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Review of PhD thesis

Anisotropy estimation of Lower Paleozoic shales from northern Poland using microseismic data

by

Wojciech Gajek

Reviewer: Dr. Andreas Wuestefeld, NORSAR, 2007 Keller, Norway

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Microseismic monitoring has become over the past 10 years or more a widely applied technology that gives unique insight to the processes in the subsurface. Numerous commercial and academic entities provided a wide range processing approaches. The thesis analyses (amongst other things) the advanced information on anisotropy that can possibly extracted from such datasets. The effect of using anisotropic velocity models in event location is analysed. Furthermore, a different way of looking at event locations using a probabilistic approach is presented. These two aspects of microseismic data are very relevant and as such, this thesis is a welcome contribution to the community and will hopefully serve to better understand the response of the subsurface to man-made stress changes.

This thesis comprises several papers by Wojciech Gajek. In general, this thesis is well written, and concepts are clearly presented. Chapter 2 presents a detailed (synthetic) parameter study on the effect of anisotropic velocity models on the event location. At several occasions I feel the conclusions of the individual chapters are rather summaries, lacking interpretation and outlook. Furthermore, on some occasions I feel that results are given rather qualitatively ("large", "significant", "good aggreement", "not parallel"). It is good scientific practice to give quantitative values, to let the reader decide on significance here. This can then be followed in the discussion and conclusion by a qualitative opinion

The thesis shows the enthusiasm and interest invested by Wojciech Gajek in this work. He analyzed in detail several aspects of microseismic processing and interpretation. In conclusion, I recommend this thesis to be accepted for further proceeding by the PhD committee. The below remarks do not impact my assessment of the thesis as a whole. They can be considered by the author in further publications or when publishing the thesis as a monograph and discussed during the public defense.

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General comments:

Furthermore, I suggest to make figure captions more descriptive to make the thesis more accessible to a broader audience. In particular I struggle to understand Figure 3.11. This in my experience helps to get the occasional reader (of papers) interested to read und try to understand the text. This is getting ever more necessary with the general increase of publications, which leads to readers first scanning through the figures and then deciding if it is worth reading the full publication.

Note that most comments below are meant as general indications for future work. Formulations such as "should" are not meant as requests for changes, but rather as indication of how to address such issues in future work in the upcoming career as a scientist.

Andreas Wuestefeld
Kjeller, Norway
05.02.2020

List of Symbols:

What is the difference between M_w and M_W (Moment Magnitude, and Seismic moment magnitude)

M0 is usually not reserved for Local Magnitude, but rather the Seismic Moment

Introduction:

In your definition, microearthquakes are events below $M_w < 0$. This is arbitrary, though not uncommon. What other definitions could there be?

Chapter 1:

Page 13: You mention that weak anisotropy requires $\varepsilon,\gamma,\delta \ll 1$. Can they be negative?

Page 14: Table 1.1: The values of Thomson's parameter vary within the different cases, not just between the cases. What is the reason for choosing these combinations. Thomson gives examples for real rocks. How do your parameter choices fit in?

Page 14: Table 1.1 These resulting values of difference are interesting and an important quantification of the definition of "weak" anisotropy. Here, a section with discussion and conclusion is missing in my opinion: How do these errors compare to typical error margins in standard velocity estimation methods (borehole seismics, VSP, seismic inversion)?

Page 16: Equation 1.19 is for 2D event location. It would be in my opinion beneficial to refer here to your approach, presented later, on how to obtain the 3D location.

Page 19 (and various other occasions): You are using contractions (hyphened "s", as in *What's*). I may be old-school, but in written texts, especially scientific texts, contractions shall not be used. It is used colloquial, spoken language, not written.

Page 22: last line: there seem to be two reference missing

Chapter 2

Page 27: You are using S-waves of perforation shots. Explosions are typically considered to excite no S-waves (you mention later that SH waves are barely seen on seismograms). How do you explain that S-waves are generated at all?

Page 28: A number of conclusions **ARE** drawn [...]

Page 29: the interpretation of both display types (dots and PDF-stacks) rely on the assumptions that all events are detected. Do you see any advantage for using the PDFs in this respect?

Figure 2.2 Dots have the advantage of visualizing locations interactively in 3D, something difficult to achieve in volumetic PDFs. In you displays you seem to condense all events onto a single slice, neglecting the horizontal extend (in Y-direction) of the fracture. How could you display a 3D representation of the PDF volume?

