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VALE INCO'S CREIGHTON MINE: DIGGING DEEPER BY THE DAY

The 107-year-old Creighton mine is one of six Vale Inco mines in the Sudbury area of Ontario, Canada—and is its second most profitable, thanks to its high ore grade, time in service, size of reserves and existing infrastructure. Creighton's only drawback is its depth—and the increasingly high cost of bringing the ore to surface.

Located in the western portion of the City of Greater Sudbury, at 2,400 meters (7,800 feet), the site is one of the deepest mines in Canada—a distinction that brings with it certain challenges: High rock stresses determine the mining methods, which have been designed to minimize the impact of sub-surface seismic activities, and high virgin rock temperatures have necessitated employing a novel "ice-cavern" cooling network, through which ventilation air is pumped to the workings.

DISCOVERING A MASSIVE ORE BODY

Creighton's copper-nickel sulphide ore body was discovered in 1856, when A.P. Salter observed marked deflections in compass readings. In 1901, the first ore was produced from the open pit. In 1906, underground stoping started and two years later the open pit ceased operations, having reached a production level of 725 tonnes (800 short tons) per day.

EVOLVING MINING METHODS

In the more than 100 years since Creighton began its underground operations, its mining method has understandably varied and evolved considerably. Shrinkage mining gave way to square-set stoping, cut-and-fill mining, block caving and post-pillar mining before the mine reverted back to shrinkage mining and mechanized undercut-and-fill mining. More recently, the large-diameter blasthole method combined with vertical retreat mining was introduced. In addition, mucking and support methods have likewise evolved. Trackless operations, hydraulically placed backfill, mining of rib pillars and the introduction of cement into backfill have all been implemented at one time or another.

Since the start of operations, over 155 million tonnes (171 million short tons) of ore grading—1.23 percent copper and 1.59 percent nickel—have been extracted from the Creighton property.

For operational purposes, the mine has been sectioned into districts. Division 4, which is the uppermost region of current operations, extends from the 1,100-meter to 1,650-meter level (3,570-foot to 5,400-foot level), and is open above this. Division 5 mainly consists of old workings between the 1,650-meter and

1,950-meter levels (5,400-foot and 6,400-foot levels). Division 6, which contains the bulk of the ore body, extends from the 1,950-meter level to the 2,390-meter level (6,400-foot level to the 7,840-foot level), and is open at depth. In addition, 3-shaft is currently being reactivated as a training center, and is scheduled to restart production in 2021.

DETERMINING TYPES OF ORE

Creighton is located in the southern region of the Sudbury Igneous Complex (SIC). The rocks of the SIC, which are dated at 1,850 million years, are exposed within an elliptical ring with a long-axis of 72 kilometers (45 miles) and a short-axis of 27 kilometers (17 miles).

In broad terms there are three main categories of mineralization at Creighton: sulphides associated with the sub-layer norite or quartz diorite; high-grade sulphide pods located in the footwall; and sulphides associated with shearing. The main base metal minerals contained in the Creighton ore bodies are pyrrhotite Fe(1-x) S, pentlandite (Fe,Ni)9S8 and chalcopyrite (CuFeS2). Recent encouraging exploration results below the 2,377-meter (7,800-foot) level are anticipated to add greatly to the life of the mine.

Production in 2007 yielded 793,000 tonnes (873,617 short tons) grading 1.62 percent copper and 2.8 percent nickel.

"There appears to be plenty of untapped mineralization below current working levels," explains Dave Andrews, Creighton's chief mine geologist. "In these deeper parts the ore tends to be hosted in a more granitic footwall complex. The impact that this transition (in ore geometry) has on the mining method is associated with the mineralization concentrated in narrower zones, so we may have to scale down our stoping sizes, or even switch from bulk mining to a more selective method."

Creighton mine ore is poly-metallic, with credits derived from nickel, copper, platinum, palladium, rhodium, ruthenium, iridium, gold and silver, with the bulk of the contribution from nickel and copper.

Creighton Mine uses both bulk and selective mining methods.

USING THE SELECTIVE MINING METHOD

Selective stoping, using the mechanized cut-and-fill (MCF) method, is predominantly used in flat-lying areas and for narrow, high-grade stringers. Selective mining currently accounts for approximately 5 percent of the ore extracted at Creighton.

In the MCF method, stopes are driven transversely in 4.5-meter-high (15-foot-high) lifts from an initial 7.5-meter-wide (25-foot-wide) slot. Rib pillars measuring 5-by-6-meters wide (16-by-20-feet wide) are left between stopes. Recently, MCF has been modified to MCF-drifting, where the ore body is mined longitudinally. Selective methods are currently being used in the Division 5 area (i.e., workings between the 1,650-meter and 1,950-meter levels or 5,400-foot and 6,400-foot level).

