



## ***Interactive comment on “Geophysical characterisation of two segments of the Møre-Trøndelag Fault Complex, Mid-Norway” by A. Nasuti et al.***

**A. Nasuti et al.**

aziz.nasuti@ngu.no

Received and published: 14 May 2011

We would like to thank Dr. Gerald Gabriel and Prof. Hermann Zeyen for their constructive comments and suggestions that have really helped us to prepare a new and improved version of our work. In the following, we first list the major changes made to the manuscript and second we reply point-by-point to the reviewers' comments.

Note: All page and line references refer to the new manuscript for reviewers. Changes come in blue in revised Ms and here the Answered comes after A:.

1-New information about the processing of gravity and magnetic data has been added to the text. We agree with both reviewers that quoting extensively two reports from the  
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Geological Survey of Norway (NGU) and a MSc thesis, in order to reduce a too-lengthy description of data and methods in the Ms, could appear somewhat cryptic. However, we would like to emphasize that the two reports (Nasuti et al. 2009, 2010) and the MSc thesis of A. Biedermann are completely open to anyone and can be downloaded from the net. The reader can get access to far more detailed information than it is common in traditional peer-review literature. We apologize for not having been more specific on this critical point in the original version of the Ms. We now indicate the precise web links for these documents. 2- Figures 1, 2, 3, 6, 8 have been modified. 3- A model based on geophysical data was added to figure 6. 4- A synthetic model has been attached to the document in order to show the magnetic anomaly of a dipping structure. This figure is not included in the Manuscript. 6- In Table 1 median values replaced with mean values 5- The reference list has been updated.

Replies point-by-point (reviewer 1: Prof. Hermann Zeyen) :

1. The measurements should be better described. A reference to an NGU report is not very helpful. Specifically, the geoelectric and refraction seismic lines were certainly not acquired in a single piece. What was the length of each piece and the overlap?

A: We agree with the reviewer that the data acquisition should be better described in the text and added more information in the revised version of the Ms (p.4 line 80 and p. 7 line 164). The three profiles (refraction seismic, 2D resistivity and magnetic) were acquired almost at the same location but with different lengths as illustrated in figure

6. This latter figure shows the overlap between the different profiles. In addition, the length of the 2D resistivity is now mentioned in the text (see p. 8 lines 189).

A: In order not to distract the reader with an extensive technical description of methods and procedures we prefer to refer to the NGU reports that are fully accessible online at [http://www.ngu.no/upload/Publikasjoner/Rapporter/2009/2009\\_037.pdf](http://www.ngu.no/upload/Publikasjoner/Rapporter/2009/2009_037.pdf) [http://www.ngu.no/upload/Publikasjoner/Rapporter/2010/2010\\_049.pdf](http://www.ngu.no/upload/Publikasjoner/Rapporter/2010/2010_049.pdf) We feel that the scientific paper remains in its specific focus while all scientific methods are made

fully transparent and can be checked by anyone.

2. Concerning the presentation of the results: For the seismic profile (Fig. 6), measured and calculated travel times have to be given together with shot point positions. If not, the reader cannot judge the presented model. For the resistivity profiles, the misfit has to be indicated (Res2DInv gives a value in %).

A: We modified Figs. 6 and 8 in order to introduce the information concerning the misfits of the 2D resistivity model. All travel time curves have been presented and published in Nasuti et al., 2009. We feel that it is not possible to introduce all the details on travel times without defocusing the Ms and prefer to stick to data interpretation, all technical details of our study being freely accessible on the net (see previous point and references to web links).

Why is no quantitative interpretation of the magnetic data given in Figs. 6 and 8 (however in Fig. 7)? Such a quantitative model would certainly show that the slightly simplistic interpretation of the anomaly over the fault zone is not really tenable, for anomalies M1 and M3 even less.

A: A new quantitative model is added to fig. 6. The needed informations are now clearly labeled (density, susceptibility and amplitude of the anomalies). In addition the specific locations of M1 and M3 have been reconsidered in view of the reviewer's comments.

Although the gravity data across the Tjellefonna fault have been acquired about 1km West of the interpreted line, I think they should be presented in Fig. 6 as well, together with a model.

