Downhole Seismic Imaging for mineral exploration

Acquisition at Norman West 98, Sudbury, Ontario

Report for the Core Program of the DSI Consortium

By

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1 Introduction

In December 1997, at the request of Falconbridge Ltd., the DSI Consortium planned a first downhole seismic survey at the Norman West property located in the north-east corner of the Sudbury structure.The goals of this first survey were to assess the quality of the data acquired by the consortium's single-level borehole probe, compare datasets recorded by geophones vs hydrophones and, finally, to measure the physical rock properties of the major lithological units encountered at Norman West. Although the main goals were achieved in 1997, there were still some unanswered questions and it was decided at the DSI 2nd annual meeting to return to Norman West in December of 1998, for a followup study.

For its second visit to the property the DSI Consortium planned a much more elaborated survey. From December 4th until the 14th, ten 1800 meters VSPs were collected using a multi-azimuth and multi-offset configuration. Many objectives were set for this survey of which assessing the reflectivity of the Ni-ore deposits within the host rocks of the Sudbury structure was the most important. Also, after a first year of acquisition primarily aimed at testing different sources and receivers, the DSI Consortium decided, in 1998, to test a survey design tailored for 3D imaging. This was the perfect opportunity to try out and test the newly acquired 4-level recording probe to depths reaching 1900 m.

2 Location, Property and Access

The Norman West property located in the northeast corner of the Sudbury Igneous Complex, 21km NNW of the Falconbridge smelter, and 2.8km southwest of Inco's Whistle Open pit includes the area from the Vermillion River to the west over to the junction of the north and east ranges near Selwyn Lake. The exclusively owned Falconbridge property consists of 51 leased claims and 3 patents, (surface and mining rights) totaling a nominal 960 hectares. The jointly owned property between Falconbridge and Inco(50/50) consists of 3 patents and 1 license of occupation . All the leases are in good standing until the year 2012. The DSI project area is centered on diamond drill hole N-29, 1.5km east of highway 545 along the Falconbridge/Inco's East-West property boundary in Norman Township.

The property can be accessed from highway 545, 3.0km northeast of the town of Capreol. Access from highway 545 to the project central (N-29) is from a bush road extending east off the highway 1.6km. A second access is from a North-South powerline road extending from the Whistle mine road to the north 1.5km. These are only 4*4 accessible during the winter months and skidder access in the spring/summer/and fall (Figure 1). During the drill campaign the drills were accessed via ATV or a snowmobile.

Figure 1: Access to the site required help from a skidder.

3 Norman West Geology

The Norman West property is located on the North Range of the Sudbury Igneous Complex (SIC) (Figure 2). It is located approximately 2.8 kilometers southwest of the mouth of the Whistle mine area. The basal contact of the SIC in this area strikes at 075-090^o azimuth and dips 35-45^o degrees to the south from the Vermillion river to the Whistle mine area and then swings south in a comparatively smooth arch. The Selwyn Lake area appears to represent where the contact changes to 180^o(strike and dips more steeply at 75-85^o) to the west. The fault patterns at the mid to north end of Selwyn Lake are affected by the bend in the contact at the Whistle mine. Composite sets of structures in a north to northwest and northeast directions dominate the area.

Principal lithologies on the property include the upper Granophyre unit(GRPH) , Transition Zone (TRZN), Felsic Norite (FNOR), Mafic Norite (MNOR) , and a basal zone of Sublayer (SLN,SLG,SL) and can be viewed on Figure 2. Other rocks types generally related to the "Sudbury event" include discontinuous Late Granite Breccia (LGBX) immediately underlying the SIC, and Sudbury Breccia (SDBX) a pseudotachylite consisting dominantly of locally derived rock fragments in a fine grained, generally dark colored matrix of comminuted rock and mineral fragments. The Sudbury Breccia occurs as a network of small to large veins cross cutting the footwall rocks. The footwall rocks consist of granite (GR), Felsic Gneiss (FGN), Mafic Gneiss (MGN), Migmatites (MIG) , Mafic Volcanics (BSLT), Gabbro (GABB) and Diabase Dykes (MD,MDIA) .