EMPLOYING THE BULK MINING METHOD

Where the ore body is massive and steeply dipping, the bulk method is used and currently accounts for approximately 95 percent of the ore extracted from Creighton. The preferred bulk method employed is slot-slash.

Vertical retreat mining (VRM) was introduced in the mid-1980s to replace the cut-and-fill mining method. The slot-slash mining method, a modified VRM, was introduced in the late 1990s and replaced the VRM mining method. The change from VRM to slot-slash was designed to reduce blast damage by minimizing the number of blasts. Both these methods are bulk mining methods which utilize 152-mm (6-inch) production blastholes drilled from a top-sill and breaking through into a bottom-sill. The holes are filled with explosives and blasted, where the broken ore is picked up by a load-haul-dump (LHD) on the bottom-sill and dumped into an ore pass.

In the slot-slash mining method, a slot raise is drilled into the stope, using a 1.2-meter (4-foot) diameter raise bore hole. The production holes at the bottom of the stope, as well as those around the slot raise, are loaded with explosives and blasted. The method creates more free blasting faces and allows Creighton to mine a stope with fewer blasts.

The stope height varies between 26 and 61 meters (85 and 200 feet), but the “internal” horizontal dimensions vary little, so the ore produced from a single stope may vary from 6,300 to 91,000 tonnes (7,000 to 100,000 short tons). Some secondary blasting may be required in lower-grade ore.

In the Division 6 area, an underhand sequence is used, with mining proceeding downward adjacent to previously filled stopes. However, the underhand method does impose constraints on both the sequence (a rigid echelon must be adhered to) and fill quality, but has the significant advantage of reducing seismic activity as no pillar sills are formed. Additionally, with the stresses being pushed out to the abutments, there are no permanent sills / pillars being created, and mining recovery is therefore increased.

“Due to the depths at which we are mining, it is very important that we follow this sequence,” admits Alex Henderson, Vale Inco’s manager for business planning and mines technical services for the Ontario Operations. “If we didn’t, we could end up with considerable seismicity. In this area, the horizontal stresses are two times those of the vertical stresses. We are hoping that with depth, the stress differential between horizontal and vertical will become homogeneous.”

Drilling for development purposes is undertaken by two boom jumbo drills with Caterpillar® R1700G, 6-cubic-meter (8-cubic-yard) capacity diesel LHDs mucking and tramming in both development and in the stopes. Trucks are being employed in the lower areas to bring the broken ore to the underground crusher station at the 2,100-meter level (7,000-foot level).

MANAGING SEISMIC ACTIVITY

One of the major considerations for the mining engineers at Creighton are the sub-surface seismic occurrences, which are initiated by mining / excavation activity.

“The majority of significant seismic events that we experience at Creighton are due to the presence of slip-faults,” explains Henderson, “with the majority of seismic events occurring during or shortly after a production blast. At the end of a shift we leave a new face for several hours to ‘seismically decay,’ before we re-enter that area. We monitor these areas, using an array of geophones placed strategically around the mine, and if we feel the decay rate is not as we would anticipate, we will temporarily close down this section of the mine and extend the period before we will allow re-entry to take place. There have been several times when we have followed this protocol and have managed to avoid any incidents that would have put our workers in harm’s way.”

The mining methods employed were developed internally by Vale Inco over time using stress models. “One of the major innovations which we are currently working on,” explains mine manager Kelly Strong, “are not the mining methods themselves, but the support methods that follow. Creighton has never been a single support system mine. We currently employ a series of support systems in development and production drifts, and haulage areas.”

These support systems include cemented tailings as hydraulically-placed backfilling; shotcreteing; shotcrete arches; enhanced supports; and large diameter split-set bolts— 46-millimeter-diameter (1.8-inch) unclipped compared to the traditional 34-millimeter-diameter (1.3-inch) unclipped split-sets.

“These ‘fatty’ split-sets are too robust to be put in by hand, so we employ one-man operated Bolter units, which are able to drill and set these 46-millimeter-diameter (1.8-inch) sets in place,” says Strong. “This Boltec is a remote-running machine, so the operator is able to work from a cabin some distance from the unsupported zone. This is significant as we often find ourselves driving drifts underneath backfill.”

The backfill contains mill tailings from the Clarabelle plant, which are pumped as a slurry (40 percent solids to 60 percent water) along 40-centimeter (16-inch) diameter surface pipes to a holding tank where it is agitated while waiting to be mixed with cement / fly ash before being pumped underground to act as backfill.

