirmed as uneconomic, these stopes are removed from the mine plan and are not included in the mineral reserve estimates. The cut-off value is a proxy for the cut-off grade.

Mineral reserves are reported using the mineral reserve definitions set out in SK1300. The reference point for the mineral reserve estimate is the point of delivery to the process plant.

Areas of uncertainty that may materially impact all of the mineral reserve estimates include: long-term commodity price assumptions; long-term exchange rate assumptions; long-term consumables price assumptions; changes to mineral resources input parameters; changes to constraining stope designs; changes to cut-off grade and NPR assumptions; changes to geotechnical (including seismicity) and hydrogeological factors; changes to metallurgical and mining recovery assumptions; the ability to control unplanned dilution; and assumptions as to the continued ability to access the site, retain mineral and surface rights titles, maintain environment and other regulatory permits, and maintain the social license to operate.

22.12 MINING METHODS

The Ontario Operations use conventional bulk stoping or narrow vein cut-and-fill mining methods, depending on the mine and geological setting. Mines are Owner-operated and use conventional equipment.

All underground mines have an effective Ground Control Management Plan that is updated annually. This provides a robust basis for geotechnical evaluation, modelling and mitigation measures.

The Ontario Operations maintain a Seismic Risk Management Plan, which is based on a seismicity management policy, and is designed to identify, assess and manage seismic hazards. Five mines were considered to be seismically active at the Report date, consisting of Coleman, Creighton, Copper Cliff, Garson and Totten.

Either sand or mill tailings are used as a hydraulic backfill, with the type of fill materials dependent on the proximity of a mine to the Clarabelle Mill and the availability of proximal alluvial sand sources. High-density (paste) backfill is only used at the Main area of the Garson Mine.

Hydrological planning relies on historical norms and information. Most of the water that reports to the underground operations is from three sources: pumped in, surface runoff, or ground water. Water entering the mines from precipitation is minimal, except for the Copper Cliff Mines and Creighton Mines that have open pits or cave areas connected to the underlying working areas. Both these mines have been in operation for many years, and have systems and procedures in place to handle these inflows.

Each mine developed a production schedule that contained production and cost information for every producing area within the mine, based on mineral reserve estimates. Production schedules were limited by process and infrastructure constraints such as ventilation, drift development, LHD/haulage, backfilling, and muck circuit/storage. The assemblage process activities are used to derive costs based on historical and budgeted rates. These plans were collated into an overall production schedule for the Ontario Operations. Based on this schedule, the forecast mine life is 22 years (2022–2043).

22.13 RECOVERY METHODS

The Clarabelle Mill design was based on a combination of metallurgical testwork and familiarity gained during historical processing. The process methods and equipment used at the Clarabelle Mill are conventional to the industry. The process facilities in use are appropriate to the mineralization styles. The plant will produce variations in recovery due to the day-to-day changes in ore type or combinations of ore type being processed. These variations are expected to trend to the forecast recovery value for monthly or longer reporting periods.

The Copper Cliff Smelter uses methods conventional to the industry. The process facilities in use are conventional, and are appropriate to product produced. All of the precious metal-bearing metallic material and some of the nickel sulphide material is sent to the Copper Cliff Nickel Refinery. The remaining nickel sulphide is roasted in fluid bed roasters. The resulting nickel oxide is processed in the Copper Cliff Refinery, the Clydach Refinery, or is marketed as-is. Sulphur dioxide from the roasters is fixed and sold as sulphuric acid and liquid sulphur dioxide.

The Copper Cliff Refinery uses process methods and equipment that are conventional to the industry, with the exception of the pressure carbonyl plant. The carbonyl process has a long history, being first used at the Clydach Refinery in 1902. The carbonyl process is well understood, and the equipment requirements for the process are conventional for pressure carbonyl processing. The refinery produces pure nickel pellets, pure nickel powders and ferro-nickel pellets, which are sold directly to market. It also produces copper cathodes that are plated from solution and sold to market. Three slurries, a nickel–cobalt carbonate slurry, a slurry-rich in precious metals containing platinum-group metals, silver and gold and a slurry enriched in platinum-group metals and selenium–tellurium, are sent to the Port Colborne Refinery.

The Clydach Refinery is a carbonyl process plant that produces a nickel powder for sale. The carbonyl process is well understood, and the equipment requirements for the process are conventional for pressure carbonyl processing.

The Port Colborne Refinery is an electro-cobalt refinery and precious metals upgrading facility. The refinery uses process methods and equipment that are conventional to the industry.

22.14 INFRASTRUCTURE

All key infrastructure supporting mining and processing operations is built and operational, and is suitable for LOM purposes. No accommodations camps are operated. Personnel live either in Sudbury or in surrounding settlements.

Waste rock is currently primarily stored underground.

The Central Tailings Area became operational in 1936 and is become the primary management site for tailings and waste generated from the Ontario Operations. The facility has sufficient storage for LOM needs. Vale meets the requirements of the Ontario Ministry of Natural Resources (MNR), Lakes and Rivers Improvement Act, uses safety guidance provided by the Canadian Dam Association, and internal risk management frameworks to ensure dam safety. Vale has undertaken numerous studies on the Central Tailings Area to update various aspects of the facility to meet current dam engineering practices. A detailed Operations Manual is in place and is regularly updated.

There are two main storage areas in the central and northeastern areas of the smelter that were designated for storage of cooled slag. Haulage trucks transport the slag from the main facilities to these storage areas. There is sufficient slag storage capacity to support the LOM plan.

The general water management strategy for several facilities peripheral to the Central Tailings Area involves collecting and treating impacted runoff. The strategy is common to the Copper Cliff, Creighton and Stobie Mines, Clarabelle Mill, the Central Tailings Area, UPA, smelter complex, Nickel Refinery, and the Copper Cliff and Nolin Creek waste water treatment plants. The Ontario Operations monitor levels, flows and water balances on a regular basis.

Process water for the Clarabelle Mill is sourced from the UPA. Fresh and drinking water for the Sudbury area infrastructure is sourced primarily from the Vermilion River catchment. The primary water source for Port Colborne is the Welland Canal. Currently, water for the Clydach Refinery is partly sourced from the Swansea Canal. The Clydach Refinery undertook in 2017 to install a complex recycled, closed-loop, cooling water circuit. Once completed in 2022, water will no longer be sourced from either the river or the canal. There is sufficient process and fresh water availability to support the LOM plan.

Electrical power for the Ontario Operations is primarily sourced from grid supply (approximately 80%). A portion of the demand (about 20%) is met by Vale's hydroelectric power facilities. The Clydach Nickel Refinery obtains all of its power from a local utility. There is sufficient power availability to support the LOM plan.

22.15 MARKET STUDIES

Vale has an internal marketing department that is tasked with monitoring global commodities markets for the products from the Ontario Operations.

None of the products from the Ontario Operations are subject to product specification requirements from end users to be saleable.

The LOM pricing forecasts using a consensus approach based on long-term analyst and bank forecasts, supplemented with research by Vale's internal specialists. The forecast uses annual predictions for the period 2022–2026, reverting to a long-term fixed forecast from 2026 for the remaining mine life.

The terms contained within the concentrate sales contracts are typical and consistent with standard industry practice, and are similar to contracts for the supply of nickel and copper concentrate throughout the world. Depending on the specific contract, the terms for the nickel and copper concentrate sale are either annually negotiated, benchmark-based treatment and refining charges, or in the case of spot agreements are based on fixed treatment and refining charges based on market terms negotiated at the time of sale.

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

Contracts may be entered into for goods and services required to operate underground mining operations. On occasions, mining contractors may be employed for specific mine development projects. The largest in-place contracts include transportation, purchase of fuel, reagents and other process consumables, ground support and mining equipment leases. The terms contained within the contracts are typical of, and consistent with, standard industry practices.

22.16 ENVIRONMENTAL, PERMITTING AND SOCIAL CONSIDERATIONS

Vale's Ontario Operations are one of the largest integrated mining complexes in the world, including both mines and processing operations, some dating back to the early- and mid-1900s. Environmental regulations and awareness has progressed significantly from the beginning of our operations in Ontario and the company has engaged in baseline studies, various improvement and legacy reclamation initiatives and other activities to ensure compliance as the regulatory regime changes.

All pertinent baseline information as per standard of the day is available in the Closure Plans for the mine sites and surface plants, including: land use, topography, regional geology, local geology and mineralogy, soil, climate and hydrology, hydrogeology, terrestrial plant and animal life and aquatic plant and animal life, with relevant updates provided in the subsequent Closure Plan amendments.

As the mines and plant sites have continued to expand, supporting environmental studies have been completed to assess site environmental conditions, and to support permit applications and decision-making processes.

