The impact of seismic nodes on enhancing subsurface imaging for mining - a case study over the Tamarack Nickel field

Eamonn Murray, Andrew Stone, Celina Giersz, Amine Ourabah – Stryde*
Brian Bengert – Talon Metals Corp.

Summary

In the past, the use of 3D reflection seismic acquisition for mapping ore bodies in mining exploration has been limited. This can be attributed to concerns about its applicability in geologically complex, hardrock environments and the high cost of conventional 3D acquisition systems. However, recent years have seen a shift, with the introduction of smaller, more cost-effective nodal systems, prompting the mining industry to re-evaluate its potential. There is an increasing interest in utilizing 3D seismic from the initial exploration phase through to the advanced extraction planning on mature sites. We show how velocity models derived from first-break refraction tomography for one particular high-density survey assist in the 3D mapping of the overburden/bedrock contact of a magmatic intrusion and provide extra detail to the extent of the low velocity ore bodies beneath. The potential for cross-hole tomography surveys to be complimented by first arrival data from a surface deployed 3D grid of continuously recording sensors is also examined.

Introduction

The Tamarack North Project, operated by Talon Metals in Minnesota State, USA, is focused on exploring magmatic nickel sulphide deposits within a sinuous North-South trending intrusive complex. The focal point of the Tamarack North Project encompasses the 7 km northern extension of the Tamarack Intrusive Complex (TIC). Originating from a multistage magmatic event linked to the early evolution of the Midcontinent Rift (MCR), the TIC constitutes a mafic to ultramafic body, with the youngest intrusion dated at 1105 Ma (Goldner, 2011). The TIC has intruded into Animikie Group siltstones and sandstones, overlain unconformably by shallow Cretaceous fluvial and tidal sediments, along with more recent glacial till sediments and peat. The topography features minimal relief, leading to poor drainage and the dominance of lowland conifers surrounding environmentally-sensitive sedge meadows and marshland.

The TIC's geometry, delineated by a well-defined aeromagnetic anomaly (Figure 1), reveals a curved, elongated intrusion striking north-south to southeast over 18 km. Described as resembling a tadpole shape, the configuration includes an elongated, northern tail measuring up to 1 km wide and a large, 4 km wide ovoid-shaped body in the south.

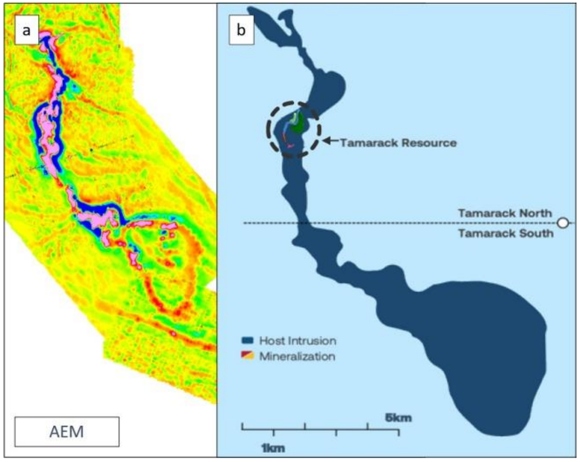

Figure 1: Geometry of the Tamarack Intrusive Complex (TIC); (a) airborne electromagnetics survey (AEM) outlining 'tadpole' feature, (b) the Tamarack Resource Area (TRA) circled.

Nickel sulphide mineralization within the intrusion stems from the concentration and segregation of liquid sulphide

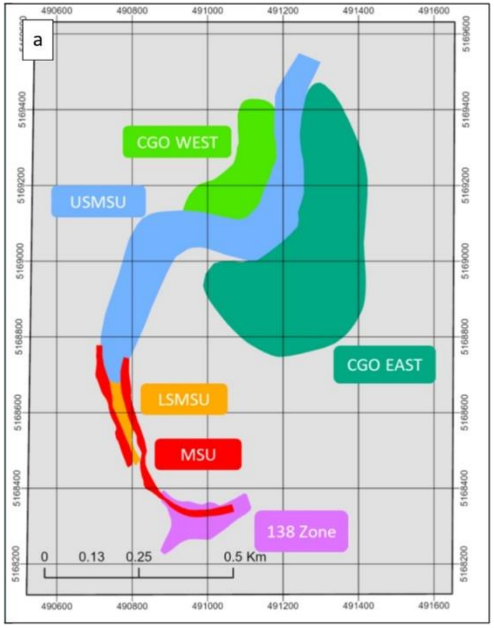

Figure 2: Ore bodies classification within the TRA, including the massive sulphide unit (MSU).