"When we backfill a stope we have to do this in stages to enable the excess water to percolate down through the fractures in the rock," says Strong. "We are currently examining the use of pastes for backfilling purposes, but to date no decision has been made on their commercial use at Creighton."

HANDLING ORE AND WASTE

All ore is hoisted up 9-shaft, using a 5,200-kilowatt (7,000-horsepower) double-drum hoist and two 13.5-tonne (15-ton) aluminium skips. Ore arrives at the hoisting shaft from one of three distinctive areas: Division 4, 5 or 6.

- Division 4 ore is mucked to ore passes that feed a diesel locomotive on 1,500-meter (5,000-feet) level. Material is trammed for 1,400 meters (4,500 feet) to a crusher, with the crushed ore being conveyed to the 1,600-meter (5,280-feet) level loading pocket at 9-shaft. The skipping rate from this level loading pocket is 308 tonnes (340 short tons) per hour.
- Division 5 ore is mucked to ore passes that feed a diesel locomotive on 1,950-meter (6,400-feet) level. Material is trammed to an ore pass that feeds the 2,000-meter (6,600-feet) level crusher, with this crushed material reporting to the 2,036-meter (6,680-feet) level loading pocket at 9-shaft.
- Division 6 ore is trucked up a ramp by trucks to the dump at 2,124-meter (6,970-feet) level. This material is then mucked into the 2,133-meter (7,000-feet) level crusher, which feeds the crushed material (via a conveyor) into the same 2,036-meter (6,680-feet) level loading pocket at 9-Shaft as the Division 5 ore. The skipping rate from this 2,036-meter (6,680-feet) level loading pocket is 272 tonnes (300 short tons) per hour. All personnel and materials access the mine via the 9-shaft cage.

The mine is now looking at alternatives to trucking this ore upward along the ramp. "We have a great deal of ore at depth and we need to make sure we do not squander the wealth here on an unsuitable and unsustainable ore movement method," says Henderson. "We are probably talking about putting in a secondary internal hoisting system with a bin to enable ore transfer from one shaft to the other."

PROVIDING ADEQUATE VENTILATION

Creighton 9-shaft workings are ventilated with 45,000 cubic meters (1.6 million cubic feet) per minute of fresh air, using a single pass system. Fresh air is drawn from the surface through a mass of broken rock located in old stopes in the vicinity of 3-shaft, which forms an "ice cavern" due to the cold winters and the moisture in the air. This ice-cavern acts as a heat exchanger, warming the air in the winter and cooling the air during the summer. The sub-surface air temperature averages 3 degrees Celsius (37 degrees Fahrenheit), with a small seasonal variation.

As a result of the ice cavern system, it has not been necessary to provide mechanical refrigeration so far. To date the savings in terms of plant, maintenance and power consumption have been very significant. Creighton was one of the first mines in Canada to employ this simplistic, though novel, ice-cavern cooling system.

"Because in the near future we will be working beyond the limit of our current cooling system," explains Strong, "we are having to look at a number of alternatives. One option would be to supplement our ice caverns with an expensive mechanical refrigeration plant. The alternative would be to expand the open-pit in order to increase the catchment area / cooling-surface available for the air being drawn underground. However, it is still too early to say which option will be chosen. Modeling work in this department continues."

PROCESSING ORE

The ore from Creighton mine is crushed underground before being hoisted to the surface and into surface loading bins, from where it is shipped by rail to Clarabelle Mill. It is then blended with ore from the group's six Ontario operational mines, as well as from third parties, as it is unloaded at the mill. This blended ore is fed through a crushing circuit then ground through a series of ball and rod mills before entering flotation. In flotation, the non-mineral- bearing rock and the majority of pyrrhotite are rejected and pumped to the tailings area. The mineral bearing pentlandite is then recovered and pumped to the smelter for further processing. A chalcopyrite, or CU rich concentrate, is also separated and sold to third parties.

In the near future, the mine plans to begin production of higher grade separate copper and nickel concentrates, with precious metals (platinum, palladium, gold and silver) reporting to the copper side. Nickel concentrate would continue to be treated at Copper Cliff, while copper concentrate would be treated elsewhere by a third party.

PROTECTING THE ENVIRONMENT

For generations, the Sudbury area has been associated with deforestation due to logging and smelting activities.

Considerable progress has been—and continues to be—made in returning the area to pre-mining conditions. "There has been considerable effort invested in this area to restore the landscape, and to make good some of the environmental damage that has taken place here over the last 150 years," explains Art Hayden, superintendent of safety for Vale Inco operations in the Sudbury area. By and large the Sudbury Soils Study gave the area a clean bill of health.

