Illumination diagnosis for retrieval of reflections from ambient-noise seismic data in the Siilinjärvi mining site, Finland

Original
Illumination diagnosis for retrieval of reflections from ambient-noise seismic data in the Siilinjärvi mining site, Finland / Papadopoulou, M.; Draganov, D.; Koivisto, E.; Savolainen, M.; Sito, L.; Socco, V.. - (2020), pp. 1-5. (3rd Conference on Geophysics for Mineral Exploration and Mining, Held at Near Surface Geoscience 20202020) [10.3997/2214-4609.202020105].

Publisher:
European Association of Geoscientists and Engineers, EAGE

Published
DOI:10.3997/2214-4609.202020105

Illumination Diagnosis for Retrieval of Reflections from Ambient-Noise Seismic Data in the Siilinjärvi Mining Site, Finland

M. Papadopoulou[1], D. Draganov[2], E. Koivisto[3], M. Savolainen[4], Ł. Sito[5], V. Socco[1]

[1] Politecnico di Torino; [2] TU Delft; [3] University of Helsinki; [4] Yara Suomi Oy; [5] Geopartner s.p. z.o.o

Summary

Reflection seismic methods are becoming popular in mineral exploration, because they allow high-resolution delineation of the exploration targets, even at great depths. Seismic interferometry can be used to retrieve reflections from passive seismic data, removing the need for active seismic sources and, therefore, reducing the cost and environmental impact of exploration. The retrieval of reflections can be challenging, since passive seismic records are typically dominated by surface waves. Therefore, illumination diagnosis, a method which allows the isolation of the portions of the passive data where body-wave signals are stronger, can be a valuable step that improves the quality of the reflections retrieved from seismic interferometry and reduces the overall computational cost of the processing stage. Here, we validate the performance of the method to effectively isolate the portions of the passive data dominated by body waves and apply it on an ambient-noise seismic dataset acquired in the Siilinjärvi mining site in Finland.

Introduction

In mineral exploration, the seismic reflection method has been proven to be an effective geophysical tool that allows high resolution imaging at great depths. The possibility of using passive seismic, instead of the traditional active one, makes the reflection method even more attractive, since it reduces the overall cost and the environmental impact of exploration. Moreover, it allows data acquisition in areas where the use of active sources is restricted due to logistics (e.g., in presence of challenging surface conditions, rough topography), or safety reasons (e.g., in the proximity of industrial activities). The seismic reflections can be extracted from passive-source data by applying seismic interferometry, which allows the retrieval of the Green's function between pairs of receivers as if one of the receivers would be a source. The method has been successfully applied to ambient-noise data for the extraction of both surface waves (SW, e.g., Shapiro and Campillo 2004) and body waves (BW, e.g., Draganov et al. 2009). Nonetheless, the extraction of BW, which is the target in exploration, can be challenging, since ambient-noise records are typically dominated by SW. A possible solution to enhance the retrieval of BW, and at the same time reduce the computational cost of the processing stage, is to use only the portion of the records where BW are dominant, using the illumination diagnosis method proposed by Almagro Vidal et al. (2014). Here, we optimize and apply illumination diagnosis on ambient-noise data recorded in the Siilinjärvi mining site in Finland.

Method

The recorded noise is split in panels (time windows) for which cross-correlation is performed for a unique virtual-source position. For each correlated panel, the slant-stack transform is computed and the maximum amplitude of the transform, for events passing through the virtual-source positions at time t=0 s, is found. The corresponding slowness value (p) is compared to a threshold, user-defined slowness, p_{lim}, which represents the limit between the characteristic slowness of SW and BW. This allows to automatically separate the panels dominated by BW from the ones dominated by SW. Only the noise panels for which $p<p_{lim}$ are chosen for subsequent processing. Since SW events coming from the cross-line direction are expected to have high apparent velocity, the method should be applied on, at least, two crossing lines, to avoid misinterpreting SW noise as retrieved reflections. A panel is selected for further processing only when it is characterised by a low dominant p along both lines.

