Paper 40

In-mine Exploration and Delineation Using an Integrated Approach

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ABSTRACT

The exploration and delineation of the 1D Lower sulphide zone at CVRD Inco's T-3 Mine in Thompson, Manitoba is described. In Thompson area mines, geology has traditionally played an important role in the exploration and delineation strategies because of the complicated stratigraphy and geometry of the mineralized zones and because of the presence of many highly conductive geophysical anomalies, not all of which are nickeliferous. The abundance of barren sulphide has largely precluded the use of electromagnetic techniques for in-mine exploration. In Thompson, in-mine exploration usually begins with knowledge of stratigraphy and widely-spaced drilling, often consisting of borehole separations of up to 600'. Significant intersections are then followed up by drift development that allows additional underground exploration and delineation drilling to continue closer to the target. This strategy led to the 3500 Level exploration drift in CVRD Inco's T-3 mine in Thompson. Beginning in 2000, after the 3500 Level drift development was completed, sets of fanned boreholes were drilled on sections separated by 100'. In late 2000, a geophysics program began in boreholes collared on the 3500 Level with concurrent seismic tomography and optical televiewer surveys. Prior to the start of the 1D Lower zone geophysics program, several different models of the ore envelope existed, however, it was suspected that local flattening of the mineralized zone was a possibility largely because of knowledge gained during mining of the 1D Upper zone. Seismic tomography images provided the first independent confirmation of the local flattening of the ore envelope. A structural geology program, beginning with core-based measurements and continuing with the optical televiewer, was carried out in a significant number of the exploration and delineation boreholes drilled from the 3500 Level. The integration of borehole, stratigraphic, geophysical and structural geology information added confidence to the ore interpretation for what became the 1D Lower orebody. The geophysical aspects of the exploration and delineation program in the 1D Lower zone in T-3 mine in Thompson were designed to take advantage of experience gained by CVRD Inco Exploration through a series of tests of single-hole and cross-hole geophysical techniques. These tests, which were performed prior to the start of the 1D Lower program, will be reviewed in this paper.

INTRODUCTION

Exploration for nickel has been ongoing in the TNB (Thompson Nickel Belt) by CVRD Inco since the late 1940's. The early exploration consisted of airborne electromagnetic and magnetometer surveys, followed by detailed ground surveys and diamond drilling (Dowsett, 1967). This systematic exploration led to the discovery of several nickel deposits in the early 1950's including the Thompson deposit in 1956, the Pipe deposits in 1957 and the Birchtree deposit in 1962. The drilling success at the Thompson deposit led to the construction of a fully integrated mine-mill-smelter complex in Thompson beginning in 1956. Since that time, a total of six deposits have been brought into production in the TNB including the Thompson Mine (T-1, T-2 and T-3 headframes), the Birchtree Mine, Pipe No. 1 Mine, Pipe No. 2 Mine, Soab North Mine and Soab South Mine.

In sulphide exploration, the geophysical techniques of choice are normally EM (electromagnetic) based techniques dictated by the large contrast in host rock conductivity (typically 10^{-3} to 10^{-4} S/m) compared to sulphide conductivity (massive sulphide conductivity up to 10^{5} S/m) (King et al., 1996a, King 1996b and Watts, 1997). In the TNB, the use of EM geophysical surveys (airborne, ground and borehole) is complicated by the presence of highly conductive, barren sulphide in and near the target stratigraphy. These nuisance, large-scale conductors often have historically resulted in numerous EM anomalies requiring expensive and time-consuming follow-up (Dowsett, 1967). Despite this drawback, EM techniques have played an important role in the exploration program in the TNB for the identification of potential targets which are then prioritized based on knowledge of geology and stratigraphy.

In TNB mines, exploration and delineation has traditionally relied heavily on geology and stratigraphy. Because of the complicated geometry of the mineralized zones, confidence in ore envelope interpretations (continuity and geometry) between widely spaced holes carries a very low level of confidence. For this reason, a significant amount of effort and money is invested in development and subsequent detailed drilling close-in to the

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target in order to accomplish exploration. During the exploration phase, as borehole density increases and confidence in ore envelope interpretation increases, sulphide zone exploration becomes orebody delineation.

Many mining companies utilize geophysics for in-mine exploration and orebody delineation purposes (King et al., 1996a, Fallon et al., 1997 and Cochrane et al., 1998). The use of geophysics for in-mine applications is often driven by the economic impact, for example, decreasing the total number of delineation boreholes required to define an orebody. For example, it was economically justified to continue the use of the optical televiewer in the 1D Lower program, i.e., the use of the televiewer substantially increased the number of structural features available to help model the ore and mineral envelopes. At the time, the manual core-based technique was a time-consuming and therefore, more costly technique. However, since ore envelope geometry is very complicated in Thompson, the justification for cross-hole geophysical surveys was purely the need to acquire additional information between boreholes. Ultimately, however, the cost of such surveys must be balanced against the value of the information acquired, i.e., performing cross-hole surveys between every pair of available boreholes would be very costly and thus not feasible. More specifically, an awareness of the cost incurred by the limited range of seismic tomography is important and necessary.

The T-3, 1D Lower zone exploration program, which began late in 2000, was designed to take advantage of the experience gained by CVRD Inco Exploration during many test programs. The decision was made, for example, to use seismic tomography instead of RIM for cross-hole sulphide delineation, north-seeking gyro became the tool of choice for borehole orientation and both acoustic and optical televiewer probes were tested although it was thought that the optical televiewer would not deliver sufficiently good images to warrant its continued use. It was, in fact, the use of the acoustic televiewer that was suspended because the exploration and delineation program was not driven by geotechnical questions but by geological and ore interpretation questions. The optical televiewer images were of sufficient quality to allow the interpretation of geological and structural features in underground boreholes and thus, the core-based measurements were replaced by the optical televiewer for the T-3, 1D Lower program.

Single borehole physical property measurements supplemented and assisted with the ore envelope interpretation. For example, a full waveform sonic probe was purchased just prior to the start of the underground exploration program in the 1D Lower zone, and the new tool was tested in several of the boreholes located on the 3500 Level. Since the tool was relatively new and a data processing procedure was not yet perfected, the confidence level in the results was low and, at the time, not all of the data was processed. Additional geophysical surveys (for example, inductive conductivity and natural gamma) were carried out in boreholes in the T-3, 1D Lower zone, however these will not be covered in detail because they did not contribute significantly to the exploration and delineation of the zone.

REVIEW OF METHODS AND TOOLS TESTED AT CVRD INCO

The following summarizes test work at CVRD Inco Exploration related to RIM (Radio Imaging Method), seismic tomography, north seeking gyro, acoustic televiewer, optical televiewer and Coretec.

In 1992, a geophysical test site was established at the McConnell deposit (Mwenifumbo et al., 1993), located in Sudbury, Ontario, and owned by CVRD Inco. The borehole geophysical logging was originally performed by the Geological Survey of Canada (Killeen et al., 1995) with support from CVRD Inco. At McConnell, a thick, massive sulphide, pyrrhotite-rich orebody is penetrated by many boreholes, including a section consisting of five boreholes ideally suited for testing cross-hole geophysical techniques. Figure 1 shows an example of the results of the physical property logging in one of the boreholes on the section.

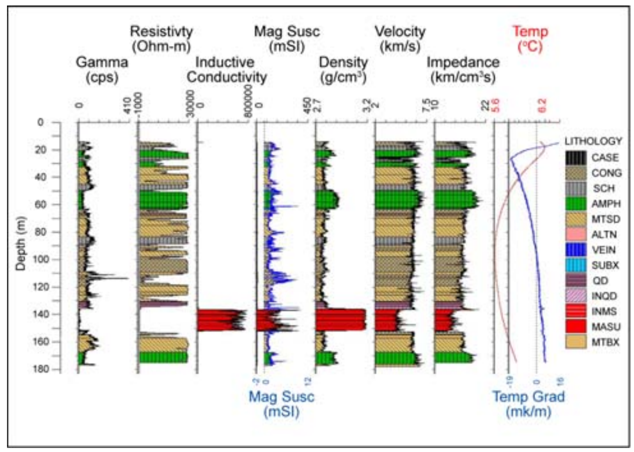

Figure 1: Physical property logging results from borehole 78930-0 located at the McConnell geophysical test site

In particular, note the contrast between the host rock and the sulphide orebody for conductivity/resistivity, p-wave velocity and density. Although most of these details were previously known, the McConnell physical property measurements inspired tests of several cross-hole methods including RIM and seismic tomography.

Previous studies demonstrated the sulphide applications of RIM (Thomson et al., 1992). In 1994, the JW-4 borehole RIM system was tested at two sites (McConnell and Levack) located near Sudbury, Ontario (Fullagar et. al, 1994). The JW-4 is an electric-field, amplitude-only borehole RIM system operating at frequencies between 0.5 MHz and 32 MHz. The system is ideal for exploring for conductive anomalies and is capable of a large range (up to 1 km at low frequencies) because of the typically resistive nature of the host rock. RIM is very sensitive to the presence of sulphide, however, a disadvantage of the technique is that relatively thin stringers are sufficient to cause complete attenuation of the signals. Based on the results of the initial surveys by Fullagar (Fullagar et al., 1994), CVRD Inco Exploration began an in-house program that included tests at surface and underground sites in the Sudbury and Thompson areas in the mid-1990's. As the in-house tests progressed, the main focus of the project became the conversion of copper-shielded to fibre-optic borehole cables to eliminate cable waves (McDowell and Verlaan, 1997). Subsequent to the fibre-optic conversion, tests surveys were conducted at several sites in Sudbury (including McConnell) and two sites in Thompson in early 1997. At the time, in-house data processing consisted of choosing an electric field amplitude threshold and displaying only those raypaths having signals larger than the threshold. Figure 2 shows the results of a survey performed at the McConnell site after the system was converted to fibre-optic cables. Figure 3 shows a RIM survey performed in the 1C area (2460 Level) of T-3 mine in Thompson. This survey crudely imaged the main ore zone, however, it did not yield sufficient detail to make the technique useful in close-in exploration or delineation applications in Thompson area mines.

Since the JW-4 RIM measurements were made using a distributed electric field transmitter and receiver, conductive zones (including intervals containing very low nickel or simply too thin to be included in the ore interpretation) found adjacent to the main mineralization caused significant attenuation outside the area of interest (this is observed in Figure 3 above the orebody in BH 95724-0).

The seismic tomography technique (McGaughey, 1990) was also tested extensively by CVRD Inco Exploration because of the unique low velocity anomaly presented by the pyrrhotite-rich nature of sulphides in CVRD Inco's Canadian mines (see Figure 1). Seismic tomography test surveys began in mid-1995 in the Sudbury area with the first survey performed at the McConnell deposit using a standard seismograph and blasting cap sources. Figure 4 shows the results of the survey performed by the Noranda Technology Centre. Although the survey successfully imaged the massive sulphide deposit, the disadvantage of blasting caps was that there was significant potential for damaging the source hole.

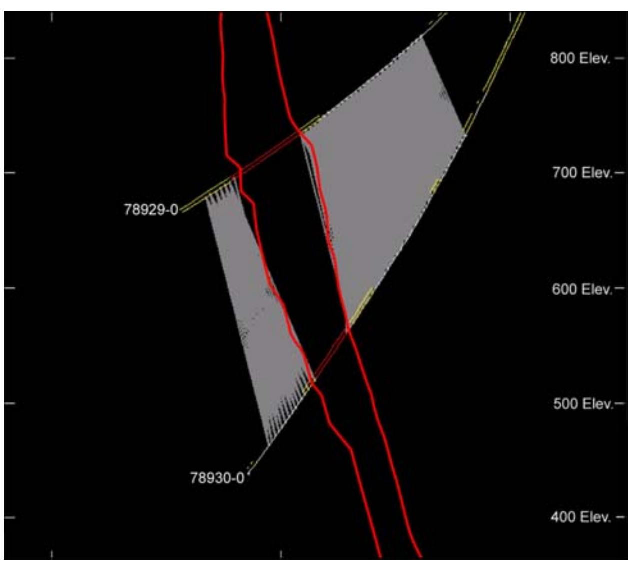

Figure 2: RIM survey between boreholes 78929-0 and 78930-0 at McConnell. Orebody outline shown in red.

