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## Deep Targeting Iron-Oxide Mineralization Using Reflection Seismic Method: A Case Study from the Ludvika Mines Of Sweden

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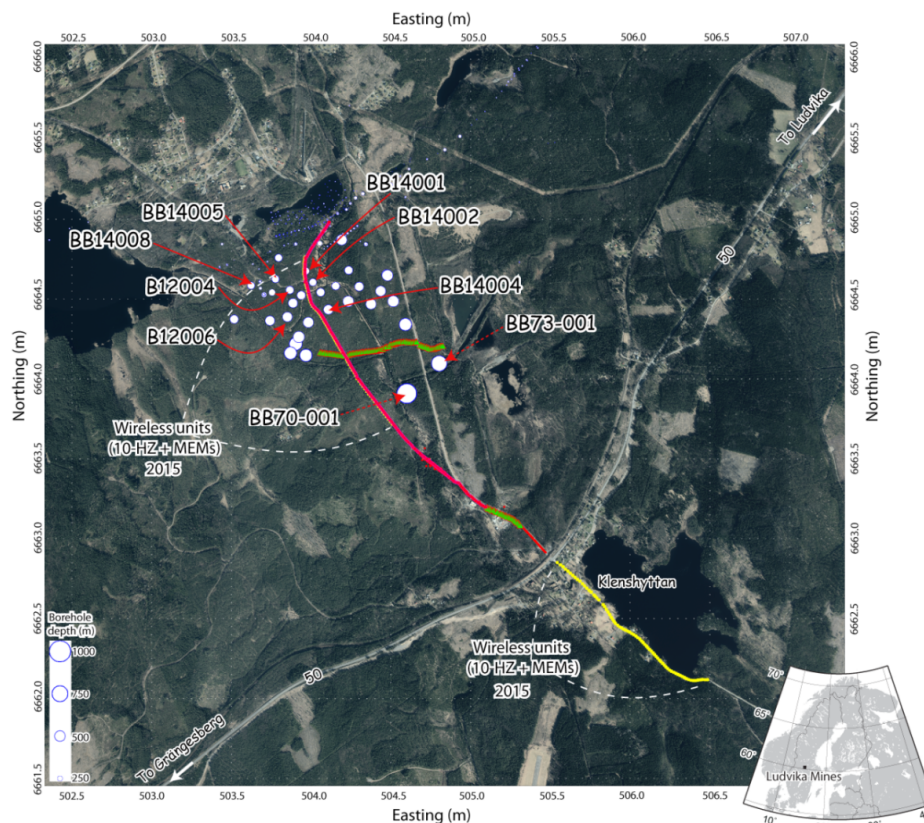
### Summary

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Blötberget, in the Ludvika Mines of Bergslagen mineral district of central Sweden, is well-known for its iron-oxide, sometimes apatite-rich, deposits. There is also a renewed interest in exploring and mining the deposits due to accessibility to the market and recent advancements made in the mining and metallurgical technologies. During two field campaigns (2015 and 2016), high-resolution reflection seismic data were acquired using both cabled- and wireless-recorders as well as a landstreamer system. In this study, we have merged the two datasets and process them together to provide deeper information on the extension of the mineralization and potential unknown resources at depth. We show how the merged dataset images the mineralization much better and deeper than known also potential reflections under the known ones that can be targeted through a drilling program. This study demonstrates reflection seismic method is a powerful tool for imaging iron-oxide mineralization at depth. We argue that they should be acquired more routinely at the site for mineral exploration purposes. It also paves the way for justifying a 3D seismic survey in the area.

## Introduction

Utilization of seismic methods for mineral exploration has recently increased significantly. Compared to the others geophysical methods, seismic methods have the advantages of (1) relatively high resolution at depth and (2) greater penetration making them more convenient for deep targeting (see Malehmir *et al.*, 2012 and references therein) particularly when combined with other geological and geophysical knowledge-based data. Many metallic deposits produce strong seismic contrasts with their hostrock due to the high concentrations of oxides and sulphides (essentially density), allowing them to generate a strong seismic signal (reflection or diffraction). One of the major and most historical mining areas in Sweden is the Bergslagen mineral district. Mineralization in the Bergslagen comprises of banded iron formation (BIF), skarn-type iron-oxide deposits and apatite-rich iron-oxide deposits (Stephens *et al.*, 2009). Several investigations were recently carried out within part of the district, Blötberget of Ludvika Mines, involving mainly downhole physical property measurements of the mineralized zones and their host rocks (Maries *et al.*, 2017), a pilot test to use a seismic landstreamer (2015) for deep exploration (Malehmir *et al.*, 2017) and a follow-up conventional seismic survey (2016) using planted-type geophones to check the results from the streamer survey and provide deeper information on the mineralization and potential structures that may be relevant when mining commences at the site (Maries *et al.*, 2017). In this study, we have merged both the 2015 and 2016 datasets, processed them together and present a deeper continuation of the known deposits from the site allowing a much improvement of potential mineral resources at depth and potentially additional ones occurring a few hundreds of meters under the current mineralized horizons.