Site description

The Siilinjärvi phosphate (apatite) mine is located in eastern Finland (Figure 1a). The deposit (mainly carbonatite-glimmerite) extends to a currently known depth of 700 m, and is hosted mainly by granite and gneiss (O'Brien et al. 2015). Previous studies (Malehmir et al. 2017) have shown that the ore body is characterized by a complex reflectivity pattern, caused by the intrusion of diabase dykes and tonalite-diorite, as well as fracturing and shear zones. A 2D/3D active- and passive-record seismic dataset was recorded in the area in 2018, with the target of mapping the extension (lateral and in depth) of the deposit, especially towards the south of the main mine pit (Figure 1b). The passive array (Figure 1b) consists of 578 wireless vertical-component geophones (10 Hz), which recorded noise almost continuously for 13 days (24th of September to 6th of October) at 500 Hz, and the data were stored in 1-minute segy files, with a total size of 765 GB. Here, we analyse the data recorded from the stations along lines SM2 and SM3 (highlighted in red in Figure 1b), which consist of 45 and 62 receivers, respectively, spaced at 50 m.

Data processing and results

The 1-minute-long segy files were split into 10-s panels. To select the processing strategy that would optimize the retrieval of BW, we performed tests on noise panels where BW were dominant, due to the passing of military jets which occurred at known time periods. In Figure 2a, we show the 10-s record of line SM2 (top) and SM3 (bottom), capturing the passing of a jet on 25/09/2018 at 11:27 am. In both records, a high-amplitude event, corresponding to the plane wave generated by the jet, is clearly visible. The corresponding raw correlations (Figure 2b), computed using as virtual source the trace located at the intersection of the two lines (green point in Figure 1b), present high levels of noise, which hinders the identification of the plane wave, particularly for line SM3 (bottom panel of Figure 2b). In Figure 2c we present the same correlations, after applying a band-pass filter (20 Hz – 80 Hz) and deconvolving using a short window extracted around t=0 s from the autocorrelated virtual-source trace. Since the quality of the event of interest was significantly improved, the same filtering was applied on the entire dataset, prior to the illumination diagnosis.

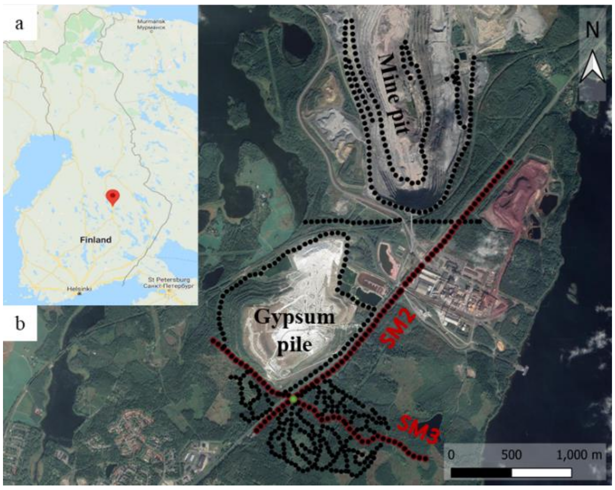

Figure 1 *a) Map of Finland where the location of the Siilinjärvi mine is indicated. b) Wireless-station array (black dots) of the 2018 passive seismic survey. In red, we highlight lines SM2 and SM3, used in the current work, and in green we show the trace position used as virtual source for the correlations in Figures 2b and 2c and Figures 3a and 3b.*