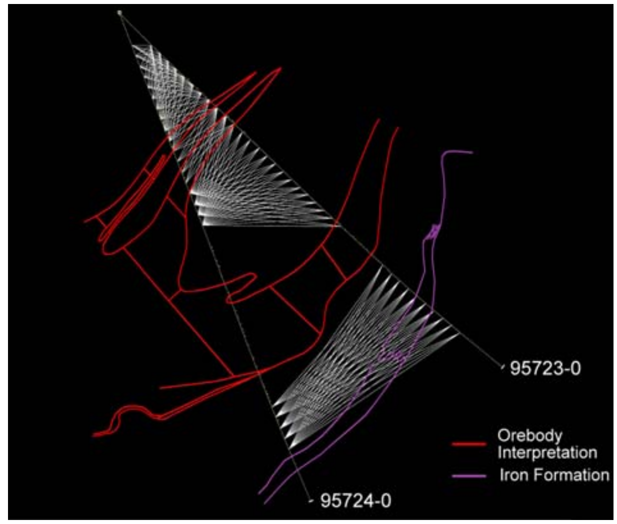

Figure 3: RIM survey in T-3, 1C boreholes. Orebody outline shown in red.

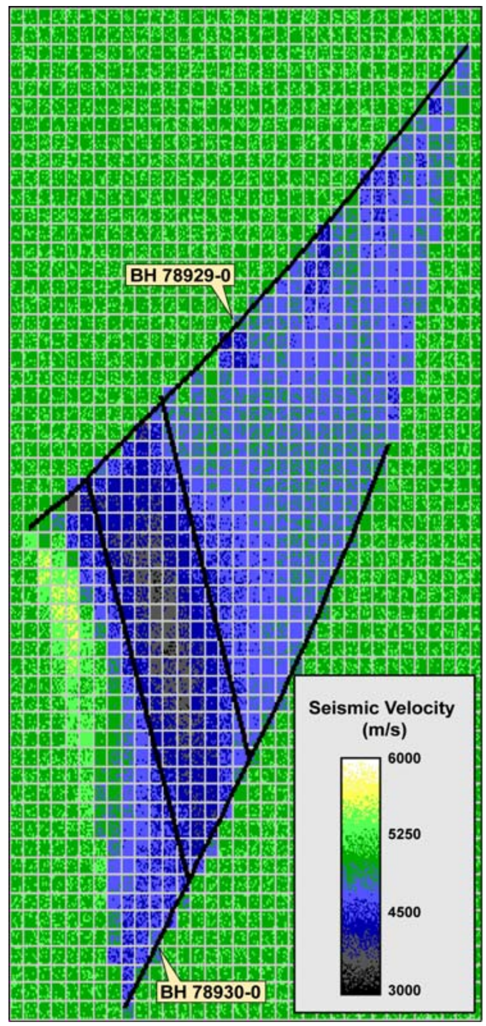

Figure 4: Results of the blasting cap seismic tomography survey between boreholes 78929-0 and 78930-0 at McConnell. Approximate orebody outline shown in black between the boreholes.

The first test of a piezoceramic-source seismic tomography system at CVRD Inco occurred in late 1996 at the McConnell deposit in Sudbury (Wong, 1997 and Wong, 2000). Several modifications to the system continued during late 1996 and early 1997 including downsizing of the transmitter to allow it to fit into BQ (2.36" diameter) boreholes. The Jodex Geoscience Corrseis survey successfully duplicated the blasting cap survey at McConnell as shown in Figure 5.

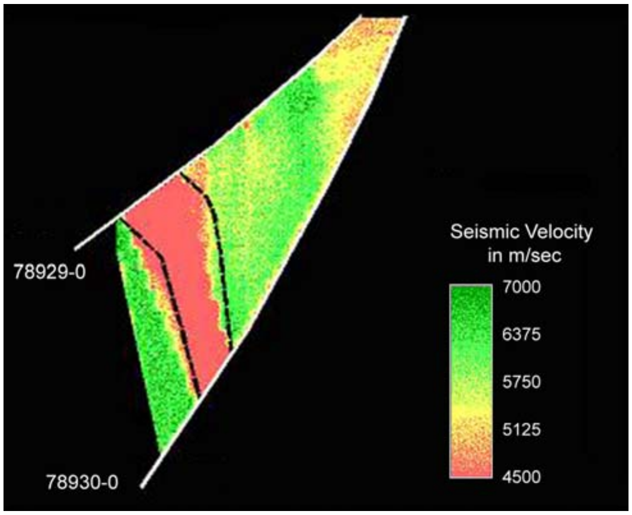

Figure 5: Results of seismic tomography survey between boreholes 78929-0 and 78930-0 at McConnell. Approximate orebody outline shown in black.

The acquisition of high frequency seismograms without the use of blasting caps resulted in additional seismic tomography surveys being performed using the Jodex and Vibrometric Oy systems. Surveys were completed at several sites in Sudbury and a site in Voisey's Bay in Newfoundland and Labrador (Enescu, 2002) during the years spanning 1997-2000.

In early 1998, as a result of the success in Sudbury, a single panel of cross borehole seismic tomography data was acquired by Jodex in the same T-3, 1C boreholes previously used for RIM. The survey successfully imaged the main part of the orebody and showed a good contrast between the mineralization and the host rock as shown in Figure 6.

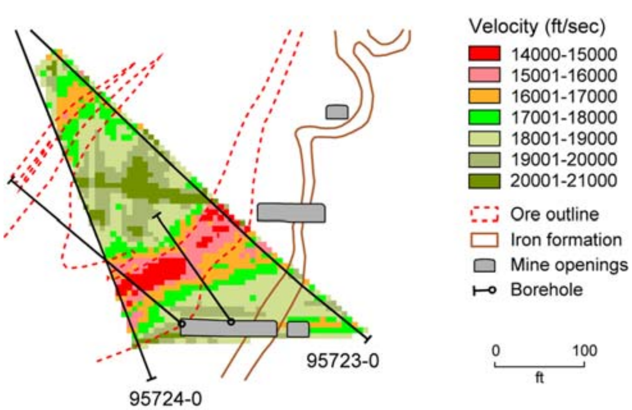

Figure 6: Results of the T-3, 1C seismic tomography survey. Orebody outline shown in dashed red.

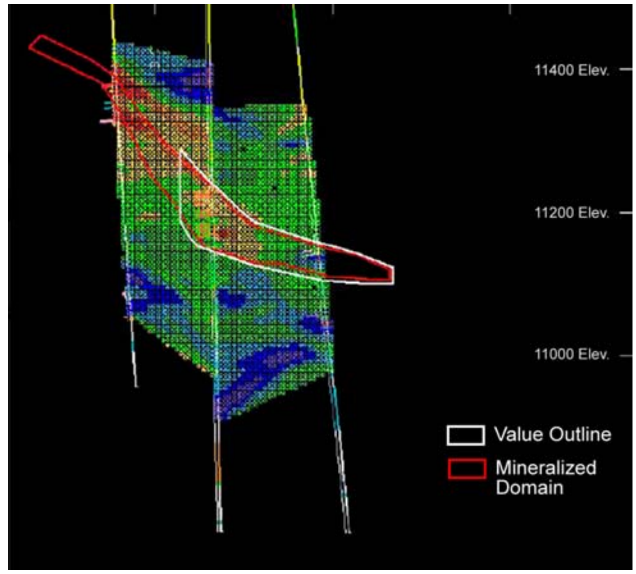

Figure 7: Seismic tomography results in two sets of boreholes located in Levack near Sudbury. Ore envelope outlines shown in red and white. The seismic velocity panels are colour coded red (low velocity) to blue (high velocity).

In late 1998, four sets of boreholes were surveyed using the Jodex seismic tomography system in the 1D Upper zone at T-3 mine on the 3300 Level. This survey included full-waveform sonic logging by the GSC to assist with the interpretation of the seismic tomography panels. The survey highlighted a zone of sulphide between the holes that was later verified by drilling.

The integration of cross-hole tomography data and assay data is not a new idea (Dimitrakopoulos and Kaklis, 2001). The first use of seismic tomography in an integrated (but simple) approach at CVRD Inco occurred in 2000. Seismic tomography panels acquired by Vibrometric in 1999 at a Levack site (near Sudbury) were incorporated into a resource/reserve analysis. Figure 7 shows a figure captured from an internal report issued in June of 2000. In the report it was stated, "the seismic panels were used as a general guide to the strike and dip of the sulphide mineralized domain in this area".

In retrospect, the Levack seismic tomography images appear to contain artefacts which highlight the inherent problem with the data. This and other CVRD Inco Exploration examples showed the apparent importance of borehole geometry in seismic tomography. Prior to 2000, it was believed that most of the CVRD Inco seismic tomography image artefacts were related to errors in borehole orientations. McGaughey assumes that real earth materials are anisotropic and corrects for this using the field data (McGaughey, 1990). There is no simple way to separate anisotropy effects and borehole orientation errors and both are likely present in all seismic tomography panels acquired by CVRD Inco.

At CVRD Inco, the effort to achieve better borehole orientation was partly driven by seismic tomography artefacts and partly by the requirements of resource and reserve evaluation. Historically at CVRD Inco (Roque, 2007), dip and azimuth measurements were made using tropari and dip was also measured using acid tests. Azimuth was later measured using magnetic-based instruments like the Sperry Sun Single-Shot.

The problem with magnetic-based measurements in the presence of magnetic pyrrhotite is obvious. Film gyros were introduced at CVRD Inco beginning in the mid-1990's and were a dramatic improvement over magnetic-based measurements. An inherent limitation of the film gyro was that it measured the borehole orientation relative to the collar of the borehole and therefore, an independently determined start azimuth was required. Commonly, the film gyro was "sighted" or aligned with a surveyed picket. However, this worked only for steeply dipping boreholes or boreholes having dips greater than 80º. For flatter holes, a magnetic compass was used to "eyeball" the start azimuth.

To address the need for better borehole orientation, a test of an oil-industry north-seeking gyro was performed in Sudbury area boreholes in May of 2000. Gyrodata Incorporated was contracted to survey a total of 11 boreholes (including one borehole that intersected an underground drift at a local mine). Several of the holes were also used for seismic tomography surveys. For the breakthrough borehole, the foot-of-hole coordinates from the north-seeking gyro survey compared very well with surveyed coordinates, see Table 1. For the remainder of the boreholes in Table 1, the existing borehole orientations were determined using a combination of film gyro and magnetic-based measurements. The breakthrough borehole was also logged by Sperry-Sun Drilling Services using their north-seeking Finder gyro (manufactured by Scientific Drilling International) and the results were similar to Gyrodata's.

The results of the Gyrodata surveys and additional experience with the north-seeking gyro in the Sudbury area indicated that inaccurate start azimuths are a major contributor to errors in borehole orientation. The independent determination of the borehole azimuth proved to be a very valuable and time-saving feature of the north-seeking measurement, in particular for underground applications.

In Table 1, boreholes labeled A-D were used for seismic tomography surveys. Worst-case geometry errors for pairs of similar boreholes used for seismic tomography purposes would result in large hole-to-hole distance errors, in some cases significantly decreasing the detectability of sulphide-related velocity anomalies.

Accurate borehole orientations are also very important for 3-D orientation of features extracted from acoustic and optical televiewer images. Televiewers provide oriented 3-D images of the borehole wall that, if of sufficiently good quality, allow the identification of joints, faults and borehole breakouts (acoustic televiewer), and geological features including contacts, foliations and folds (optical televiewer).

Figure 8 shows the results of the first test of the acoustic televiewer in a Sudbury area CVRD Inco borehole. This test was conducted in early 1999.

Based on this test, the acoustic televiewer was used to log a number of boreholes at Voisey's Bay later in 1999. Boreholes at two sites in the Sudbury area were also logged with the acoustic televiewer in mid-2000. The main use of the acoustic televiewer data was the identification of joints and their orientation, and the identification of borehole breakouts and their orientation (related to the orientation of the major principle stress). The purpose of this logging was to identify geotechnical domains and the local stress environment for mine design purposes (Maybee et al., 2002).

Late in 1999, an optical televiewer was used to log a test borehole in the Sudbury area. The results are shown in Figure 9.

Table 1: Gyrodata north-seeking gyro results from the Sudbury area. FOH (Foot-of-Hole) differences are measured in a horizontal plane and are relative to borehole length. Breakthrough hole is BH E.