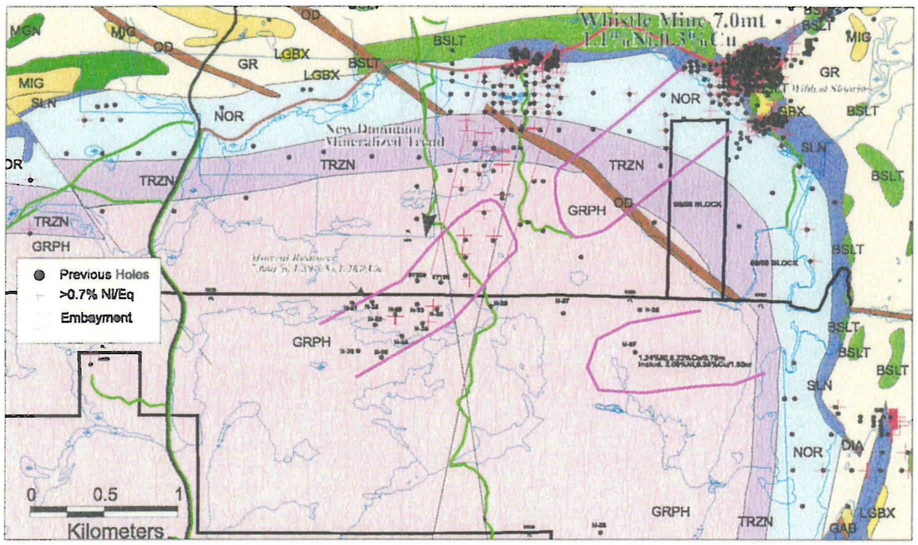

Figure 2: Norman West Regional Geology Map.

Structure, particularly faulting, appears to play an important role in the distribution of SIC units with one significant offset noted in the area. The transition zone (TRZN) contact is cut by regionally extensive northwest trending faults which offset the contact in a right lateral sense. These faults are commonly occupied by late, post SIC event, olivine diabase dikes (OD). The surface expression of these faults are typically depressions and ponds.

The Whistle Mine(7.0mt@1.10%Ni,0.30%Cu) is the only past producer along the contact in this area with several other notable mineral occurrences.

The general geology of the SIC is discussed in several other papers and the reader is directed to these for more detailed descriptions (Dressler, 1984; Lafleur and Dressler, 1985).

Contour maps for the base of the Sublayer and the base of the Late Granite Breccia and isopach maps of the Mafic Norite + Sublayer and Late Granite Breccia are compiled from existing drill hole data for the Norman West area. The contour map for the base of the Sublayer and LGBX show variations in the dip of the plane by the spacing of the contour map. Depressions in the base of the SIC embayments, troughs, or terraces are the principle control on the distribution of sulphide mineralization within the Sudbury Basin. The contour map of the LGBX also displays the base of the lower zone (6.0mt@ 1.63%Ni,1.47%Cu) in the northeast corner of the deposit area. The contours show a 20^o (plunge to the mineralization to the southwest. The regional isopach map for the northeast corner of the basin shows three well-developed embayment structures. The Whistle Embayment structure hosts two known deposits (Whistle Mine and Norman West Deposit) and has potential to host more. The Sublayer within the Whistle embayment on Falconbridge's property (Norman West Deposit Area) ranges from 70 meters thick in hole N-30A to 270 meters thick in hole N-36. An isopach map of the LGBX thickness provides a slightly different view of the embayment from the Sublayer isopach. Thickness of the LGBX in the Norman West area varies from 20 to 250 meters thick. The LGBX forms a well-defined border to the north east and the south west of the thick Sublayer terrace, and locally forms dams of breccia material within the embayment. This mimics the Hardy-Longvack area and the Victor area (other Falconbridge properties on the Sudbury Structure) where the LGBX forms levees about thick Sublayer filled troughs.