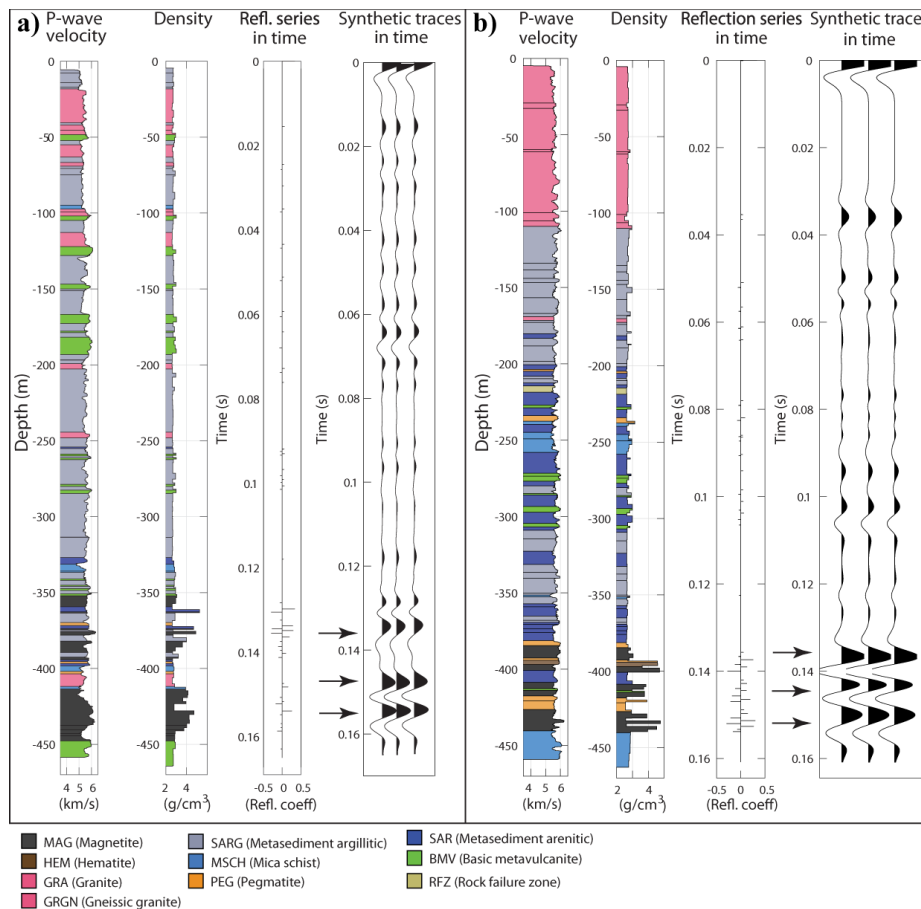


**Figure 1** Aerial photo showing the location of Blötberget in the Ludvika Mines, seismic profiles of 2015 and 2016 surveys and existing boreholes with those downhole logged. The 2016 survey only focused on the northern part of the road 50 and included another profile on its northern portion.

## Background

The study area is located in Blötberget mining area of the Ludvika Mines (Figure 1) and it is known for its rich and high quality iron-oxide deposits. Seismic reflection data were acquired in two field campaigns (2015 and 2016). The 2015 survey was designed as a pilot test for a landstreamer where

data were acquired using a combination of wireless recorders (south of the road 50 and on the northern part of the profile) and landstreamer MEMS-based sensors. The 2016 survey consisted of two profiles, one positioned along the same profile as the 2015 one but only north of the road 50 (cabled units and 24 wireless units in southern part of the profile were used) and another one, shorter, that was positioned perpendicular to the main one (only wireless units, green line in Figure 1). The aim of the 2016 survey was to deep target the mineralization towards the south-east and with the perpendicular one to provide information on the lateral extension of the mineralization. A 500-kg Bobcat drophammer source was used for both surveys. Six boreholes have so far been downhole logged (labelled in Figure 1) providing crucial information about expected seismic signal from different structures and the mineralization. Examples of downhole sonic logging data and laboratory density measurements for example two boreholes are shown in Figure 2 (Malehmir *et al.*, 2017; Maries *et al.*, 2017).