BHID	BH Depth (ft)	Collar Dip Difference (º)	Collar Azimuth Difference(º)	FOH Difference (%)
A	510	1.08	0.56	6.08
B	620	0.16	1.42	0.81
C	520	0.31	2.42	3.27
D	660	0.34	2.77	4.09
E	1061	0.6	0.54	0.91
F	3868	0.44	1.0	2.92
G	3540	0.03	3.95	3.31
H	3598	0.25	0.4	1.75
I	1380	0.13	6.2	1.01
J	3821	1.0	5.0	2.85
K	4350	0.54	3.33	2.18

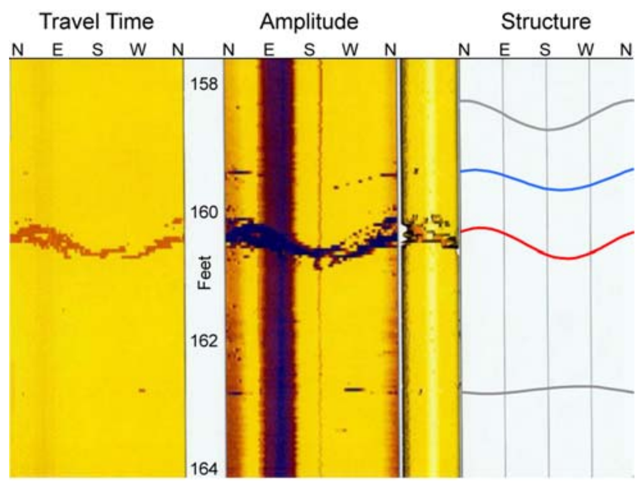

Figure 8: Image from the first acoustic televiewer test at CVRD Inco in Kelly Lake borehole 97112-0

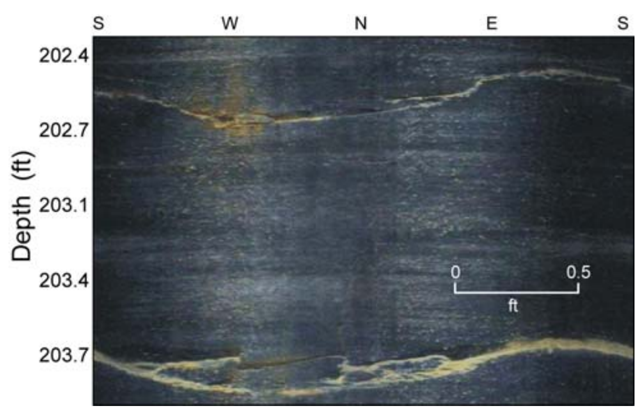

Figure 9: Image from the first CVRD Inco optical televiewer survey in Lady Violet borehole 97103-0

The first optical televiewer logging was performed in a short, large diameter (4") vertical borehole located in an area designated as a geophysical test site. The borehole wall was clean (no grease was used during drilling) and the borehole water was clean (suspended particles had settled). It was believed that the very high quality of the images was due to these factors. At the time, this test generated very little genuine interest because it was believed that the tool would not produce good images in the borehole conditions typical in mine environments. The Figure 9 image shows healed joints or fractures, however, the real power of the optical televiewer in mining applications is contact and fold identification and orientation.

Oriented core measurements were first used by CVRD Inco during surface exploration in Thompson in the 1990's using a method called Coretec. This method uses a reference-marked acid test tube attached to a corresponding reference-marked core tube during diamond drilling. The "Top of Hole" reference defined by the acid line etch is then transferred to the core and traced along the core for the interval of core that can be fitted back together. The core is set in a bench jig with the Top of Hole line facing upwards with the dip provided by the acid tube test and core azimuth provided by borehole orientation surveys. The structural features on the core can now be measured using this oriented core. As with most core orientation methods, the disadvantages include incorrect handling by drillers, lack of core orientation through poor ground conditions and the time-consuming nature of the bench measurements. Coretec was implemented underground for the first time in Thompson in the 1D Lower zone (3500 Level) diamond drilling.

The methods and tools experience reviewed in this section was instrumental in the design of the exploration and delineation program for the 1D Lower zone. The key knowledge gained was reflected in the decision to use seismic tomography instead of RIM for cross-hole surveys. It was thought (and later verified by inductive conductivity logging) that RIM would not operate well in the very conductive environment (i.e., for the same reason that EM- based techniques do not work well for larger scale near and in-mine exploration in Thompson). At the time, most available RIM equipment delivered electric field amplitude measurements meaning that transmitter and receiver antennae are extended and average along the borehole. The advantage of seismic energy for close-in exploration and delineation is that it is capable of being transmitted through sulphide zones. Since seismic tomography and televiewer logging was planned, borehole orientation was deemed to be very important and the change to north-seeking gyro from the originally planned film gyro was easily justified. The emphasis on optical televiewer instead of acoustic televiewer was dictated by the relatively high quality of the images and the geological requirement of exploration and ore delineation. Additional single borehole physical property measurements were performed to either supplement the seismic tomography or with an eye on future applications. Natural gamma was tested to determine its relationship to lithology and its usefulness as a depth alignment tool for seismic tomography sources and receivers. Inductive conductivity was tested to determine its usefulness as a grade control tool in the 1D Lower zone.

REGIONAL GEOLOGY - TNB

The TNB is a linear feature 8-40 km wide that extends for more than 160 km in length along the boundary between the Churchill and Superior geological Provinces as shown in Figure 10. The bedrock consists of reworked Archean basement gneisses and Early Proterozoic cover rock, all of which are intensely deformed. Several subparallel lineaments divide the Belt into blocks of distinct metamorphic grade. The rocks to the west of the Burntwood Lineament, containing the Birchtree Mine and Pipe Mine, exhibit lower to middle-amphibolite facies metamorphism while to the east, where the Thompson Mine is located, the metamorphic grade reaches upper-amphibolite facies.

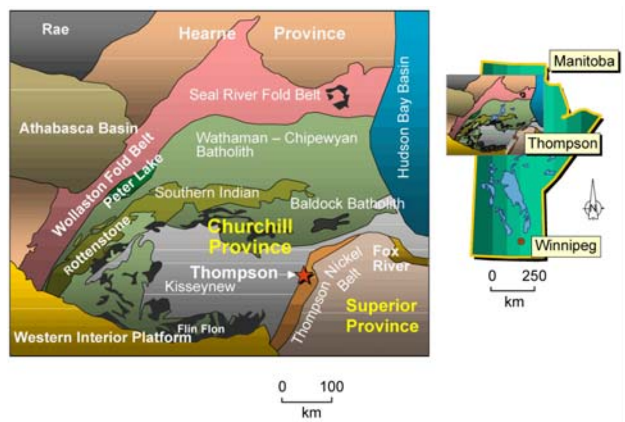

Figure 10: Geological provinces (L) and location of the TNB in Manitoba (R)

The Proterozoic assemblage, shown in Figure 11, exhibits a distinct tectono-stratigraphy that is common throughout the TNB. From stratigraphic base to top, the Proterozoic Ospwagan Group includes the Manasan Formation, Thompson Formation, Pipe Formation, Setting Formation, and the Bah Lake Formation.

The Manasan Formation unconformably overlies Archean gneiss basement and consists of siliceous clastic sediments. It is subdivided into a thin basal conglomeratic layer and fine-grained quartzites (M1), and an upper semi-pelitic schist unit (M2). This unit as a whole is the most universally distributed sedimentary unit in the TNB.

The Thompson Formation, overlying the Manasan Formation, consists of predominantly chemical sediments. The lower calcareous unit is composed of varying proportions of dolomite, diopside + microcline, or olivine ± diopside ± microcline. The Thompson Formation also includes chert, graphitic sulphide facies or silicate facies iron formation.

The Pipe Formation consists of three sub-units or members. The lower P1, not always recognizable, includes thin layers of silicate and sulphide-facies iron formation, pelitic schist, and quartzite. It appears to be the stratigraphic host of the Pipe nickel Deposits. The overlying P2 is a thicker unit of pelitic schist, most commonly containing varying amounts of sedimentary sulphide and graphite. It is the host for the Thompson and Birchtree ores and most other nickel occurrences. The P3 consists of a series of siliceous to ferruginous-sediments, prominent silicate-facies iron formations with magnetite and chert. The major component of the P3 is chemical sediment.

The Setting Formation, the uppermost sedimentary unit, is relatively thick in most locations. It consists of an immature clastic sequence of interlayered quartzite and pelitic schist. Calcareous concretions are diagnostic. Mafic volcanics commonly occur in the upper part of the Setting Formation.

The Bah Lake Formation consists of mafic to ultramafic-volcanics and represents the top of the known Proterozoic sequence. Within this sequence, pillowed to massive flows, fragmental rocks, minor tuffs and exhalative layers are recognized.

All the deposits in the belt are contained within the sulphide rich Pipe Formation (P2 member) of the Ospwagan Group metasediments (strata bound). In general, the overall shape of the deposits or mineral envelope mimics the shape of the hosting stratigraphy. Therefore, information about the larger scale geology assists with the interpretation of the orebody. Figure 12 shows the TNB and the details of the Thompson structure with the location of the individual orebodies which make up the Thompson mine.

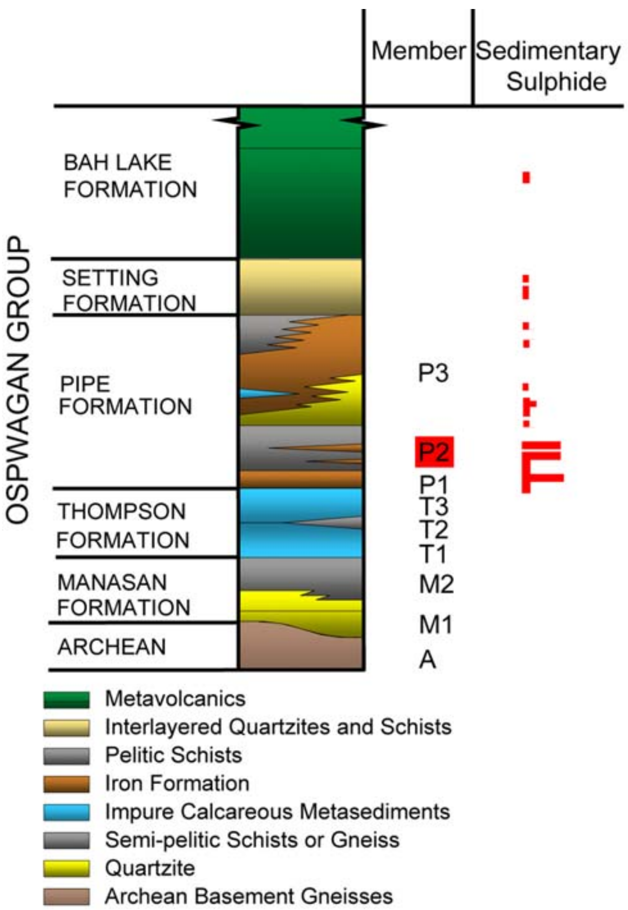

Figure 11: Stratigraphy of the Ospwagan Group, TNB, Manitoba.

EXPLORATION AND DELINEATION OF THE T-3, 1D LOWER ZONE

Mine Geology

At Thompson mine, the main orebodies are found on the east limb of the Thompson structure or Dome (Figure 12). The 1D Lower is the down plunge extension of the 1D deposit. It is the northern-most ore currently being mined in Thompson mine and it extends to depth from the 3500 Level.

From west to east, the 1D geology consists of footwall quartzites and iron formations, followed by the ore hosting P2 schist, an example of which is shown in Figure 13, followed by a repetition of the footwall rocks and more of the ore-hosting horizon.

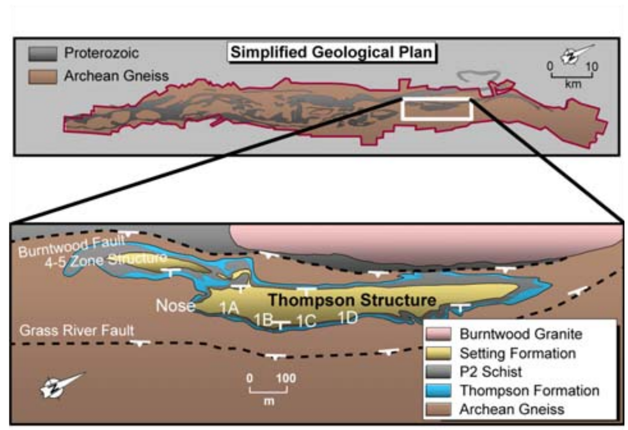

Figure 12: The TNB with the Thompson structure outlined in white (upper) and the Thompson structure with the orebodies of the Thompson mine (lower).