At all mines, baseline and supporting environmental studies are completed to assess both pre-existing and ongoing site environmental conditions, as well as to support decision-making processes, and if applicable, permit applications for new projects as these are brought on stream. Characterization studies were completed for all environmental media including soil, water, waste, air, noise and closure.

Plans were developed and implemented for all Ontario Operation mine sites to address waste management, spill prevention and contingency planning, water management and fugitive dust management.

Vale has 16 closure plans for aspects of the Ontario Operations, covering the Central Tailings Facility, Clarabelle Mill, the Copper Refinery, Crean Hill Mine, Creighton Mine, Frood–Stobie Mine, Garson Mine, Levack–Onaping-Coleman Mines, the nickel refinery, Copper Cliff North Mine, Port Colborne Refinery, Shebandowan Mine and mill, Copper Cliff Smelter complex, Copper Cliff South Mine, Whistle Mine and Totten Mine. Closure plans for all operating sites were submitted to the relevant regulatory authorities, and there are plans in place for three closed sites (Whistle Mine, Shebandowan Mine and mill site, and Crean Hill Mine) in accordance with Part VII of the Ontario Mining Act.

Vale developed closure cost estimates associated with the chosen rehabilitation strategy for each property. The estimate also includes an expected schedule for closure-related expenditures. Closure costs are included in the mine site financial models as cash costs, on an annual basis for all sites. The largest closure costs are associated with the process plant and mining infrastructure. The escalated closure cost estimate for the Ontario Operations, as at year-end 2021, is US$2,060 million.

All known and anticipated permits and approvals are in place to support operations. These include permits for air quality, noise emissions, taking and discharging water, and tailings, waste rock and waste disposal. Where permits have specific terms, renewal applications are made of the relevant regulatory authority as required, prior to the end of the permit term.

Vale routinely engages with four Indigenous communities in the Sudbury Basin and the Métis Nation of Ontario. Vale has signed agreements with AAFN, WFN, SAFN and the MNO – Region 5. With respect to the Totten Mine, Vale has a signed Impact Benefit Agreement with the Sagamok Anishnawbek First Nation. There are currently no known consultation obligations which would materially impact the mineral reserve estimates. However, consultation obligations may need to be satisfied before new areas that currently only have mineral resource estimates can be developed.

Due to the proximity of the local communities to the Central Tailings Area, mill, refinery and smelter operations, especially the Town of Copper Cliff, Vale also continues to engage the local communities of interest that may be impacted by future development.

22.17 CAPITAL COST ESTIMATES

Capital costs are based on recent prices or operating data. Unit costs for in-house mine development are based on historical actual costs. Mobile equipment that is leased is included in operating costs. Lease periods typically range from two to five years. Lease costs are charged to capital while the equipment is doing capital work. Purchased equipment is allocated for in the capital plan. Mobile equipment and fixed asset costs are based on supplier quotations and/or current examples. Sustaining capital cost forecasts are based on forecast mine development and construction needs, mobile equipment re-build/replacement schedules and fixed asset replacement and refurbishment schedules.

The overall capital cost estimate for the LOM is US$5,429 M. 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

22.18 OPERATING COST ESTIMATES

Operating costs are based on actual costs seen during operations and are projected through the LOM plan. Historical costs are used as the basis for operating cost forecasts for supplies and services unless there are new contract terms for these items. Labour and energy costs are based on budgeted rates applied to headcounts and energy consumption estimates.

The long-term mine operating cost model accounts for the impact of varying production rates on the direct variable costs. As a mine approaches the end of mine life, the indirect and distributed costs are reduced in line with the projected lower production rates. The processing operating cost estimates are the budget year cash costs applied to the mineral reserves mined throughout the LOM plan. These processing costs include both variable and fixed plant components. Since the throughput for the processing plants decreases over the LOM plan, the fixed cash cost component of these processing plants is stepped down in a logical progression as the feed decreases.

Operating costs total US$13,781 M over the LOM. 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

22.19 ECONOMIC ANALYSIS

The financial model that supports the mineral reserve declaration is a standalone model that calculates annual cash flows based on scheduled ore production, assumed processing recoveries, metal sale prices and C$/US$ exchange rate, projected operating and capital costs and estimated taxes. The financial analysis is based on an after-tax discount rate of 7.5% following a mid-year convention. All costs and prices are in unescalated “real” dollars. The currency used to document the cash flow is US$. All costs are based on the five-year plan approved budget. Post 2026, costs were estimated based on the 2022–2026 period. Revenue is calculated from the recoverable metal and the long-term forecast of metal prices and exchange rate.

The financial estimates are based on a combined federal and provincial income statutory tax rate of 25% and a provincial mining statutory tax rate of 10%, before processing allowance. Depreciation rates for corporate income tax purposes have been applied, on a declining balance basis, at the base rates of 25% for depreciable tangible capital property and 30% for mine development. For mining tax purposes, depreciation has been approximated on a declining balance basis for mining (30%) and processing property (15%). Provincial mining processing allowance is further deducted as applicable. The mining tax paid is deductible for corporate income tax purposes.

The post-tax $NPV_{7.5\%}$ is US$1,177 M. As the cashflows are based on existing operations where all costs are considered sunk to 1 January 2022, considerations of payback and internal rate of return are not relevant.

A Sensitivity analysis was performed on metal prices, metal recovered, capital costs and operating costs. The Ontario Operations are most sensitive to the following arranged in order from most to least sensitive: nickel price, recovered nickel, copper price, operating cost, recovered copper and capital costs.

22.20 RISKS AND OPPORTUNITIES

22.20.1 RISKS

Factors that may affect the mineral resource and mineral reserve estimates were identified in Chapter 11.16 and Chapter 12.7 respectively.

Risks to the Ontario Operations as a whole include:

- Changes to the regulatory, permitting and monitoring regimes set out in Chapter 17.1, Chapter 17.2, and Chapter 17.4, and the taxation assumptions in Chapter 19.4 could affect mine planning, infrastructure operation, closure planning, capital cost assumptions, overall operating cost assumptions, the duration of the LOM plan, and the economic analysis that supports the mineral reserve estimates;
- Changes to the social licence assumptions, changes to relationships with First Nations groups, and changes to relationships with stakeholders in the Sudbury area could affect the social licence to operate, and the duration of the LOM plan;
- Non-renewal of the OIC permits, such that Vale cannot export nickel, copper and PGM products outside of Canada for further refinement. This could affect operation of the Clydach Refinery. Changes could also affect marketing assumptions, operating assumptions, the duration of the LOM plan, and the economic analysis that supports the mineral reserve estimates;
- Five of the mining operations are classified as seismically active. While those operations have a Seismic Management Plan in place, designed to identify, assess and manage seismic hazards, there remains potential for unexpected seismic disturbance. Seismic events have the potential to change geotechnical and hydrological assumptions, sterilize portions of the mine plan, result in an increase in capital costs to repair damaged equipment and infrastructure, increase operating costs due to mitigation measures, and impact the economic analysis that supports the mineral reserve estimates;
- Geotechnical and hydrological assumptions used in mine planning consider historical performance, and to date historical performance has been a reasonable predictor of current conditions. 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 reserve estimates;
- Mining methods are based on a combination of historical performance of selected mining methods in the various Sudbury mines, orebody orientations, and consideration of factors such as geological, geotechnical, and hydrological settings. The selected mining method as envisaged in the LOM plan may vary due to operational reasons. Changes could occur in that instance to the actual mine plan in terms of redesigns and resequencing, in supporting requirements such as ventilation, haulage, equipment, and production rate, in estimations of sustaining capital and operating costs, production schedules, and could impact the economic analysis that supports the mineral reserve estimates;
- Recovery methods assume the Clarabelle Mill, Copper Cliff Smelter and refinery, Clydach Refinery and Port Colborne Refinery will be operational for the LOM. The LOM plan incorporates costs and recoveries for these facilities based on historical performance, and to date historical performance has been a reasonable predictor of current conditions. However, if costs and recoveries vary, either positively or negatively in future performance, there is a risk that the assumed process (mill, smelter, refinery) recoveries, capital or operating costs will differ from those envisaged in this Report, and that there could be an impact on the economic analysis that supports the mineral reserve estimates;