**Figure 2** Examples of laboratory density measurements and downhole sonic logging data from boreholes (a) BB14005 and (b) BB14002 (for locations see Figure 1), intersecting the mineralization at 400-450 m depth. 1D-synthetic seismograms suggest that a strong seismic signal can be expected from the mineralization.

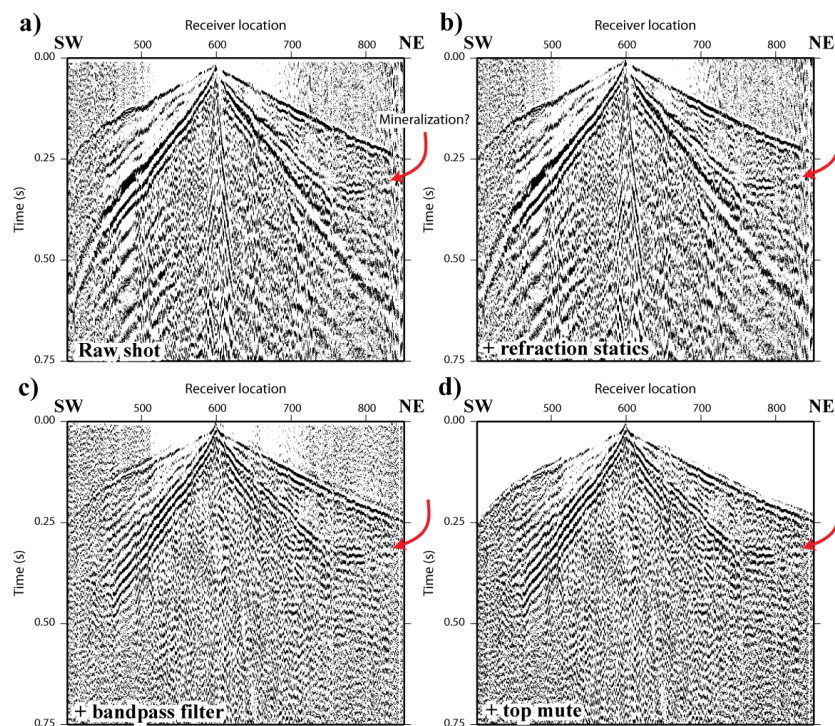
### Seismic data

For deeper targeting the mineralization, we merged the datasets from the 2015 and 2016 surveys along the main profile. To avoid complications because of different positioning (in particular elevation) of receivers and sources in the two surveys, we applied refraction static corrections to both datasets prior to their merging. The processing then focused on attenuating ground-roll and source-generated noise through bandpass filtering and amplitude-frequency balancing. Figure 3 shows an example shot gather from the 2016 data where a reflection interpreted to be from the mineralization is already visible in an example raw shot gather but become more pronounced after a few steps of prestack processing.



## Discussion

Figure 4 shows a portion of the stacked section for the 2015 data and the merged datasets processed in this study. A constant velocity of 6000 m/s was used to convert the stacked section to depth. The known mineralization is visualized with the seismic section. We are aware that the reflections are slightly steeper than what shown here. When comparing carefully, the landstreamer data from the 2015 survey while show a strong reflection associated with the mineralization (Figure 4a), they only image this down to 1000 m depth (estimated using the apparent dip from the stacked section and a background velocity of 6000 m/s). The merged dataset however shows the mineralization deeper (Figure 4b) and has much higher resolution and quality. Aside the reflection from the known mineralization, we are able to identify a set of strong reflections a few 100s' meter below the known ones (red arrow in Figure 4a,b). There is no borehole for validating this interpretation and hence worth considering it in the near future. We estimate an increase of approximately 15-20 Mt of iron-oxide resources based the seismic image and an assumption that it has similar thickness and lateral extension as those known at the shallower depths.



