## Physical Rock Properties of Host Rocks and Sulphide Mineralization at Lalor

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### Introduction

An analysis of physical rock properties was conducted to assess the main response of the ore zones and host rocks at Lalor on seismic data, including possible effects of alteration and post-sulphide metamorphism. For this analysis, we used wireline logging data acquired in boreholes located close to or intersecting the deposit and measurements (Vp, Vs, and density) made on 45 core samples. The implication of this petrophysical analysis for seismic reflectivity is discussed below in terms of both host rocks and sulphide mineralization.

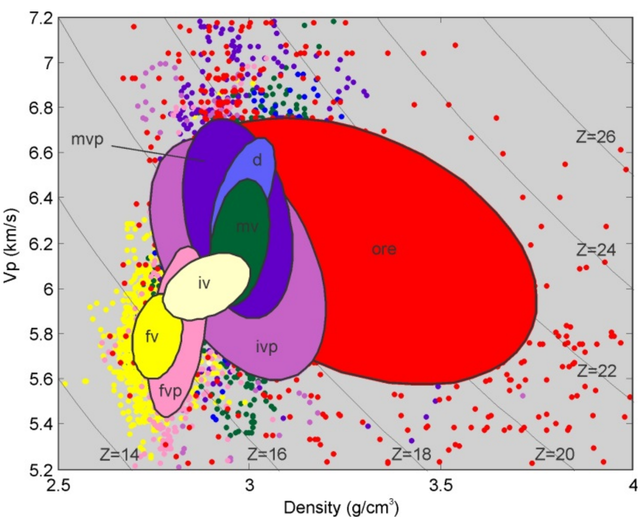


**Figure 10.** P-wave velocity and density of the main lithological units intersected in ten boreholes (see Figure 1 for collar locations). Units include felsic volcanic rocks (fv), intermediate volcanic rocks (iv), mafic volcanic rocks (mv), diorite (d), felsic volcanic protolith (fvp), intermediate volcanic protolith (ivp), mafic volcanic protolith (mvp), and ore. Lines of constant acoustic impedances (Z) are also shown. The ellipses are defined from the principal component analysis of each lithological unit with the minor and major axes representing one standard deviation from the mean.

### Properties of Host Rocks

Figure 10 shows the P-wave velocity and density from the logging data acquired in ten boreholes (DUB183, DUB185W03, DUB186, DUB189, DUB191, DUB195W05, DUB202, DUB209, DUB245, and DUB253). Those boreholes contain both wireline logging data and geochemical data which allowed the classification of the most altered footwall rocks according to their protolith. For the petrophysical analysis, we only selected wireline logging data located near geochemical sample points (i.e., within a maximum distance of 1.5 m from a geochemical data point). The geochemical data were used to determine the protolith (i.e. rock type of origin). This quantitative approach based on geochemistry was preferred over the more qualitative approach using visual core descriptions, especially in the most altered part of the footwall. Also shown on Figure 10 are ellipsoids determined from principal component analysis and representing the mean and scaled eigenvectors of the covariance matrix of the distribution of each lithological unit. The major and minor axes of the ellipses correspond to one standard deviation. Given the relatively large spread of data points for some of the lithological units, the results presented below are based mostly on the ellipses from the principal component analysis.