- The Central Tailings Area is the central repository for tailings and certain types of waste for the Ontario Operations. It is also a major process water source. While Vale has undertaken numerous studies on the Central Tailings Area to update various aspects of the facility to meet current dam engineering practices, there may be areas that require additional updates or upgrades. Where these have not been contemplated in the LOM plan, such updates could affect capital and operating cost estimates, and there could be an impact the economic analysis that supports the mineral reserve estimates;
- Closure costs for the entire Ontario Operations are estimated at US$2,060 million, and closure costs are estimated out to 2148. This forecast may change if additional mineral reserves can be identified that would prolong the mine life, or if mining activities cease prior to the projected 2044 date;
- Assumptions that the long-term reclamation and mitigation of the Ontario Operations can be appropriately managed within the estimated closure timeframes and closure cost estimates;
- The management of water quality impacts, and the associated regulatory implications, resulting from past practices when environmental protection programs and regulations were less robust remains a significant risk;
- Market studies, commodity prices, and exchange rates are based on the most current information available to Vale. While mineral resource, mineral reserve and economic analysis for the LOM use this information, there is a risk of recession or upturn in commodity markets that could have an impact, either negative or positive, on the commodity pricing and exchange rate assumptions, and on the economic analysis that supports the mineral reserve estimates;
- Capital costs are considered to have a reasonable basis, assuming equipment and infrastructure operates as envisaged. Unexpected equipment or infrastructure failures will result in increases to the capital cost estimate as such equipment or infrastructure is repaired or replaced. That will have an effect on the economic analysis that supports the mineral reserve estimates;
- Operating costs are considered to have a reasonable basis, assuming equipment and infrastructure operates as envisaged, and inputs, such as wages, power costs, consumables costs remain as forecast in the LOM plan. Changes to these assumptions will result in changes to the operating cost estimates, and on the economic analysis that supports the mineral reserve estimates;
- The mines have many legacy old workings that cannot be accessed and assessed for asset condition, and historical mining that connects to surface old workings. As such, there are uncertainties with the operations' ability to manage water and prevent water inrush;
- The Ontario Operations are planning productivity improvements as a result of the implementation of new processes such as dispatch and short-term scheduling. There is a risk that the mines will not achieve the forecasted improvement, potentially impacting cashflow.

22.20.2 OPPORTUNITIES

Opportunities for the Ontario Operations as a whole include:

- Conversion of some or all of the measured and indicated mineral resources currently reported exclusive of mineral reserves to mineral reserves, with appropriate supporting studies;
- Vale conducts internal mining studies using mineral resource estimates to determine if there is potential for new or in-mine expansion projects to be built. If these studies support mineral reserve estimates and can be incorporated into the LOM plan, such projects represent upside potential for the Ontario Operations;

- Upgrade of some or all of the inferred mineral resources to higher-confidence categories, such that such better-confidence material could be used in mineral reserve estimation;
- Higher metal prices than forecast could present upside sales opportunities and potentially an increase in predicted Project economics;
- Increased emphasis on core drill budgeting and execution to ensure a healthy mineral inventory pipeline is in place to capitalise on the potential of the Ontario Operations. This includes a robust target ranking and review process to ensure the right deposits and targets are prioritised to potentially extend the LOM.

22.21 CONCLUSIONS

Under the assumptions presented in this Report, the Ontario Operations have a positive cash flow, and mineral reserve estimates can be supported.

23 RECOMMENDATIONS

The QPs make the following recommendations totalling approximately US$101 M:

- Complete detailed study for Copper Cliff Mine Expansion Project. This project envisages the development of the 191, 178, and 712 orebodies to sustain production through the North and South shafts at the Copper Cliff Mine. The recommended budget is about US$54.8 M, and includes provision for engineering and advanced development for collection of geological, geotechnical, and metallurgical data, and studies into alternate low-cost mining methods;
- Complete a study that will examine developing the Copper Cliff Mine Pit. The deposit has the potential to provide low-cost mill feed from an open pit mine, and use available capacity at the Clarabelle Mill. The proposed budget is approximately US$17.3 M;
- Complete a study on the development of the 400 and 310 deposits, located at depth in the Creighton Mine. A budget allocation of about US$19.8 M is recommended, and work should focus on studying alternate mine access alternatives, including development of a winze or extension of ramp network at depth, to mine high-grade mineralization below the 8590 Level;
- Complete, in conjunction with Glencore, a study on developing the 24N, BL28, and NR14 zones, located at 1500–2800 m below surface at the Victor Mine. The study should focus on using existing Nickel Rim South infrastructure for the development evaluation. The proposed budget is approximately US$9.5 M.

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24.2 ABBREVIATIONS AND SYMBOLS

Abbreviation/Symbol	Term
DA-ID2	dynamic anisotropy inverse distance weighting to the second power
DTM	digital terrain model
G&A	general and administrative
GPS	global positioning system
ICP	Inductively coupled plasma
IP	induced polarization
LOM	life-of-mine
LOMP	life-of-mine plan
NN	nearest neighbor
NPV	net present value
NSR	net smelter return
OK	ordinary kriging
QA/QC	quality assurance and quality control
QP	Qualified Person
RQD	rock quality description
SAG	semi-autogenous grind
SG	specific gravity
SME	Society for Mining, Metallurgy and Exploration
TSF	tailing storage facility
US	United States
UTEM-4	University of Toronto Electro Magnetometer
XRF	X-ray fluorescence

24.3 GLOSSARY OF TERMS

Term	Definition
acid rock drainage/ acid mine drainage	Characterized by low pH, high sulfate, and high iron and other metal species.
amphibolite facies	One of the major divisions of the mineral-facies classification of metamorphic rocks, the rocks of which formed under conditions of moderate to high temperatures (500° C, or about 950° F, maximum) and pressures. Amphibole, diopside, epidote, plagioclase, almandine and grossular garnet, and wollastonite are minerals typically found in rocks of the amphibolite facies
ANFO	A free-running explosive used in mine blasting made of 94% prilled aluminum nitrate and 6% No. 3 fuel oil.
azimuth	The direction of one object from another, usually expressed as an angle in degrees relative to true north. Azimuths are usually measured in the clockwise direction, thus an azimuth of 90 degrees indicates that the second object is due east of the first.

Term	Definition
ball mill	A piece of milling equipment used to grind ore into small particles. It is a cylindrical shaped steel container filled with steel balls into which crushed ore is fed. The ball mill is rotated causing the balls themselves to cascade, which in turn grinds the ore.
Bond work index (BWi)	A measure of the energy required to break an ore to a nominal product size, determined in laboratory testing, and used to calculate the required power in a grinding circuit design.
comminution/crushing/grinding	Crushing and/or grinding of ore by impact and abrasion. Usually, the word "crushing" is used for dry methods and "grinding" for wet methods. Also, "crushing" usually denotes reducing the size of coarse rock while "grinding" usually refers to the reduction of the fine sizes.
concentrate	The concentrate is the valuable product from mineral processing, as opposed to the tailing, which contains the waste minerals. The concentrate represents a smaller volume than the original ore
crosscut	A horizontal opening driven across the course of a vein or structure, or in general across the strike of the rock formation; a connection from a shaft to an ore structure.
crown pillar	An ore pillar at the top of an open stope left for wall support and protection from wall sloughing above
cut-and-fill stoping	If it is undesirable to leave broken ore in the stope during mining operations (as in shrinkage stoping), the lower portion of the stope can be filled with waste rock and/or mill tailings. In this case, ore is removed as soon as it has been broken from overhead, and the stope filled with waste to within a few feet of the mining surface. This method eliminates or reduces the waste disposal problem associated with mining as well as preventing collapse of the ground at the surface.
cut-off grade	A grade level below which the material is not "ore" and considered to be uneconomical to mine and process. The minimum grade of ore used to establish reserves.
data verification	The process of confirming that data has been generated with proper procedures, has been accurately transcribed from the original source and is suitable to be used for mineral resource and mineral reserve estimation
decline	A sloping underground opening for machine access from level to level or from the surface. Also called a ramp.
density	The mass per unit volume of a substance, commonly expressed in grams/ cubic centimeter.
depletion	The decrease in quantity of ore in a deposit or property resulting from extraction or production.
development	Often refers to the construction of a new mine or; Is the underground work carried out for the purpose of reaching and opening up a mineral deposit. It includes shaft sinking, cross-cutting, drifting and raising.
diabase	US terminology for an intrusive rock whose main components are labradorite and pyroxene, and characterized by an ophiolitic texture. Corresponds to a diorite.
dilution	Waste of low-grade rock which is unavoidably removed along with the ore in the mining process.
discounted cash flow (DCF)	Concept of relating future cash inflows and outflows over the life of a project or operation to a common base value thereby allowing more validity to comparison of projects with different durations and rates of cash flow.
drift	A horizontal mining passage underground. A drift usually follows the ore vein, as distinguished from a crosscut, which intersects it.
easement	Areas of land owned by the property owner, but in which other parties, such as utility companies, may have limited rights granted for a specific purpose.