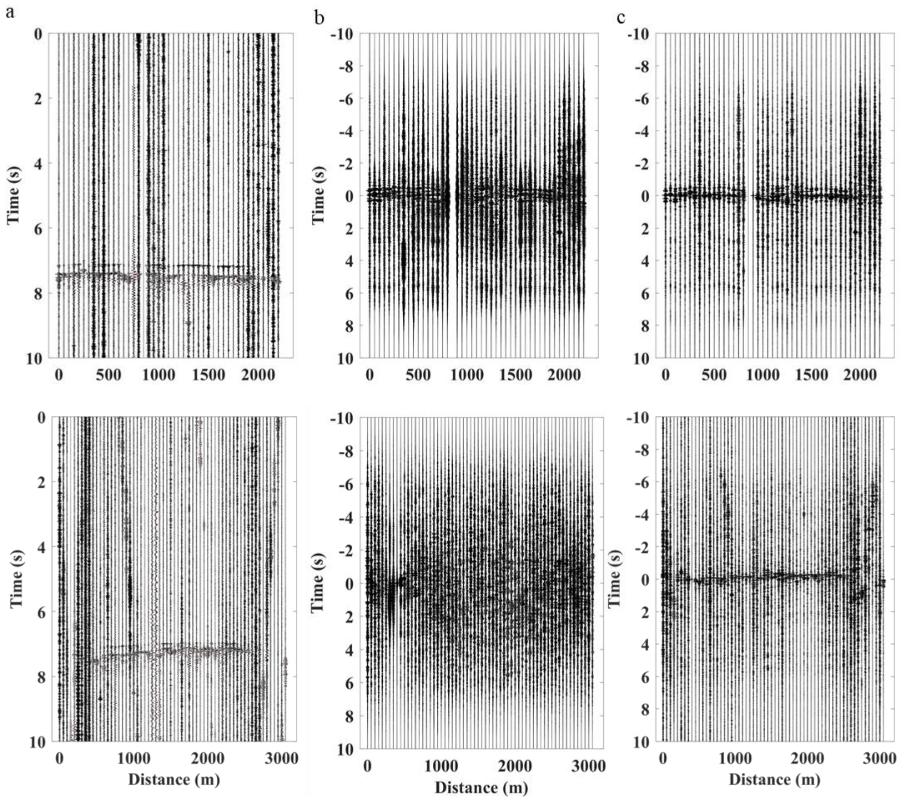

Figure 2 *a) Raw noise panels capturing the passing of a military jet, which occurred on 25/09/2018 at 11:27 am, recorded on line SM2 (top) and SM3 (bottom), and their corresponding b) raw and c) filtered correlations.*

We tested the performance of the illumination diagnosis by assessing its ability to identify the top and bottom panels of Figure 2c (labelled as "1" in Figures 3a and 3b, respectively) as BW-dominated and identify them among five additional random 10-s panels, numbered from "2" to "6" in Figure 3a (line SM2) and 3b (line SM3). The discrimination result is given in Figures 3c and 3d, for lines SM2 and SM3, respectively. The crosses represent the slowness of the maximum-amplitude event in the τ-p spectrum for each panel, and are compared with the threshold p_{lim} (green lines in Figures 3c and 3d), which was chosen as 2.5x10^{-4} s/m, based on prior knowledge of the SW phase velocities on the site (Colombero et al., 2020). Events with $p<p_{lim}$ were identified as BW (blue in Figures 3c and 3d) and the ones with $p \geq p_{lim}$ were identified as SW (magenta in Figures 2c and 3d). These results show that only the panels of interest (labelled as "1" and highlighted by the red box in Figures 3a and 3b) were identified as BW-dominated for both lines, while panel "4", identified as BW-dominated only in line SM2, was excluded from further processing, proving the efficiency of the method.

The results of the illumination diagnosis on all the correlated panels of the 13-day dataset are given for SM2 and SM3 in Figures 4a and 4b, respectively. We highlight in magenta the maxima corresponding to SW and in blue the ones corresponding to BW. Even though more than 97 % of the maxima correspond to SW, we were able to identify 1366 noise panels with dominant BW along both lines, which were automatically extracted and will be subject to further processing for reflection retrieval.

