Review Report of Dominique Fournier's PhD thesis

(Examiner Dr Michel Chouteau)

1. *Scholarly merit*

I have read and examined the thesis "Advanced potential field data inversion with l_p-norm regularization" with great pleasure and interest. The overarching goal of the research work presented is the ability to recover from potential field data, subsurface models that are more coherent with the known or expected geology. In brief, there are three main parts in this research. The first part concerns implementation of a method to obtain a suite of models (from smooth to compact bodies) that all fit the data using an objective function with various sparsity assumptions on the model and model gradients. In order to establish the "best model" from those models a strategy is proposed to extract the dominant features from the resulting models. The second part concerns improvement of the magnetic vector inversion using spherical coordinates and sparse norms. The third part, an application to potential field data from the Kevitsa deposit in Finland show that the methods and the tools developed in the thesis result in models close to the known geology and showing physical properties (density, susceptibility, remanent magnetization) in good agreement with the ones measured on rock samples. In the development of those approaches numerous improvements have been made to cope with large model grids, reduce bias (with scaling) and improve stability in the inversion process and better recover limits of the structures (boundary, strike, dip, etc.).

The methods are generally described clearly and in detail and are usefully illustrated with synthetic examples. Results obtained on synthetic examples and on survey data (gravity, aeromagnetic) from Kevitsa deposit convincingly show that the developed inversions allow the recovery of realistic models (sharp/smooth boundaries) and for MVI inversion the determination of magnetization with stable orientation within units.

In the Conclusion chapter (8), implications of the work are listed. They mainly concern the capability of running large problems (data, model grids), of developing semi-manual to automatic methods for selecting optimal inversion parameters. Limitations of the proposed methods and perspective for future work are given. Overlapping anomalies mostly causes limitations. Future work includes recovering remanent magnetization from joint inversion of multiple datasets and use of machine learning for improving quality control of parameters.

The candidate has been able to link together all those various developments and improvements in a well-structured and well-written thesis. The document is written in good English language with very few misspelling/typo errors. Illustrations are of excellent quality and instructive, and figure captions are usually complete.

2. *Recommended revisions*: see attached list

3. *Overall recommendation*

   This is an excellent PhD thesis. I recommend that the candidate proceed to oral defence. Only minor revisions are needed (they are indicated in the list provided below)

4. *Questions for oral defence*

   4.1. Page 57, line 21: About exploring the model space, "I set $p_x = p_y = p_z$ in all cases". You have not given a reason for setting the p's to the same values. (1) Give the underlying

reason/impact for this. (2) What would be the impact on the recovered models to set p_x, p_y, and p_z at different values (0, 1, 2)?

4.2. Page 62, line 20: "As I am dealing with strictly positive magnetic susceptibility κ…". This is OK when you apply the inversion method to modelled data for which you know that κ is positive. In real applications, magnetic anomalies arise from susceptibility contrasts that can be positive or negative even if the true susceptibilities are positive (caused by ferromagnetic, antiferromagnetic, paramagnetic minerals). What would you do in that case for your sparse magnetic vector inversion?

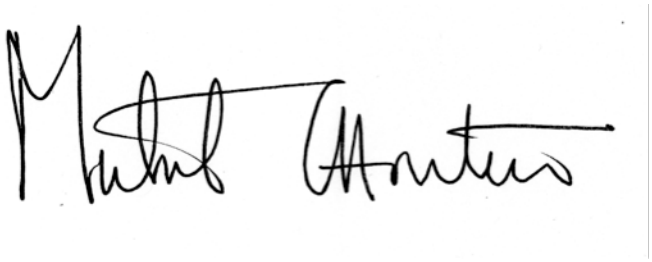
4.3. Page 102, line 3: in performing correlation using a moving window between the average PCA model and each of the m_i solutions, you have used a 20 x 20 pixels window. Why? What are the criteria for selecting an "optimal" moving window for a given inverted model? (See your comments at page 104, lines 1-7). Could it be automatically selected for a given data coverage?

4.4. Page 122, 7.3 Magnetic inversion, line 5: "I determined experimentally a 10 nT uncertainty floor value to the data". What kind of procedure or method did you use to determine the 10 nT uncertainty floor value in the magnetic survey data?

List of Revisions:

- Lay summary is missing
- Preface: page iv, 3d paragraph: "Improvements to the magnetic vector inversion…round of revisions". It is said that the paper is first "accepted" and then that it is "currently in the second run of revisions". What is the real status?
- Chapter 1, page 1, line 4: "The vast majority of known deposits have been discovered this way". This statement, with no accompanying reference to support it, comes after a suggestion that density and magnetic measurements on rock samples along with geological characterization (texture, structure) are the usual data used by geologists to discover deposits. Is that correct even in regions of exposed rocks?
- Page 2, eq. 1.3: $\hat{r}$ is not defined. I suppose it is $\vec{r}$, vector r.
- Page 9, line 8, "…originates from EarthFLs core". I assume that it is "Earth's core".
- Page 13, line 11: "As derived by Nagy (1966)"
- Page 21, line 11: "…wavelet domain (Li and Oldenburg, 2003)"
- Page 22, line 1: "…implementation, Cox et al (2010)"
- Page 31, Figure 3.1: top left figure should be labelled (b) and not (a).
- " " : usually the word "anomaly" is used for the anomalous geophysical response caused by a body or a geological structure. In the case here, the word "body", "structure" should be used. Also, as mentioned in the text, it is simpler to say "…a grid placed 5 m above flat topography" than "… a grid placed 15 m above the anomaly".
- Page 42, line 16: "…in Figure 5 (a)". There is no Figure 5 (a). Do you mean Figure 3.5 (a)?
- Page 57, last line: "…the anomalous region the ~~velocity~~ density is relatively smooth…"
- Page 67, eq. 4.9: In the expression of the Koenigsberger ratio Q, it is the ratio of the remanent magnetization over the induced magnetization and not the opposite, as written.
- Page 77, line 4: "…shows no apparent correlated signal (Fig 4.8 d)."
- Page 80, eq. 5.2: eq. 5.2 is wrong and not equivalent to eq. 3.5 as stated. The first term (smallness) should be norm squared and a plus "+" sign is missing before the second term.
- Page 87, line 8-9: "I determine the contribution… in Figure 5.2(c)". The test cell $m_{x'}$ is not shown or indicated in Fig. 5.2c.
- Page 88, line 6, end of line: (e) should read (f).
- Page 100, eq. 6.3: m_P should be replaced by m_A.
- Page 101, line 11: "Figure 6.6 shows the parametric…inversions and the average PCA model m_A". In Fig 6.6 only the edges extracted from all nine inversions are shown, not the ones from the average model.
- Page 104, 6.2 Dip and strike estimation, line 1: "In Chapter 5,…"
- Page 112, line 9: "Geological Survey of Finland"
- Page 120, line 15: "…Kevitsa appears to ~~by~~ be more or less…"
- Page 133, Figure 7.12: "(Top) Horizontal…sections". The top figures are not horizontal sections.
- Page 137, line 10, end of the line: The reference paper is missing.
- Page 140, Appendices, 9.1 Partial volumes: This whole part would be easier to follow if a figure would be plotted to show the geometry of the two prisms and their intersection.
- Page 142, 6th reference: should read Hillier (and not Hillier)

- Page 144, last two references (Lelievre and Oldenburg, 2009) are identical.
- Bibliography (pages 141-149): every occurrence of Phd should be written PhD; GEOPHYSICS should be changed to Geophysics.



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