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Review of the PhD Thesis by Artur Marciniak *Analysis Uncertainty-driven imaging in environmental studies*

The topic of this thesis, although not clearly indicated in the title, is related to the one important and urgent problem in geoscience, namely, to the investigations of the influence of rapidly changing climate and extreme and unusual weather conditions on so-called Critical Zone (CZ) of the Earth. The CZ comprehends the biological, chemical, physical and geological materials and processes that work together at the surface region of the Earth (Brantley et al. 2007, Parsekian, 2015). The CZ stars from the upper limit of vegetation and continuing all the way to the bottom of the ground water. To understand the effects of the rapidly changing climate and to ensure sustainable and safe living environment it is essential 1) to know the structure of the CZ and 2) to predict the dynamical processes in the CZ under influence of various weather and climate conditions.

As shown in recent CZ studies (Parsekian et al., 2015), the near-surface geophysical techniques, such as high-resolution seismic refraction and reflection methods, MASW, electrical resistivity tomography (ERT), EM induction methods, ground-penetrating radar (GPR), nuclear magnetic resonance (NMR) etc. play a very important role in investigation of the CZ. There is a number of successful studies of weathering and hydrological processes and of observations of temporal changes in physical properties of rocks in the CZ under influence of weather variability. Therefore, the present thesis is an important contribution to this emerging area of near-surface geophysics application. Several case studies presented in the thesis include permafrost areas in the Arctic, glacial and periglacial landforms in Spitsbergen, mountain areas in the Outer Carpathians, Poland.

The thesis is based on compilation of papers, and the results presented in the thesis are published in six papers in peer reviewed journals. The personal contribution of the candidate to the published results is significant and clearly indicated in Author Contribution Statements. The candidate is the first author in Papers I, V and VI, with personal contributions of 70%, 50% and 30%, respectively. In Papers II, III and IV the personal contribution of the candidate is 20%, 10% and 20%, respectively, and he was involved into writing and revision of the text of all papers.

I have no particular questions related to the papers included into compilation, as all of them have already passed through standard peer-reviewing process.

The thesis generally demonstrates that the candidate's skills in geophysics has been developed during his PhD career stage and that the candidate is able to plan and carry out independent research. Thus, my general conclusion after examining the thesis is that the candidate is qualified for a PhD degree and is ready to proceed to the post-doctoral stage of his research career. In the following I provide more detailed replies to several obligatory questions posed by Polish regulations.

1. *Assessment of the candidate's general theoretical knowledge in the discipline and the ability to independently carry out scientific research*

In my opinion, the thesis demonstrates that the candidate has the solid knowledge of theoretical background of all the geophysical techniques that were used in the papers included into compilation. In addition, the thesis shows deep knowledge of the candidate in forward modelling and inversion of geophysical data (MASW, refraction tomography, ERT) and uncertainly evaluation for each technique. According to Author Contribution Statement, he was involved in all the stages of research at each case-study area, starting from fieldwork and experiment design to data processing and interpretation and writing scientific publications. The ability to carry out independent research is additionally proved by the fact that all the papers passed through the standard peer-reviewing process.

2. *The justification that the solution of the problem in the doctoral dissertation is original*

In order to investigate the structure of the CZ in several case studies presented in the thesis, the candidate proposed to use multi-method approach. Although integration of multi-method data is not a novel idea, there are always problems related to the practical realisation of multi-method experiments (in particular, in harsh conditions of polar or mountainous areas considered in this thesis) and to the development of the workflow for multi-method data interpretation. The candidate proposes to integrate different near-surface geophysical techniques on the base of uncertainty analysis. In Paper I he proposed to integrate several seismic methods using multi-step approach, in which the workflow proceeds from the method with large uncertainty and resolution capability (both in depth and horizontal), namely, MASW, to the high-resolution methods like travel-time tomography and seismic imaging. The uncertainty is treated as a parameter delineating the space of possible solution for each method. This idea is further developed in Papers IV, V. Finally, in Paper VI the candidate presents the workflow for multimethod (multimethod seismic, ERT and DTM) data processing that results in a landslide model for mountainous area. This approach to construct workflow for multimethod data processing could be considered as an original development of the candidate.

In addition, the study resulted in several important discoveries and new knowledge about the CZ in study areas. They are summarised on page 11 of the Introduction.

3. *Opinion regarding the candidate's admission to the public defence of the doctoral dissertation*

Generally, the thesis can be considered as satisfying the requirements for compilation-of-papers type PhD thesis and the candidate can be admitted to the public defence of a doctoral dissertation.

As a weakness of the thesis, I need to mention that all the papers included into the compilation are lacking comparison of physical parameters obtained by analysis of multi-method geophysical data (seismic velocities, electrical resistivities) with the petrophysical information. I found comparison with the borehole data only in Paper IV. Although the results of direct laboratory measurements of rock properties or borehole data are not always available for each study site, a lot of information for comparison can be found in literature or can be estimated for known theoretical multiphase rock models (for example, model including rock matrix and water/ice in different proportions). Such comparison is particularly useful, if the seismic methods are combined with the ERT or EM induction techniques. Moreover, such comparison is providing additional background for uncertainty analysis and sensitivity of each method to temporal variations in rock properties caused by weather variability. The candidate pointed out that such knowledge is important (pages 14-15 in Introduction), but unfortunately, this information was not utilised in the papers. This is the reason why I cannot propose this thesis for application for the distinction.

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Brantley S. L., Coldhaber M. B. & Ragnarsdottir K. V. (2007) Crossing disciplines and scales to understand the critical zone. Elements. 3. Pages 307-314. DOI: 10.2113/gselements.3.5.307

Parsekian, A. D., K. Singha, B. J. Minsley, W. S. Holbrook, and L. Slater (2015), Multiscale geophysical imaging of the critical zone, Rev. Geophys., 53, 1–26, doi:10.1002/2014RG000465.