The physical rock properties at Lalor are in general agreement with properties obtained elsewhere in the Flin Flon Belt (Fowler *et al.*, 2005; White *et al.*, 2012) or in other volcanogenic massive sulphide mining camps (Salisbury *et al.*, 2003; Malehmir *et al.*, 2013). Similar to many volcanogenic massive sulphide mining camps, the contrast of acoustic impedances between felsic and mafic volcanic rocks is generally sufficient to generate reflections (see Salisbury *et al.*, 2003). The contrast of acoustic impedance indicated by the separation between the ellipses corresponding to these units (fv and mv on Figure 10) is sufficiently large to produce prominent reflections (i.e., a reflection coefficient of 7.3% using mean values of ellipses on Figure 10). Volcanic rocks of intermediate composition (iv on Figure 10) have acoustic impedances between felsic and mafic volcanic rocks suggesting that contacts between iv and either fv or mv may not generate prominent reflections (i.e., a reflection coefficient less than 4.2% using mean values of ellipses on Figure 10). Diorites (d in Figure 10) have high acoustic impedances similar to mafic volcanic rocks, suggesting that they may generate reflections when in contact with felsic volcanic rocks (i.e., a reflection coefficient of 8.8% using mean values of ellipses on Figure 10). Those estimated reflection coefficients are representative of most contacts in the hanging wall and in the least altered part of the footwall (i.e., footwall units in yellow and green on Figure 5). In the footwall, the physical properties of the most altered rocks (units in pink to purple on Figure 5) are controlled by the composition of their protolith. Similar to the contacts between mafic and felsic rocks in the hanging wall, rocks with a mafic protolith (mvp ellipse on Figure 10) will generate a strong reflection when in contact with rocks with a felsic protolith (fvp ellipse on Figure 10). In this case, the mean values of ellipses on Figure 10 suggest a reflection coefficient of 6.9%. Rocks with intermediate protolith cover a wide range of P-wave velocity and density (see ivp on Figure 10) but they are generally closer to the ellipse of rocks with mafic protolith. In fact, the mean values of rocks with intermediate and mafic protolith are relatively similar, suggesting that intermediate-felsic protolith contacts may also produce detectable reflections (i.e., a reflection coefficient of 5.5% using mean values of ellipses on Figure 10). For the most altered footwall rocks, we also compared the physical rock properties of both protoliths (felsic and mafic) and their metamorphosed equivalents (gneiss and schist). Figure 11 shows the distribution of Vp/Vs and acoustic impedance for gneiss and schist (Figure 11a) and for felsic and mafic protoliths (Figure 11b). Gneiss and schist cannot be distinguished on the basis of acoustic impedances (Figure 11a) whereas protoliths of mafic and felsic composition have slightly overlapping but yet separated acoustic impedances (Figure 11b; see also fvp and mvp on Figure 10). This confirms that contacts between protoliths of felsic and mafic volcanic origin may generate reflections whereas a juxtaposition of gneiss and schist might not. It is important to note that each of the felsic and mafic protoliths are found in both gneiss and schist. Figure 11 also shows a moderate separation between gneiss and schist and mafic-felsic protoliths with respect to Vp/Vs. The Vp/Vs separation between schist and gneiss (Figure 11a) is possibly related to well-developed foliation (anisotropy) in the schist. However, no anisotropy measurements are available to confirm this hypothesis. The cause of the Vp/Vs separation between mafic and felsic protoliths is still ambiguous but could be related to compositional variations.