Term	Definition
electrowinning.	The removal of precious metals from solution by the passage of current through an electrowinning cell. A direct current supply is connected to the anode and cathode. As current passes through the cell, metal is deposited on the cathode. When sufficient metal has been deposited on the cathode, it is removed from the cell and the sludge rinsed off the plate and dried for further treatment.
encumbrance	An interest or partial right in real property which diminished the value of ownership, but does not prevent the transfer of ownership. Mortgages, taxes and judgements are encumbrances known as liens. Restrictions, easements, and reservations are also encumbrances, although not liens.
feasibility study	A feasibility study is a comprehensive technical and economic study of the selected development option for a mineral project, which includes detailed assessments of all applicable modifying factors, as defined by this section, together with any other relevant operational factors, and detailed financial analysis that are necessary to demonstrate, at the time of reporting, that extraction is economically viable. The results of the study may serve as the basis for a final decision by a proponent or financial institution to proceed with, or finance, the development of the project. A feasibility study is more comprehensive, and with a higher degree of accuracy, than a pre-feasibility study. It must contain mining, infrastructure, and process designs completed with sufficient rigor to serve as the basis for an investment decision or to support project financing.
flotation	Separation of minerals based on the interfacial chemistry of the mineral particles in solution. Reagents are added to the ore slurry to render the surface of selected minerals hydrophobic. Air bubbles are introduced to which the hydrophobic minerals attach. The selected minerals are levitated to the top of the flotation machine by their attachment to the bubbles and into a froth product, called the "flotation concentrate." If this froth carries more than one mineral as a designated main constituent, it is called a "bulk float". If it is selective to one constituent of the ore, where more than one will be floated, it is a "differential" float.
flowsheet	The sequence of operations, step by step, by which ore is treated in a milling, concentration, or smelting process.
footwall	The wall or rock on the underside of a vein or ore structure.
frother	A type of flotation reagent which, when dissolved in water, imparts to it the ability to form a stable froth
gangue	The fraction of ore rejected as tailing in a separating process. It is usually the valueless portion, but may have some secondary commercial use
granulite facies	One of the major divisions of the mineral facies classification of metamorphic rocks, the rocks of which formed under the most intense temperature-pressure conditions usually found in regional metamorphism. At the upper limit of the facies, migmatite formation may occur. Temperatures of 650–1,100 °C (1,200–2,000 °F) and pressures of 3–10 kilobars may be reached. The more common minerals include pyroxene, biotite, garnet, calcium plagioclase, and quartz or olivine.
greenschist facies	One of the major divisions of the mineral facies classification of metamorphic rocks, the rocks of which formed under the lowest temperature and pressure conditions usually produced by regional metamorphism. Temperatures between 300 and 450 °C (570 and 840 °F) and pressures of 1 to 4 kilobars are typical. The more common minerals found in such rocks include quartz, orthoclase, muscovite, chlorite, serpentine, talc, and epidote
hanging wall	The wall or rock on the upper or top side of a vein or ore deposit.
hydrometallurgy	A type of extractive metallurgy utilizing aqueous solutions/solvents to extract the metal value from an ore or concentrate. Leaching is the predominant type of hydrometallurgy.

Term	Definition
indicated mineral resource	An indicated mineral resource is that part of a mineral resource for which quantity and grade or quality are estimated on the basis of adequate geological evidence and sampling. The term adequate geological evidence means evidence that is sufficient to establish geological and grade or quality continuity with reasonable certainty. The level of geological certainty associated with an indicated mineral resource is sufficient to allow a qualified person to apply modifying factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.
inferred mineral resource	An inferred mineral resource is that part of a mineral resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. The term limited geological evidence means evidence that is only sufficient to establish that geological and grade or quality continuity is more likely than not. The level of geological uncertainty associated with an inferred mineral resource is too high to apply relevant technical and economic factors likely to influence the prospects of economic extraction in a manner useful for evaluation of economic viability. A qualified person must have a reasonable expectation that the majority of inferred mineral resources could be upgraded to indicated or measured mineral resources with continued exploration; and should be able to defend the basis of this expectation before his or her peers.
internal rate of return (IRR)	The rate of return at which the Net Present Value of a project is zero; the rate at which the present value of cash inflows is equal to the present value of the cash outflows.
IP	Geophysical method, induced polarization; used to directly detect scattered primary sulfide mineralization. Most metal sulfides produce IP effects, e.g. chalcopyrite, bornite, chalcocite, pyrite, pyrrhotite
liberation	Freeing, by comminution, of particles of specific mineral from their interlock with other constituents of the ore.
life of mine (LOM)	Number of years that the operation is planning to mine and treat ore, and is taken from the current mine plan based on the current evaluation of ore reserves.
magnetic separation	Use of permanent or electro-magnets to remove relatively strong ferromagnetic particles from para- and dia-magnetic ores.
measured mineral resource	A measured mineral resource is that part of a mineral resource for which quantity and grade or quality are estimated on the basis of conclusive geological evidence and sampling. The term conclusive geological evidence means evidence that is sufficient to test and confirm geological and grade or quality continuity. The level of geological certainty associated with a measured mineral resource is sufficient to allow a qualified person to apply modifying factors, as defined in this section, in sufficient detail to support detailed mine planning and final evaluation of the economic viability of the deposit.
metathetic	Chemical reaction between two compounds in which parts of each are interchanged to form two new compounds
mill	Includes any ore mill, sampling works, concentration, and any crushing, grinding, or screening plant used at, and in connection with, an excavation or mine.
mineral reserve	A mineral reserve is an estimate of tonnage and grade or quality of indicated and measured mineral resources that, in the opinion of the qualified person, can be the basis of an economically viable project. More specifically, it is the economically mineable part of a measured or indicated mineral resource, which includes diluting materials and allowances for losses that may occur when the material is mined or extracted. The determination that part of a measured or indicated mineral resource is economically mineable must be based on a preliminary feasibility (pre-feasibility) or feasibility study, as defined by this section, conducted by a

Term	Definition
	qualified person applying the modifying factors to indicated or measured mineral resources. Such study must demonstrate that, at the time of reporting, extraction of the mineral reserve is economically viable under reasonable investment and market assumptions. The study must establish a life of mine plan that is technically achievable and economically viable, which will be the basis of determining the mineral reserve. The term economically viable means that the qualified person has determined, using a discounted cash flow analysis, or has otherwise analytically determined, that extraction of the mineral reserve is economically viable under reasonable investment and market assumptions. The term investment and market assumptions includes all assumptions made about the prices, exchange rates, interest and discount rates, sales volumes, and costs that are necessary to determine the economic viability of the mineral reserves. The qualified person must use a price for each commodity that provides a reasonable basis for establishing that the project is economically viable.
mineral resource	A mineral resource is a concentration or occurrence of material of economic interest in or on the Earth's crust in such form, grade or quality, and quantity that there are reasonable prospects for economic extraction. The term material of economic interest includes mineralization, including dumps and tailings, mineral brines, and other resources extracted on or within the earth's crust. It does not include oil and gas resources as defined in Regulation S-X (§210.4-10(a)(16)(D) of this chapter), gases (e.g., helium and carbon dioxide), geothermal fields, and water. When determining the existence of a mineral resource, a qualified person, as defined by this section, must be able to estimate or interpret the location, quantity, grade or quality continuity, and other geological characteristics of the mineral resource from specific geological evidence and knowledge, including sampling; and conclude that there are reasonable prospects for economic extraction of the mineral resource based on an initial assessment, as defined in this section, that he or she conducts by qualitatively applying relevant technical and economic factors likely to influence the prospect of economic extraction.
modifying factors	The factors that a qualified person must apply to indicated and measured mineral resources and then evaluate in order to establish the economic viability of mineral reserves. A qualified person must apply and evaluate modifying factors to convert measured and indicated mineral resources to proven and probable mineral reserves. These factors include, but are not restricted to: mining; processing; metallurgical; infrastructure; economic; marketing; legal; environmental compliance; plans, negotiations, or agreements with local individuals or groups; and governmental factors. The number, type and specific characteristics of the modifying factors applied will necessarily be a function of and depend upon the mineral, mine, property, or project.
net present value (NPV)	The present value of the difference between the future cash flows associated with a project and the investment required for acquiring the project. Aggregate of future net cash flows discounted back to a common base date, usually the present. NPV is an indicator of how much value an investment or project adds to a company.
net smelter return royalty (NSR)	A defined percentage of the gross revenue from a resource extraction operation, less a proportionate share of transportation, insurance, and processing costs.
open pit	A mine that is entirely on the surface. Also referred to as open-cut or open-cast mine.
open stope	In competent rock, it is possible to remove all of a moderate sized ore body, resulting in an opening of considerable size. Such large, irregularly-shaped openings are called stopes. The mining of large inclined ore bodies often