from the silicate magma (Naldrett, 1999). At the Tamarack North Project, various mineralized zones occur within distinct host lithologies, exhibiting different mineralization styles and varying sulphide concentrations (Figure 2). Of particular interest are the massive sulphide unit (MSU) with a maximum Ni content of 12% and the semi-massive sulphide unit (SMSU) boasting a Ni content of up to 5% (Figure 3).

Figure 3: Example of SMSU mineralization type.

Past attempts to delineate the position and extent of the ore bodies has seen the use of mostly non-seismic geophysical methods; such as electromagnetics. In this paper, we review an attempt to examine the contribution that could be made to this developing picture using the surface seismic method.

Method and Results

A wide variety of airborne, ground, and borehole geophysical surveys have been conducted at the Tamarack Project including; electromagnetics, magnetotellurics, surface gravity and resistivity. A reflection seismic survey has previously been carried out in 2006 with three 2D lines acquired in an attempt to better understand the deep structure of the TIC, and potentially delineate massive sulphide targets. The results demonstrated some potential for the method, but did not support at the time the viability of conducting a large-crew surface 3D seismic survey in this environmentally sensitive terrain.

With the introduction of smaller, low-cost nodal systems in recent years, Talon has decided to revisit this potential in 2023 with a small (1 sqkm), yet dense 3D survey located directly over the Tamarack Resource Area (TRA). The work was carried out by Talon's in-house geophysics team using Explor's acquisition service. The nature of the terrain dictated a low impact acquisition style and this was partly achieved by using Explor's in-house developed, hand-portable PinPoint source (Châtenay and Thacker, 2017). The equipment can be carried by crews on foot that leave minimal footprint on the survey area.

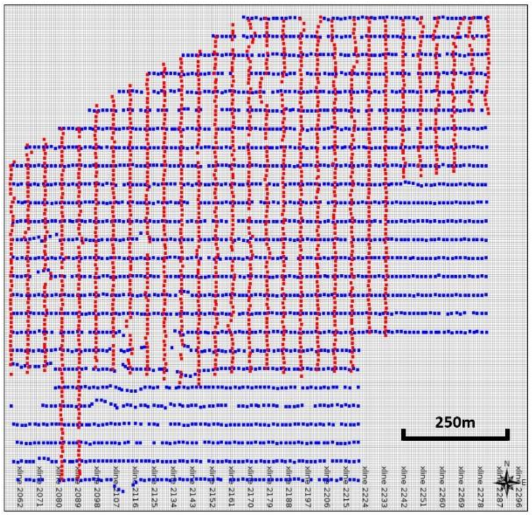

Figure 4: The 2023 3D seismic survey over the TRA. Receiver lines (blue) spaced 40m apart, oriented East-West with a 10m inline spacing between sensors. Source lines (red) placed orthogonally with a 40m spacing and 10m between inline SP positions.

On the receiver side, the cableless Stryde Nimble node system was used (Ourabah, 2021). The lightweight sensor was carried into the field in backpacks on foot in teams of 2/3. Its compact size allowed many to be deployed in a single round trip, reducing the need for frequent resupply and avoiding the use of heavy motorized vehicles. The autonomous nodes recorded at 2 ms sample rate for 24 hours/day without the need for redeployment for the full active survey duration of 11 days. The continuously recording nodes also open the possibility for processing of the passive seismic dataset to generate shear velocity models of the near-surface, with a view to non-active source surveys in the future and an even lower environmental footprint.