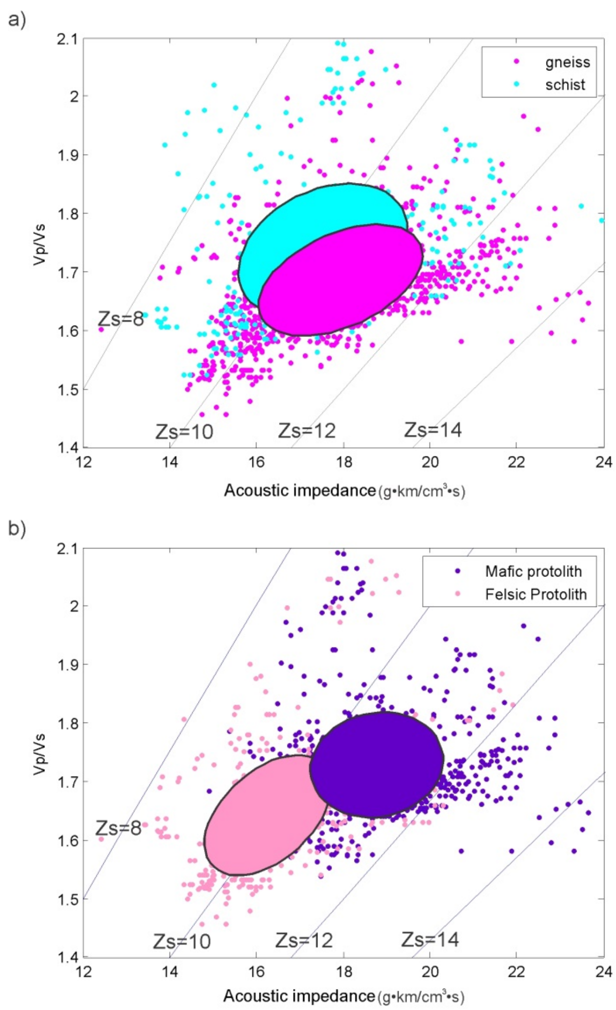


**Figure 11.** Physical rock property of (a) schist and gneiss (b) felsic and mafic protolith in ten boreholes (see Figure 1 for collar locations). The same logging data is used for (a) and (b) but categorization relies on geological description in (a) and protolith defined from $Zr/TiO_2$ in (b). Schist and gneiss have a similar range of acoustic impedance but are slightly separated along the Vp/Vs axis. Felsic and mafic protoliths although partly overlapping, show different ranges of acoustic impedance possibly explaining many reflections in the most altered part of the footwall. Lines of constant elastic impedances (Zs) are also shown on this figure.

## REFLECTIVITY OF ORE

As shown in Figure 10, the mineralized zones cover a wide range of acoustic impedances suggesting that ore zones with various compositions have different physical rock properties and/or ore intervals also include weakly mineralized rocks. As part of their core-logging procedure, Hudbay Minerals divided the mineralized intersections into 9 classes representing rocks with minor indication of mineralization to solid massive sulphides. All mineralized intersections in boreholes including non-economical intervals followed this classification. Although mostly qualitative, this classification provides a means to assess the physical rock properties of various ore classes of the deposit and estimate their potential reflectivity against host rocks or against ore with different composition. Figure 12 shows the P-wave velocities and density for the nine ore classes. All 12 boreholes with logging data at Lalor were used in Figure 12. Near-solid to solid sulphide (R62 in Figure 12) and near-solid sulphide (R63 in Figure 12) intersections generally have higher densities which result in higher acoustic impedances. The solid massive sulphides (R61 in Figure 12) span across a wide range of impedances mostly related to changes in density and includes some values typical of non-mineralized host rocks. Those values suggest that some of the intervals identified as solid massive sulphides also included sub-intervals with weak or no mineralization. Many logging data points from the solid sulphide class (R61) have high impedances and overlap with the near-solid and near-solid-to-solid sulphides but generally have lower P-wave velocity typical of sphalerite (see Salisbury *et al.*, 2003). Other mineralized classes are associated with stringer of sulphides and disseminated mineralization and have significantly lower acoustic impedances, some very similar to impedances of host rocks (R64 to R69 in Figure 12). In general, density is the primary property allowing discrimination between near-solid to solid sulphides (R61 to R63) and stringers and disseminated sulphides (R64 to R69). Density measurements on samples from both zinc and gold zones conducted as part of the resource evaluation by Hudbay Minerals also confirm this trend. Density for the zinc zones ranges from 2.66 to 4.75 g/cm$^3$ with an average of 3.59 g/cm$^3$ (Carter *et al.*, 2012). In comparison, the disseminated gold zones have an average of 2.84 g/cm$^3$ with values ranging between 2.72 to 3.79 g/cm$^3$.