Term	Definition
	requires leaving horizontal pillars across the stope at intervals in order to prevent collapse of the walls.
peridotite	A plutonic rock which has a mafic content equal to or greater than 90, and the olivine content, divided by the total plagioclase, orthopyroxene and clinopyroxene content is greater than 40.
plant	A group of buildings, and especially to their contained equipment, in which a process or function is carried out; on a mine it will include warehouses, hoisting equipment, compressors, repair shops, offices, mill or concentrator.
portal.	The surface entrance to a tunnel or adit
Poisson's ratio	The fraction of expansion divided by the fraction of compression
preliminary economic assessment	A study, other than a pre-feasibility or feasibility study, that includes an economic analysis of the potential viability of mineral resources
preliminary feasibility study, pre-feasibility study	A preliminary feasibility study (prefeasibility study) is a comprehensive study of a range of options for the technical and economic viability of a mineral project that has advanced to a stage where a qualified person has determined (in the case of underground mining) a preferred mining method, or (in the case of surface mining) a pit configuration, and in all cases has determined an effective method of mineral processing and an effective plan to sell the product. A pre-feasibility study includes a financial analysis based on reasonable assumptions, based on appropriate testing, about the modifying factors and the evaluation of any other relevant factors that are sufficient for a qualified person to determine if all or part of the indicated and measured mineral resources may be converted to mineral reserves at the time of reporting. The financial analysis must have the level of detail necessary to demonstrate, at the time of reporting, that extraction is economically viable
probable mineral reserve	A probable mineral reserve is the economically mineable part of an indicated and, in some cases, a measured mineral resource. For a probable mineral reserve, the qualified person's confidence in the results obtained from the application of the modifying factors and in the estimates of tonnage and grade or quality is lower than what is sufficient for a classification as a proven mineral reserve, but is still sufficient to demonstrate that, at the time of reporting, extraction of the mineral reserve is economically viable under reasonable investment and market assumptions. The lower level of confidence is due to higher geologic uncertainty when the qualified person converts an indicated mineral resource to a probable reserve or higher risk in the results of the application of modifying factors at the time when the qualified person converts a measured mineral resource to a probable mineral reserve. A qualified person must classify a measured mineral resource as a probable mineral reserve when his or her confidence in the results obtained from the application of the modifying factors to the measured mineral resource is lower than what is sufficient for a proven mineral reserve.
proven mineral reserve	A proven mineral reserve is the economically mineable part of a measured mineral resource. For a proven mineral reserve, the qualified person has a high degree of confidence in the results obtained from the application of the modifying factors and in the estimates of tonnage and grade or quality. A proven mineral reserve can only result from conversion of a measured mineral resource.
qualified person	A qualified person is an individual who is a mineral industry professional with at least five years of relevant experience in the type of mineralization and type of deposit under consideration and in the specific type of activity that person is undertaking on behalf of the registrant; and an eligible member or licensee in good standing of a recognized professional organization at the time the technical report is prepared. For an organization to be a recognized professional organization, it must: (A) Be either:

Term	Definition
	(1) An organization recognized within the mining industry as a reputable professional association, or (2) A board authorized by U.S. federal, state or foreign statute to regulate professionals in the mining, geoscience or related field; (B) Admit eligible members primarily on the basis of their academic qualifications and experience; (C) Establish and require compliance with professional standards of competence and ethics; (D) Require or encourage continuing professional development; (E) Have and apply disciplinary powers, including the power to suspend or expel a member regardless of where the member practices or resides; and; (F) Provide a public list of members in good standing.
raise	A vertical or inclined underground working that has been excavated from the bottom upward
reclamation	The restoration of a site after mining or exploration activity is completed.
refining	A high temperature process in which impure metal is reacted with flux to reduce the impurities. The metal is collected in a molten layer and the impurities in a slag layer. Refining results in the production of a marketable material.
right-of-way	A parcel of land granted by deed or easement for construction and maintenance according to a designated use. This may include highways, streets, canals, ditches, or other uses
rock quality designation (RQD)	A measure of the competency of a rock, determined by the number of fractures in a given length of drill core. For example, a friable ore will have many fractures and a low RQD.
royalty	An amount of money paid at regular intervals by the lessee or operator of an exploration or mining property to the owner of the ground. Generally based on a specific amount per tonne or a percentage of the total production or profits. Also, the fee paid for the right to use a patented process.
semi-autogenous grinding (SAG)	A method of grinding rock into fine powder whereby the grinding media consists of larger chunks of rocks and steel balls.
shaft	A vertical or inclined excavation for the purpose of opening and servicing a mine. It is usually equipped with a hoist at the top, which lowers and raises a conveyance for handling men and material
specific gravity	The weight of a substance compared with the weight of an equal volume of pure water at 4°C.
stope	An excavation in a mine, other than development workings, made for the purpose of extracting ore.
strike length	The horizontal distance along the long axis of a structural surface, rock unit, mineral deposit or geochemical anomaly.
tailings	Material rejected from a mill after the recoverable valuable minerals have been extracted.
tunnel	A horizontal underground passage that is open at both ends; the term is loosely applied in many cases to an adit, which is open at only one end
uniaxial compressive strength	A measure of the strength of a rock, which can be determined through laboratory testing, and used both for predicting ground stability underground, and the relative difficulty of crushing.
Young's modulus (elastic modulus)	A property of a material that defines how easily that material can stretch and deform

25 RELIANCE ON INFORMATION PROVIDED BY THE REGISTRANT

25.1 INTRODUCTION

The QPs fully relied on the registrant for the information used in the areas noted in the following sub-sections. The 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 for more than 100 years;
- 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, the mineral tenure (concessions, payments to retain property rights, obligations to meet expenditure/reporting of work conducted), surface rights, water rights (water take allowances), royalties, encumbrances, easements and rights-of-way, violations and fines, permitting requirements, and the ability to maintain and renew permits was obtained from the registrant.

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, and 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.

26 Appendix A: Mineral Tenure and Surface Rights.

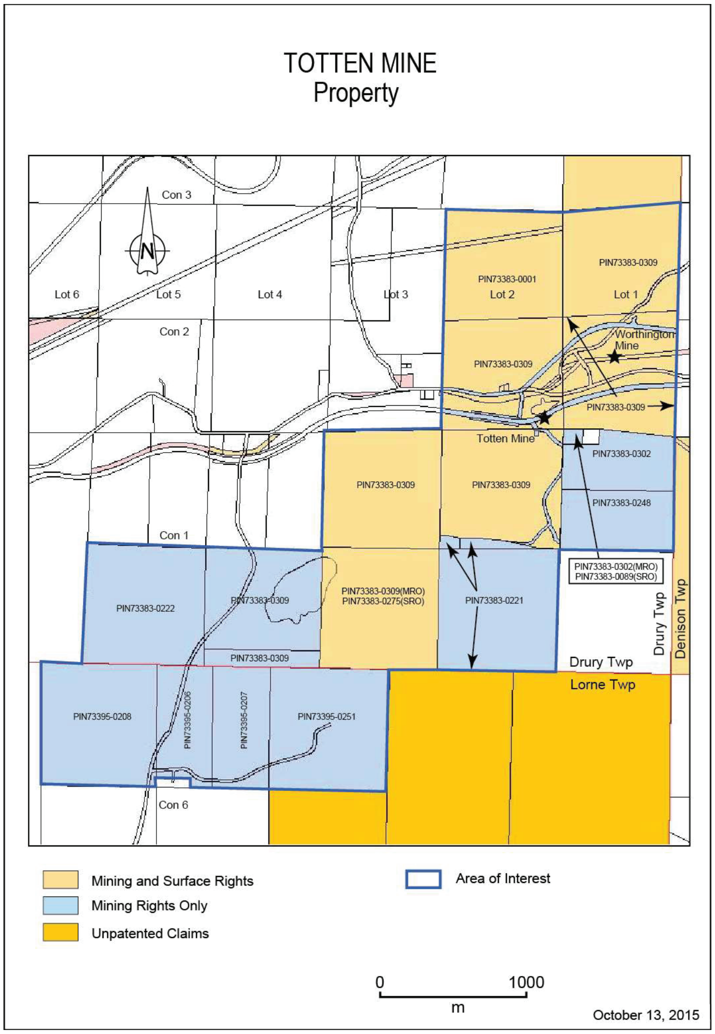
All land tenures in the Sudbury area were established based on Method 118 for Sectional Townships with Single Fronts under RRO 1990 Reg. 1029 under the Ontario Surveys Act.

Tenure and surface rights holdings within the MRMR footprint, are summarized in the following compilation table. Figures showing the locations of these holdings are provided after the compilation table. All figures were prepared by Vale in 2021 for inclusion in this Report.