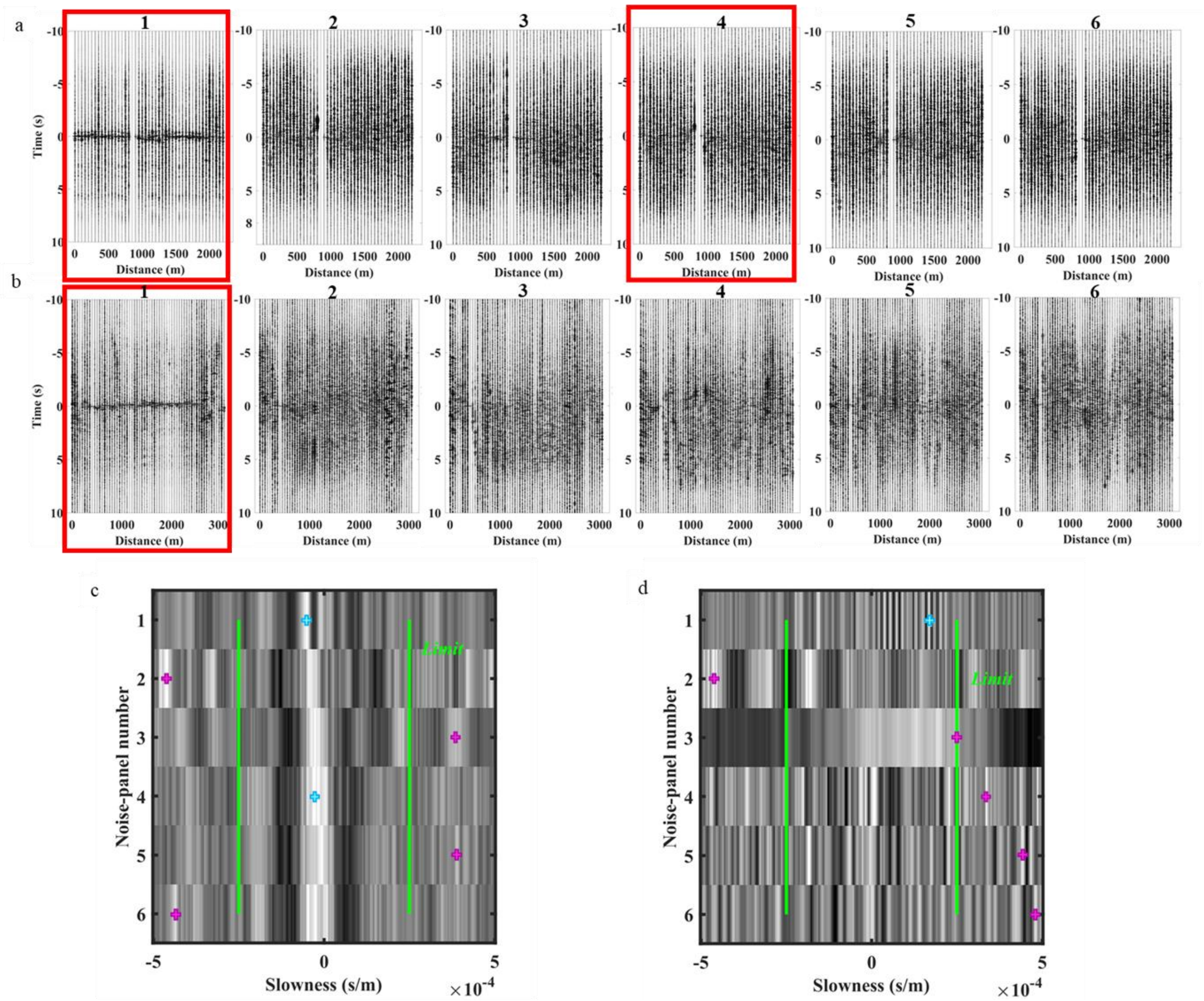

***Figure 3** Six test correlation panels for line a) SM2 and b) SM3. Illumination diagnosis applied to the six test correlation panels of c) line SM2 and d) line SM3. In (c) and (d), the crosses highlight the dominant slowness. Blue crosses correspond to panels found to be dominated by BW (red boxes in Figures 3a and 3b) and magenta – the ones dominated by SW.*