A: The gravity data has been acquired parallel to the fault close to profiles shown in figure 6 (because it was impossible to measure high resolution gravity data across the fault in this region). The only reliable information we could extract from the gravity data was that gravity shows low values in the middle of the valley and these can reflect the overburden and/or a "weak" fault zone (i.e. with low density rock). In turn, we tried to

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improve our magnetic model (see figure 6) in agreement with the comments from the two reviewers.

3. The interpretation of the magnetic data in Fig. 6 is in my opinion not consistent. The authors say on p. 167-168 that contacts between rocks with contrasting magnetic properties are commonly associated with positive (better than "up") and negative (instead of "down") magnetic anomalies. This is true, but if the fault zone as such is magnetized, the maximum in the N would not appear at Norwegian latitudes. So, if magnetics sees the fault zone, the higher magnetization would be concentrated along the northern and southern limits and be more or less normal in its centre. Compare with Fig. 7 where a more standard effect of a magnetized fault zone has been modelled.

A: By means of synthetic modelling (see the attached Synthetic Model file) the shape of anomaly M2 (Fig. 6) can be reproduced assuming a south dipping magnetized body. We acknowledge that in itself the model is not a firm proof, however, a south-dipping body remains consistent with the geology of the area where most discontinuities, in particular foliation planes, dip towards the south (see discussion section). Our final interpretation is that the dip of the presumed fault zone together with orientation of the profile (with an azimuth of 302 degrees) are responsible for the observed shape of the magnetic anomaly

However, does magnetics see the fault zone on Fig. 6? The anomalies are located clearly N of the areas where seismics and resistivity see them (50-100 m with respect to seismics for M2; no relation with seismics and resistivity for M3; M1 is in between seismics and resistivity, where the resistivity effect is not obvious). For such a high resolution dataset, this difference is not negligible. How could this be explained?

A: We acknowledge that the match between the different anomalies revealed through different geophysical methods is not perfect (in particular between S1, R1 and M1 and to some extent between S3, R3 and M3, see Fig. 6) and discuss it thoroughly in the text, casting doubts about the significance of some of these anomalies. However, a

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very good spatial correlation is found between S2 and R2, if we take into account the uncertainties inherent to the methods used (see Nasuti et al. 2009, 2010), and even M2, considering that magnetics is the most noisy and ambiguous data set we used here. All this allows us to be confident on the existence of a major fault zone at the location of S2, M2 and R2 but we admit that the existence of the two other structures remains more speculative.

How can the higher magnetization in the fault zone be explained? What produced the higher magnetization in these samples? Is the statistics based on four samples significant? By the way, the large variability of susceptibility values makes that their distribution is better described by an exponential probability distribution than by a Gaussian one, which implies that the median is a better measure of the "average" than the mean. Please indicate the median in Tab. 1.

A: Because it appears to belong to the same fault system, the Tjellefonna fault zone has certainly magnetic properties similar to the ones of the Tjelle fault, exposed only a few km to the west (Redfield and Osmundsen 2009). The Tjelle fault zone is enriched in magnetite, most probably because of syn-tectonic fluid circulations and mineralizations (Biedermann 2010), and, therefore, presents relatively high magnetic susceptibility values. Admittedly, our study would gain support if more than four samples from fault zones of the area would be analyzed. However, many faults of the MTFC are known to coincide with pronounced magnetic anomalies (e.g. Biedermann 2010, Nasuti et al. 2010); fact that it is fully consistent with the enrichment in magnetite recorded for the Tjelle fault zone.

A: All other minor changes (i.e. "up and down") have been made in the new version of the Ms (see P9. line 206 and P9. line 215& 216). .

4. Concerning the resistivity profiles, I would have some questions as well: First of all: can you be sure that the anomalies you see near the base of your models are real and not an artifact of the 2D interpretation of a 3D structure? We get this kind of undulations

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very often with Res2DInv, which has a tendency to introduce them in the areas of low resolution. This happens especially in the areas of missing deep data due to the shift between line segments. A few resolution tests would be welcome.

A: We agree that 2D resistivity presents serious limitations in the case of 3D objects. This is precisely the reason why we have acquired various datasets using different geophysical methods. However, we acknowledge that 3D effects can eventually contaminate our results, in particular in the case presented in figure 8 where seismic data is lacking. On the other hand, we feel that 3D effects might be negligible in the case of the Tjellefonna fault (Fig. 6), because the geological structures observed in the field and surrounding our study area show a clear cylindrical pattern (see Fig.2).

