

IGF-SN-420-03/23

SEKRETARIAT NAUKOWY INSTYTUT GEOFIZYKI PAN	
05	WPLYNEŁO 2024w.
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Krakow, 03 VI 2024

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## Review

of the doctoral dissertation prepared by Quang Nguyen

titled "Processing and interpretation of new and vintage multi-channel reflection seismic data offshore Poland"

made at Institute of Geophysics Polish Academy of Sciences under the supervision of Prof. dr. Michał Malinowski.

### 1. Scope and purpose of the work

The peer-reviewed dissertation consists of two publications that appeared in 2023 in foreign scientific journals with impact factors 3.4 (Solid Earth) and 4.2 (Marine and Petroleum Geology):

- Nguyen, Q., Malinowski, M., Mazur, S., Stovba, S., Ponikowska, M., and Hübscher, C.: Post-Caledonian tectonic evolution of the Precambrian and Palaeozoic Platforms boundary zone offshore Poland based on the new and vintage multi-channel reflection seismic data, EGUsphere [preprint], *Solid Earth*, <https://doi.org/10.5194/egusphere-2023-2909>, 2023.
- Nguyen, Q., Malinowski, M., Kramarska, R., Kaulbarsz, D., Mil, L. and Hübscher, C., 2023. Gas-Escape features along the Trzebiatów fault offshore Poland: Evidence for a leaking petroleum system. *Marine and Petroleum Geology*, 156, p.106431.

In both works, the PhD student is the first author. The publication lists the elements of the manuscript for which the Doctoral Student was responsible. In the first article the PhD Student's participation in the publication is assessed as: Conceptualization, Methodology, Data Curation, Writing – Original Draft preparation, Software, Visualization. In the second article the PhD Student's participation in the publication is assessed as: Conceptualization, Methodology, Data Curation, Writing – Original Draft preparation, Software, Visualization. The Doctoral Student does not indicate his percentage contribution in the dissertation.

The purpose of the work and the main theses of the work have been clearly written down. The PhD student aims to develop processing workflows and then use the processed and reprocessed data in seismic interpretation related to selected geological problems of the study area. The work uses both new seismic data, obtained

from the BalTec project (2016), and attempts to reprocess older, lower quality data from the PGI-TNO'97 dataset.

The aim of the thesis was to combine new and old seismic data in such a way as to recognize the complex structure of the south-western Baltic Sea. For this purpose, the PhD student acquired raw data from the BalTec project, which was collected by the Federal Institute for Geosciences and Natural Resources Germany (BGR) in the Baltic Sea in 2016. Around 850 km of the multi-channel seismic data were acquired in the Polish EEZ. The BalTec data were unique by providing imaging directly from the seafloor (multibeam, Parasound data) to the deeper sedimentary layers along the same transects. The PhD student also used data acquired in 1996-98 by the Netherlands Institute of Applied Geophysics (TNO), PGI-TNO'97 for which he performed reprocessing thus completing the study area. In order to obtain a detailed picture of the sedimentary cover and its substrate in the study area, the PhD student developed a processing and imaging strategy for shallow-water marine seismic reflection data for this dataset and this is described in the reviewed dissertation. The theme undertaken by the Doctoral Student is ambitious, requiring above all the construction of a workflow for processing new and old seismic data, integrating different qualities of data and interpreting them comprehensively.

## 2. Structure and content of the dissertation

Basically, the dissertation is well organized. The text of the dissertation comprises 180 printed pages, comprising: 6 chapters, a list of figures, tables and abbreviations, abstracts in English and Polish, an introduction, a summary, a bibliography and two appendices. The structure of the work is correct and clear, with an appropriate number of tables and figures. Tables and figures are both, necessary and helpful. In the work, the Doctoral Student collected and used a large number (249 literature items in total) of publications from foreign and national journals. The literature list requires minor reorganization.

### Introduction:

Provides a general introduction to the research topic and includes a detailed highlighting of the questions to which the Doctoral Student seeks answers in his dissertation. The Author poses three main questions that he tries to answer: 1. What are the problems of shallow marine seismic data acquired in the southern Baltic Sea? How efficient is the processing workflow of the new BalTec seismic data? How much reprocessing improves the image of the vintage 2D seismic data compared to the original processing flow? 2. What novel information can be interpreted from the new BalTec data? In particular, what is the structural relationship between the Caledonian Deformation Front, Koszalin Fault and sedimentary cover in the transition between EEC and WEP? 3. Is there any evidence in the BalTec data of gas escape from the deep sediments offshore Western Pomerania? If yes, what is the gas's potential origin

and how could it migrate to the seafloor? Is the gas trapped below the seafloor or leaking to the water layer?

In this thesis, the PhD Student looking for answer the questions posed by:

- creating a processing process for seven BalTec profiles (~1000 km) from raw shots to time-migrated sections, with particular emphasis on noise removal and multiple reflections;
- re-processing of archival 2D seismic data (~950 km) from the PGI-TNO'97 dataset;
- use of the newly processed and re-processed data, together with selected older profiles off Bornholm (DBE data) for seismic interpretation of the Koszalin Fault area;
- integration of BalTec MCS, multibeam and hydroacoustic data to identify the presence of shallow gas off the coast of West Pomerania, using structural and quantitative (AVO) seismic interpretation.