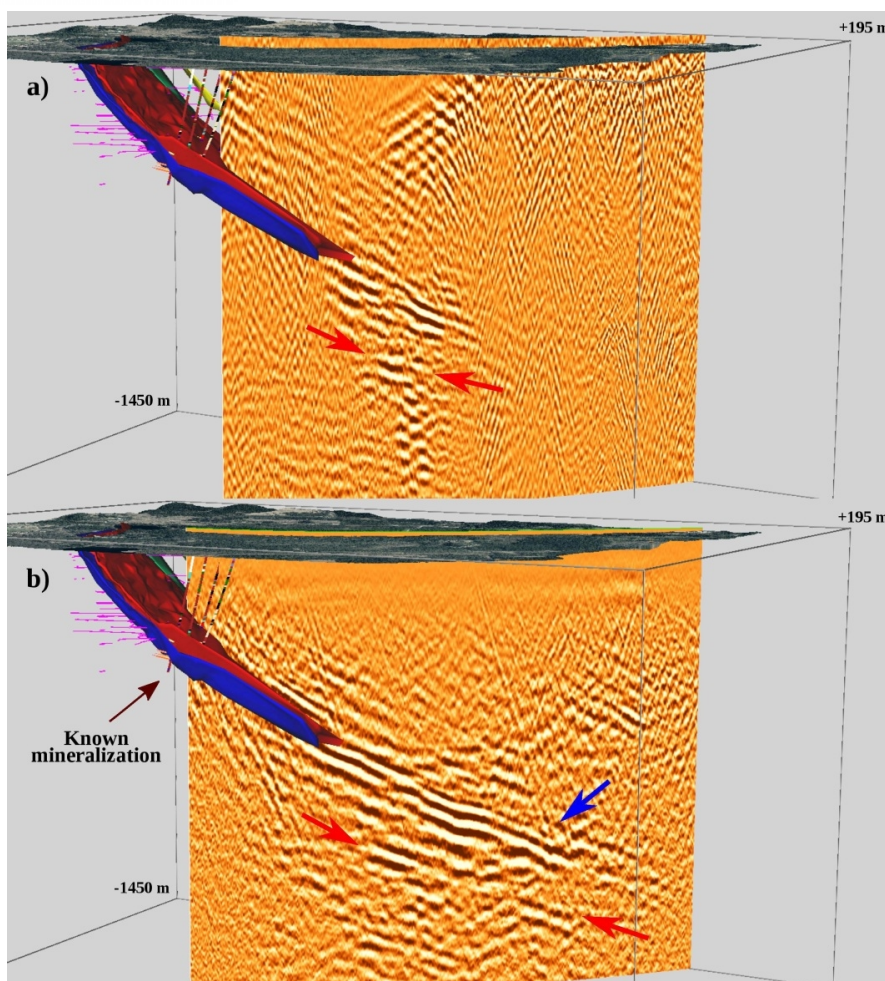
**Figure 3** An example (a) raw shot gather from the 2016 survey, (b) after refraction static corrections, (c) bandpass filtering and (d) top mute. Red arrow marks a reflection interpreted to originate from the mineralization.

## Conclusions

We have processed two sets of seismic data acquired at different campaigns for iron-oxide exploration at depth in this study. We show clear reflection signature of the mineralization, its possible depth extent and additional resources that can be targeted under the current known ones. This study is encouraging and illustrates the potential of seismic methods for deep exploration of similar type deposits in the area and elsewhere in the world.

## Acknowledgements

This study was carried out within the Smart Exploration project. Smart Exploration has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 775971. The 2015 and 2016 surveys were conducted under ERA-MIN1 StartGeoDelineation project, sponsored by Vinnova, SGU, Tekes, Nordic Iron Ore (NIO) and Yara. We thank NIO for their collaboration in this study.



**Figure 4** 3D views of unmigrated seismic sections visualized with the known mineralized horizons for (a) the 2015 landstreamer data and (b) the merged 2015 and 2016 datasets. While both datasets image the known mineralization, the merged dataset shows much higher quality, images deeper extension of the mineralization (blue arrow) and indicates potential resources to be found a few hundreds of meter under the known ones (red arrows).

## References

- Malehmir, A., Durrheim, R., Bellefleur, G., Urosevic, M., Juhlin, C., White D.J., Milkereit, B. and Campbell, G. [2012] Seismic methods in mineral exploration and mine planning: A general overview of past and present case histories and a look into the future. *Geophysics*, **77**, WC173-WC190.
- Malehmir, A., Maries, G., Backström, E., Schön, M. and Marsden, P. [2017] Developing cost-effective seismic exploration methods using a landstreamer and a drophammer. *Scientific Reports*, **7**:10325.
- Maries, G., Malehmir, A., Backström, E., Schön, M., Marsden, P. [2017] Downhole physical property logging for iron-oxide exploration, rock quality, and mining: An example from central Sweden. *Ore Geology Reviews*, **90**, 1–13.
- Maries, G., Malehmir, A., Backström, E., Schön, M., Marsden, P. [2017] Reflection seismic imaging of Iron-oxide deposits- An example from Bergslagen mining district of Sweden. 79<sup>th</sup> EAGE Conference & Exhibition, Paris, France, June 2017.
- Stephens, M.B., Ripa, M., Lundström, I., Persson, L., Bergman, T., Ahl, M., Wahlgren, C.-H., Persson, P.-O. and Wickström, L. [2009] Synthesis of the bedrock geology in the Bergslagen region, Fennoscandian Shield, south-central Sweden. *Report of Sveriges Geologiska Undersökning Ba 58*, 259.