On the other hand, I do not really agree with the claim that the resistivity on Fig. 6 shows a southward dip of the fault zone. Also the southern limit seems to have a slight dip, but to the North. Here again, some tests with synthetic models would be necessary in order to clarify whether a southward dip could really produce this resistivity image (the southern limit) and/or whether the image could be due to an effect of the asymmetric overburden shown in the seismic model and/or simply a reduction of the width of the fault zone with depth.

A: Indeed, synthetic tests were conducted in parallel by some of our colleagues (Reiser et al. 2009). We acknowledge that we should have emphasized this crucial point before submitting the previous version of the Ms. The aim of the tests was to explore the ability of 2D resistivity to determine dip and width of imaged fracture zones (see also Ganerød et al, 2006). These studies show that we can confidently determine locations and dips of fracture zones, in particular thanks to the gradient array that we used in our measurements. In conclusion, the northern part of anomaly R2 (Fig. 6) shows a slightly south-dipping edge while the southern boundary appears subvertical. As mentioned previously, a south-dipping fault zone is consistent with the regional structure.

1- Ganerød, G. V., Rønning, J.S., Dalsegg, E., Elvebakk, H., Holmøy, K., Nilsen, B.

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and Braathen, A. 2006: Comparison of geophysical methods for sub-surface mapping of faults and fracture zones in a section of the Viggja road tunnel, Norway. Bull Eng Geol Env (2006) 65: 231 – 243). ISSN: 1435-9529 (Paper) 1435-9537  
2- Reiser, F., Dahlin, T., Rønning J.S., Lise Solberg, I., 2009. Resistivity Modelling of Fracture Zones and Horizontal Layers in Bedrock. NGU Report 2009.070. [http://www.ngu.no/upload/Publikasjoner/Rapporter/2009/2009\\_070.pdf](http://www.ngu.no/upload/Publikasjoner/Rapporter/2009/2009_070.pdf)

5. Purely formal aspects: In several places, it is difficult to follow the arguments because information is missing or comes much later in the paper. E.g. \* p.161: "abrupt change in elevation": in which sense? where is the elevation higher, N or S of the fault? This is not clearly visible on the map. A: The elevation is higher in the southern of MTFC (added to text p1.line 17)

\* still p.161: A reference to a paper "in preparation" (Nasuti et al., 2011) is not very helpful. Nasuti et al., 2011 replaced by extended abstract from EAGE conference (Nasuti et al., 2010b).

\* p. 164, lines 9-10: "Such high amplitude noise ... had to be removed..." - how was this done? A: The high amplitude noise has been removed by a low-pass filter with 50 Hertz cut-off filter; added to the text (page 164. line10).

\* p. 164: The samples are referenced by letters A-L. These letters are given on Fig. 5, but this figure is only mentioned much later. It should be indicated already here. On the other hand, the reference to Fig; 4 is not useful here. The reference to the samples is modified (P.5, line 108).

\* p. 170, lines 27-28: the faults are not visible on the topographic map. Please mark them. \* Fig. 2: what are the thin black lines (e.g. just north of the letter "d" in Langfjorden)? It is difficult to distinguish between the different data sets. Especially refraction and reflection seismics have too similar colors, as well as gravity stations and magnetics. \* Fig. 3: color scale might be shifted to distinguish between on- and offshore. \* Fig. 6: It is not clear what R1 and R3 refer to. My impression is that R1 refers to the

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lower resistivities below the letters, whereas R3 refer to those above the letters.

A: The thin lines show the faults as interpreted by bedrock geologists well before this study (Tveten et al. 1998). Fig. 3 is modified and a small line has been added to figure legend in order to show the possible fault. The coastlines show the offshore-onshore boundary in Fig. 2 and 3.

Different colors have been used to make the profiles clearer, however, because of the large number of data sets and because of the color of the background map, we recognize that it might take sometime to decipher the figure on paper and apologize for it. In addition because the refraction seismic coincides with resistivity and magnetic profiles, changing the color will not change the visibility of it. Reflection seismic profiles are shown as bold lines with distinct red colors. However, we point out that the figure appears to us very easy to read when seen on screen.