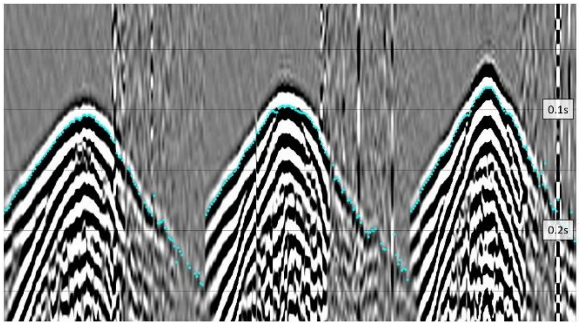

Figure 5: A snapshot showing the quality of the pinpoint source's 1st arrival with the picked first arrival in cyan.

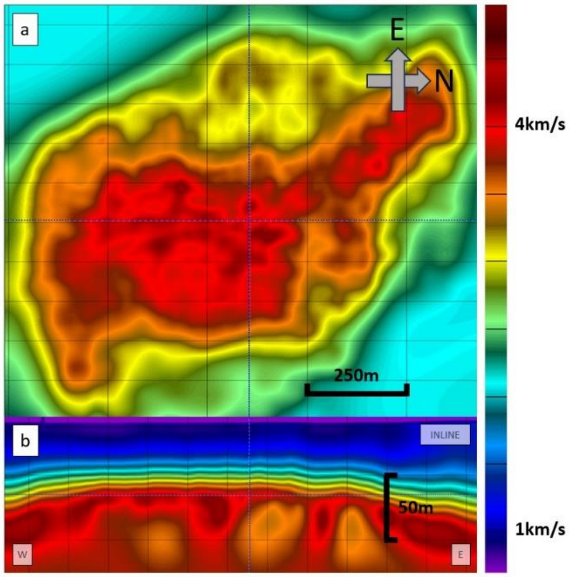

Figure 6: P-wave velocity model output from tomographic inversion; (a) depth slice at 65m, (b) inline cross-section slice through central part of the survey

The nodes were deployed over a period of 2 days in a conventional orthogonal setup with receiver lines spaced 40m apart, oriented East-West with a 10m inline spacing between sensors (Figure 4). Source lines were also arranged with a 40m spacing with 10m between inline SP positions. A total of 1,749 shots were acquired, firing into a fixed 3D receiver grid of 2,287 nodes.

Unfortunately, the Ni sulphide ore bodies of interest, hosted within the intrusion, do not present an impedance contrast to the seismic reflection method. At the interface between the two, an increase in density is accompanied by a corresponding decrease in velocity, cancelling out one another. Calculated reflection coefficients are below 0.05 and reflection seismic is effectively blind to the presence of the ore bodies. However, refraction tomography has the capability to sense the decrease in velocity and so offers the possibility for mapping in 3D the extent of the under-explored Nickel mineralization within the TRA and the wider Tamarack area.

As part of the seismic reflection processing, refraction statics corrections (tomostatics) are applied to account for the near-surface variations in refractor velocity and depth. First arrivals are picked on all shots generating 3,903,425 first breaks (Figure 5). These are input to non-linear, first-arrival tomographic traveltime inversion (Zhang & Toksoz, 1998), with iterations run until convergence is achieved. This process ray traces synthetic traveltimes for each shot such that the difference between the input and synthetic first break picks are minimized. A P-wave velocity model of the near-surface is output, to a depth limited by the diving waves' penetration, which for this survey was approximately 100m.

The inversion is run in an iterative cascade using ever finer grids with the output models from the preceding step used as input to the next. Grid dimensions for the final step are 10 x 10 x 5 m with 8 iterations being run to produce a convergence to a final global RMS error of < 8ms between the raw picks and the inversion's modelled picks.

The resulting P-wave velocity model (Figure 6) is able to detect the bedrock/top intrusive contact producing static corrections which correct time distortions on CMP stacks convincingly (Figure 7). Stacks have improved coherence and continuity with reduced structure. A picked horizon from the model, chosen to be representative of the bedrock interface (iso-velocity contour 3200m/s), is compared against that derived from Talon's drilled overburden survey.