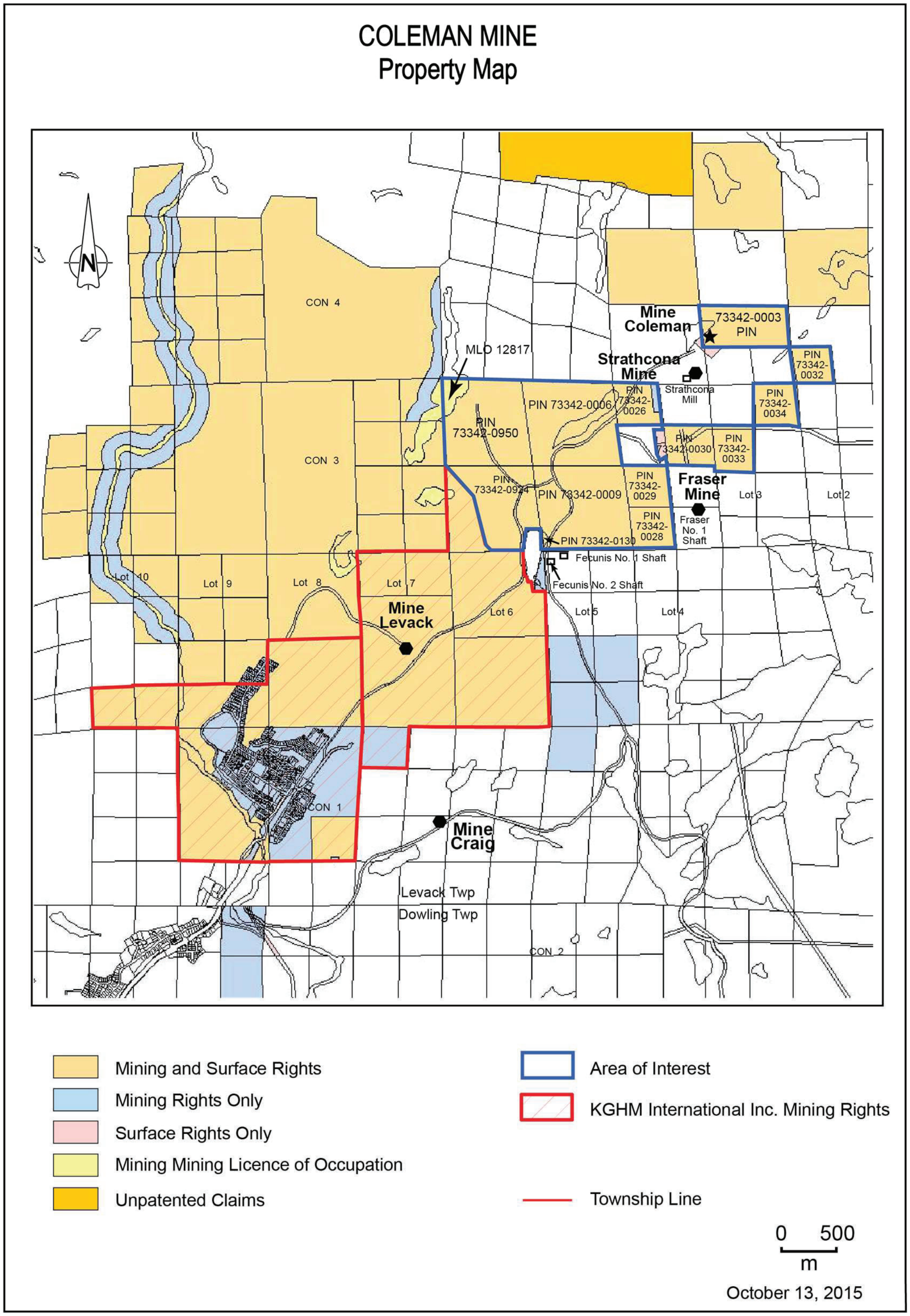
Appendix : Table 26-1: Mineral Title Summary by Licence, Ontario Operations

Deposits	Licenses	# of Licenses	Area (ha)
Blezard	73497-0096, 73497-0156, 73497-0159, 73498-0612, 73498-0537	5	262
Coleman	73342-0003,73342-0006, 73342-0009, 73342-0026, 73342-0028, 73342-0029, 73342-0030, 73342-0032, 73342-0033, 73342-0034,73342-0130, 73342-0924, 73342-0950, MLO-12817	14	446
Copper Cliff	73599-0070, 73599-0071, 73599-0072, 73599-0580, 73599-0593, 73599-0755, 73599-0828, 73600-0254, 73600-0271, 73370-0005, 73370-0036, 73370-0037, 73370-0038, 73370-0039, 73370-0041, 73370-0042, 73370-0057, 73370-0064, 73370-0065, 73370-0066, 73370-0067, 73370-0068, 73370-0069, 73370-0070, 73370-0071, 73370-0072, 73370-0073, 73370-0076, 73370-0079, 73370-0082, 73370-0084, 73371-0033, 73371-0035, 73371-0036, 73371-0039, 73371-0051, 73371-0077, 73371-0082, 73371-0094, 73371-0115, 73371-0117, 73371-0198	43	2,912
Creighton	73368-0297, 73368-0016, 73368-0042, 73371-0046, 73371-0113, 73371-0174, 73371-0175, 73368-0089, 73368-0091, 73368-0094, 73368-0095, 73368-0096, 73368-0097, 73368-0098, 73368-0099, 73368-0100, 73368-0101, 73368-0105, 73368-0116, 73368-0117, 73368-0119, 73368-0121, 73368-0240, 73368-0246, 73368-0264, 73368-0265	26	1,177
Garson	73492-0141, 73495-1212, 73495-1213, 73495-1298, 73495-1044, 73492-0355, 73492-0398, 73492-0487, 73493-0067, 73493-0150, 73493-0151, 73493-0161, 73493-0282, 73493-0297, 73493-0298, 73493-0299, 73493-0315, 73493-0316, 73493-0326, 73493-0331, 73493-0334, 73493-0379, 73495-0351, 73495-0454, 73495-0837, 73495-1313, 73495-1305	27	825
Copper Cliff Mine Pit	73601-0195, 73601-0196, 73601-0198, 73601-0052, 73601-0068, 73601-0070, 73601-0208, 73601-0192, 73601-0199, 73601-0219, 73601-0194, 73601-0243, 73370-0119,73370-0005	14	941
Stobie	73497-0015, 73601-0027, 73601-0029, 73601-0084, 73601-0230, 73497-0149	6	525
Totten	73383-0275, 73383-0302, 73395-0206, 73395-0207, 73395-0208, 73395-0251, 73383-0001, 73383-0089, 73383-0221, 73383-0222, 73383-0248, 73383-0309	12	993
Victor	533510, 73510-0085, 73510-0086, 73510-0198, 73510-0244, 73511-0257, 73511-0258, 73511-0259, 73511-0261, 73511-0262, 73511-0263, 73511-0276, 73511-0277, 73511-0285, 73511-0299, 73511-0300, 73511-0301	16	355
Total		**163**	**8,437**

