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## ***Interactive comment on “Spectral induced polarization measurements for environmental purposes and predicting the hydraulic conductivity in sandy aquifers” by M. Attwa and T. Günther***

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Received and published: 30 April 2013

Review of "Spectral induced polarization measurements for environmental purposes and predicting the hydraulic conductivity in sandy aquifers" by Attwa and T. Günther. This manuscript is dealing with the inversion of SIP data to predict permeability. This is a good manuscript that can be published in HESS with some moderate revisions, which are listed below in the order they appear in the ms.

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- 1) Maybe remove " environmental purposes and" from the title.
- 2) The abstract is very long. It should be condensed into a single paragraph and reduced by 20%.
- 3) The in phase resistivity is not a good predictor of anything because petrophysical models show that only the real (in phase) and quadrature (out of phase or quadrature) conductivities have a clear physical meaning (electromigration versus polarization). The real resistivity and the imaginary resistivity are composite of the in phase and quadrature conductivities, so there are a mix of electromigration and polarization processes.
- 4) Introduction: the relation between in phase conductivity and permeability was discussed and numerically investigated by the people of Schlumberger back in the 80s (Sen, Johnson and co-workers). I am surprise to see no reference to their work. See also along the same vein Bernabe and Revil (1995) that was the base for many subsequent work in this area.
- 5) Regarding the paragraph page 5318, Revil and co-workers have recently argued that a very general model can be derived and unify all the dataset into a unified relationship. see revil et al. (2012), Revil (2013), Revil et al. (2013a, b). So I disagree with these comments ! Revil also found a unified relationship between the quadrature conductivity and surface conductivity (which follows some ideas developed by Borner). In the same papers, Revil and co-workers found unified relationships for the relationship between the quadrature conductivity, the CEC and the specific surface area.
- 6) Equation 1: Ok for the ref of Vinegar and Waxman but these authors havce datasets that are not showing too much frequency dependence so they don't discuss too much this relationship (they use it mostly to define frequency bounds for the models).
- 7) Going from Eq. 1 to Eq. 2 is a bit risky as there is no formal proof that the characteristic length scale for polarization is the pore size (see an extensive discussion of this

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problem in Revil et al., 2012).

8) For the reasons I mentioned above, it is not at all equivalent to use the components of the complex conductivity or the components of the complex resistivity. In the first case the in phase and quadrature conductivity have clear physical meaning, this is not the case in the second case. I think therefore that the approach used in the present paper is partly wrong. It would be much clearer to follow what other researchers have done so far: using the in phase and quadrature conductivities instead of the in-phase and quadrature resistivities (the latter are NOT the inverse of the former, only the complex resistivity is the inverse of the complex conductivity).

9) Equation 6: the permeability model for a CPA is also described in Revil (2012) but the resulting equation is distinct than Eq. 6.

10) Equation 7 is correct only if there is a relationship between surface and quadrature conductivity. This subject has been discussed a lot in Revil (2012, 2013) who came with a relationship between these two parameters. It is unclear however if this relationship is universal or not.

11) Equation 10: A new unified model can be found in Revil et al. (2012), Revil (2013) and Revil et al. (2013a, b) that seems to work for all sedimentary rocks and that bypass the need for calibration or flush factors. Equation 11: it seems that a similar equation was discussed by Tong and co-workers.

12) Much more data should be shown on the 33 core samples including tables of their properties, Cole Cole parameters, etc. and more figure of the data (especially in phase and quadrature conductivities, resistivity magnitude and phase are useless in terms of physical meanings as they mix electromigration and polarization processes).

13) What is missing is a good inversion of the formation factor from the lab data (which requires doing the conductivity measurements at least at two salinities to correct for surface conductivity) and also an investigation between the surface and quadrature

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conductivities.

14) Page 5331, again much more discussion on the literature discussing the relationship between the characteristic relaxation time and the pore size should be given, see for example the discussion in Revil et al. (2012, 2013a, b) and Revil (2013). As the permeability depends on the formation factor, this parameter should be carefully evaluated too. The approach is a bit half-baked.

15) Discussion: is the IP effect of roots the same of the root alive or dead. In a recent paper, Revil and Co-workers models the effect of biological cells upon IP (Revil, A., E. Atekwana, C. Zhang, A. Jardani, and S. Smith, A new model for the spectral induced polarization signature of bacterial growth in porous media, *Water Resour. Res.*, 48, W09545, doi:10.1029/2012WR011965, 2012). They found that dead cells do not produce high IP effects.

16) Regarding the correlation between Spor and the quadrature conductivity: the authors missed a part of the recent literature in which a universal function was found between the specific surface area or the CEC and the quadrature conductivity (Revil, 2013, Revil et al., 2013a, b).

17) For the reasons exposed above I disagree with the statement " Our laboratory measurements indicate that for inhomogeneous sandy aquifers the direct relation between K and tau is not applicable" Recently developed models (assumed to be universal by their authors) are not tested so I don't think this statement is valid or at least it is not demonstrated to be invalid. As a big part of the recent literature is missing here, I consider the conclusions as not correct. I think the authors should pay attention to these models rather than ignore them, and they should tests them. They should allow others to see their dataset and if psosible testing these relationships.

18) There are many places where English needs to be correct. e.g., the last sentence of the abstract " A further, an application of this approach on 2-D SIP data is recommended." is not clear to me.

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19) The map of Germany in the insert should be simplified and should be readable. This is presently not the case.

20) Figure 2: It should to show the resistivity and phase but the parameters that have a physical meaning are the in phase and quadrature conductivities. Figure 3: put a title to the figure before starting in the caption with "a)". Figure 4: please label the z axis properly.

21) Figure 5: did you saturated the core samples under vacuum?

22) Figure 6: I would like to see much more data condensed in few figures together and showing the in phase and quadrature conductivities. At this point the manuscript requires to display much more data including some tables.

23) What is the reproducibility of the data?

24) Figure 7: hard to read!

25) Again plotting K versus the in phase resistivity or quadrature resistivity is meaningless as these parameters are composite of electromigration and polarization processes. I regret that the authors did not try a more in depth analysis of their lab data with existing models.

26) Figure 11: It would be good, if possible, to put some error bars.

27) Figure 12 is the kind of useless plot if you consider recent developments in IP: the relationship between K and Tau involves also the formation factor (Revil et al, 2013) and therefore for samples of different porosities, it is obvious that K would not correlate with Tau alone. It obvious that you have spent quite a time doing the lab work and working on the field data interpretation. It is a bit sad that there is only a small effort that has been devoted to the data analysis regarding existing petrophysics.

A. Revil, 4/29/2013

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Interactive comment on *Hydrol. Earth Syst. Sci. Discuss.*, 10, 5315, 2013.

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