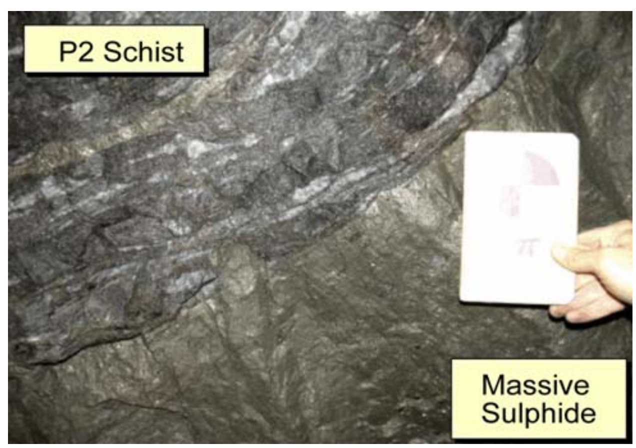

Figure 13: Example of a contact between a P2 Schist and massive sulphide

The 1D Lower was first tested in the late 1970's by widely spaced surface diamond drilling. In the mid 1990's, an underground drilling campaign increased the drill density to between 400 and 600 feet. Based on previous experience obtained in the southern parts of the Thompson mine environment, the typical pre-1999 interpretation of the 1D Lower mineralized zone was as shown in Figure 14.

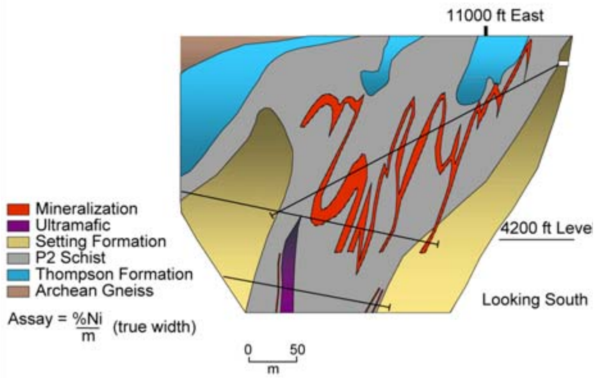

Figure 14: Schematic showing the pre-1999 1D Lower ore interpretation

In Figure 14, the orebody is shown to be steeply dipping with multiple folds. Based solely on borehole sulphide intersections, the interpretation shown is not obvious. Because of structural and geometrical complexities, the continuity and shape of the mineralized zones proved to be difficult to interpret, even for experienced geologists. As exploration progressed and boreholes were drilled, it became clear that the 1D Lower zone was not as depicted in Figure 14. In 1999 and 2000, mines geologists began mapping, understanding and predicting the structural controls on the ore in the upper portions of the 1D. It was suspected that parts of the zone were flatter than previously believed. This understanding influenced the planning of the Lower zone exploration/delineation drilling campaign scheduled for 2000 to 2003. The 1D-Lower project was designed to clarify the observations from the upper zone by drilling a denser pattern of boreholes and using geophysical and structural geology tools in an integrated manner. The goal was to increase the degree of confidence in ore delineation practices being used in CVRD Inco's TNB mines. To accommodate this work, a drift was driven out into the structural hangingwall at the 3500-foot level, and boreholes were drilled on 100' sections.

In total, 88,500' of BQ diamond drilling was completed in 135 holes from the 3500L exploration drift, initially on 100' centres with some infill drilling between sections where ore/mineral envelope continuity was less predictable. The drilling pattern on each section was a fan array and the core was processed and logged by one geologist for consistency.

Geophysics

Beginning in late 2000, a variety of single borehole and cross-borehole geophysical surveys were performed in boreholes drilled from the 3500 Level exploration drift.

North-seeking gyro borehole orientation

Since seismic tomography and televiewer surveys were planned, film gyro borehole orientation surveys were originally scheduled in all of the boreholes located on the 3500 Level. The accuracy of the results of both seismic tomography and televiewer surveys is critically dependent on accurate borehole orientations. It has been demonstrated that borehole geometry errors can lead to significant velocity artifacts in seismic tomography images. In addition, features extracted from optical and acoustic televiewer images are transformed into true 3-D coordinates using borehole orientation information.

The film gyro (provided by Sperry Sun Drilling Services) measures the borehole orientation relative to the start azimuth of the borehole and thus requires an independently determined start azimuth. This can be determined by sighting the gyro on surveyed spads in the drift (for steeply dipping boreholes) or by surveying two points on a pipe inserted into the collar. After logging a number of boreholes with the film gyro, it was decided to test a north-seeking gyro. Several of the boreholes were re-logged (by Sperry Sun Drilling Services) with a north-seeking gyro (Finder gyro, manufactured by Scientific Drilling International) and the results were compared to film gyro results. The dip and azimuth comparison for one borehole on the 3500 Level are shown in Figures 15 and 16.

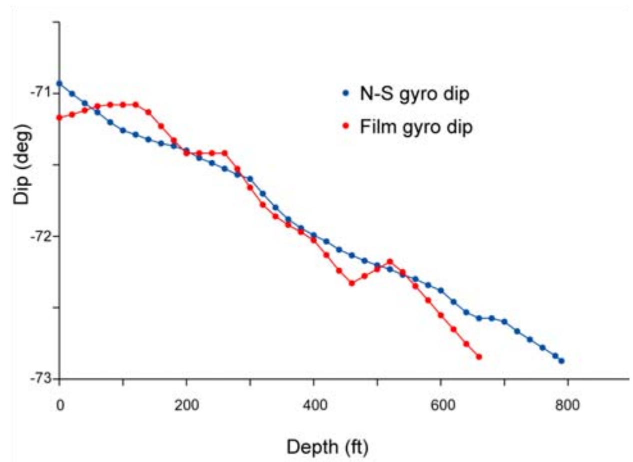

Figure 15: Film gyro dip compared to N-S (North-Seeking) gyro dip in BH (borehole) 5 on the 37900 N section

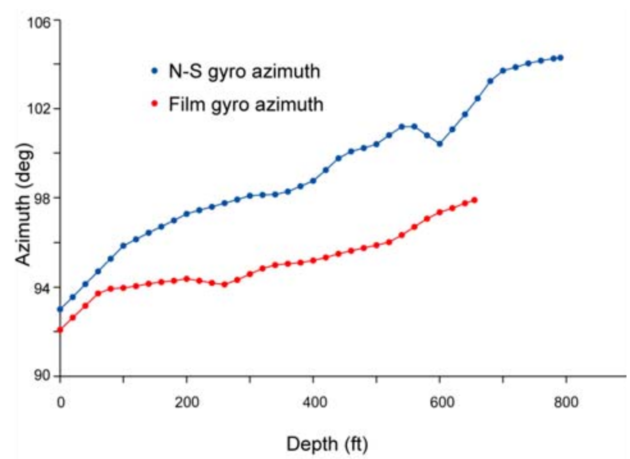

Figure 16: Film gyro azimuth compared to north-seeking gyro azimuth in BH 5 on the 37900 N section

Figure 15 shows that for dip, on average, film and north-seeking gyro measurements are similar. For azimuth (Figure 16), however, there is a significant difference between the film and north-seeking gyro measurements. Because of the widespread use of north-seeking technology in the oil industry, and because of a test of a north-seeking gyro undertaken by CVRD Inco in early 2000 (summarized in Table 1), it was decided to use the north-seeking gyro to measure the start azimuth in the boreholes previously logged with the film gyro and as a replacement in the remainder of the boreholes on the 3500 Level.

An added benefit of accurate borehole orientation surveys is accurate ore envelope interpretations on sections. Figure 17 shows a histogram of differences between north-seeking surveyed foot of hole and layout foot of hole. For 122 surveyed boreholes (500' - 1100' in length) the average difference was 33' with 9 of 122 FOH's located in excess of 100' off the section on which they were drilled. The average difference is a significant fraction of the section-to-section spacing and will affect the 3-D ore interpretation and the resulting sections cut from the 3-D model.

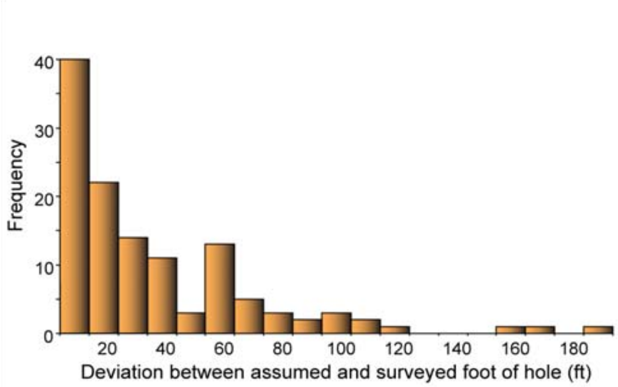

Figure 17: Difference between north-seeking surveyed foot of hole and assumed foot of hole (layout)

Physical property measurements

An example of borehole physical property measurements performed in the 1D Lower zone is shown in Figure 18.

Both spectral and total counts gamma measurements were performed in boreholes on the 3500 Level (spectral gamma in seven boreholes and total counts gamma in 15 boreholes). A cursory attempt was made to correlate the gamma logs with lithology and it was found that a significant portion of the natural gamma responses showed no strong correlation with lithology, likely because of the dominance of P2 Schist (SCH) in the boreholes. In addition, a thin section study confirmed that several of the peaks showing elevated counts, as expected, were correlated with increased amounts of potassium. The other main purpose of the natural gamma acquired in this study was to determine its usefulness, in this environment, for depth correction for seismic tomography transmitters and receivers. Figure 18 shows that there are a number of anomalous peaks in the natural gamma log that would allow it to be used for depth correction for other geophysical methods provided that a sufficient number of markers can be identified in the lithology. The usefulness of depth correction markers became evident as seismic tomography data processing progressed and apparent geometry-related errors were encountered.

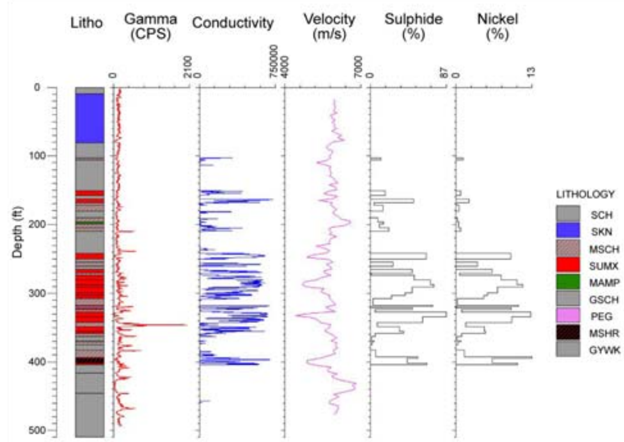

Figure 18: Physical properties measured in BH 3 on the 37900 N section: (L-R) total counts gamma, inductive conductivity and p-wave velocity. Also shown for reference are calculated total sulphide content and assayed Ni grade.

Inductive conductivity logging was performed in approximately 40 boreholes located on the 3500 Level exploration drift. The conductivity logging illustrated the large amount of conductive mineralization present in the 1D Lower zone. Conductivity logs from approximately 15 boreholes were compared to assayed Ni grades to determine the correlation between probe response and Ni grade. Highly conductive nuisance (nickel poor) intervals constituted approximately 15% of the samples and rendered the inductive conductivity tool less useful for grade control than it is in Sudbury area mines (McDowell, 2004).

Full waveform sonic was performed in a total of five boreholes (three on the 37900 N section, one on the 37200 N section and one on the 37300 N section. The aim of the measurements was to provide complementary velocity information to assist with the interpretation of the seismic tomography panels. The full waveform sonic tool was manufactured by Mount Sopris Instruments and consisted of a single transmitter (variable frequency) and two receivers (Oden et al., 2002). Stationary readings were acquired on 3.28' intervals in the three boreholes on the 37900 N section and continuous readings (on 0.328' intervals) were acquired in the other two boreholes. Velocity extraction for the stationary readings (example shown in Figure 18) was performed using a manual threshold, first-arrival picking procedure. For the continuous logs, processing was only recently accomplished using filtering and semblance. The quality of the logs (both stationary and continuous) was generally poor and significant effort was required in order to extract p-wave velocity. Because of the effort required for processing the stationary readings, velocity was extracted from the full waveform logs for only one of the three boreholes. In addition, semblance processing did not perform well for the two-receiver continuous logs and thus, confidence in the p-wave velocity measurements is considered to be relatively low.