The city recently won a UNESCO award in recognition of the environmental restoration work that has gone on in the Sudbury area. "We have invested more than $1 billion to reduce emissions by more than 90 percent," says Hayden.

A closure plan for Creighton was filed in July 2001, in accordance with the Ontario Mining Act. The plan identifies various site rehabilitation activities that can be conducted prior to and following site closure. Closure costs are estimated to be approximately US$10 million.

MEETING WATER QUALITY GUIDELINES

Surface water from the mine site flows naturally through to the tailings area. This water is then piped to water treatment plants and upon meeting water quality guidelines, is discharged into the local watershed.

Underground, Creighton is a relatively dry mine, with the majority of the water generated coming from backfill and drilling equipment. Mine water is collected in main dirty water sumps located on four levels between 579 meters (1,900 feet) and 2,100 meters (7,000 feet). Water below the 2,100-meter (7,000-feet) level is collected on three levels before being pumped to the 2,100-meter (7,000-feet) level main sump. Solids are allowed to settle in these sumps and clear water is pumped to surface in stages.

GENERATING POWER

Creighton receives approximately 25 percent of its electrical power from the Vale Inco electrical grid, and the rest is taken from the provincial grid. At full production, Creighton consumes on average between 10.5 and 11.0 million kilowatt hours per month, at a price (mid-2007) of approximately US$0.06/kWhr. Approximately 60 percent of the electrical power is used for ventilation, 20 percent for hoisting (personnel and rock), and 20 percent for pumps, crushers, mobile equipment and production drilling.

TAKING ADVANTAGE OF THE MINING BOOM

The current mining boom has had both a positive and negative impact on operations at Creighton. "The rise in metal prices means that there are now areas in the mine, such as lower grade zones and remnant mining zones, which we can now look at as economically exploitable, whereas before they were not," says Strong. "In addition, we have recently started bottom-sill-slashing as an innovative way to get higher extraction rates where ore is extremely valuable."

On the reverse side, given the level of competition that exists on a global scale, Strong says Creighton is having difficulty recruiting experienced miners, operators and technical staff required for mine expansion and new projects. "The result of this is that we are spending a great deal of time and effort on training such people. This is in spite of the fact that Creighton's turnover in staff—particularly the technical ones—is still low."

PARTICIPATING IN NON-MINING ACTIVITIES

On the non-mining side, Creighton houses the Sudbury Neutrino Observatory, which was opened by Stephen Hawking, the Nobel Prize winner, world famous astrophysicist and best-selling author of "A Brief Moment in Time." The facility is considered, in the rarefied world of particle physics, to be a world-class facility. The laboratory is located some 1,800 meters (6,000 feet) underground.

In addition, and in an effort to reduce its environmental footprint, Creighton also houses underground greenhouses, where tree seedlings are grown year-round despite harsh winters on the surface.

LOOKING TO THE FUTURE

Creighton's managers identified a number of priorities for technical staff that were deemed worthy of further work, including:

- The continued exploration of the up-and-down-plunge extents of the deposits
- The completion of the scoping study to identify the optimal mining methods and infrastructure for mining at depths of up to 3,000 meters (10,000 feet)

"Not only are there great opportunities at depth," explains Henderson, "but there is also some remnant ore that has been left behind in old workings. Some of this ore was bypassed over the last 100 years as being either uneconomic or because the mining method of the day did not allow it to be mined, but it is now being extracted safely and economically."

Strong estimates the mine is about three-quarters of the way through its at-depth exploration drilling program, which will delineate ore volumes, grades and stresses. "After that there is a great deal of engineering work that needs to be done to justify shifting the category from being a resource to a reserve," Strong explains, outlining three major work areas in which the mine is currently involved:

- Developing the mine internally down to the 2,500-meter (8,200-foot) level (i.e., two more levels).
- Exploring the potential to develop the mine at the 3,000-meter (10,000-foot) level.
- Drilling from both the surface and underground to properly exploit the 402 orebody ores above the 610-meter (2,000-foot) level.

Down to and beyond 3,000 meters (10,000 feet), the major challenge is to determine if the mining method Creighton is using at 2,377 meters (7,800 feet) is still viable—given that seismic activity increases at depth.

To that end, Creighton mine is working with a number of research agencies, engineering establishments and technical universities, as well as the Centre of Excellence in Mining Innovation (CEMI) to determine if the current mining method will continue to be a safe workable mining method at depth.

"In addition, we are examining other mining methods that are being employed in other deep or seismically active mines," says Henderson. "I have no doubt that in the future, the world will come to Creighton to see how it should be done."