Anonymous Referee #1

Dear referee,

Thank you for reviewing our manuscript. We appreciate your comments and suggestions and have stated our comments and changes in the text below every comment.

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This is a review of "Large-scale electrical resistivity tomography in the Cheb Basin (Eger Rift) at an ICDP monitoring drill site to image fluid-related structures", by Nickschick et al. that aims to use geophysics to image fluid relevant structures in deep formations. This is an interesting application of a rarely-applied deep electrical imaging method and seems to be within the scope of the journal. The manuscript is written in acceptable English and the figures are well drafted, though several of the figures could be combined. The organization is adequate, but could be improved. Given that the claimed focus of the work is to elucidate fluid-related structures, I find that C1 there is relatively little treatment of this subject in the interpretation and discussion. Specific comments related to each of these general observations may be found below. I recommend that the manuscript be returned to the authors for revisions.

General comments: 1) strengthen the interpretation and discussion of fluids, or recast the purpose of the work towards structures (or whatever else seems most appropriate). 2) combine figures as noted 3) reorganize the text as noted, specifically focus on making the introduction flow better, ensuring that all content is in the appropriate section, and shortening the background section 4) given my comments below related to the complexities of interpreting ERT data due to convolved signals from porosity, chemistry, saturation, and clay, I suggest adding a focused section to the discussion (or interpretation) section clearly explaining how you tease apart these elements in your data.

We have focused more on the interpretational part and your suggestions about rearranging our text. More information about the local lithological and petrophysical properties are now provided and we stressed the relevant information. We reworked the figures and tried several combinations of your suggestions. Please bear in mind that we had to keep the figures large enough to be readable. Moreover, we had another critical evaluation of our text structure and argumentation chain and reworked it according to both referees' comments. Please refer to each specific comment below for more information.

Specific comments:

Introduction: the structure of the introduction is awkward, particularly because it immediately jumps into site description, without giving any big-picture setup or explanation.

Please understand that in fact the site is of utmost importance for using this method, this is why we start with the site and not the method. Understanding the situation foremost provides essential information about the "whys" and "hows". Stating the situation, the overall problem and this study's place in the overall context of the ICDP initiative - featuring several different (bio-)geoscientific projects – allows us to put our rather unconventional method and setup into the right light.

Page 1, L12: "series of open questions" Either state those questions here, or move this text to where the questions are stated.

We omitted the confusing sentence. The open question about the magmatic ascent and CO2 degassing are not to be confused with the key questions we stated for this geoelectric survey.

Page 1, Line 20: Change "drills" to "drilling"

Done.

Page 2, Line 33-34 & Page 3, Line 1: While I certainly agree that ERT is sensitive to fluids as indicated here, this justification for the ERT method seems incomplete because the several earth properties that control resistivity can be difficult to tease apart to attribute. As indicated on P2L34, the measurement is sensitive to porosity, salinity, saturation, and clay content all at the same time, and therefore the only way to retrieve any one of these parameters is to know three others. Section 2.1 is very long and covers a wide variety of topics. Readability would be improved if this section was shortened and focused specifically on the topics most related to the manuscript.

We now include a table of the rare petrophysical parameters known from other studies (Dobeš et al. 1986), see comment below. Also, additional information (logging data) from a recent study (Bussert at al. 2017) about the topmost layer of weathered phyllitic basement in the fluid ascent zone is added. As mentioned, the complex interaction of porosity, salinity, saturation, and clay content is not trivial, and we are confident to make our statements more plausible. Please remember, that this experiment is about studying the subsurface resistivity distribution to find potential fluid pathways and/or fluid caused interactions with the rocks (geological situation). We also omitted several sentences that are not immediately important for our experiment, such as information about swarm earthquakes etc.

P6L32 – P7L1: Suggest breaking this into two sentences.

Done. We restructured this part and omitted the part about the Marianske Lazne Complex and the Tepla Barrandian, as this also fits the category "too much geologic information" (see previous comment).

P7L3: Suggest to add a reference to support this statement on low resistivity areas.

We added references that both describe the fluid-induced alteration to clay minerals in general and the inferred resistivity changes related for the target site. See also next comment.

P7L4&5: The topic of MT surveys was introduced back on Page 6: This text here seems repetitive, I suggest to reorganize or reword.