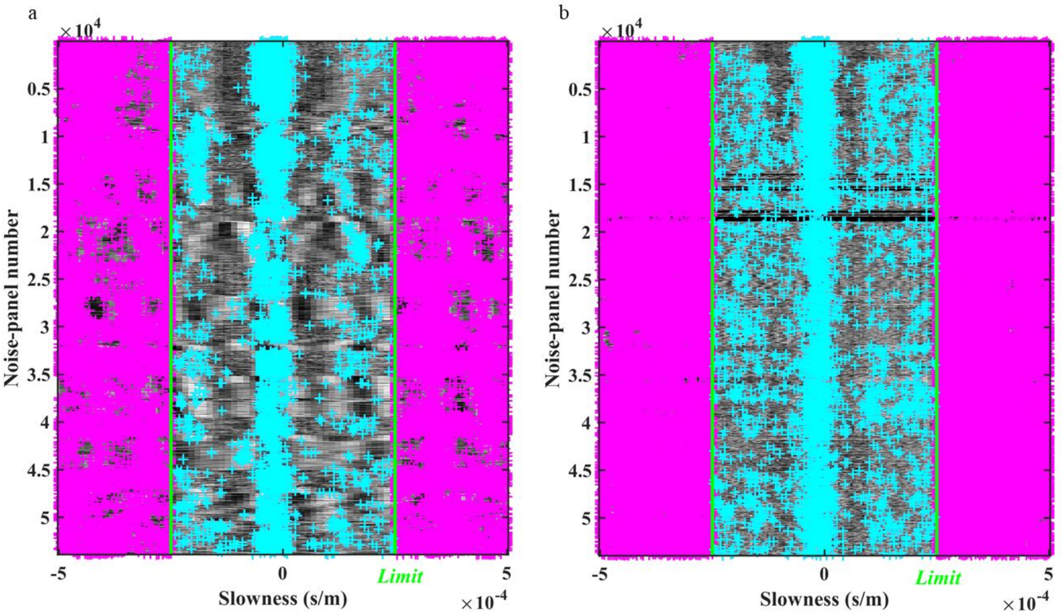

Figure 4 *Illumination diagnosis applied to the complete 13-day record along line a) SM2 and b) SM3. Blue crosses correspond to panels dominated by BW, while magenta to panels dominated by SW.*

Conclusions

We have shown that valuable body-wave (BW) information is contained in the ambient-noise records of the Siilinjärvi mining site, making seismic interferometry a good candidate for retrieving seismic reflections. Tests on noise panels dominated by BW showed that the illumination-diagnosis method is a fast and reliable tool that can help improve the retrieval of BW reflections, improving the applicability of passive seismics on such a large-scale exploration dataset.

Acknowledgements

Smart Exploration has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 775971. We thank Yara Suomi Oy for their very kind hospitality. The data were acquired using combined seismic equipment of Uppsala University and Geopartner Sp. z.o.o., for which we are thankful. We thank everyone who participated in the survey, especially the M.Sc. and Ph.D. students whose work was vital during the field work.

References

Almagro Vidal, C., Draganov, D., van der Neut, J., Drijkoningen, G. and Wapenaar, K. [2014]. Retrieval of reflections from ambient noise using illumination Diagnosis. Geophysical Journal International.

Colombero, C., Papadopoulou, M., Da Col, F., Koivisto, E., Sito, Ł., Savoilainen, M. and Socco, V. [2020]. Extraction of surface-wave dispersion curves from ambient noise data in a mineral exploration site in Finland. EAGE extended abstracts.

Draganov, D., Campman, X., Thorbecke, J., Verdel, A. and Wapenaar, K. [2009]. Reflection images from ambient seismic noise. Geophysics, 74, A63–A67.

Malehmir, A., Heinonen, S., Dehghannejad, M., Heino, P., Maries, G., Karell, F., Suikkanen, M. and Salo, A. [2017]. Landstreamer seismics and physical property measurements in the Siilinjärvi open-pit apatite (phosphate) mine, central Finland. Geophysics, 82(2), B29–B48.

O'Brien, H., Heilimo, E. and Heino, P. [2015]. The Archean Siilinjärvi carbonatite complex. In: Mineral deposits of Finland. Elsevier, 327–343.

Shapiro, N. and Campillo, M. [2004]. Emergence of broadband Rayleigh waves from correlations of the ambient seismic noise. Geophysical Research Letters, 31, L07614.