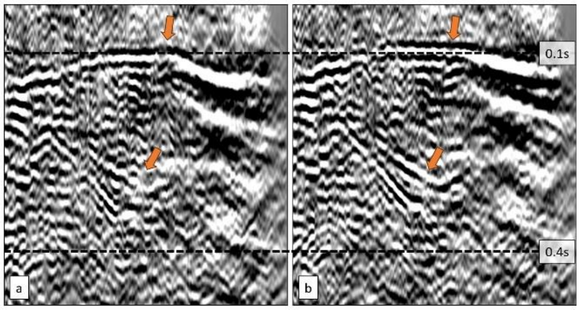

Figure 7: CMP stack demonstrating improvement seen after application of tomostatics; (a) elevation-based statics, (b) tomostatics

Whilst a good correspondence is generally seen across the survey area, there are some places where the more pronounced structure from the overburden survey is not evident in the refraction tomography model (Figure 8). Simple depth-stretching of the seismic reflection stack image using the refraction tomography velocity model shows reduced structure compared to that generated with the same model flexed to match the bedrock shape of the overburden survey.

Talon has had much success in delineating the ore body anomalies with cross-hole tomography. An expertise developed in-house and using the numerous (553) existing boreholes in the TRA. A sparker source fired at various depths within one borehole is detected by a receiver string in a nearby, adjacent well. Typical distances between wells are less than 100m.

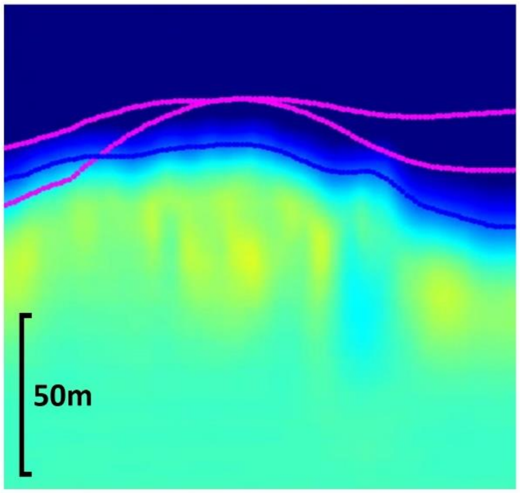

Figure 8: A picked horizon (blue) from the P-wave velocity model representative of the bedrock interface (iso-velocity contour 3200m/s) compared against those derived from Talon's drilled overburden surveys (magenta).

One such survey was conducted towards the tail end of this survey, after the active source part of the surface seismic had been completed, but whilst some nodes were still deployed in the field. Examination of the continuous records from the nodes shows that the sparker source can be detected on the surface sensors up to 1 km from the well-head (Figure 9). First breaks are picked and fed through a tomographic inversion to produce a P-wave velocity model. Unfortunately, the number of sensors still recording was only 10% of that originally deployed and the resulting P-wave velocity model is of limited insight, but it does highlight the potential for future cross-hole tomography models to be complimented by first arrival data from a surface deployed array of sensors. A method similar to a reverse 3D VSP.

Conclusions

The combination of a new generation of compact nodal systems with portable sources has allowed the efficient acquisition of valuable seismic datasets, in a very sensitive environment, enhancing the subsurface imaging of the Tamarack field. Despite the low impedance contrast of the sulphide ore bodies within the host formations, refraction tomography emerged as a promising tool, providing a high-resolution velocity model in the top 100 m of the seismic volume. The fine-grid 3D mapping of the bedrock interface compliments and extends the data provided by Talon's overburden drilling survey. The continuous recording, which is a free by-product of modern nodal systems, provides opportunities to exploit events occurring during the recording period, such as ambient noise and in-well sparker sources, to derive additional information about the subsurface.

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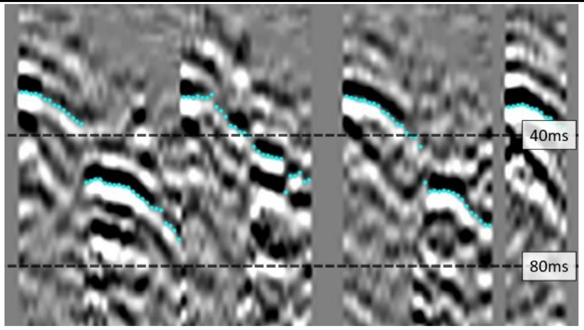

Figure 9: Reciver gathers generated from the nodes' continuous records with picks of the sparker source's first arrival displayed (cyan).