We agree that this lead to unnecessary confusion and thus reworked it. It now states:

"With the aim to reach deeper structures up to 5km, several magnetotelluric investigations in the western margin of the Bohemian Massif and along the 9HR seismic profile (Cerv et al., 1997, 2001; Pícha and Hudeková, 1997; Di Mauro et al., 1999) have been carried out since the 1990 resulting in very coarse conductivity models."

instead of a whole paragraph as before.

P8 L2: suggest to delete: "imaging a pathway from"

Done.

P8 L6-8: This text seems out of place. The authors have used this section to explain existing data, however this short paragraph indicates availability of data and explains their method for using it but does not explain the data. Could be rewritten to be more appropriate for this section, or moved to methods.

Previously, we did not present key facts for the experiment here. We have added the relevant information here in form of a short paragraph about the assumed petrophysical properties, based on former drill sample and log measurements from Dobeš et al. (1986) and recent log data from Bussert et al. (2017). The text now states:

"In addition to this geological constraint, we regarded the results from Dobeš et al. (1986): Their report contains valuable petrophysical information from previous studies about the different stratigraphic units in and below the Cheb Basin which we have summarized in Tab. 1. The phyllitic-granitic basement is characterized by low porosities of less than 5% compared to the sedimentary deposits on top, which feature porosities of 15-30%. Resistivity, however, may vary drastically, depending on heterogeneities within the sediments and whether fluids such as mineral waters or CO_2 are present or not and the report does not specifically state where the samples were taken from. For this area, Bussert et al. (2017) provides additional information. Not only do they mention the occurrence of highly mineralized water in the central part of the HMF, their geophysical log of the HJB-1 drill reveals resistivities of 5-10 Ωm for the sediments of the Cypris formation and 10-20 Ωm for the topmost part of the weathered phyllites. They are about one order of magnitude lower than the values presented in Dobeš et al. (1986) - stressing the importance of regarding the occurrence or absence of fluids even more."

Table 1. Petrological description of the stratigraphic layers of sediments and basements below the Cheb Basin, translated from Dobeš et al. (1986)

Name of stratigraphic unit	rock type	Porosity [%]	electrical resistivity [Ωm]	
			minimum-maximum	average
Vildštein	gravel, sand, clay	30.0	14-1600	350
Cypris	clay, silt, carbonates	14.5-21.5	50-1500	-
Main Seam	lignite, sand, clay	22	7-50	15
Lower Sand & Argillaceous	gravel, sandy clay	-	3-150 (depending on saturation)	7.5
Phylliitic basement	weathered phyllite	3.2	75-140	110
Phyllite basement	unweathered phyllite	1.0	500-1800	890
Granitic basement	granite	5.0	65-650 (weathered); > 650 for unweathered	-

P8-L10-12: As indicated above, the nature of ERT interpretations is that these several properties all affect the measurement together, and therefore it is difficult to point to any one contributor as the primary control on electrical properties. Large porosity could have the same effect as high conductivity fluid in small pores. Low saturation could have a similar affect to small porosity. I think it is inaccurate of the authors to say "ERT is qualified for the detection of fluid signatures" without carefully explaining this statement in the context of how each material fraction contributes to the measured electrical signals.

We agree that our argumentation seemed a bit weak without presenting more specific information. To substantiate our point, arguments describing the available information (and limits) of certain parameters were added to the manuscript. The area here is rather specific and thus, our general statement that ERT is a tool to detect fluids in general is not well-written. As a source, we have the article of Dobes et al (1986) featuring petrophysical studies (density, porosity, resistivity). For example, they determined the phyllitic basement to feature porosities of less than 5%, much lower than the Tertiary sediments (20-30%). Including this kind of information supports the statements made in the manuscript (see also comment before). But it should be mentioned that this published data are not clearly connected with information about depths of samples or logs – differences to our situation might occur.
Also, we have implemented information about the mineral water earlier in the article, which should help the reader to understand the geologic situation for this site as the fluid-rock interaction plays a significant role (see comment before). It was previously only mentioned in the interpretation, yet provides essential information for understanding the target area's complexity – especially considering the very low resistivity encountered here (see comment P8 L6-8 and Page 21, Line 28).

P8 L20-21: ". . .for practical and theoretical reasons, most suitable for large-scale ERT experiments. . ." Please explain why, related to both practical and theoretical reasons. This seems like an important element of this manuscript given that such large scale measurements are so uncommon. It is also counterintuitive since Dipole Dipole configurations are well known to have poor signal to noise in comparison with nested arrays, for example.

