Seismic interferometry for surface-wave attenuation: A case of study from the Ludvika Mines of Sweden

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DOI
10.3997/2214-4609.201902494

Publication date
2019

Document Version
Final published version

Published in
25th European Meeting of Environmental and Engineering Geophysics

We_25th_B05

Seismic Interferometry for Surface-Wave Attenuation - A Case Study from the Ludvika Mines of Sweden

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Summary

In exploration seismology, surface waves generated by active sources usually mask events of interest like reflections and diffractions. This is exacerbated in high-noise, near-mine environments where the targets have often low-impedance contrasts. We present a purely data-driven approach for surface-waves attenuation in active-source reflection seismic data acquired at the Ludvika mining area of central Sweden in 2016. We apply seismic interferometry to the data in order to retrieve dominant surface waves between receivers. We then subtract them from the original data in an adaptive way for their attenuation. Our results show that the surface waves are well suppressed and the target mineralization signature is boosted allowing new features to be revealed. After a simple pre-stack processing, we obtain cleaner seismic sections with more continuous reflections.

Introduction

Compared with other exploration geophysical methods, seismic methods allow obtaining greater resolution when the targets are at relatively larger depths. This is one of the motives why the utilization of seismic methods in mineral exploration has increased considerably in the past few years. Nevertheless, in exploration seismology, and especially in high-noise, near-mine environments where the targets are often characterized by low-impedance contrasts, active-source-generated noise, i.e., ground roll, could unfavorably interfere with (cover) the desired reflections. Frequency-wavenumber (f-k) or frequency-offset (f-x) filtering methods are usually applied for surface-waves attenuation. However, they can be ineffective when the ground roll occupies the same regions in the f-k and f-x spaces as the reflected waves.

In order to improve the delineation and geometry of target bodies and their host rock, generation of high-resolution seismic images of the subsurface through new and effective methods is required. Therefore, in this study, we propose to estimate the surface-waves energy between receivers by applying seismic interferometry (SI). We then adaptively subtract the estimated surface-waves energy from the original data to obtain cleaner reflections. We apply these techniques for imaging the iron-oxide mineralization in Blötberget in the Ludvika mining area, south-central Sweden, using reflection data acquired in 2016 (Malehmir et al. 2017; Maries et al. 2017b).

Background - Blötberget iron-oxide deposit

Blötberget mining area of the Ludvika Mines of Sweden (Figure 1) is well known for its rich and high-quality iron-oxide deposits. The mineralization in Blötberget consists of magnetite and hematite. Additionally, apatite and small amounts of quartz and calc-silicate minerals are present. Towards the southwest and down to a depth of 500 m, the mineralized units dip about 45°. Further below, the units start dip gentler until the known depth of approximately 850 m; further in depth, characterization is still required (Maries et al. 2017a).

In 2016, a 2D reflection seismic dataset was acquired in the study area using wireless (red line) and cabled recorders (blue line) (Maries et al. 2017b). The spacing between the receivers was 5 m. A 500-kg Bobcat drophammer was used as the seismic source with a spacing of 5 m.

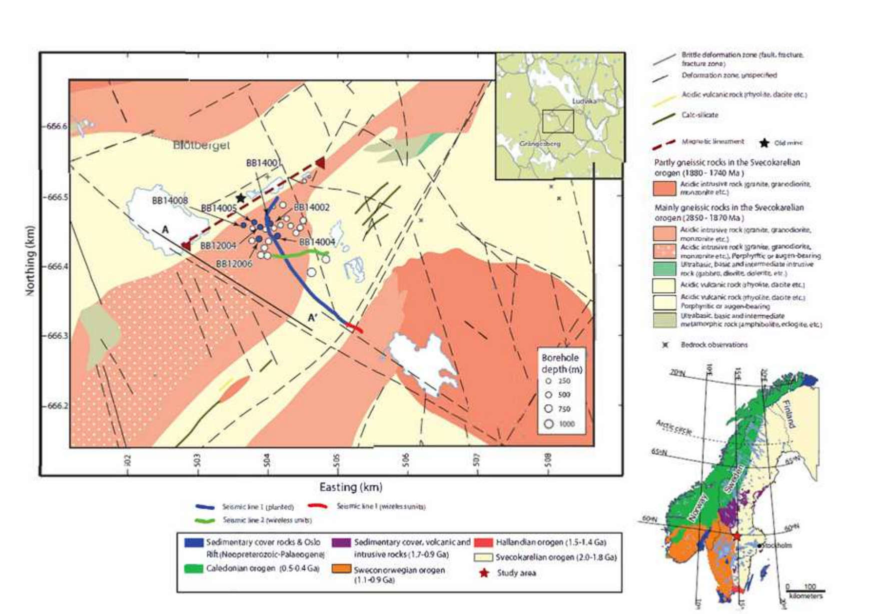

***Figure 1**. Bedrock map of the Blötberget mine showing the location of the seismic profile (blue line) used in this study (modified from Maries et al. 2017a).*