The lower zone (LGBX) mineralogy in the Norman West area comprises of samples from Hole N-29 and N-26 representing massive to heavily disseminated and net-textured sulphides. Pyrrhotite is the major sulphide with pentlandite that makes up 5 to 26 vol% of the sulphides. In the samples in N-29 the chalcopyrite makes up to 5 vol% or less of the sulphides in the samples and pyrite makes up 1 vol% or less of the sulphides. Three pyrrhotite and pentlandite grains were analyzed to give 3-point average compositions. Pyrrhotite has from 0.47%wt Ni to 0.77 and the average Ni in Po is 0.65%wt. Pentlandite defines blocky chains and aggregates that outline Po grains . In hole N-29 @ 1909m within the massive Po(4.59%Ni) sample the Platinum group minerals were analyzed qualitatively. Sperrylite (PtAs2), merenskyite(PdTe2), altaite(PbTe), and a BiTe(tsumoite BiTe) were found as single phase to multi-phase grains from 2-5 microns in size.

4 Field Preparation

It took most of 3 months to plan the 1998 Norman West survey. This survey was different in many aspects to the survey of the previous year. To save on dynamite cost and acquisition time, it was decided to rent an 8-level probe from Vibrometric Oy. When added to our 4-level, it enabled us to record in 2 boreholes simultaneously. Close to a month before the experiment, scientists at the GSC went to Sudbury to scout for the location of 5 shot points with the help of the Falconbridge project geologist. Bedrock outcrops were selected for all shot points. Three shot holes, 5m deep and 3" in diameter, were drilled at each shot point. This provided reserve holes in case one would cave in after a blast (Figure 3). Water was used to tamp the shots. Each shot point was provided with running water 24 hours a day by three pumps to prevent the water lines from freezing.

In-kind contribution to the survey by Falconbridge Ltd was critical to its success. Beside usual logistical help like access to the boreholes and basic information about the geology, Falconbridge Ltd. provided a full time field technician for the duration of the survey, supervised the drilling of the shot holes, contracted the dummy-probing of the boreholes and accurate surveying of the shot locations, gave us access to a skidder, pumps, propane heaters, an ATV, and detailed information about the mineralization at Norman West.

High velocity boosters and zero delay seismic caps were ordered a month in advance to ensure on time delivery from Calgary. Day boxes were rented for the duration of the survey for safe storage of the unused powder and detonators.

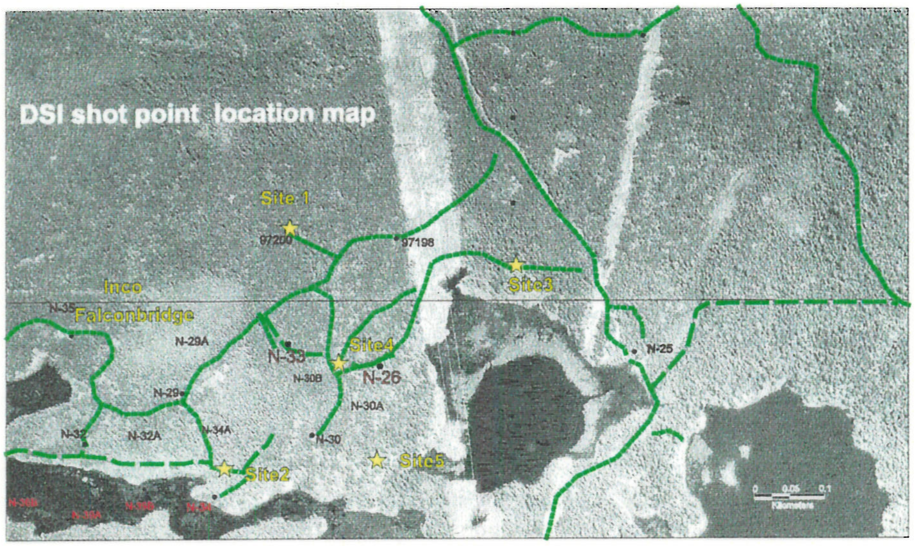

Figure 3: Shot locations for the 1998 Norman West DSI Experiment.