We included more information about the reason for this particular setup. It is correct that these large profiles are quite uncommon, but we chose a dipole-dipole setting for mainly logistic reasons, as this is the setup with a permanent layout of separate voltage dipoles and a moving current dipole that requires a minimum of cables and thus field effort.

1) An ERT profile of almost 7 km, crossing several streets, a large factory, dirt roads and agriculturally used fields in a rural area provides quite a challenge. A dipole-dipole setup allows us to connect only neighbouring electrodes with cables for both voltage readings and current injections and still allows for proper signals after appropriate data processing. Using configurations where several hundreds of meters of cable have to be pulled through shoulder-high crops was simply impossible.
2) We expected to see subvertically oriented structural changes in form of faults and potential fluid paths, which are known to exist from previous studies, thus choosing a configuration that is more sensitive towards that.
3) As this large-scale setup has been used in multiple areas before (up to 23 km profile length), a certain familiarity with the whole procedure was given to guarantee a proper workflow. Special statistical signal processing methods (drift correction, selective stacking, cross correlation) of the time series of potential differences are applied to improve clearly the signal-to-noise ratio.

In the text you'll now find the paragraph:
"The data acquisition was performed using the dipole-dipole configuration (AB MN, with A and B being the current injection electrodes and M and N being the potential electrodes) which is, considering the cost-effect-relation for practical and theoretical reasons, most suitable for this large-scale ERT experiment. Transmitter and receiver units are physically separated on two lines reaching maximum dipole separations of 6.5 km (Fig. 1) while keeping the total length of required cables to a minimum as only neighbouring electrodes have to be connected. Considering crop growth in June in this rural area and traffic by agricultural farming machines in general, other arrays are not effective with large cable spreads of several kilometers. Furthermore, we expected vertically oriented features (faults, "fluid channels"), as seen in previous studies (Nickschick et al., 2015), supporting the choice of using a dipole-dipole setup and achieving good results in previous studies at different location with a similar setup (Flechsig et al., 2010; Pribnow et al., 2003; Schmidt-Hattenberger et al., 2013)."

Figure 2: I suggest either merging this with Figure 1 or Figure 3 to make a 2-panel figure, OR perhaps merging all three to make a single 3-panel figure.

We have tried several combinations of these three figures. All three figures are quite important: Figure 1 serves as the overall background for our introduction and the geologic situation (magmatic processes, existence of the main geologic features of granitic intrusion, phyllitic basement and Tertiary deposits). Figure 2 is major source of litho-stratigraphic information which allows our interpretation (in combination with petrophysical information) and absolutely necessary. Figure 3 provides the local information that is crucial for understanding our measurement procedure (gaps sue to roads, regional railway, villages), shows the drill locations and important features like the degassing area of the HMF and the two main tectonic features.
However, we rearranged these figured. We switched figures 2 and 3 to separate the regional location from previous results and then going back to the location with everything included that is important to the experiment.

Page 9, L2: "greater distances" suggest to replace this with actual distance numbers.

Done.

Figure 4 seems unnecessary and could be deleted.

Agreed. We removed this figure.

Page 11, Line 9: Please deleted “A number of”

We deleted this.

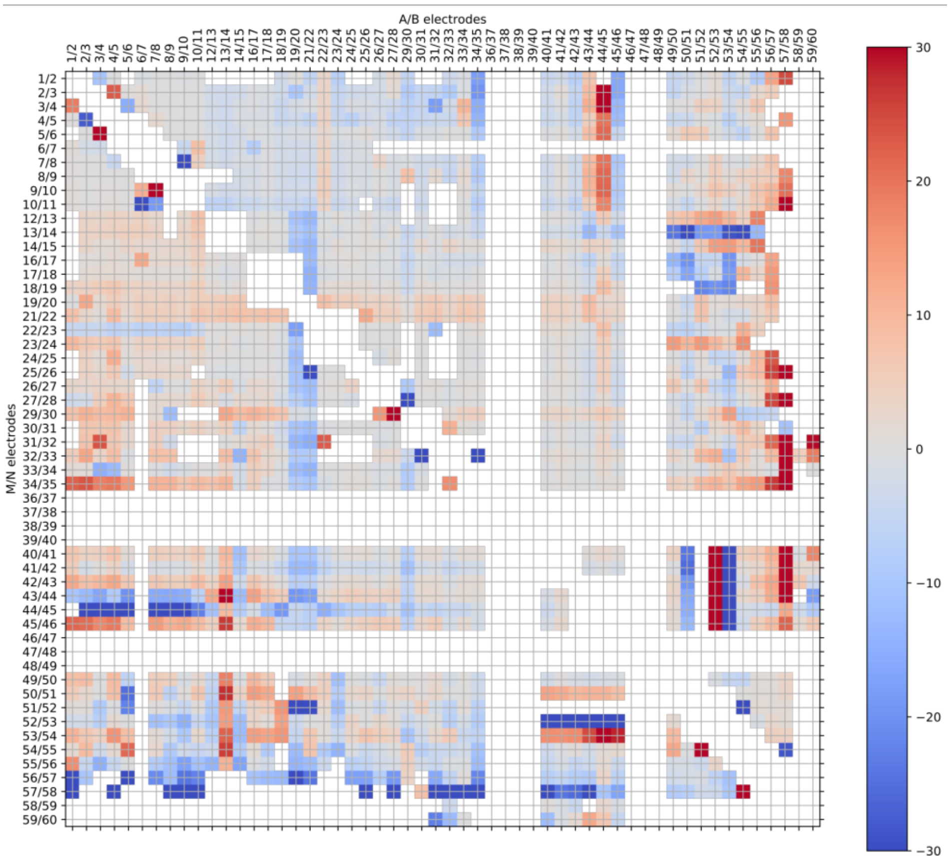
Page 12, L22: “Figure 6” Which panel of Figure 6 is being described here?