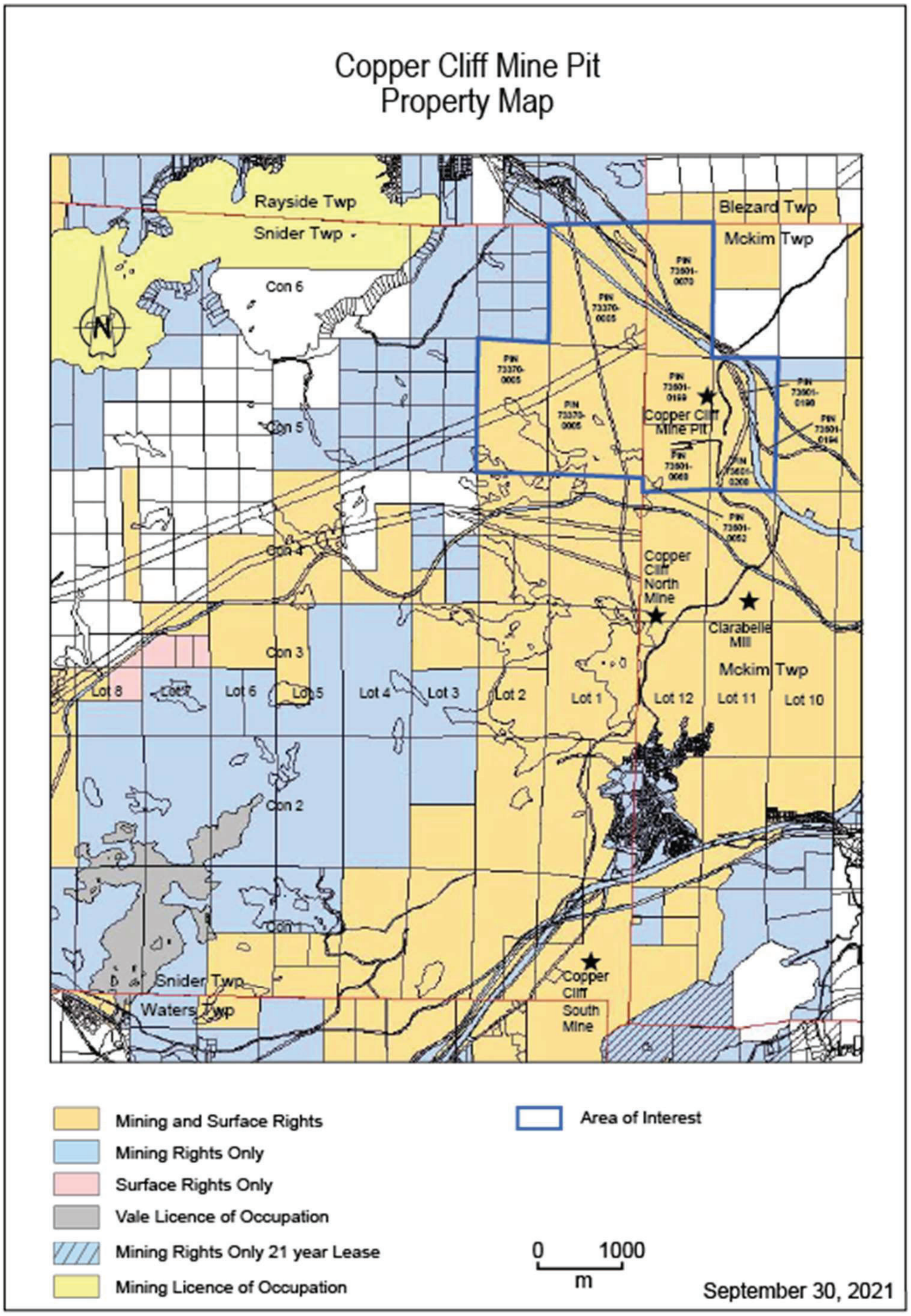
Appendix: Figure 26-1: Totten Mine



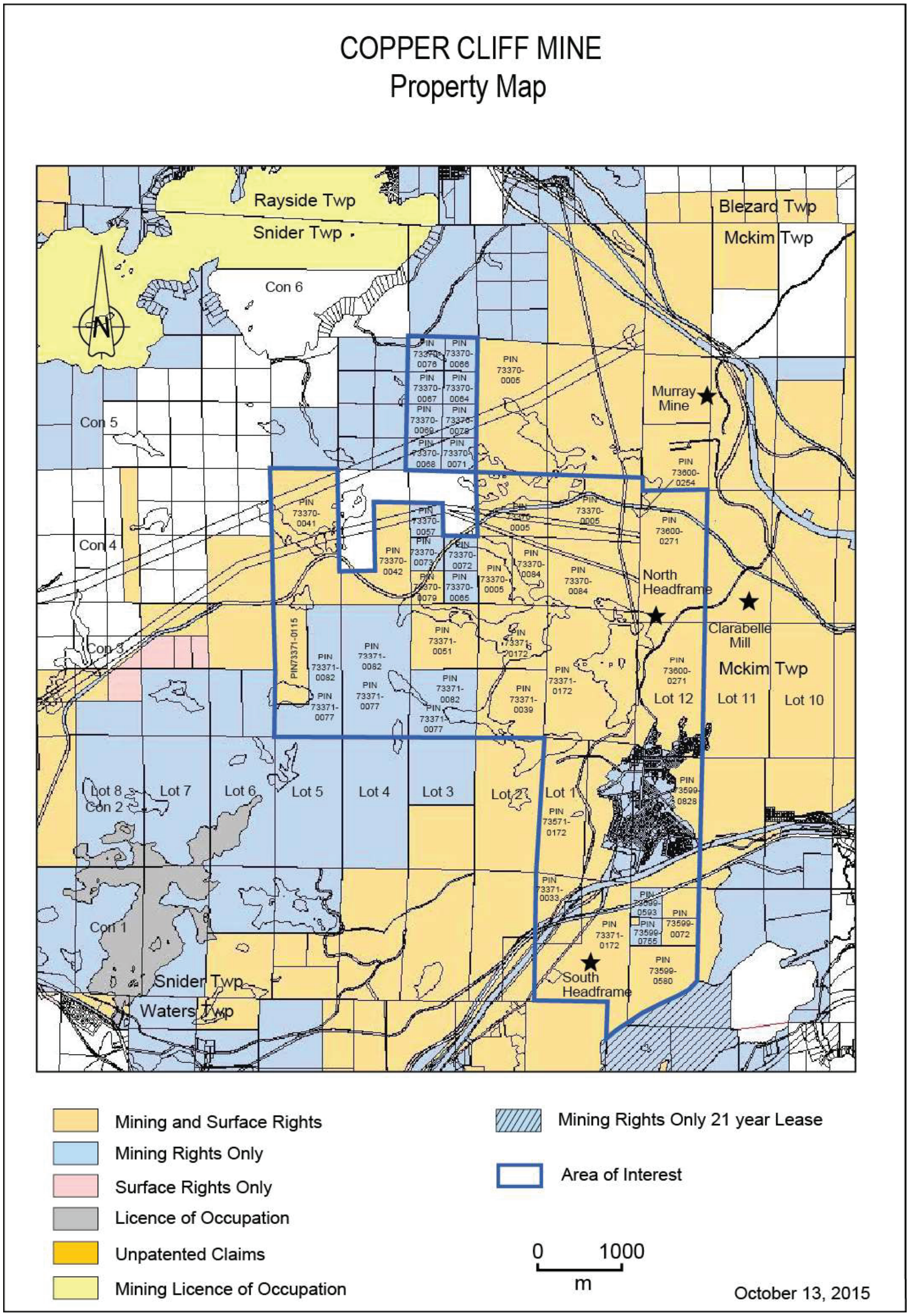
Appendix: Figure 26-2: Coleman Mine



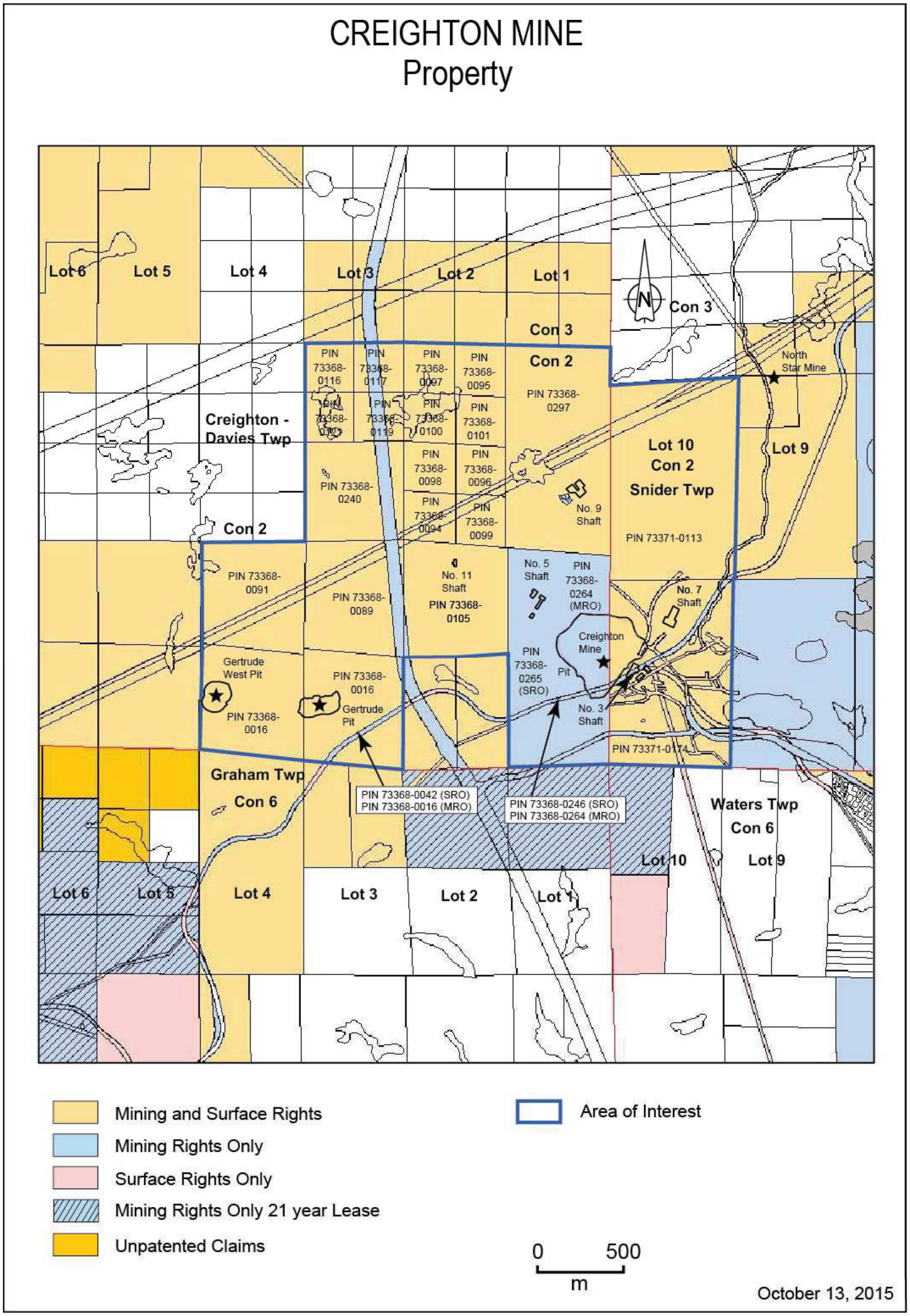
Appendix: Figure 26-3: Copper Cliff Pit