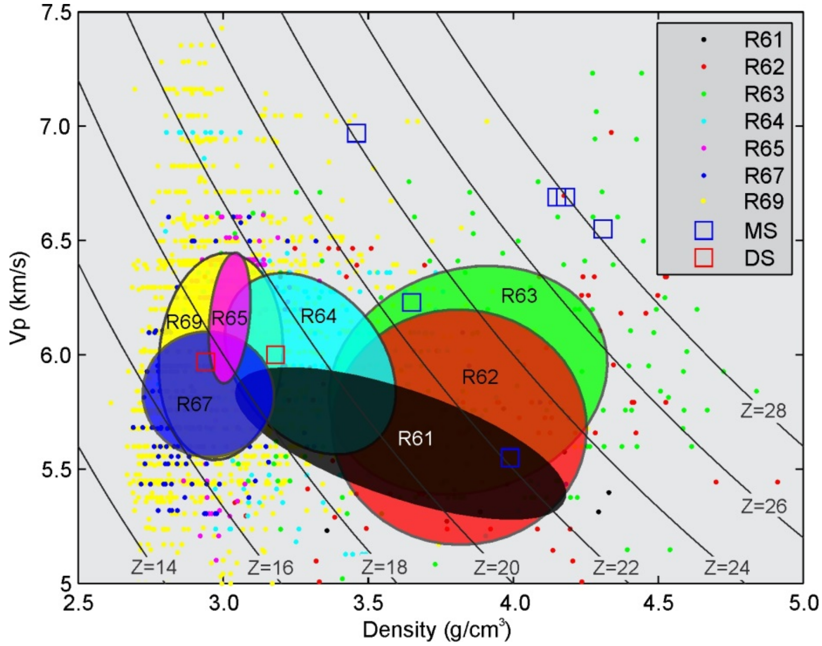


**Figure 12.** P-wave velocity (Vp) and density for the various ore classes identified during the geological logging of the cores. R61: solid sulphides; R62: near solid to solid sulphides; R63: near solid sulphides; R64: disseminated to near solid sulphides; R65: disseminated sulphides; R66: well-mineralized to disseminated sulphides; R67: well-mineralized intersection; R68: cherty ore zone; R69: mineralized intersection. Squares represent measurements on core samples from massive (MS) and disseminated (DS) sulphides. P-wave velocity measurements on samples in this figure were done at 80 MPa.

A total of 1957 and 1455 density measurements were made for the zinc and gold zones, respectively. Physical rock property measurements (Vp, Vs, and density) made on massive and disseminated sulphide rock samples show similar results (see squares on Figure 12). In this case, massive sulphide core samples are from pyrite-rich intersections which also have high P-wave velocity (Figure 12).

These results (Figure 12) and comparison with Figure 10 confirm that reflections can be expected from near-solid to solid sulphides when juxtaposed against any rock units in the Lalor area. However, most of the disseminated sulphide zones which constitute an economically important part of the deposit (i.e., the gold and gold-copper zones) will generate weak to very weak reflections or no detectable reflections. This is even more likely when the generally smaller size of the gold-rich zones is considered. Similar to electromagnetic methods which tend to respond well to solid sulphides, seismic methods can only directly reveal the shallower semi-massive-to-massive sulphide zones of the Lalor deposit. However, given the close proximity of some ore zones, their small thickness, and possible interference with lithological contacts near the ore zones, it is also possible that some reflections might be indirectly associated with some disseminated zones (see section on the interpretation of the Lalor 3C-3D seismic data).

## CONCLUSIONS

Physical rock properties show that zinc-rich massive sulphide zones which are associated with pyrite have high acoustic impedances that are sufficient to produce prominent reflections when juxtaposed against any host rocks. The disseminated gold-rich zones which constitute an economically significant part of the deposit cannot be imaged directly with seismic reflection methods. Physical rock properties also show that contacts between felsic and mafic volcanic rocks regardless of the intensity of hydrothermal alteration and metamorphism are the most likely cause of reflections in this area.