Seismic interferometry for surface-wave retrieval and suppression with adaptive subtraction

SI can estimate the Green's function between receiver locations by cross-correlating seismic observations at those locations. When SI is applied to active-source data, virtual sources are generated at the position of the receivers. For a line survey, as all active sources are at the surface, they all will contribute to the retrieval of the direct P- or S- and surface waves because all of them fall into the so-called stationary phase region (Snieder 2004). This way, the result obtained by SI will be dominated by surface waves, as they are the most energetic arrivals in a recording from active sources at the surface. For this study, we do not retrieve the surface waves in the northernmost 50 stations of the dataset where the line is curved. In this part of the line, the estimation of surface waves is hampered due to the fact that just a few receivers are positioned inline with the active sources.

Note that in order to obtain good estimations of the surface waves for each shot gather, the position of the retrieved virtual sources (which corresponds to receiver positions) need to coincide with the position of the active sources. For the particular case of the Ludvika dataset, we can assume that the surface waves will be well represented since there are active sources at each receiver location. These estimates can be adaptively subtracted from the full responses recorded in the field. We refer to this technique as interferometric ground-roll removal (Dong, et al. 2006; Halliday et al. 2010; Konstantaki et al. 2015). To perform adaptive subtraction, we estimate a shaping filter that minimizes the difference between the field-recorded data with the ground roll and the surface waves retrieved from the application of SI to the field-recorded data.

Results

Before applying SI, we perform a power-spectrum analysis of the Ludvika 2016 dataset and filter it with a band-pass filter to reject frequencies that might contain reflection and refraction events. This way, we retrieve SI data with minimal reflection energy. The thus prepossessed data are then subjected to SI and adaptive subtraction from the original data.

Figure 2a shows an example of a recorded common-source gather. We can see that the record is contaminated by surface waves that overlap the mineralization signature (red arrows). In Figure 2b, we show the result after surface-wave suppression. We can see now that new features are revealed at later times and the mineralization signature is clearer.

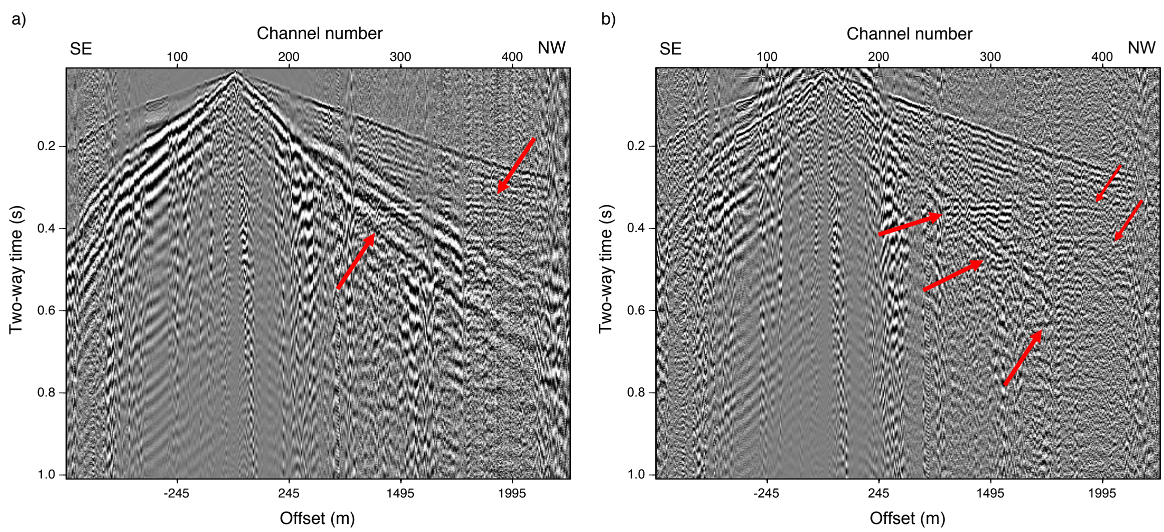

Figure 2. *a) An example of common-shot gather acquired in the Blötberget mining area and used for adaptive subtraction of surface waves. b) Result after adaptively subtracting the surface waves estimated with SI from a).*

After the interferometric suppression of the ground roll, we continue with a conventional CDP processing sequence to obtain a stacked section of the subsurface. The processing is focused on noise attenuation and signal enhancement by frequency filtering in order to illustrate the effectiveness of the proposed method. We apply a low-cut frequency filter to remove any noises that remain in the dataset and an automatic gain control for amplitude balancing. After this, we perform a velocity analysis along the line. We examine constant-velocity stacks and we create a 2D velocity model to generate a final stacked section of the subsurface.

