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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Daniel Wamriew

PhD Program: Petroleum Engineering

Title of Thesis: Location and source mechanisms of induced seismic events

Supervisor: Professor Dmitri Koroteev
Co-supervisor: Professor Roman Pevzner, Curtin University

Name of the Reviewer: Vladimir Cheverda

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Date: 25-08-2022**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

1. Brief evaluation of the thesis quality and overall structure of the dissertation.

The PhD thesis of Daniel Stephen Wamriew is devoted to the analysis and development of the current trends in modern geosciences - machine learning and the use of the Distributed Acoustic System (DAS). The author very well noted the relationship of these areas - for the successful application of machine learning, large amounts of data are needed, the collection of which is very effectively provided with the involvement of DAS. The successes achieved here in providing the necessary instrumental base and the growth of available computing resources make it possible to predict with confidence the expansion of the scope of these methods.

The dissertation consists of five main sections: Introduction, review of the current state of work in this area, presentation of the theory used, description of the case studies considered by the author, conclusion and plan for further work.

In the introductory part of the dissertation, Daniel quite fully describes the current level of development of this direction in relation to the Earth sciences. However, in my opinion, insufficient attention is paid to the description of the application of these methods in seismology, in particular for monitoring the process of stress accumulation in seismically active areas. In my opinion, the problem of controlling the stressed state of the medium in relation to ensuring the safety of such complex engineering structures as bridges, tunnels and others deserves more attention. Undoubtedly, the use of machine learning and DAS to monitor the state of hydrocarbon reservoirs is a very important and demanded task, but processes such as stress accumulation and the formation of areas of increased fracturing caused by this are also a very important and interesting task.

I consider the author's understanding of the need to involve both synthetic and field data as an undoubted merit of the work. It is the former that ensure the conduct of fully controlled numerical experiments, when both the model of the medium and the sources of microseismic are fully known. On this path, a very effectively implemented by the author opportunity opens up for a thorough study of the proposed method, starting from achievable accuracy and up to noise immunity. In my point, the author does not pay enough attention to explaining the possibility of determining the polarization of the wave field using DAS.

I will add that it seems to me appropriate in the part devoted to modeling the wave field, to present in more detail the specific numerical algorithms used by the author. Apparently, this is a ray method, so I would like to see a description of its applicability in terms of the requirements for the geometric structure of the boundaries in the model used. Here it would be interesting to know the author's expectations for the applicability of more accurate algorithms, primarily finite differences or spectral elements. In this case, it would be interesting and important to find out the influence of the choice of the method for numerical simulation during training. Namely, when conducting training, use the ray method, then apply the constructed neural network to the data obtained by finite-difference modeling. At the same time, choose a model such that the data for processing contains events that are not described by the ray method, for example, the presence of diffracted waves. Thus, the influence of the perturbation in the training data set on the result of its application to a specific problem will be studied.

In conclusion, I emphasize that the results presented in the paper cover a very wide range of problems in the field of Earth sciences and clearly confirm the author's qualifications, which, in my opinion, are quite consistent with the PhD degree. In addition, it should be noted that the applicant is fluent in mathematical methods in relation to the theory of seismic wave propagation in three-dimensional media, both in terms of their theoretical description and in terms of mastering a very complex apparatus of modern numerical methods for modeling wave processes and constructing correct algorithms for solving inverse problems. It should also be noted that the applicant has a deep

understanding of various aspects of the current state in the field of localization and description of microseismic events, especially in relation to the monitoring of hydrocarbon reservoirs.

2. The relevance of the topic of dissertation work to its actual content

I have no doubts that the content of the work is fully consistent with the topic of the dissertation. In order to verify this, it is enough to analyze its table of contents. As I already noted, it consists of an Introduction, a review of the state of the art, a presentation of the method used and its application to synthetic and field data, a conclusion and a plan for further research. All of them contain either a review of studies already conducted in this direction, or a presentation of approaches developed by the author. To confirm my words, I will give the titles of some sections that are most closely related to the research topics (the numbering of the sections is taken from the dissertation):

2.2. Reservoir characterization: 2.2.1. Microseismology in reservoir characterization.

3.2. Detection of microseismic events.

3.3. Source mechanism of microseismic events.

3.4. Distributed acoustic sensing.

3.5. Convolutional neural networks.

The list can go on and on, but it is already clear that all sections of the work are directly related to the topic of the dissertation:

3. The relevance of the methods used in the dissertation

The research carried out in the process of working on the dissertation is based both on reliable, repeatedly proven methods, and on the original developments of the author. The first ones I would include:

• Use of the ray method based on dynamic ray tracing in a layered medium;

• Construction of a matrix representation for a wave field excited by sources described by seismic moment tensors;

• Application of the method of least squares for solving overdetermined systems of linear algebraic equations.

• Construction and training of neural networks for solving the problem of localization of microseismic events for data with a high level of noise.

The original solutions proposed in the work include:

• Development of numerical methods for the full wave form inversion, aimed on the simultaneous reconstruction of the velocity structure of the medium and the localization of the location of sources of microseismic oscillations within it;

• Adaptation of the regression approach to perform triple inversion of the full wave field: detection of events, localization of their sources and reconstruction of the velocity model;

• On this basis, the AlexNet [Krizhevsky et al., 2017] architecture, originally developed for image recognition, was applied in order to accomplish the tasks of location of microseismic events and velocity model update, in real-time, from raw microseismic data.

4. The scientific significance of the results obtained and their compliance with the international level and current state of the art

The scientific significance of the work primarily lies in the consistent, carefully thought-out and justified implementation of the approach to the localization of microseismic events based on:

1) Accurate modeling of wave fields by applying the ray method based on the implementation of dynamic ray tracing; the use of dynamic tracing makes it possible to ensure not only the correct calculation of the kinematic characteristics of the wave field, but also in some cases provides correct information about the behavior of its dynamics;

2) A reliable solver for an overdetermined system of linear algebraic equations. This system arises during the reconstruction of the seismic moment tensor, which determines the action of sources of microseismic events.

3) Combining the developed methods for building a neural network focused on the simultaneous detection and localization of seismic events, updating the velocity model and reconstructing the source type. The latter is very important for determining the distribution of the stress field in the medium.

4) Development of methods that ensure the assimilation of DAS data.

5. The relevance of the obtained results to applications

The practical applicability of the results obtained is beyond doubt. Suffice it to say that Chapter 4 is devoted to presenting the results of approbation of the developed neural network on a representative series of numerical experiments. I consider it especially important that such testing was carried out on both synthetic and field data.

6. The quality of publications.

First of all, it should be noted that all the publications cited are related to the topic of the dissertation. Two of them are abstracts of reputable international conferences (SPE and EAGE), and three articles have been published in journals from the Scimago Q1 quartile (Sensors; Computers & Geosciences; Remote Sensing). Thus, I can confidently characterize the level of publications of the applicant as very high in relation to a doctoral dissertation.

Provisional Recommendation

[X] *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

[ ] *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

[ ] *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*