Fig. 6 has been modified in order to show the anomalies more clearly.

Please also note the supplement to this comment:

<http://www.solid-earth-discuss.net/3/C128/2011/sed-3-C128-2011-supplement.pdf>

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Interactive comment on Solid Earth Discuss., 3, 159, 2011.

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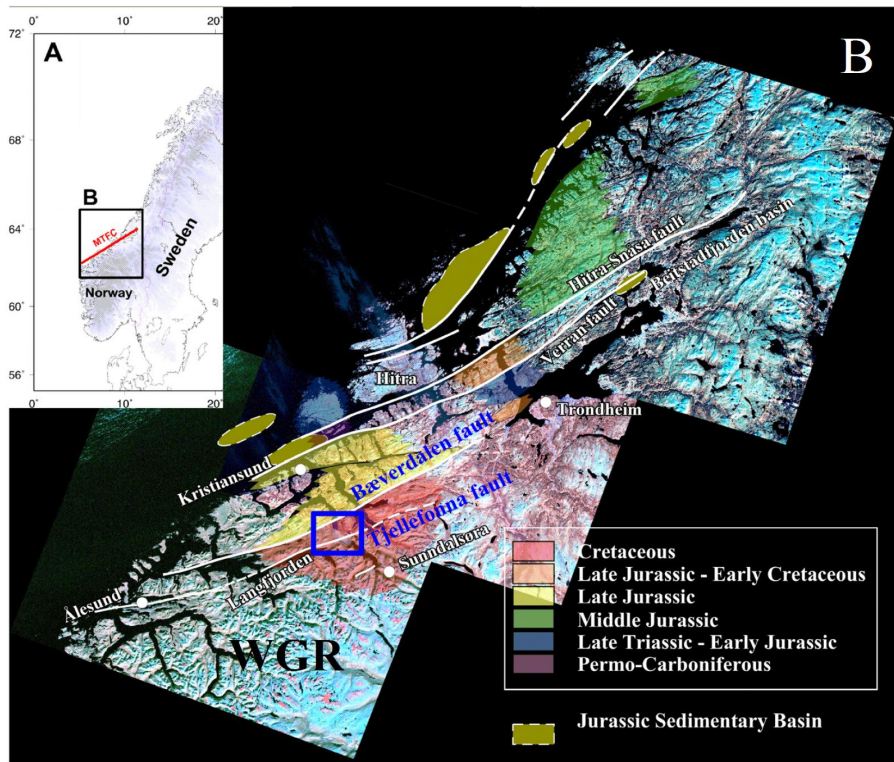


Fig. 1. Fig. 1

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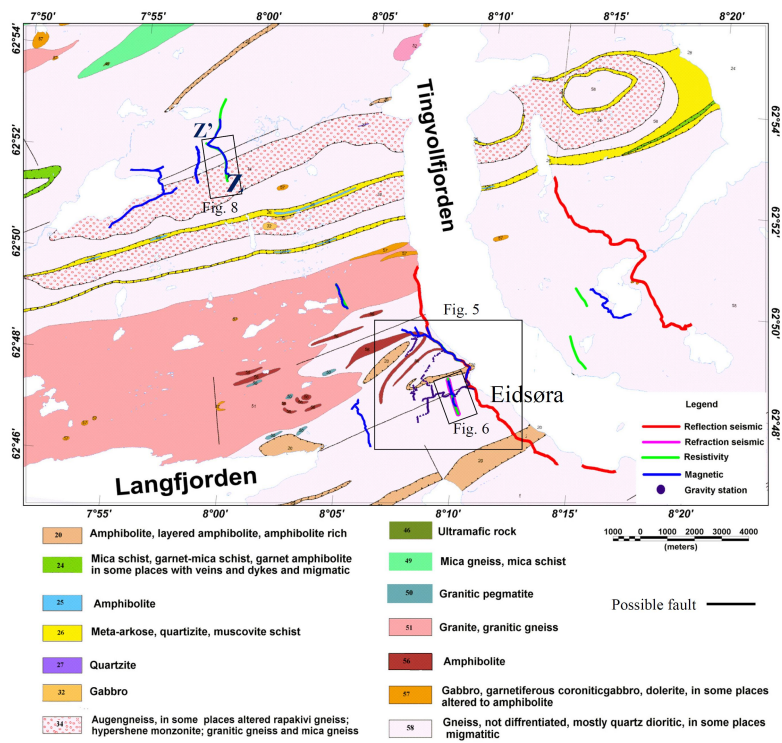