Figure 19 shows the average velocity for each lithological unit present in the boreholes logged with the full waveform sonic probe. The plot was generated using LogTrans (Fullagar, 1999), using a 5' moving window with sample length equal to logging interval in the continuous full waveform sonic logs. The plot illustrates the difficult target for seismic tomography presented by the mineralized zone in the 1D Lower. The lowest average velocity is found in the SUMX (sulphide matrix containing 25% - 75% sulphide), however, the abundance of schists (SCH) and the velocity variability in the schists and to a lesser extent, in the skarn (SKN), may prevent the detection of the full range of SUMX. In fact, the velocity variability in the schists (SCH, GSCH or granitic schist, and MSCH or mineralized schist, i.e., schist containing less than 20% sulphide) occupies approximately the complete top half of the velocity range of SUMX.

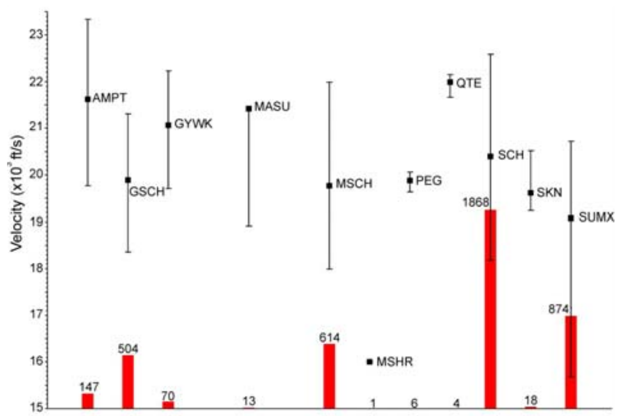

Figure 19: LogTrans summary of velocity for each lithological unit found in the holes logged with the full waveform sonic probe. Population size for each unit plotted as a histogram.

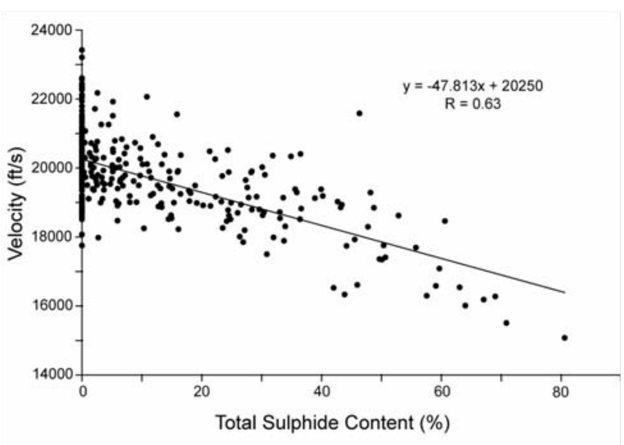

Figure 20: Correlation between p-wave velocity and calculated total sulphide for boreholes logged with the full waveform sonic probe

Figure 20 shows the correlation between p-wave velocity and calculated total sulphide. Assay results were used to calculate the total sulphide (using empirical relationships) for each sample and these were merged with the velocity logs in Datamine software. Composites were then calculated in Datamine for 5' intervals and normalized by density.

Figure 20 shows a similar result to that of Figure 19 in that the mineralized zone in the 1D Lower presents a difficult target for seismic tomography. Unmineralized host rock (total sulphide equal to zero) ranges in velocity from approximately 18500 ft/s to in excess of 22500 ft/s.

Seismic tomography

Seismic tomography was performed in two sets of panels. The first set of panels was surveyed in December of 2000 and included three panels on the 37900 N section and one incomplete cross-sectional panel between the 37800 N section and the 38000 N section (this panel was not completed because of the loss of the seismic transmitter in one borehole). The second set of panels was surveyed in April 2001 and included one panel on the 37200 N section, one panel on the 37300 N section and one cross-sectional panel between the 37200 N section and the 37400 N sections. Figure 21 shows a 3-D view of the velocity tomography inversion results for the all of the panels surveyed in the 1D Lower zone.

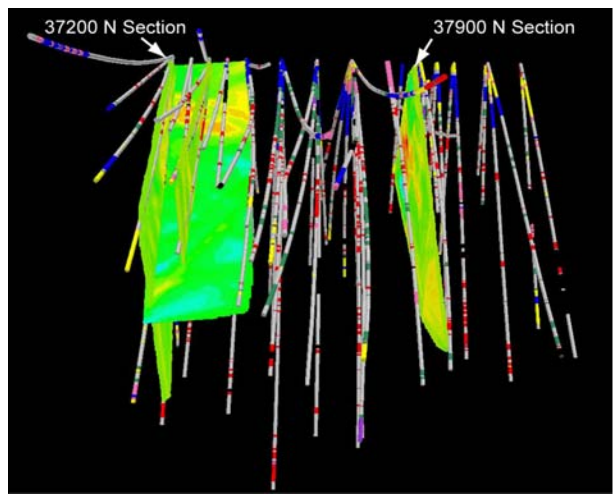

Figure 21: 3-D view of seismic tomography panels

The seismic tomography data was acquired by Jodex Geosience Limited using their piezoceramic transmitter and hydrophone receivers. The main obstacle to acquiring good quality seismograms was the mine operational noise. Specifically, percussion in-the-hole drills, nearby scooptrams and ore tumbling down ore passes resulted in high noise levels, which at times precluded data acquisition. It is estimated that approximately 50% of the time, the mine noise saturated the seismic tomography data acquisition system. Despite the high noise levels, data acquisition was relatively efficient with large numbers of seismograms being acquired during the quiet periods. The number of seismograms per panel ranged from 6500 to 12000. The quality of the seismograms was generally good during quiet periods with data acquisition stopped when signal-to-noise fell below acceptable levels.

First arrivals were picked by the contractor and delivered to CVRD Inco usually within two or three days of completion of data acquisition. The first-arrival data was inverted using a standard SIRT routine and the results were displayed first in Datamine at CVRD Inco Exploration and then in Gemcom at the minesite. For the purposes of this paper, all the data acquired in the exploration and delineation program was imported and displayed in an in-house 3-D visualization software called Insight (Polzer, 2007).

Figures 22-24 show the first-arrival inversion results from the seismic tomography panels. The size of the disks on the boreholes indicate total sulphide content calculated based on assay results. The lithology (shown as colour coding on the boreholes) and seismic tomography velocity (background panel) legends are shown on each Figure.

Figure 22 shows the velocity inversion results on the 37900 N section together with the ore envelope interpretation based on seismic tomography. For reference, BH 3 is 500' long.

In Figure 22, the area outlined in white contains what are deemed to be artefacts. The seismic tomography interpretation shows that the large intersection at the bottom of BH 5 is not well connected to any intersections in adjacent boreholes except possibly parallel to the BH 5. The seismic tomography ore envelope (outlined in dark grey) is characterized by a relatively flat dip compared to the dips depicted in Figure 14.

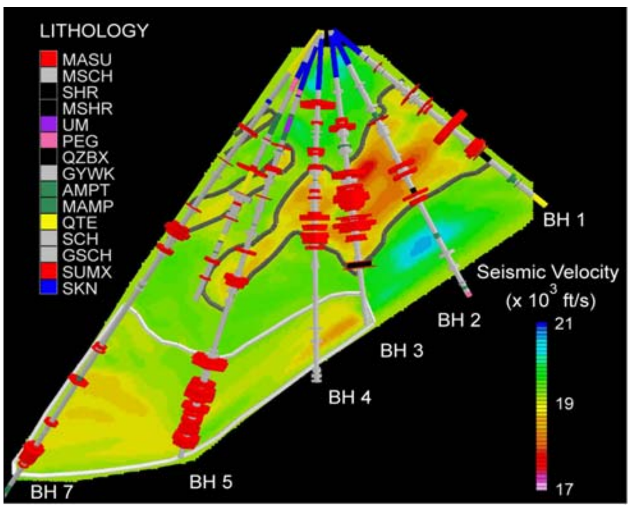

Figure 22: 37900 N section seismic tomography results looking South. Seismic tomography ore envelope interpretation shown in dark grey.

Figure 23 shows the seismic tomography results for the 37300 N section together with the seismic tomography ore envelope interpretation. For reference, the BH's on the 37300 N section are approximately 720' long.

In Figure 23, the main part of the mineralized zone in the upper portion of the panel is well detected by seismic tomography. The sense of the dip of the ore envelope (outlined in dark grey) is opposite to the one shown in Figure 22 and, again, the dip is relatively flat compared to the dips shown in Figure 14. Several less evident low velocity zones in the lower part of the panel that are not consistently confirmed by the presence of sulphide in the boreholes are not outlined as part of the ore envelope interpretation.

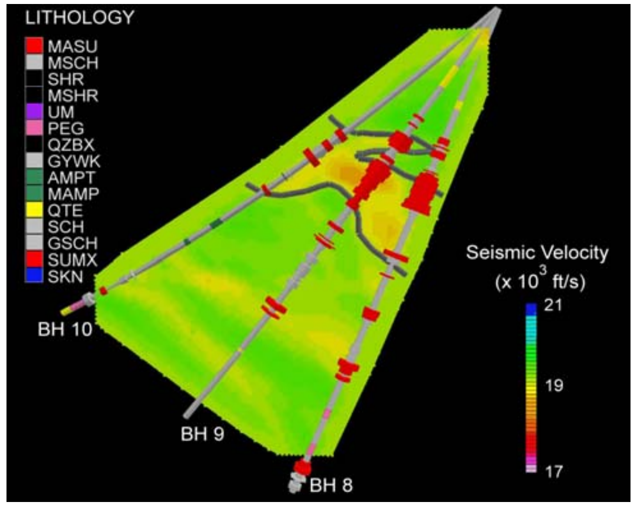

Figure 23: Seismic tomography results for 37300 N section looking South. Ore envelope interpretation shown in dark grey.

Figure 24 shows the seismic tomography results for the 37200 N to 37400 N cross-sectional panel. The dark grey line on the low velocity zone in the upper portion of the panel shows the interpreted trend of the low velocity zone according to seismic tomography. For reference, BH 11 is 815' long.

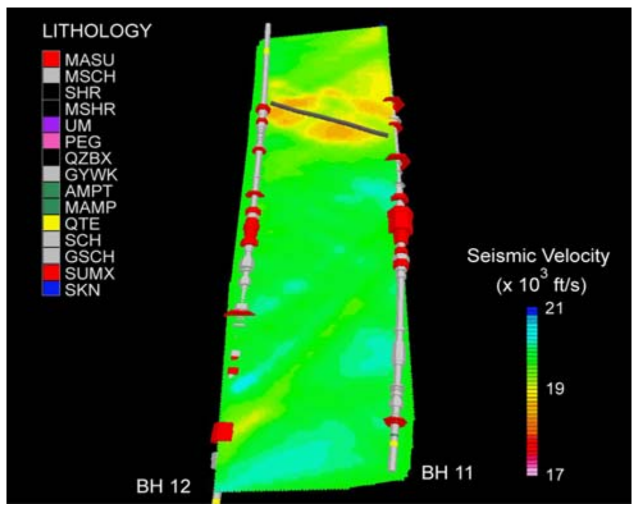

Figure 24: Seismic tomography results for the 37200 N to 37400 N cross-sectional panel looking west. The interpreted trend of the low velocity zone is shown in dark grey.

In Figure 24, many of the sulphide intersections below the upper low velocity zone are not well detected by the seismic tomography. The discrepancies between the sulphide intersections and the low velocity zones detected by seismic tomography are assumed to be related to the following:

- As shown in Figures 19 and 20, the 1D Lower zone appears to have a complicated velocity signature. Care must be exercised in relating velocity trends noted in the results of the full waveform sonic logging (performed at 30 kHz) to the details of the seismic tomography velocity (performed at 4 kHz), however, variable velocity schists may interfere with the detection of SUMX.

- Relatively large “apparent” borehole geometry errors are evident in several seismic tomography panels despite the use of the north-seeking gyro to determine borehole orientation. The geometry-like errors, evidenced in the non-flat velocity versus angle plots for the panels (Cosma and Enescu, 2002), may be due to anisotropy.
- Complicated stratigraphy or lithology. The lithology is not continuous even in holes that are quite close together. It is known that there are many folds (and interfering folds) in the area. The result of the folding may be that the trend of the sulphide is not continuous between the co-planar boreholes used for the seismic tomography surveys.
- There are a significant number of intersections (approximately 15%) that show very low Ni content. These intersections would not normally be included in orebody interpretation, however, seismic tomography cannot differentiate between Ni rich and Ni poor sulphide.