5 Data Acquisition

Overall data acquisition for the Norman West 98 experiment went well. The weather was collaborative during the whole survey. The crew of nine consisted of 5 shooters, 2 winch operators, one trouble shooter and one observer. A total of 739 shots and 10 VSPs were recorded in 7 days. The typical work day started at 7:00 am and we kept shooting until darkness at 4:45 pm. No official lunch break was scheduled. It took a total of 9 days for the whole survey including transportation from and to Ottawa, setup, acquisition and retrieval of the equipment.

5.1 Acquisition parameters

From the beginning it was decided to design this survey as high-resolution profile. Beside having a 5m sampling interval along the boreholes and dynamite in slim shot holes coupled to bedrock, we used a very small time sampling rate of 0.00025 seconds for a record length of 2 seconds. This provides a spectrum with unwrapped frequencies up to 2000Hz. The data was recorded with a 24-bit DAS-1 Oyo seismograph using up to 37 channels including an uphole geophone as a second option to calibrate the shooting boxes delay in time. Observer notes were taken by hand and transferred on an Excel spreadsheet after each level of recording. At the end of every day, the data was kept on the seismograph and was also backed up on optical drives in the field as well as on the hard disk of the survey computer. Quality checks were performed after every day of recording by identifying bad traces, noise levels and geometry information.

5.2 Survey Geometry

Five shot points were selected around boreholes N-26 and N-33. Positioning of the sources enabled multi-azimuth and multi-offset coverage (Figure 3). The 10 VSPs that were collected covered all quadrants around the boreholes with offsets ranging from 75 to 300 meters. Shot were recorded in both boreholes simultaneously. Data cables connected both winches to the seismograph. In order to be able to retrace the probe orientation in the borehole, all 5 shots were recorded before the tools were move to another position deeper into the ground. Information was collected every 5 meters along the boreholes from 100m to 1900m below the surface. This survey geometry provides subsurface mapping information over distances at least half of the shot-receiver offset and is able to detect amplitude anomalies more than a kilometer away from the boreholes. Shots were placed both in the updip and downdip directions. According to the known geological features most of the lithological reflections should be imaged with the updip shot points (Figure 4). On the other hand, localized diffractors should be imaged by all shot points dispersing the reflected energy in all directions. This survey geometry should enable us to address most of the possible causes of reflections at Norman West.