Fig. 2. Fig. 2

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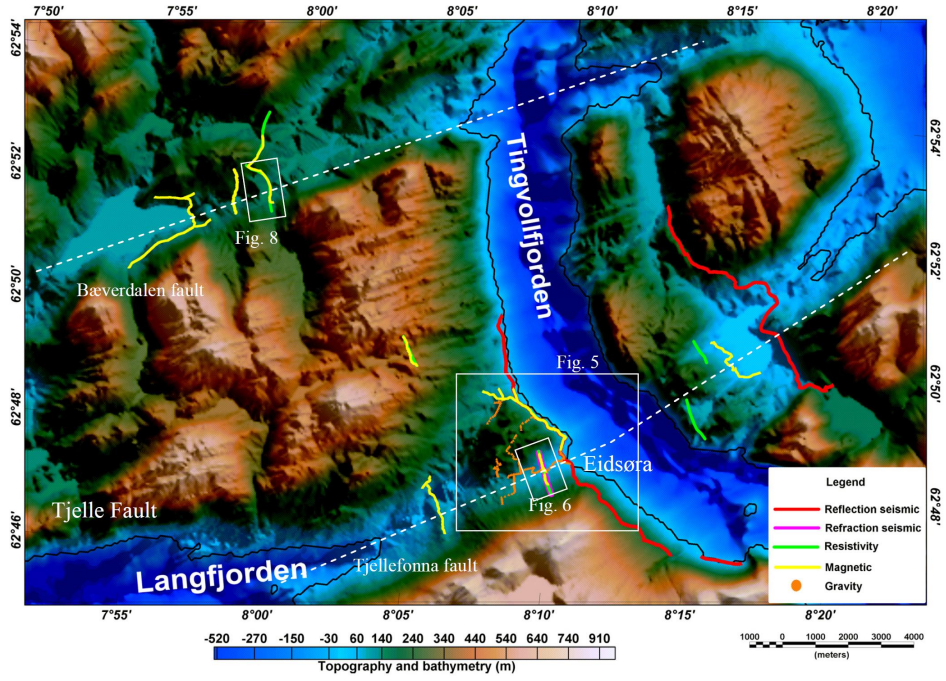