#### Chapter 1:

Presents an overview of regional tectonic and structural elements in the south-western part of the Baltic Sea. The author describes the study area in terms of geographical, geological and sedimentological location and tectonic

#### Chapter 2:

Presents the dataset used in this PhD dissertation.

BalTec (2016) seismic data were used as the main seismic data sets throughout the dissertation, and several selected profiles of the processed PGI-TNO'97 (1996-1998) and DBE (Danish Bornholm Enclave, 1982) data sets were used to confirm and comprehensive the seismic interpretation. The BalTec dataset had 7 profiles (BGR16-201, 202, 212, 256, 257, 258, 259) in the Polish EEZ, extending to the German, Danish and Swedish EEZs (total length approximately 1000 km). Data were available as raw shot gathers together with the onboard processing results (migrated stacks).

The PGI-TNO'97 seismic profiles were acquired in 1996-98 by the Netherlands Institute of Applied Geophysics (TNO) onboard the M.V. "Dr Lubecki" vessel, provided by the Maritime Institute, Gdansk, in the Baltic Sea. The data (ca. 4000 km total length) covered Polish EEZ and also partly the adjacent German, Danish, and Swedish EEZs. The seismic data were initially processed at TNO up to stacked sections.

DBE (Danish Bornholm Enclave) 2D seismic data, acquired offshore Bornholm in 1982 by Western Geophysical were also used. Only post-stack time migrated versions were available, the quality of this data was considered relatively good at the time of acquisition.

#### Chapter 3:

Presents background for the methodology used in the thesis. This chapter is a description of both the methodology of procedures and methods used in the work, as well as a description of the theoretical basis of these methods. The Doctoral Student describes the most important issues related to the processing and interpretation of marine seismics and AVO analysis. Seismic surveys conducted in shallow water environments and deep water environments come with distinct challenges due to the differences in water depth, geological conditions, and survey logistics. Author classifies marine seismic disturbances as a guided waves, side-scattered noise, streamer noise, random noise and multiple reflections and shows possible ways to eliminate them. It also shows the effects of applying correction procedures.

#### Chapter 4:

Presents the processing workflow of the BalTec dataset and the reprocessing workflow of the vintage PGI97 dataset.

The PhD Student developed an optimal seismic data processing process for selected BalTec seismic profiles offshore in Poland. Due to the acquisition in a shallow water environment, it will focus on the attenuation of multiple reflections and guided waves through the cascading application of SRME,  $\tau$ -p deconvolution, water bottom F-K filtering and parabolic multiple Radon elimination. The presented workflow is universal and can be used (with possible corrections) for other multi-channel seismic data acquired in the shallow waters. Post-stack migration results of older PGI97 seismic data showed a significant improvement in the overall data quality compared to the original processing images. The author also adds that the reprocessed profiles did not significantly contribute to the interpretation presented in the study.

#### Chapter 5:

Presents the interpretation of the Koszalin Fault zone and Caledonian Deformation Front based on vintage and new seismic datasets. This chapter is an edited version of the submitted manuscript: Nguyen, Q., Malinowski, M., Mazur, S., Stovba, S., Ponikowska, M., and Hübscher, C.: Post-Caledonian tectonic evolution of the Precambrian and Palaeozoic Platforms boundary zone offshore Poland based on the new and vintage multi-channel reflection seismic data, *EGUsphere* [preprint], *Solid Earth*, <https://doi.org/10.5194/egusphere-2023-2909>, 2023.

In the article the PhD Student's participation in the publication is assessed as: Conceptualization, Methodology, Data Curation, Writing – Original Draft preparation, Software, Visualization.

The aim of this study was to create an optimal seismic data processing process for selected BalTec seismic profiles offshore Poland. Due to the acquisition in a shallow water environment, the processing strategy focused on suppression of multiple reflections and guided waves, through cascaded application of SRME,  $\tau$ -p deconvolution, Water bottom F-K filtering, and parabolic Radon multiple elimination. The processing presented here can be easily adapted to other multichannel seismic



data acquired in the Baltic Sea. The improvement of the quality of older seismic data was also investigated PGI97 using modern processing techniques. Unfortunately, the reprocessed profiles did not contribute significantly to the interpretation, mainly due to the original acquisition limitations, post-stack migration results show a significant improvement in overall data quality compared to the original processing images presented in the article: Krzywiec, P., Kramarska, R. and Zientara, P., 2003. Strike-slip tectonics within the SW Baltic Sea and its relationship to the inversion of the Mid-Polish Trough—evidence from high-resolution seismic data. *Tectonophysics*, 373(1-4), pp.93-105. [https://doi.org/10.1016/S0040-1951\(03\)00286-5](https://doi.org/10.1016/S0040-1951(03)00286-5). This in turn confirms the need and validity of the reinterpretation. An attempt was also made to interpret the seismic succession of sediments lying above the crystalline basement in the transition zone between the Precambrian and Palaeozoic platforms. A lack of reference to well logging data was an unquestionable drawback.

