

Authors response to Interactive comment on “Archie’s Law – A reappraisal”

By P. W. J. Glover

Anonymous Referee #1

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This document is a response to the comments made by Anonymous Referee 1.

Referee’s comment: This paper seeks to bring clarity to a field that has become increasingly murky since empirical modifications to Archie’s Law have yielded a large range of fitting-parameter values that remain unexplained. The author takes a step by step approach to an analysis of the sources of systematic error in the measurement of the rock properties pertinent to Archie’s Law. He discusses the relative importance of each and provides helpful recommendations for best practice. In this way, this will be a powerful contribution the Petrophysics community and a strong reminder to use empirical laws with caution (or better: with critical thinking) when theoretical laws are available. Prior to publication I have some minor remarks which I’d like to see addressed.

Author’s response: the author thanks the referee for her/his kind words and understanding.

(1) **Referee’s comment:** The author states that the data here presented must remain “unattributable” in order to be published. This may be normal in industry settings but, from a scientific point of view, this is alarming. At the very least, non-disclosure of the provenance of the rocks used herein precludes reproduction of the work by the interested reader, which is poor scientific practice. In the Data Availability section, the author reiterates that these data are confidential. I find this unappealing in a to-be peer reviewed scientific article and it would be desirable to divulge the data sets presented. This is especially true for a journal such as Solid Earth where the data availability is a key component of their open access policy.

Author’s response: I fully agree with the referee on this point. It is extremely annoying when we have to conform to industrial sensibilities, while understanding that they put a lot of investment into obtaining the data, I would have hoped that it would have been possible to at least identify the fields. Consequently, I have contacted the company in question, copying in the referee’s comment. I have only recently received a reply, which is that I have to conform to the original agreement on the use of the data. While the company

concerned notes that there is a move towards greater transparency for data within both the academic community and the commercial sphere, some data is of particular sensitivity, and they consider this data to fall within that definition.

Changes to manuscript: I have made a note in the manuscript that the company concerned has been asked to release the provenance of the data, and we have included as much of that information as it is possible within the licence.

- (2) **Referee's comment:** No experimental methodology is quoted that would indicate to the reader how the author measured the resistivity values quoted. Nor is a reference given for the data in which a methodology is contained. While it may be a routine measurement technique, the author goes on to critique the methods employed by others. As such one would expect a pristine methodology protocol to be a useful addition herein.

Author's comment: This is a very good comment, and very valid. The data itself was made by an oil service company, or maybe even several, commissioned by the company who owns the data. I have inserted into the manuscript notes to that effect together with a short description of how these typical and routine measurements are made within the industry. The manuscript already contains recommendations for making the best possible measurements.

Changes to manuscript: Four additions have been made: (i) a note about the importance of the methodology used to make the measurements with regard to the following inferences in the paper, (ii) a note about typical routine measurements of this nature and how they are carried out within the oil industry, (iii) a note about how the measurements made here were made within a service company that had been commissioned by the company that owns the data, and (iv) a reiteration of the author's comment that the quality of data used in the paper represents a typical industry routine electrical measurement, that can be taken to include the problems that such routine electrical measurements would normally include.

- (3) **Referee's comment:** The premise of the manuscript is that Eq. 1 is theoretically valid and that Eq. 2 is not. The question the author asks is then why is Eq. 2 widely used? The answer the author gives, in the form of a long discussion that is the majority of the manuscript, is concerned with measurement error in (almost) all previous studies. However, another possibility that is only given cursory mention (by way of Eq. 4; see below) is that Eq. 2 is in fact more valid and that an additional piece of physics is necessary to properly understand the empirical value. Were this indeed the case, the author points out that

would need to be variable in porosity to account for the “paradox” as porosity approaches 1. The author may be interested to pursue statistical predictions of pore space spatial correlation lengths (to give one example) for random heterogeneous media. These descriptions often contain the key pieces of information that predict well how the role played by empirical adaptations of idealized laws for rocks are in fact wrapped in the random heterogeneous nature of porous materials.

Author’s comment: I am glad that the referee understand the argument very well. The reason I do not follow this in the current paper is because I have no further idea of how to develop this side of the argument. The referee has given me some ideas with his/her comment which I will be looking at with a view to including it in further publications. I do not see the point in significantly delaying this publication to carry out what would be further significant research.

Changes to manuscript: There are no changes to the manuscript.

- (4) **Referee’s comment:** Eq. 4 and Eq. 5 are, as the author rightly states, identical to Eq. 2. This is a good example of over-analysis where simple statements would suffice. In this example: early on the author states clearly and confidently that Eq. 2 is an empirical modification of the more theoretically rigorous Eq. 1. Then rather Than repeat Eq. 2 in another form to demonstrate that there may indeed need to be a modification made, one could simply state that indeed one possibility is that Eq. 2 is the true answer and, therefore, that the physical meaning of α -parameter should be found. Instead the author restates Eq. 2 as Eq. 4, replacing with and deciding that we might like to know to what is related. This is a roundabout way of suggesting that the empirical modification would be justified if were better defined.

Author’s comment: I agree that equations 4 and 5 are identical to Equation 2. Nevertheless, they serve a purpose. These equations are generic forms of equation that are written in this way in order to understand the implications of various errors in the formulation of Archie’s law. They formed the foundation for the arguments employed when discussing errors in porosity (Section 5.1 and equations 7 and 8) and when discussing errors in fluid salinity (Section 5.2 and equations 10, 11). Consequently equations 4 to 11 form a set of generic equations, each pair of which examine the effect of an error in one of the parameters of the original equation, Equation 1.

Changes to manuscript: a sentence has been added to make my comment above clear to the reader of the paper.

- (5) **Referee’s comment:** On line 18 of page 10, the author states that it not possible (currently) to determine which porosity is appropriate for use with Eq. 1. This is not in keeping with the author’s assertion that

Eq. 1 is theoretically rigorous. If it is founded on good theoretical grounds as I conclude that it is, then the porosity required is the measured porosity that best approaches the true total porosity. However, Eq. 1 contains the resistivity of water in the pores. In this case, it may be the most desirable to consider only water-saturated pores.

Author's comment: I thoroughly agree with the referee.

Changes to manuscript: I have inserted the paragraph into the paper to make the referee's point.

- (6) **Referee's comment:** The author refers to himself as I in places, e.g. I hypothesize (line 22 on page 9), and to himself as we in other places, e.g. We have compared (line 12 on page 7). Please standardize and be consistent.

Author's comment: I agree that the active verb has been used a number of occasions, which is odd considering that I prefer the passive myself.

Changes to manuscript: I have changed all of the active verbs to passive verbs to ensure consistency.

- (7) **Referee's comment:** The text is often verbose and points are overstated. While I appreciate the rigour the author has brought to these problems associated with empiricism in Petrophysics, there is a limit to how much analysis is necessary to establish the errors associated with misuse of empirical fitting when theoretical laws are available.

Author's comment: I accept the referee's comment and have attempted to modify the manuscript to make it less verbose. However, accuracy in analysis often requires more words than you would think.

Changes to manuscript: Small modifications been made throughout the manuscript to make it less verbose.