Despite the apparent limitations of the technique in the 1D Lower environment, seismic tomography added valuable information about the large-scale dip of the mineralized zone. Seismic tomography was used to assist with the interpretation of diamond drilling and ultimately complemented the televiewer-derived interpretation.

Acoustic and optical televiewers

Acoustic and optical televiewer logging began in 1D Lower boreholes in December of 2000. After the first tests of the televiewers on the 37900 N section, it became apparent that the quality of the optical televiewer images was much better than originally speculated. Figures 25 and 26 show comparisons of optical and acoustic televiewer images in a borehole on the 37900 N section.

The acoustic televiewer shows joints more clearly than the optical televiewer while the optical televiewer is superior for geological applications such as foliations and contacts.

Figure 26 shows an additional example of the advantage of the acoustic televiewer over the optical televiewer for geotechnical applications, i.e., the detection of borehole breakouts.

After the initial test of televiewers on the 37900 N section, it was decided to terminate the use the acoustic televiewer and continue only with the optical televiewer. Coretec measurements were being performed concurrently, however, this was a very manual operation that did not yield continuous measurements in the boreholes. Optical televiewer, on the other hand, was capable of delivering continuous measurements with less chance of error in the orientation of the features.

Figures 27 and 28 illustrate the typical use of the optical televiewer for contact and fold detection and orientation in the 1D Lower zone.

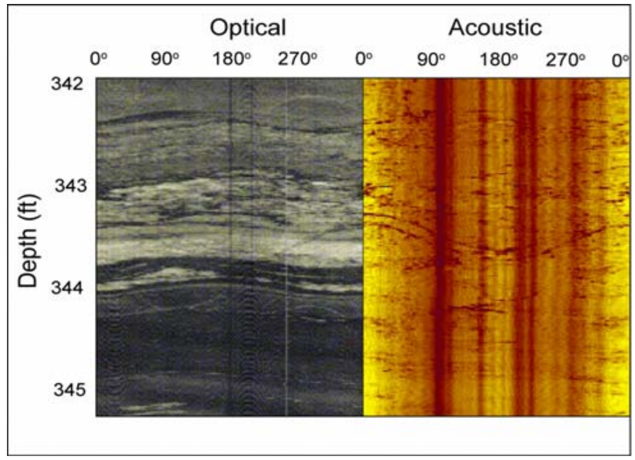

Figure 25: Optical and acoustic televiewer images in BH 5 on the 37900 N section

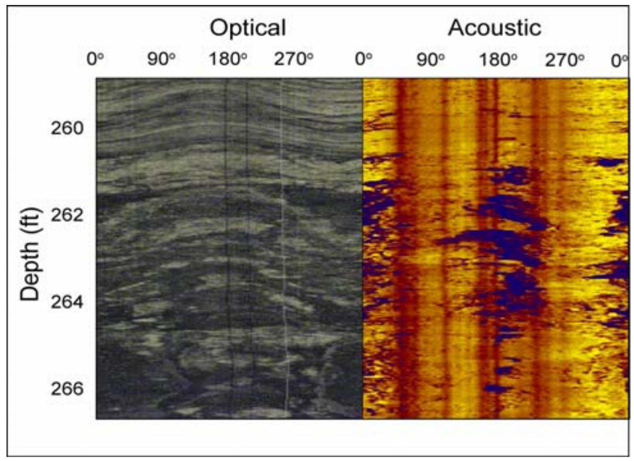

Figure 26: Optical and acoustic televiewer images in BH 5 on the 37900 N section

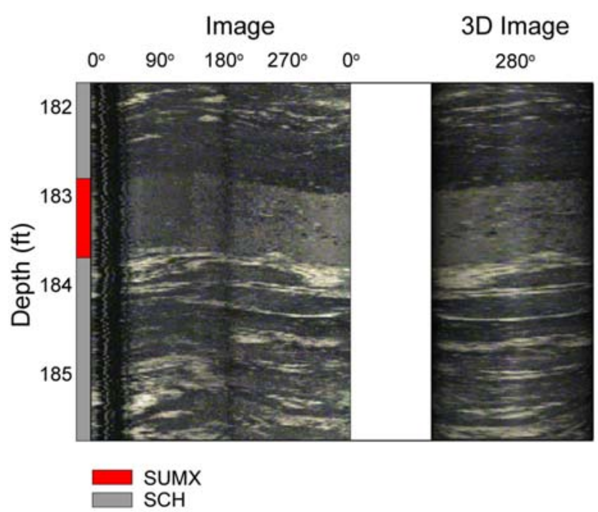

Figure 27: Optical televiewer image showing SUMX contacts. The 3-D core image is shown on the right.

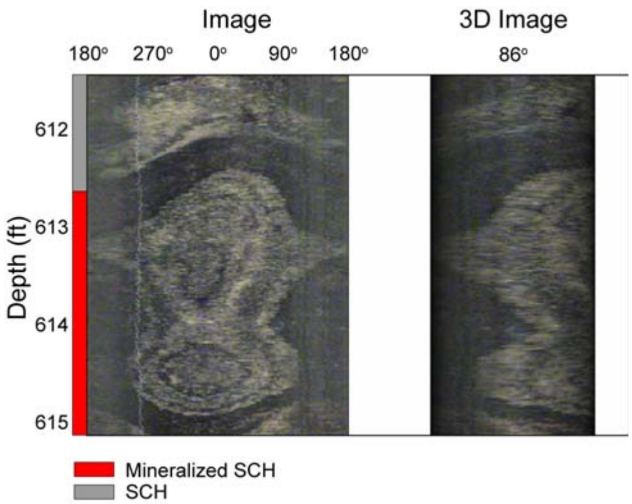

Figure 28: Optical televiewer image showing a fold. The 3-D core image is shown on the right.

Applied Structural Geology

The aim of applying structural geology in the 1D Lower zone was to acquire reliable structural data in multiple domains to assist with the delineation of the ore and mineral envelopes between holes and sections. In this case, the ore envelope refers to a body limited by local cut-off grades, whereas mineral envelope refers to a body limited by the extent of the mineralization and its trends. For envelope determination in the 1D Lower, the P2 schist is considered to be mineralized when it contains nickel in excess of 0.5%.

The P2 member of the Pipe Formation (the ore-hosting unit) is commonly delineated by using the structural hangingwall (Thompson Formation) contacts and footwall (Setting Formation) contacts. The P2 member is rheologically and temperature/pressure-wise, for the most part, less competent than the adjacent units; hence, it (and contained ore) is molded around the more competent footwall and hangingwall units. Furthermore, massive sulphides are far less competent than the host rock or P2 member and this creates opportunity for solid-state displacement of sulphides during deformation. The location of sulphide bodies within the host rock is controlled by the location, geometry and distance to open spaces available during the sequence of structural phases observed in 1D Lower zone. Ore contacts are conformable and also transgressive to the host rock fabric indicating the injected nature of the sulphide bodies. Ore is normally located around mine-scale fold noses and limbs, jogs, shear zones, and the many styles of their intersections, each giving a particular shape to the massive sulphide body. Figures 29 and 30 show some of the styles of the 1D ore and mineralization.

As a result of the structural work performed in the 1D Lower, three mineralized sulphide domains were observed: the FW (FootWall), mid, and HW (HangingWall) bands. The FW band, which is near the Setting Formation, shows a simple tabular geometry with ore contacts mostly conformable to foliation. The HW band is highly complex and the mid band behaves somewhat similar to the HW band. These three bands are separated by shear zones. It was observed that the geometry of the Thompson Formation plays an important role in the shape and complexity of the underlying HW band. Effort was thus invested in modeling the lower and upper contacts of the Thompson Formation to allow their use as indicators of the shape and style of the adjacent ore.

The three domains were determined by observing the various patterns defined by the fabric elements on stereonets shown on Figures 31-34. The access to the ore bands was accomplished through drilling and, as indicated previously, the source of structural information was Coretec and optical televiewer. WellCadTM was used to extract planar features from the borehole optical televiewer images. A small number fold axes were obtained using Coretec, however, the majority of the structures were extracted from optical televiewer images using two in-house software programs to read and process linear features and fold asymmetry from WellCad™ (Monteiro and Koronovich, 2006a and 2006b). An example of a fold that was observed underground in the crosscut access to the 3500 level is shown in Figure 35. This example shows the typical scale of folds observed in boreholes using the optical televiewer probe.

Figure 29: Pegmatitic granite (white) P2 member (black) and massive sulphide (metallic beige) underground in the 1D. Note that the P2 member is rafting within the massive sulphides; however, the contacts are mostly conformable.

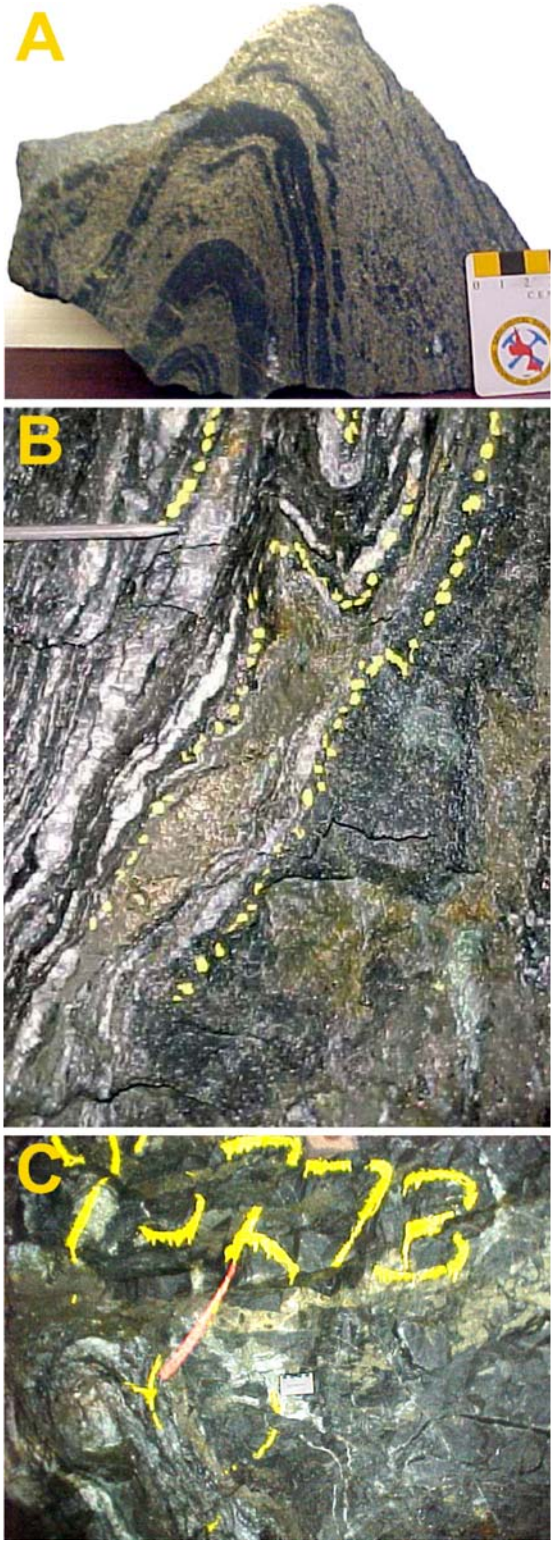

Figure 30: Additional styles of ore in the 1D: (A) and (B) are folded massive sulphide bodies and (C) is a conformable and transgressive massive sulphide stringer.

