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Ayse Kaslilar Sisman
PhD, Senior Lecturer
Department of Earth Sciences
Villavägen 16, S-752 36 Uppsala
Sweden
Mobile: +46-(0)70-2159179
E-mail: ayse.kaslilar@geo.uu.se
Web page: https://www.geo.uu.se/

REPORT on ***Michal Chamarczuk*'s** doctoral dissertation titled: ***Development of seismic body-wave interferometry imaging for mineral exploration.***

Extracting Green's function by seismic interferometry (SI) using active and passive sources became increasingly popular in the last decades. SI is widely applied to ambient noise records in crustal seismology and it is efficiently used particularly in seismically quiescent areas to image the subsurface. Besides its wide and effective applications in seismology, SI is successfully applied in engineering and environmental seismology, and recently in mine exploration using both active and passive sources.

The demand for raw materials is growing, and it is important to explore the mineral resources in a sustainable manner by minimizing the impact on the environment and climate. Therefore cost-effective, sustainable, environmental and climate friendly mineral exploration is crucial for climate neutral world.

Imaging subsurface with the help of seismic noise records is an environmentally friendly and cost-effective method when compared to active source seismic studies. Therefore, improving or developing new methodologies in this field is an important effort having great potential to be widely applied in future studies.

Extracting useful information from passive data requires sufficiently long records which depends on the material properties of the subsurface, the complexity of the medium and the depth of the target. That means a detailed and large amount of data processing is necessary to get the subsurface image. Therefore, contributions to efficient data processing are essential.

Machine learning (ML) methods became very popular in recent years for geophysical applications. ML may contribute to efficient, (near) real-time data processing and for re-planning of the seismic survey when necessary.

In this thesis, cost-effective body-wave reflection imaging methodologies based on SI are proposed and developed for mineral exploration. Two continuous noise field data sets are used and the feasibility of the methods are examined. These passive seismic imaging methods can contribute to sustainable, environmental and climate friendly mineral exploration.

Based on the published articles, the summary of the thesis is given as follows:

The thesis by *Michal Chamarczuk* titled *Development of body-wave seismic interferometry imaging for mineral exploration* is in total 155 pages.

The thesis consists of the following sections: Summary, introduction, summary of papers, summary and conclusions, references, list of the papers, acknowledgements, reprints and author contribution statements.

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Paper 1: *Chamarczuk M. et al., 2019, Automatic 3D illumination diagnosis method for large-N arrays: Robust data scanner and machine-learning feature provider, Geophysics 84(3).*

In the first paper, an efficient and robust automatic detection method is developed to identify the body-waves that can be further used for reflection imaging. The feasibility of the method and ML techniques in the detection of body waves is examined by using large-N arrays. The effectiveness of the two-step wavefield evaluation and event detection method (TWEED) is shown both in synthetic and field data collected in the polymetallic mine in Eastern Finland. The proposed method can discriminate body and surface waves. This work is supported by the projects COGITO-MIN and IG PAS.

Paper 2: *Chamarczuk M. et al., 2020, Unsupervised Learning Used in Automatic Detection and Classification of Ambient-Noise Recordings from a Large-N Array, Seismological Research Letters 91(1).*

In this paper, a methodology is proposed for the automatic classification of events from Large-N array continuous noise records. The proposed method combines array processing and ML techniques for unsupervised clustering of the continuous seismic records and allows the detection of different types of events such as surface and body waves generated by different sources. Classified events can be used for further processing like surface wave tomography, reflection imaging and similar. The method is applied to the field data collected in the polymetallic mine in Eastern Finland. This work is supported by the project COGITO-MIN.

Paper 3: *Chamarczuk M. et al., 2021, 2D body-wave seismic interferometry as a tool for reconnaissance studies and optimization of passive reflection seismic surveys in hardrock environments, Journal of Applied Geophysics, 187.*

In this paper, a 2D seismic interferometry processing workflow for continuous data is proposed by considering both event-driven and noise volume approaches. Multidimensional deconvolution, crosscorrelation and crosscoherence based SI methods are applied to noise data and their results are compared and discussed. The aim of this study is to select the optimum SI processing flow and provide an initial target delineation by using 2D records, which can further be used for designing and processing efficient 3D exploration surveys. The method is applied to the field data collected in the polymetallic mine in Eastern Finland. This work is supported by the project COGITO-MIN.

Paper 4: *Chamarczuk M., et al., 2021, Characterization of drilling-related noise and curvelet-based evaluation of seismic-interferometric reflections for imaging of iron-bearing formations in Pilbara, Western Australia, Geophysical Journal International.*

In the past few decades imaging while drilling became a technique both in tunnelling and drillbit operations. Near real time imaging can help safe drilling operations, and to mitigate geological and environmental hazards during drilling.

In this paper, the noise data generated by the drill bit is used to characterize and classify different noise sources related to specific field operations during drilling. After noise characterization, the virtual source gathers of reflection events can be used for active-source data processing and imaging purposes. The main goal is to extract the useful information which will contribute the best for imaging the subsurface by reflected body-waves during drilling. For this purpose, a semi-automatic data-driven curvelet-based method is proposed and the applications are shown in a field data collected in an iron ore mineralization in Western Australia. This work is supported by FULLIMAGE project National Science Centre Poland.

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In summary:

- The thesis is well organized and clearly written.
- The literature is up to date.
- The goals of the thesis are clearly stated.
- Four processing methodologies are proposed for efficient and cost-effective reflection imaging of passive seismic records in mineral exploration.
- Four papers are published in high-quality journals in the field of geophysics.
- The PhD candidate's contribution to each paper is 75%.
- The PhD candidate has also contributed to two more articles and 5 extended abstracts
- The thesis is supported by the projects ERA-MIN\COGITO-MIN, IG PAS, National Science Centre Poland\FULLIMAGE, including academia-industry collaborations.
- The field data sets used in the study are from the polymetallic mine in Eastern Finland, and iron ore mineralization in Western Australia. Having an opportunity to test the proposed/developed methods on real data is invaluable and many PhD candidates, academics and researchers do not have this chance. I believe proving or emphasizing the gaps and the needs of a proposed methodology by field data is crucial in geophysical applications. In this thesis, the proposed workflows are applied to real data and their feasibilities are examined.
- The proposed methods can further be developed and improved.
- The developed methods have the potential for industrialization.
- Particularly nowadays it is important to contribute to sustainable, resource-efficient exploration technologies, and in this manner, I believe this thesis contributes not only to scientific knowledge but also to civil society.

Conclusion:

Based on the written thesis; the topic, the content and the contributions (CRediT) of the PhD candidate to the published articles show that the candidate has good theoretical knowledge and the ability to conduct independent research.

To my knowledge, and based on these published articles in high-quality journals of geophysics, the contribution of the thesis is original.

Based on my conclusions and the arguments bulleted above,

I conclude that the PhD candidate Michal Chamarczuk can defend his thesis.

This PhD dissertation can be recommended for PhD distinction award.

Sincerely,

Ayse Kaslilar
13.07.2021