So far, only the left column (Fig. 6a) had been described, which is changed now in the text (see comment below):

Page 14, L2: “(White Columns)” what does this refer to? Which figure?

This refers to the white areas in Figure 6a. We clarified this:

Fortunately, the missing data (white areas in the lower left triangle) are mainly available through their reciprocal counterparts in the upper right triangle. Before, we had white as “zero” AND “no reciprocity available” due to the chosen color scale. This has been changed by using another color scale that represents small absolute reciprocal errors in grey and to distinguish them from missing data in white. New Figure 6b (now Figure 5b).



Page 14, L3-4: What figure does this refer to? I assume #6. “appears significantly smoother” Smoother than what? How do you know it is “significant”? If referring to Fig 6, left panel, then I disagree – if the authors intend to make this argument, then it should be supported by a quantified metric.

Agreed. It is “visually” smoother with fewer single outliers and more connected ones (linked with bad coupling and thus high noise). This allows us to disregard a chain of voltages and then prefer the mirrored values.

Reformulated the sentence: The upper right triangle (i.e. where the voltage is measured east of the current injection in the west) appears smoother and features fewer single outliers as a result of higher artificial noise in the west and better coupling conditions in the east while featuring more connected outliers linked with single dipoles (e.g. AB electrode pair 44-45, 56-57, 57-58).

Figure 6: What is the right panel here? I do not see it explained in the text. I see that it is “Reciprocity”, but what do the percentages mean?

Correct, Figure 6b was not explained in the text. This is now done and later Fig. 6b is explained accordingly:

“In theory, every combination of current and voltage dipole is measured twice by taking into account the principle of reciprocity, which states that voltage and current can be interchanged. By comparing the apparent resistivity values for forward (AB dipole ahead of MN), ρ^a_f, with the backward (AB behind MN) values ρ^a_b one can compute the relative reciprocity error

$$r = \frac{\rho^a_f - \rho^a_b}{\rho^a_f + \rho^a_b}$$

The reciprocal error is displayed in Fig. 6b. Wide areas appear grey, i.e. forward and backward data agree very well. For some data with short spacing (near the diagonal) the values deviate from zero due to different coupling. Furthermore, there are quite a few areas of significant deviations, where one needs to be removed. In general, reciprocal errors increase with increasing dipole separation and reflect the decreasing signal-to-noise ratio as a result of the strongly decaying signal strength.“

Page 15, Line 3-4: “sensitivity analysis with about 130 m, for the small profiles and 1300 m for the long one ” This is confusing – please reword and check to be sure punctuation and word usage is accurate.

We apologize, the misplaced comma made the sentence illogical.

Figure 8: This is unnecessary as a stand-alone figure. The information here should be combined with Figure 3.

We agree that Figure 8 was not well-placed. We were not capable of including the regional Bouguer gravity into Figure 3 due to an overload of information otherwise. Station locations are described in the text and thus we have removed the figure completely.

Page 17, Line 5: “stadiums” this is unusual usage of the word. Suggest replacing with a more common word.

We used “stages” instead which should fit better.