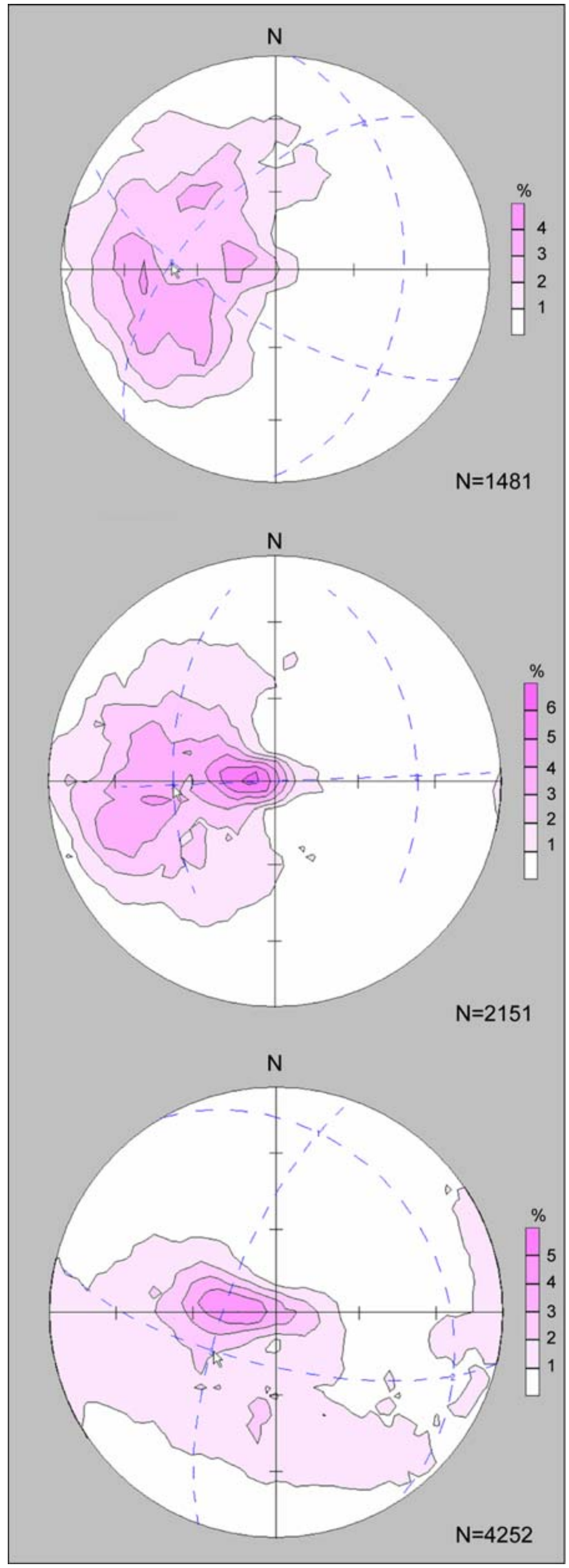

Figure 31: Top to Bottom: Foliations from domains related to the FW, mid and HW mineral envelopes.

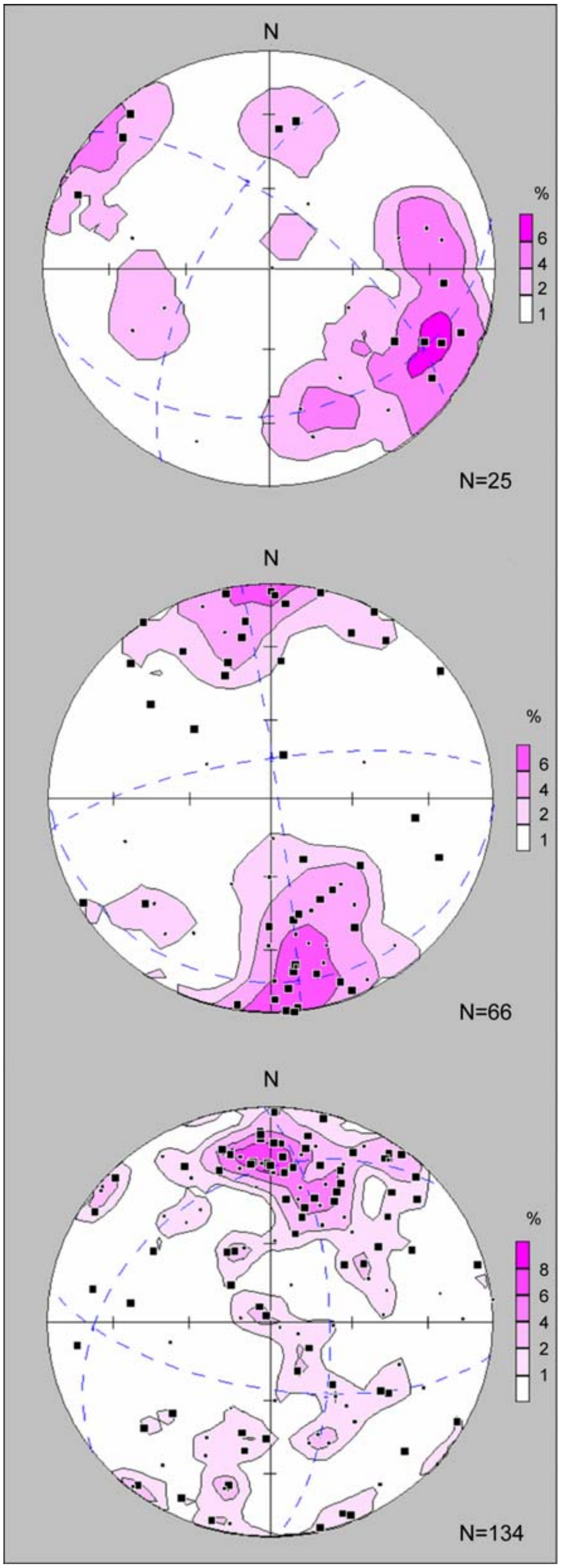

Figure 32: Top to Bottom: Fold axes from domains related to the FW, mid and HW mineral envelopes.

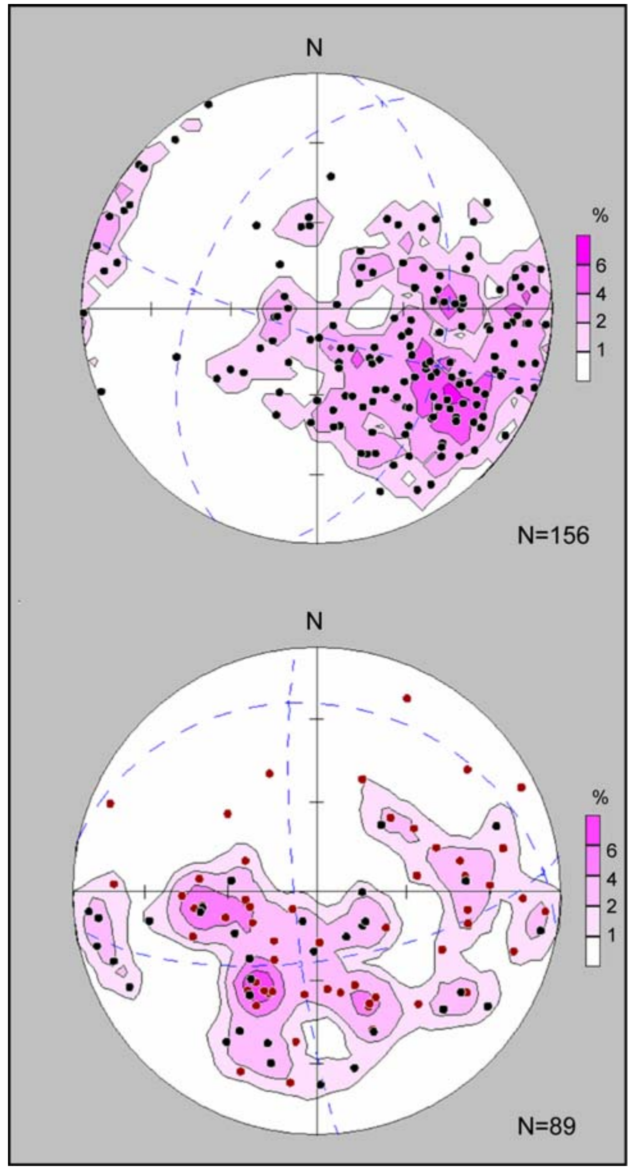

Figure 33: Axial surfaces of folds (top) and ore (red dots), and stringer contacts (black dots - bottom).

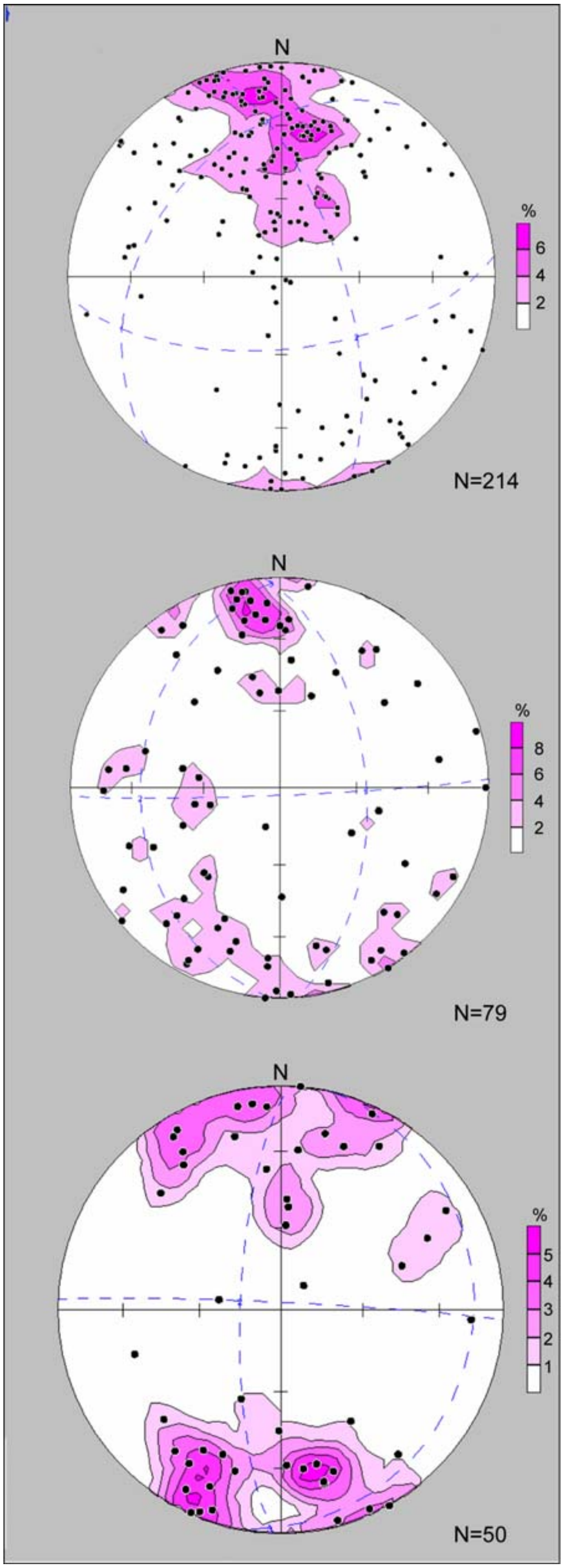

Figure 34: Top to Bottom: Fold axes from the south, center and north regions of the 3500 Level exploration drift

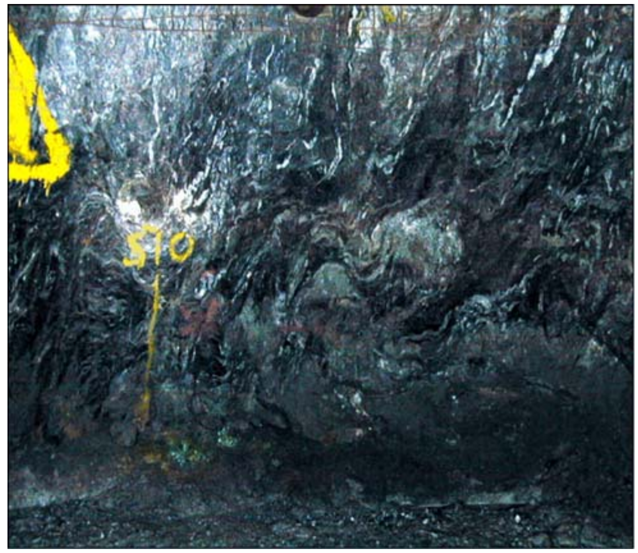

Figure 35: Meso-scale fold on the south wall of the crosscut leading to the 3500 exploration drift, where most of the collars of the 1D Lower drilling campaign were located.