In Figure 3, we show (a) the unmigrated stacked section of the subsurface for the raw field dataset and (b) for the datasets with interferometric ground-roll removal (b). The high-amplitude and high-frequency noise are clearly well suppressed while the mineralization signature is better revealed. The image is cleaner, less noisy, and the mineralization reflectors are more continuous. Additionally, after performing the SI ground-roll removal, we can see a shallower reflection around 0.1 s that now allows its interpretation. Such a reflection is obviously drowned into the surface-wave noise in Figure 3a.

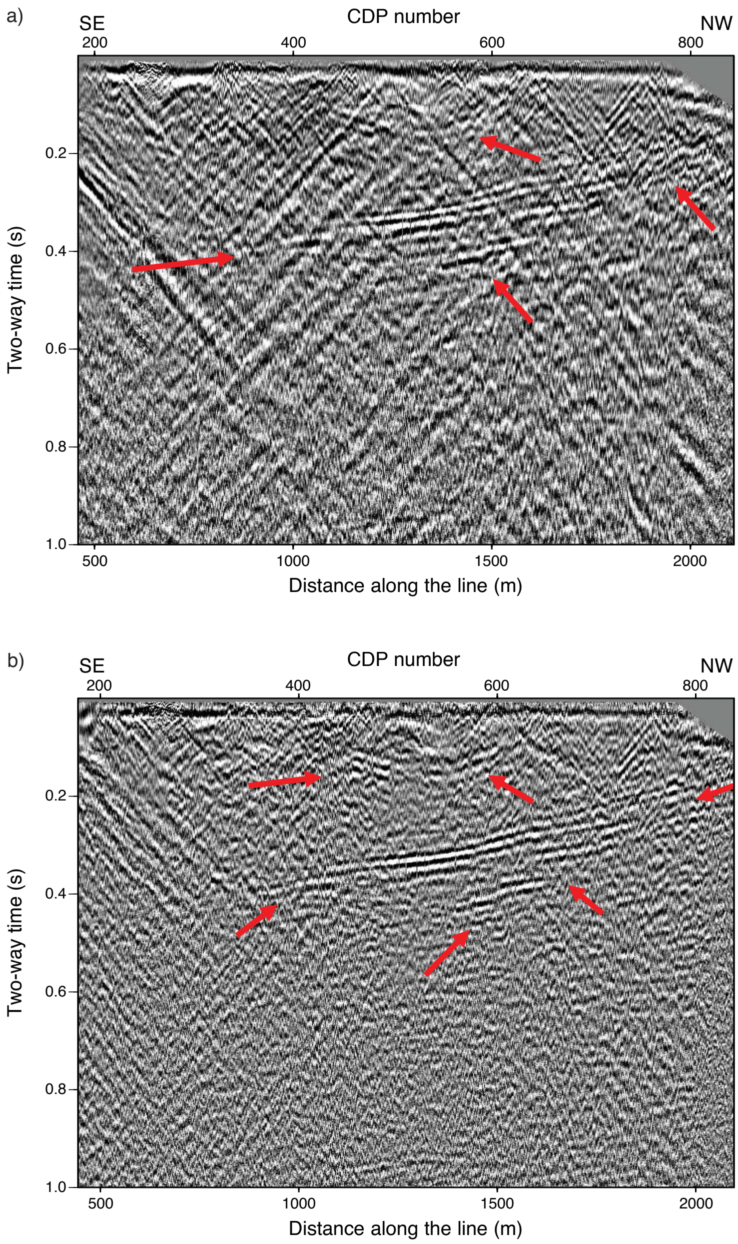

Figure 3. *Unmigrated stacked section using a picked 2D velocity model obtained from (a) the original dataset and (b) from the dataset processed for interferometric ground-roll removal.*

Conclusions

We processed a set of reflection seismic data acquired for iron-oxide mineralization exploration in Blötberget of the Ludvika mining area, south-central Sweden. We retrieved dominant surface waves between receivers applying seismic interferometry and then adaptively subtracted them from the original data. We have showed an enhanced and more continuous delineation of the mineralization and also new features above and below the known deposits. This method of surface-wave suppression is fully data-driven.

This study shows the potential of seismic methods in exploration of deep deposit targets. It also tends to show the value of legacy data and how they can be optimally reprocessed for generation of new targets using novel seismic processing techniques.

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. We thank Uppsala University and Nordic Iron Ore AB (NIO) for providing access to the datasets and collaborating with us through the Smart Exploration project. The seismic data were processed using a combination of Seismic Unix, ProMAX and software from the Delphi Consortium.

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