#### Chapter 6:

Presents the shallow gas study offshore Western Pomerania. This chapter is an edited version of the published manuscript: Nguyen, Q., Malinowski, M., Kramarska, R., Kaulbarsz, D., Mil, L. and Hübscher, C., 2023. Gas-Escape features along the Trzebiatów fault offshore Poland: Evidence for a leaking petroleum system. *Marine and Petroleum Geology*, 156, p.106431.

In the article the PhD Student's participation in the publication is assessed as: Conceptualization, Methodology, Data Curation, Writing – Original Draft preparation, Software, Visualization.

In this work, multichannel reflection seismic, high-frequency hydro-acoustic and bathymetric data were analyzed. Indications derived from the seismic data include AVO analyses, seismic chimneys, bright spots, and acoustic blanking as well as seismic attributes. The main objective was to identify gas leaks and to link them to deep-seated hydrocarbon reservoirs. Authors indicate two possible migration pathways of free gas from the potential reservoir in the Upper Triassic sediments to the seafloor: through gas chimneys and through reactivated (during the Late Cretaceous inversion) Trzebiatów fault zone. The first migration pathway might be explained that there is an inefficient seal layer on top of the Upper Triassic formation, and free gas could migrate through unconsolidated successions above to the near seafloor. The second migration pathway might be due to a strong reactivation of the existing faults, which created spaces for free gas to escape to the shallow sediments.

#### Conclusion and Outlook summarizes:

The main results of the thesis, addressing the research questions from the Introduction, and provides an outlook for further work.

### 3. Assessment of the thesis

#### Strengths:

The dissertation presents the results of a methodologically advanced analysis of seismic data. The workflow proposed by the Doctoral Student made it possible to show and confirm the structure of the analyzed area of the Baltic Sea. Should be taken into account that the geological framework is quite complicated and the tectonic history still under debate. Therefore, every contribution to establishing certainties is valuable and worth appreciating. This dissertation, based on the analyzed data, confirms the thesis that Koszalin Fault was the main structure controlling Mesozoic subsidence and Late Cretaceous-Paleocene inversion of the eastern portion of the Mid-Polish Trough offshore Poland. The Koszalin Fault reactivated older structural grain inherited from the time of Devonian continental rifting at the margin of Laurussia. The fault runs obliquely to the CDF, the feature that remained inactive since its formation at the Silurian-Devonian transition.

The analysis of gas escapes, based on various measurement methods, confirms their effectiveness in identifying this type of structures. Although the methods used are known in the literature, the PhD Student proves that they can also be successfully used to interpret marine data from the Baltic Sea. The PhD Student also attempts to assess potential migration paths and the connection with the deeper hydrocarbon reservoirs.

The dissertation presents a high level and good understanding by the Doctoral Student of the applied methodology. The dissertation is written using professional terminology, which confirms the PhD Student's mastery of seismic research skills.

The PhD Student has demonstrated the ability to both work with marine seismic data and the ability to reprocess old, lower quality data in a correct way.

Chapters 5 and 6, which are revised versions of journal articles, are skillfully integrated into the dissertation as a whole. The two articles included in the dissertation constitute a complementary set of work and the presented conclusions are supported by the presented results of the work. The remaining chapters of the dissertation complement them well.

#### Weaknesses:

The Doctoral Student reprocessed the archive data, collected in 1996-1998. Improving archive data should aim to achieve a more detailed interpretation of the data. The results of reprocessing the older PGI'97 dataset were not fully utilized in this work. I am asking for a broader comment regarding reinterpretation during the defense.

The Doctoral Student notes that he had limited access to well logging data, there was no information on well logs or detailed lithology available. At the same time, it lists 14

wells in the research area. I regret that it was not possible to obtain any data from well logging, because on the one hand, this data would confirm the results of the seismic interpretation, and on the other hand, it could complement it more precisely. If possible, please refer to this data during your defense.

Minor errors:

- The literature list requires a slight reorganization - it is generally arranged alphabetically. However, if the list includes, for example, 12 publications with P. Krzywiec as the first author, the order of these publications is random and should be sorted according to the year of publication.
- Sometimes in the dissertation, the PhD student uses not the best form of some terms, such as "borehole logging". Among Petrophysicists, when they talk about measurements using geophysical tools in boreholes, the "well logging" term is used.

#### 4. Final remarks

In summary, PhD Student represents a high level of technical experience and theoretical knowledge in the discipline. It reveals the Candidate ability to independently carry out scientific research and publish his results. The presented dissertation contributes to the improvement of methods of processing and interpretation of offshore seismic data in Poland.

My review ends with a positive opinion about the reviewed dissertation. Due to the fact that, in the light of the Reviewer's knowledge, the dissertation by Quang Nguyen entitled "Processing and interpretation of new and vintage multi-channel reflection seismic data offshore Poland" is an independent and original study by the author, it meets the requirements specified in the Act (Dz.U.2018 pos. 1668 with the later changes) of 20 July 2018, Law on Higher Education and Science, I am requesting that Mr. Quang Nguyen be admitted to the next stages of the doctoral proceedings and public defense.