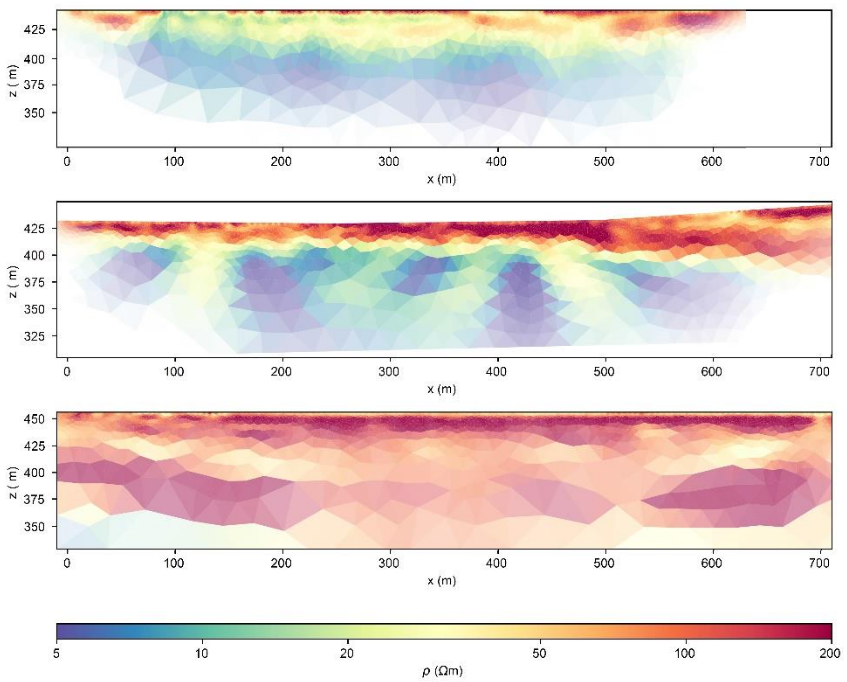
Page 17, Line 10: How is the depth of investigation calculated?

We follow an approach of cumulative sensitivity after Christiansen & Auken (2012). The maximum model depth is chosen at the depth where the total sensitivity meets a relative value of 90% (Günther 2004), implemented in BERT as the default value.

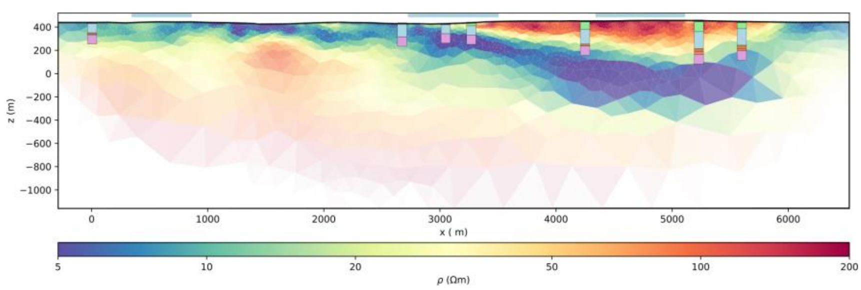
Figure 9 and Figure 10: It seems that some masking is missing from the panels of this figure. Surely the Depth of Investigation could not be equal along the entire line length of all lines?

We added an alpha shading based on the coverage for both the small and the large profiles (Figs. 9 and 10). Therefore we also had to choose a different (rainbow-type) colormap.

New Figure 9 (now Fig.7):



New Figure 10 base map (now Fig.8):



Page 20, line 12: "an excellent permeable channel for deep fluids conduct" – this is confusing as written, please reword.

"Excellent" is indeed a very strong word, we rephrased the sentence. Additionally, we included the link to studies, who also underline this statement in this area.

The text now states:

"Such tectonic/structural zones form permeable channels for the deep fluids conduct and have been mentioned before for this area Bankwitz et al. (2003b); Kämpf et al. (2013); Bräuer et al. (2008); Fischer et al. (2014, 2017)."

Page 20, Line 12-14: This should be moved to the discussion.

We have provided additional references. We do not interpret this based on our survey, we have merely linked the existing information from other studies and the existence of these faults to make the reader be able to follow our description of the gravity curve.

Page 20, Line 24-27: References should be added to support this statement.

We have added the reference to our presentation of the geologic transect as well as the relevant literature:

"Stratigraphic records mention the occurrence of phyllite at the base, yet it is described to be very heavily weathered/altered (Dobeš et al., 1986; Špicáková et al., 2000; Fiala and Vejnar, 2004; Bussert et al., 2017)"

Page 21, Line 16-17: Please indicate on which ERT image this can be seen, and where on the image.