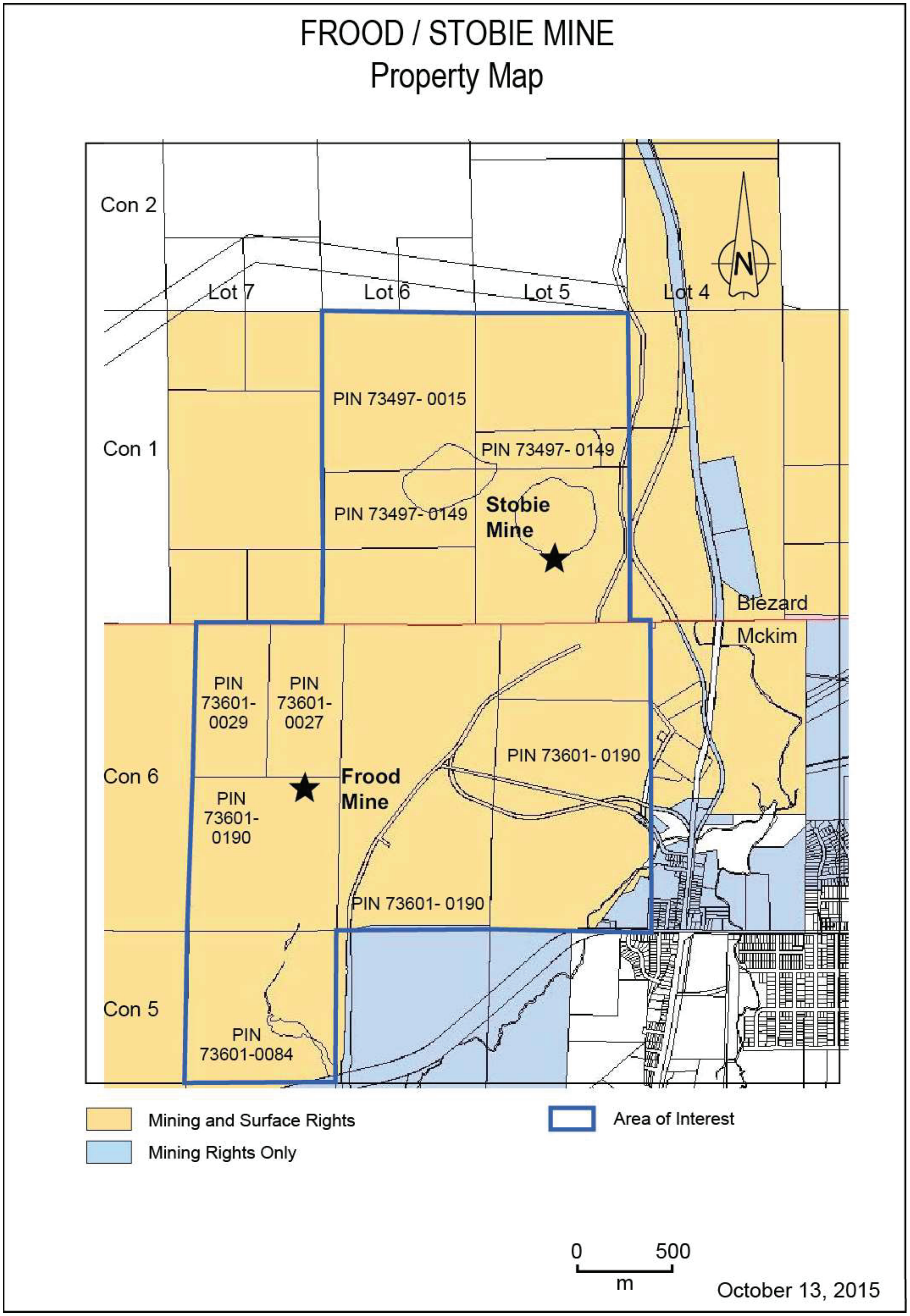
Appendix: Figure 26-4: Copper Cliff Mine



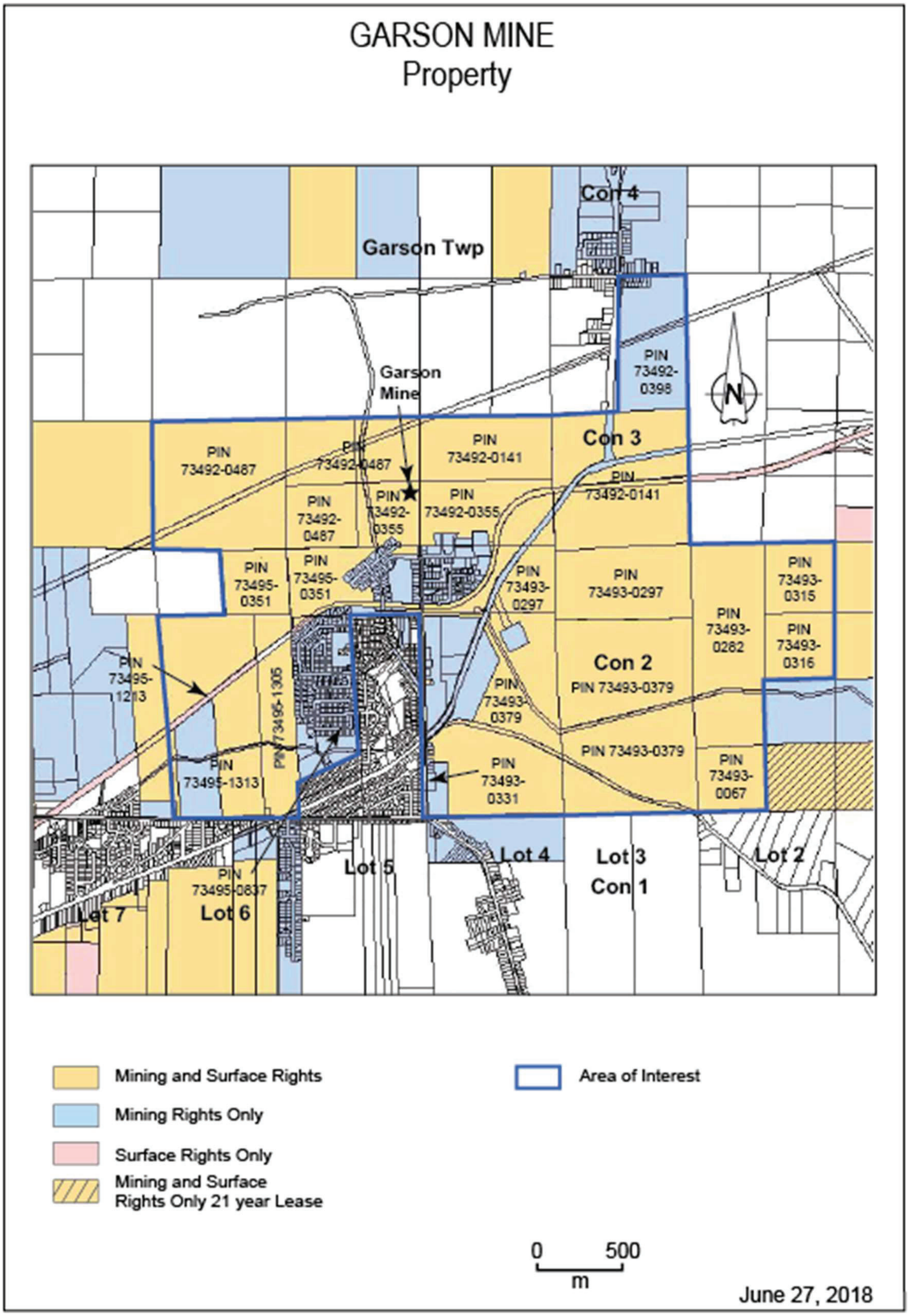
Appendix: Figure 26-5: Creighton Mine



Appendix: Figure 26-6: Stobie Mine



Appendix: Figure 26-7: Garson Mine



Appendix: Figure 26-8: Victor