Fig. 3. Fig. 3

C138

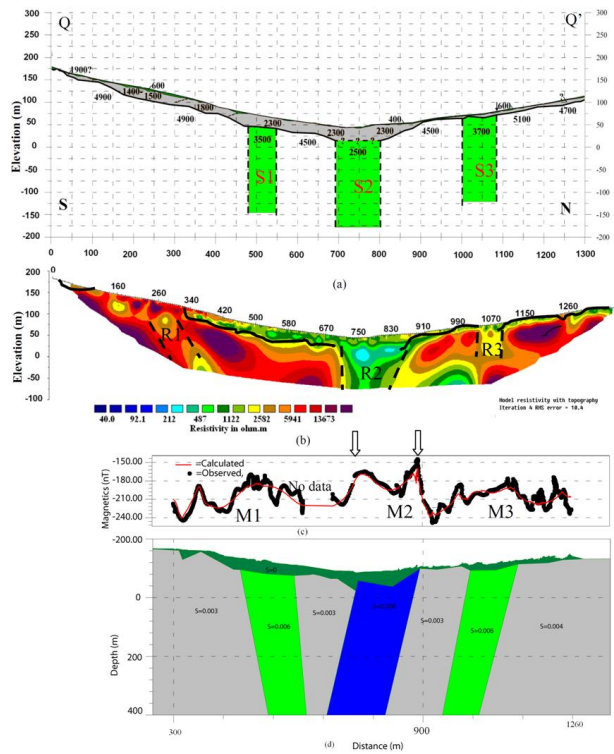


Fig. 4. Fig. 6

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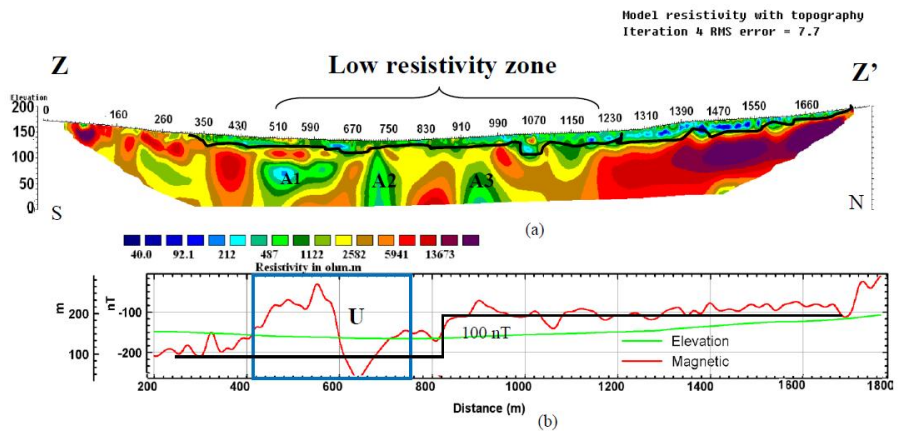
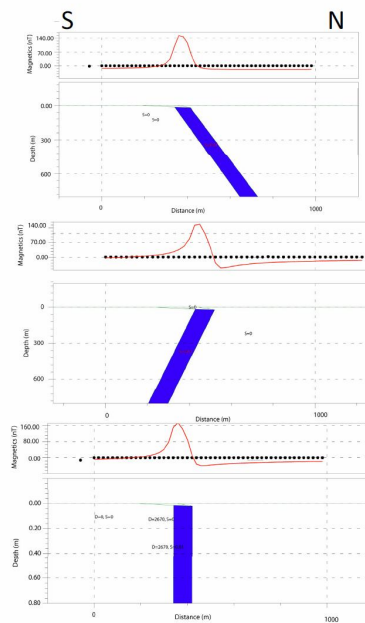


Fig. 5. Fig. 8

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Synthetic model for a dipping magnetized body. The Earth field has 75 deg with 0.3 declinations. The magnetized body has susceptibility of 0.01 SI. The profile has Azimuth of 340.

Fig. 6. Synthetic Model

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#### Figure and Table captions

**Fig. 1** Principal structural features of the Møre-Trøndelag Fault Complex (MTFC) and surrounding regions. (A) Location of the Møre-Trøndelag Fault Complex (MTFC) onshore Norway. (B) Composition of three Landsat scenes showing the major lineaments of the MTFC (after Redfield et al. 2005). The blue frame depicts the study area. WGR- Western Gneiss Region.

**Fig. 1** Simplified bedrock map of the study area (after Tveten et al. 1998). The respective locations of the different geophysical profiles are shown. The black boxes outline some of the geophysical profiles shown in Figs. 5, 6 and 8.

**Fig. 2** Several geophysical data sets have been acquired in the study area (blue box in Fig. 1). The background map depicts topography and bathymetry. The white boxes outline geophysical profiles whose corresponding results are shown in Figs. 5, 6 and 8. dashed white lines show the proposed Tjellefonna and Beverdalen faults.

**Fig. 3** Determination of the bulk density of the studied domain using the Nettleton Method. (a) Computed Bouguer anomalies along NN' using different densities. The location of this profile is shown in Fig. 5. (b) Topography of the profile with location of the gravity points.

**Fig. 5** Bouguer anomalies calculated using a reduction density of 2790 kg/m<sup>3</sup> and superposed on the geological map (Tveten et al. 1998). NN' is the traverse used to determine the reduction density (Fig. 4). PP' and QQ' are profiles shown in figures 7 and 8 respectively. Letters in black represent petrophysical sampling sites (Biedermann 2010).

**Fig. 6** Geophysical profiling across the "Tjellefonna Fault". (a) The refraction seismic profile shows three low-velocity zones (S1, S2 and S3); velocities in m/s. (b) Depth-inverted 2D resistivity profile showing three low-resistivity zones (R1, R2 and R3). Continuous and dashed lines represent the interpreted top bedrock and the edges of the interpreted main fault zone respectively. (c) Magnetic

**Fig. 7.** Figures and Table captions