This can be observed in our presentation of the small ERT, profile P2. We have also included the link in the revised text.

Page 21, Line 28: Is there any reference to support this supposed circulating mineral water?

Reliable information is scarce for this specific area. While on a regional scale, several spas exist in Karlovy Vary, Františkovy Lázně, Mariánské Lázně, Bad Brambach and Bad Elster and mineral and healing water is well-researched there, specific data is scarce for the area around our profile. The most reliable study is Bussert et al. (2017), that describes the HJB-1 drill in the center of the degassing. They describe water with an electrical conductivity of around 6800 µS cm^{-1} with a chemical mixture of Karlovy Vary and Františkovy Lázně-type water. While drilling they found pressurized horizons which act a fluid barriers, but at tectonic faults, these can malfunction. Furthermore, our profile is very close to the Soos natural reserve (Fig 1) in which we can observe several different mineral springs close by.

We added this information about the springs and nature reserve at this point and extended this paragraph which now reads:
"One key aspect in the low resistivities we observe might be related to circulation and ascent of heavily mineralized water and CO2-rich fluids. Bussert et al. (2017) mention pumping tests at the HJB-1 drill site within the main degassing area around Hartoušov and, after drilling

through a caprock-like layer and hitting a supposed aquifer at 79-85 m, encountering subthermal mineral water with a high conductivity of around 6800 µS cm^{-1} (about 1.5 Ωm). Especially the more porous sandy parts within the Tertiary deposits are aquiferous and penetrating them resulted in a sudden outburst of gaseous CO2 and water (Bussert et al. 2017). While especially the pelitic layers can be considered impenetrable to ground water, intense tectonic faulting is made responsible for the mixture of groundwater with deeper water-bearing formations along faults, joints and chasms and also with the aquiferous Lower Argillaceous-Sandy and Main Seam formations (Dobeš et al., 1986; Peterek et al., 2011; Bussert et al. 2017). This is stressed by geoelectric borehole logging in the HJB-1 drill at the HMF where throughout the Tertiary sediments resistivities of 5-10Ωm were measured and even within the topmost layers of the (weathered) basement (phyllite) resistivities did not exceed 20Ωm. Another, prominent example for the complexity of the hydrological situation is the close-by Soos Nature Reserve, which is just about 3 km to the NW of our survey profile (Fig. 2. Other mineral and ochre springs and mofettes are found within a few kilometers (Weinlich et al., 1998; Bräuer et al., 2005; Kämpf et al., 2013) and Karlovy Vary, Františkovy Lázne, Mariánské Lázne, Bad Brambach and Bad Elster are well-known for their spas and diverse mineral water sources."

Page 22, Line 3: "At at least one spot along our profile, the HMF, these fluids can propagate to the surface through the Tertiary sediments, but also at other sites expressions of fluid flow can be observed. " Please explain how this can be observed in the data measured for this experiment.

This is not well-expressed from our side, we apologize. After rewriting this sentence and adding references, it should be clearer

"Along our profile at the HMF, these fluids can propagate to the surface through the Tertiary sediments along the assumed course of the PPZ, but also at other sites expressions of fluid flow can be observed (Weinlich et al., 1998; Kämpf et al., 2013; Bräuer et al., 2014)."

Page 22, Line 15-17: Suggest to support this statement with a reference.

The reference to this can found in the preceding sentence.

Figure 11 (and reference to Figure 10): It is well known that inversions can result in over- or under-estimations of physical properties across sharp boundaries. For example, on Figure 10, from 3000 – 5500m along the line, there is a change from resistive material to conductive z=0 to z = 200 m. Here in figure 11, this is interpreted as "lower clay and sand" in a distinct unit – but how do you know this is not just an inversion smoothing artifact?

In this case, as in many others, we have the drill logs as a verification tool. The inversion was specifically done without constraints to cross-correlate "hard" evidence subsequently, which indeed worked very well. We have included the drill names in our presentation of the large-scale profile for better presentation purposes for the reader.

Page 23, Line 3: Figure 11 should be explained in the discussion, not conclusion. The conclusion section contains "summary" content and "discussion" - please rewrite this to focus on only concluding remarks.

We apologize for the layout error due to LaTeX trying to find a good spot for the figure. It should now be found in the interpretation chapter. For our last remarks, we removed the summary parts and limited it only to conclusions.