Page 33: Here you introduce the backazimuth estimation to obtain lateral extent of you event cloud. After introducing several methods to obtain hodograms used by other researchers, your own approach is presented. How does your method results compare to the others? Is your method superior?

Page 36: You say that NORSAR3D software could not generate certain phases due to challenging source effects. Could you elaborate?

Page 39: You assume a rather optimistic error of one sample standard deviation. How does this inversion perform for higher noises? Do your conclusions still hold for all your six tests?

Page 50: Figure 2.18: Can you elaborate on the apparent required layer thickness of 60m? is it an effect of grid resolution, or of head waves, or source-receiver geometry, or something else?

Page 53: your computation times are assuming a full grid search. Do you think other inversion techniques would be able to reach the global minimum or are there too many parameters?

Page 54: This section describes qualitatively the benefits of your approach. This is a long discussion with lots of information and detail. It would here in my opinion help the first-time reader to summarize and compare again quantitively the results, for example in a table.

Chapter 3

Page 55: To obtain γ, you take travel times from events. And then relocate the Microseismic events with the new velocity model. Is this a circular argument? How far did the events move?

Page 57: change perforation's => perforations'. It is plural

Page 57: Typically Figures should be referred to in sequential order. You here already refer to Figure 3.12, omitting Figure2 3.2 to 3.11

Page 61: You discard "all detection not having a proper moveout". Those events can be very interesting, if real. Obviously all your event will end up within the frac-zone. This could alter the interpretation and decision making of a frac job. Can you give examples of discarded triggers? What percentage of triggers did you discard?

Page 62: "... will guarantee accurate locations..." This is a bold statement! Can you please re-iterate on assumptions still made in the processing up to this point and how that influences accuracy. Or do you mean precission?

Page 62: Here, an additional table/figure showing how (far) event locations moved would be better to quantify the improvement. For examples histograms of errors and relative moved distance would be interesting.

Page 62/63: Can you clarify your procedure: how are Figure 3.5, 3.9 and Table 3.2 linked? How did you choose your four-layer model boundaries in Table 3.2? In table 3.5 you are using a five-layer model, with an additional bottom layer. The workflow and thought process could be explained a bit clearer in the introduction to this chapter.

Table 3.5: Your Thomson parameters are actually quite large, compared to table 1.1. Does the assumption of weak anisotropy still apply?

Table 3.5 your Gamma is significantly larger than the log-data. Do you have any explanation?

Figure 3.11 is a mystery to me. I am looking forward to hear an explanation

Page 69: Here you now claim that a calibrated VM guarantees "precise" locations. Earlier you guaranteed accurate locations. Which one is it?

Page 69: you discard "some" events because of "unrealistic" locations, errors, or azimuths. If these events were real, do you have an explanation for such events?

Figure 3.13/14 seem to show raw PDFs, while 3.15/16 also include scaling by magnitudes. Is there any reason for why you prefer here the unscaled PDFs?

Figure 3.17: There seems to be an topographic high in the bottom layer for far-offsets. Is that supported by other data (e.g. seismics) or an artefact of your inversion?

Page 75: ...J1 and J1 are not parallel o SH_max. Quantify by how much not parallel. Already 0.1 degree is strictly speaking not parallel

Page 77: “The systematic rise of the bottom layer [...]”. How much influence has the anisotropy to reach this conclusion

Chapter 4

Page 81: “a 5-layer VTI model was build”. That sounds like you have also 5 different anisotropies, but in Table 3.3 you show only constant anisotropy parameters. Which one is it? Be more precise.

Page 83: For other researchers who want to do a similar study, it would be helpful to report your processing parameters for the SWS: window lengths, filters, ... Figure 4.2 seems to shows rather long windows in the hodogram

Page 83: Did you analyse the automatic quality assessment presented in Wuestefeld et al. 2010? What are your experiences?

Page 92: You could state here explicitly that the data acquisition geometry does unfortunately not allow for such analysis following Baird et al

Chapter 5

You refer to obtaining the Microseismic Volume. But you never explicitly calculate a volume

Conclusion

Here, an outlook would be interesting. What ideas came up during your work that could not be addressed in the time frame of the thesis? Where do you suggest future research to start? What avenues you consider dead-ends and should not pursued?