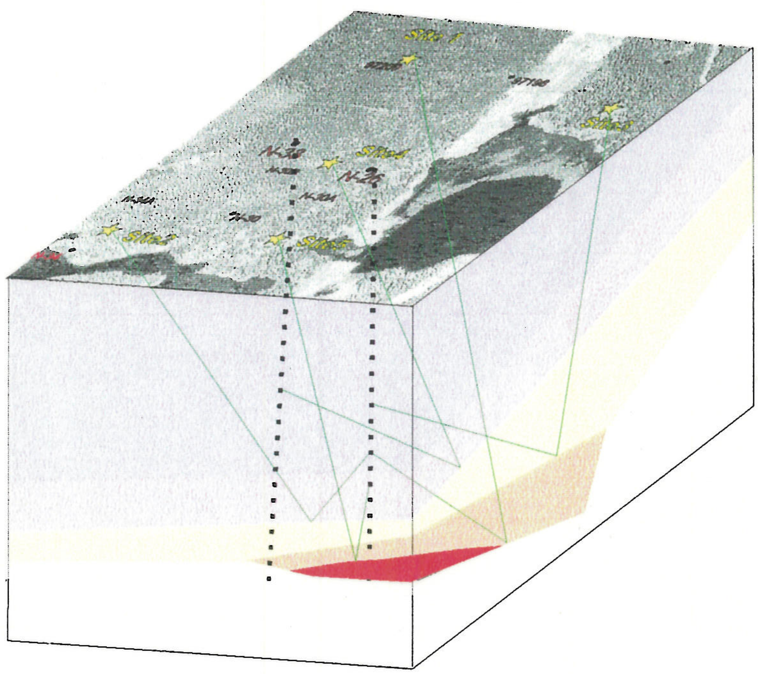

Figure 4: 3-D representation of the survey design at Norman West

5.3 Sources

Dynamite was the type of source chosen for the survey Figure 5). High velocity pentholite boosters were used in charges of 90g and 227g. Staticmaster caps with 10 meter leads were selected for their very accurate zero delay response (Figure 6). Every shot was tamped with water for better coupling with the ground. Figure 5 show an example of dynamite blast. Shot charges were increased from 90 to 227g when the receivers reached depths of about 1100m and again to 454g (1 pound) towards the bottom of the holes at 1800m. Shot holes withstood many blasts before starting to degrade making three holes per site more than enough for the average of 150 shots fired needed at each shot point. For over night safety storage, dynamite and caps were kept in different day boxes.

Figure 5: Example of dynamite blast from shot point 3

Every shooter and the observer had their own blasting box. Having as much as five shooters in the field permitted to record all five shots within five minutes several times during the survey. In good conditions, six levels of recording (30 shots, 120m on 5 VSP profiles) were acquired per hour. In the morning before breakfast all the clocks of the boxes were synchronized using standard GPS time. Each box was outputting a 5 volt TTL signal every minute mark. For each blast, the observer would communicate by radio with a specific shooter asking him if he was ready to shoot on the next minute mark. If the answer was affirmative both shooter and observer would arm their blasting boxes triggering simultaneously the seismograph and the dynamite. It was assumed that the different internal clocks would drift thus offsetting in time the two trigger signals. This is why at the end of each day the drift on each device was recorded as well as the relative drift between the observer's box and each of the blaster's boxes. Later in processing a linear drift during the day would be assumed and traces would be shifted in time accordingly.

Figure 6: Blasters equipment at Norman West including a blasting box, seismic caps, pentholite boosters and firing line.

5.4 Receivers

The downhole probes used for this survey were Vibrometric XYZ 8/24 and XYZ 4/12. The 8-level tool borrowed from Vibrometric in Finland was used in N-26 and the 4-level tool, the latest equipment acquisition for the DSI Consortium, was lowered in N-33. Overnight, tools remained clamped in the holes and depth encoder readings were recorded at the beginning and end of each recording day. The Vibrometric instrument had 8 levels spanned on 35m compared to the Consortium's instrument which has 4 levels covering 30m. Thus, Vibrometric's tool was moving by steps of 40m while the Consortium's tool had to move 5m and than 35m to keep the nominal 5m sampling. The Vibrometric crew had some problems related to their cable extension that was infiltrated by water generating cross-talk between channels. After a day, it was decided that we would not use the extension, thus limiting coverage of Vibrometric's tool to a depth of 900m. No similar problems were encountered with the Consortium's tool. At the beginning of the fourth day, the GSC 4-level tool was lowered into N-26 to finish the recording from 900m to 1875m.

6 Conclusions

The Norman West 98 acquisition campaign was a success. Good preparation before the survey ensured on time delivery of dynamite, drilling of shot holes and appropriate water supply for tamping. Logistical contribution from Falconbridge in the field was mandatory to the success of this survey. On site training of additional shooters by licensed teachers enhanced the firing rate by 60%. The use of dedicated blasting boxes at each shot hole also contributed to reduce shot interval. Ten 1800m deep VSPs were collected in seven days of recording. Mobilization and demobilization from and to Ottawa took about 3 days. The recording instruments were able to withstand pressures and temperatures encountered at 2km depth. Renting Vibrometric's downhole instruments reduced acquisition time by more than 2 days easily covering the associated costs.

Due to problems with the data quality (i.e. ringing and amplitude problems) on the data recorded in Norman West and the amount of time required to fix those problems during processing, it was suggested by the processors to include a well planned testing program on the first day of acquisition for the upcoming DSI surveys.