Particular attention was focused on the distributions and patterns that emerged from the study of the orientation of ore and mineralized contacts and ore stringers, as well as to the distribution and orientation of fold axes and their axial surfaces. In Figure 31, stereonets of the most abundant host rock fabric element, foliations, are shown. The FW band shows an average foliation orientation of 40º/094º (dip/dip-direction), comprised of three clusters at 54º/084º, 40º/131º and 18º/106º. The mid band is normally at 11º/091º; however, a second cluster is at 45º/082º. The HW band foliation is at 16º/091º. The existence of multiple clusters with large variability indicates that the foliations were folded with each domain showing different behavior. As shown in Figure 32, the fold axes orientations are at 24º/118º, 15º/172º and 25º/009º, on the FW, mid and HW domain, respectively. The axial surfaces, mostly from the mid and HW domains, are presented on Figure 33, and the main concentration falls at 55º/305º. The stereonet of ore and mineralized contacts and ore stringers is also presented on the lower part of Figure 33. Various clusters and sub-clusters are evident in this stereonet, which indicates the complexity of the sulphide contact orientation. The pattern observed in this stereonet is different than any of the patterns previously observed. This indicates that the ore planes behave distinctly, apparently mingling patterns from various fabric elements and structures, adding to the complexity and decreasing confidence in interpretations within and between drilling sections.

Figure 34 presents the pattern of fold axes obtained from the southern, center and northern ends of the 3500 Level drift indicating variations along the north-south axis. Most of this data is from the middle and upper bands. The southern end shows two clusters at 17º/352º and 08º/033º averaging about 27º/355º. Toward the center of the drift, the maximum concentration is flatter, at approximately 13º/349º. However, on the northern end the two main clusters are dipping south, at 08º/205º and 24º/167º. By comparing Figure 33 and 34, it might be suggested that the east-west dispersion of poles to contact planes could be partially explained by the north-south trending fold axes. In fact, this is one of the many structural features controlling ore shape in the 1D area.

INTEGRATED INTERPRETATION OF THE 1D LOWER ZONE

In September of 2001, a two-day geology/geophysics brainstorming session was held to review the data acquired during the first phase of drilling. This session included a discussion of the tools and methods used in the 1D Lower project and an assessment of the work completed to date with the goal of integrating the data. Despite the complexity of the various structural and stratigraphic domains, a procedure was developed to establish the "predictability" of the ore/mineral envelopes based on several indicators. These indicators were borehole density, structural complexity, ore style, stratigraphy, and geophysical features. This led to an interpretation approach which increased confidence in the ore and mineral envelopes.

Nickel grades and tenors and geology were used to project plane-to-core angles of ore/mineralization contacts on and between sections. However, it was also observed that easily recognized broader scale structural features (i.e. flattening of Archean contact or fold repetitions of stratigraphic units) were reflected in the shapes and repetitions of the ore zone. Furthermore, the P2 biotite schist that contains the mineralization and ore is highly influenced by the nearby style of structural footwall contacts (Setting Formation quartzite) and structural hanging wall contacts (Thompson Formation – impure marbles). By flagging subtle changes in the contact styles, shape changes were predicted in the nearby ore. Seismic tomography information was considered to reflect the average or larger scale features since it is sensitive in large part to sulphide content and does not differentiate between rock types and structural features.

Several examples of the integration of geology and geophysics are presented in Figures 36 and 37.

In Figure 36, the FW band is shown with fold axes, ore contacts and mineral envelope (blue wireframe) overlaid on the seismic panel. The mineral envelope was delineated after combining multiple sections that sliced through the lower band. The agreement between the mineral envelope and the seismic tomography is evident. The contribution of seismic tomography was the independent confirmation of the architecture of the mineral envelope. In Figure 36, the optical televiewer results were acquired in a total of three of seven boreholes on the section. It was previously stated that seismic tomography did not delineate the sulphide contacts found at the bottom-left side of the seismic panel (in fact, this intersection caused artefacts in the seismic image). The sulphide contacts shown overlaid on the bottom-left of the seismic panel are oriented randomly indicating the complicated nature of the intersection.

In Figure 37, the upper HW band is shown. There is a correlation between the average fold axes and the trend of the mineral body as defined by the low seismic velocity; in addition, ore contacts (red planes) also reinforce this agreement.

The current sectional interpretation (resulting from the integration of drilling, geophysics and structural geology) is shown in Figure 38. This represents a great departure from the pre-1999 interpretation shown in Figure 14. The HW, mid and FW bands are identified and the very steeply dipping and highly folded nature of the zone as shown in the pre-1999 interpretation is much flatter in the mid and HW bands.

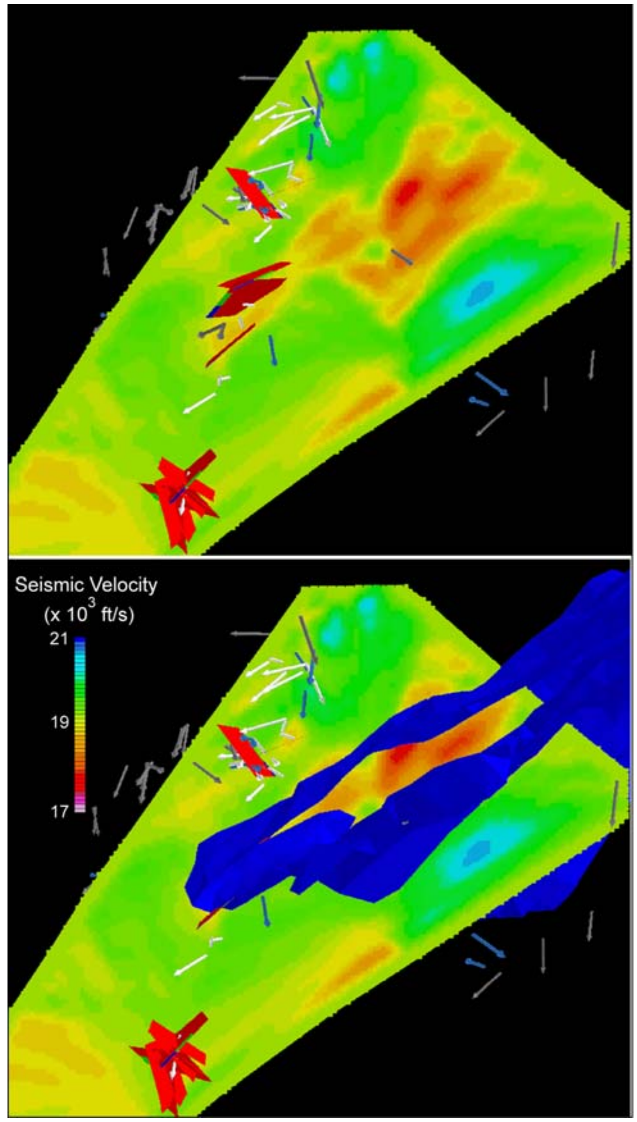

Figure 36: 37900 N section looking south. Top shows the seismic tomography panel with fold axes (grey, blue and white arrows representing different vintages) and ore contacts (red planes) overlaid. Bottom shows the final mineral envelope wireframe in blue.

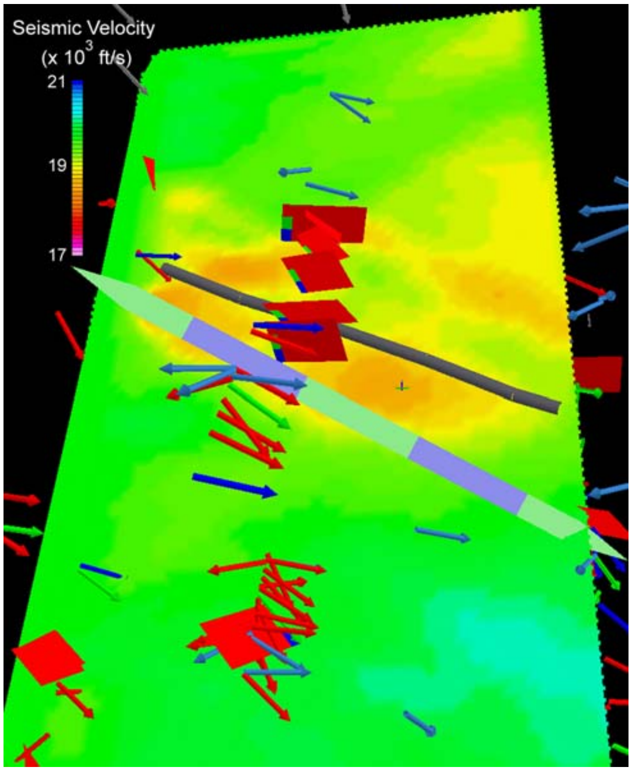

Figure 37: 37200-37400 N cross-section, looking west. The long, double-ended arrow represents the average fold axes in the southern HW band and the dark grey line represents the main trend of the seismic low velocity anomaly. Red, dark blue and green lineations represent "M", "Z" and "S" fold symmetry, respectively. The red planes represent ore contacts.

CONCLUSIONS

As with other wider and higher grade ore occurrences within Thompson Mine, the 1D Lower can be spatially correlated with dilational zones in multiple folded and faulted flatter lying stratigraphic sequences of the P2 member. As drilling and the integrated geology/geophysics program progressed, the multiple bands were segregated into three principle structural domains: FW, Mid and HW. Locally, the domains can be further segregated. The Footwall and Mid domains contain lensoidal shaped sulphide breccia bands with predictable continuity in thickness and grade along strike and down dip. The bands are north/south striking, dip at 40 to 45 degrees east, and range in thickness from very thin to 100'. The sulphide ranges from mineralized schist (10-20% sulphide) to massive sulphide (>80% sulphide), and has a variable 100% sulphide value of 10% to 15% Ni. The HW domain is more complexly folded and is therefore less predictable. Crossing the domain from west to east, the bands range from east dipping at 45 degrees to flat to west dipping at 45 degrees. As in the FW domain, the sulphide ranges from mineralized schist to massive sulphide with slightly lower 100% sulphide values of 8.5% to 9% Ni. The exploration and delineation of the mid and HW bands ultimately led to the 1D Lower zone being designated an orebody.

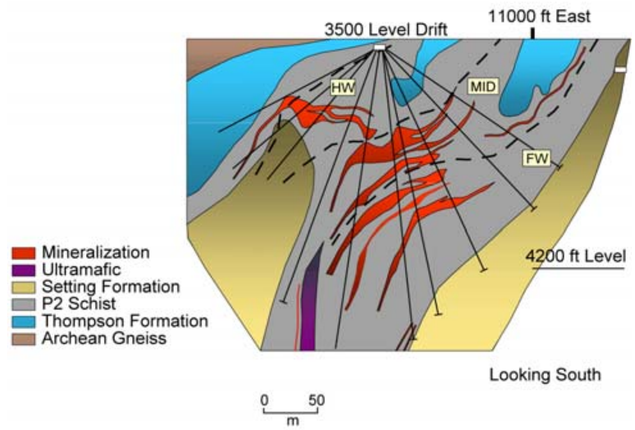

Figure 38: Current typical sectional interpretation derived from the integration of drilling, geology and geophysics

The understanding of the architecture of the host rock and the massive sulphides and mineralization was an important factor during the exploration and delineation of the 1D Lower zone. As indicated previously, not all sulphide contacts follow the rock fabric and thus, interpretation of mineral and ore envelopes is complicated. Although the large-scale shape and distribution of the ore was relatively predictable, the details required to explore and delineate the zone hole-to-hole and section-to-section required additional infill boreholes to be drilled in specific locations. In fact, for particularly complicated areas, the drilling of sufficient boreholes to allow detailed interpretation based solely on sulphide intersections would not be feasible.

When used in conjunction with borehole information, seismic tomography increased confidence in the broader-scale ore zone geometry. It yielded the first independent confirmation of the dip of the ore envelope. It was also used at an appropriate time in the project and thus, delivered information in a timely manner so that the interpretation of boreholes that were being drilled was influenced. Complementary structural features, particularly fold axes, obtained from optical televiewer images added to the interpretation between holes and sections, increasing confidence in the integrated results.

The use of the optical televiewer allowed a permanent record of the boreholes and interpretation. In total, about 12,700 structural features were collected (foliations, geologic contacts, sulphide contacts, fold axes, fold axial planes, faults and joints). About 564 sulphide contacts were mapped along with 598 fold axes; however, the vast majority (approximately 10,000) of measured structural features were foliations.

Overall, the integrated approach described in this paper resulted in more confidence in the ore interpretations for the 1D Lower zone which in turn allowed the zone to become an orebody, adding years to the life of CVRD Inco's Thompson mine.

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