

## **Interactive comment on “Thermal conductivity of unsaturated clay-rocks” by D. Jougnot and A. Revil**

**D. Jougnot and A. Revil**

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We want first to thanks the Anonymous Referee 3 for his/her constructive comments of our manuscript. We have performed the corrections corresponding to the comments made by the referee for our manuscript entitled "*Thermal conductivity of unsaturated clay-rocks*" by D. Jougnot and A. Revil. A keyed response follows.

1. The referee wrote: "*The paper's main point of interest is the thermal conductivity of rocks. Since this property is difficult to measure, the paper sets out to link the thermal conductivity to the more easily measured electrical conductivity. The stated aim is to develop a noni ntrusive measurement technique of the electrical conductivity from which the thermal conductivity can then be derived. Overall I can agree with this approach but there are some glitches: the authors seem to find the relevance*

S2749

*of the thermal conductivity self-evident, but it would strengthen the argument if the Introduction could elaborate on that; this need not be extensive, just an indication in a few lines should suffice. The single sentence devoted to it now is too concise to be convincing.*" We agree with the referee and we have changed the text accordingly in order to highlight the interest of thermal conductivity determination in the radioactive wastes storage context of unsaturated clay-rock materials.

2. The referee wrote: "*The proposed link between electrical and thermal conductivity is developed in a few equations. The presentation suffers from lack of clarity about the meaning and the dimensions of the variables, but this should be easily remedied. I consider this the major contribution of the paper, and it is worthwhile presenting it clearly.*" We agree with the referee and have extended the theoretical part of the paper by expanding the equations and the physical meaning of the parameters involved in this equations.

3. The referee wrote: "*The developed model is tested on rock samples, but the authors lost me there: the methodology is not clearly laid out (a section "Materials and Methods" is entirely lacking), and bits of it appear scattered throughout the paper. I had a hard time finding the size of the samples, the method by which they were obtained, the location and depth from which they were obtained, the composition (notably the electrical conductivity) of the liquid phase in the samples, etc.*" All these information are now more clearly described in the paper. Measuring thermal conductivity in a lab is done however with very-well established technics and the description of the lab methodology can be found in the cited papers.

4. The referee wrote: "*I also believe the samples to be disturbed and am left wondering if that does not severely hamper the test of the model: if it works on disturbed samples, how can we be sure that it works on undisturbed material as well, which probably has a very different fracture network.*" The samples have been disturbed indeed by the process of dessication at 105°C. This is clearly explained in the new version of the manuscript and this is discussed. We show however that the presence of microcracks

S2750

as a result of the strong dessication of the core samples can be handled through a low value of the cementation exponent. Such type of microcracks is also expected to be present in situ as explained in the new version of the manuscript.

5. The referee wrote: *"All in all this section of the paper is a bit hectic and confusing. If the underlying sampling technique and experimental methodology is sound, this can all be remedied by careful rewriting."* We agree with the referee and the text has been rewritten accordingly.

6. The referee wrote: *"Finally, there seems to be a discrepancy between the desire to develop a non-intrusive in situ measurement technique and the actual achievements of this paper: there is no field test after the work on cores. The authors have not even come close to proven this, and I expect this to take substantial additional work. Again this relates to the very brief introduction. Expectations are being raised to unrealistic levels. Although the long-term goal could be stated there it should also point out that this paper focuses on a first step in the desired development of a new measurement methodology."* The point of this paper is to show that in unsaturated conditions the electrical parameters used to describe electrical conductivity are consistent with those used to describe the thermal conductivity. Nothing more. The application of this methodology to *in situ* measurements is a big task in itself that is outside the scope of the present manuscript.

7. The referee wrote: *"The paper would greatly benefit from a careful rewriting. The Introduction can be extended (it is about 30 lines now) to better point out the relevance of this work, and its objectives. A Material and Methods section is highly desirable. This could also include a more extensive description of the geological formation from which the samples were taken; the geological units (see Table 2 for instance) remain clouded in mystery for me."* The introduction has been rewritten and the new version of the manuscript contains a more precise description of the COx clay-rocks with the different units and sub-units. It also gives the measurement details, the experimental setup, and additional references describing the methodology to perform measurements

S2751

of the thermal conductivity.

8. The referee wrote: *"The section introducing the model deserves a more careful presentation to improve its clarity. In its current state I find it very hard to assess the merit of this paper. I suspect but am not fully convinced the work is sufficiently novel and substantial to warrant publication in HESS. I hope a revised version sheds more light on this."* Changes have been made in that direction and we hope the new version of the manuscript will appear clearer to the referee.

9. The referee wrote: *"Please have the English checked. Many sentences are a bit awkward, and the use of present and past tense in a single paragraph occurs here and there but is usually not warranted. The use of the past tense for actions that took place in the past is often inappropriate. I suggest some improvements below, but not exhaustively. Please rethink the use of terminology. What is a "scale of porosity" (section 3)? Is the pore size the radius or the diameter? At some point "texture" (usually referring to the shape and size of the particles) is used to denote structure (the spatial arrangement of the particles, the pore architecture, the presence and nature of cracks, etc.)."* We have followed the advice of the referee.

10. The referee wrote: *"p. 2412, below l. 15: this belongs in Materials and Methods, p. 2413, top paragraph: this is a result. p. 2413, section 3: The part of section 3 on p. 2413 belongs in Materials and Methods."* We disagree with the referee to do a section entitled "Material and Methods" as we examined literature data and provides references where the (classical) methodology used to measure thermal conductivity has been extensively described elsewhere.

11. The referee wrote: *"p. 2413, l. 16. The variation in porosity seems to be extraordinarily small. What was the sample size, how many samples were there, and how were the porosity and its variation determined?"* The  $0.18 \pm 0.01$  value corresponds to the reference porosity given by ANDRA (2005). We have added a table with the average porosity measured in the different units and their standard deviation and the

S2752

methodology used to perform these measurements.

12. The referee wrote: "*p. 2413, l. 20-25: please provide references for the methods you discuss.*" The mercury intrusion experiments are based on the Washburn (1921) method (ANDRA, 2005). This is a very classical approach. A reference is now provided in the new version of the manuscript.

13. The referee wrote: "*p. 2413: please provide more detail about the two porosities you define here, and their connection to bound water. Also: how do you define bound water? p. 2413, l. 25: How do you know the fraction of the porosity that is unconnected?*" These studies were conducted by ANDRA (2005) and synthesized more than ten years of works on the COx clay-rock. The bound water is the hydration water of the mineral surface. There is no non-connected porosity in this material. This is now described in the new version of the manuscript.

14. The referee wrote: "*p. 2414, l.4-5 This is methodology. Please give more detail about the wetting process. Can hysteresis be a factor?*" Details are now given in the new version of the manuscript. There is not hysteresis as the thermal conductivity measurements are performed at equilibrium.

15. The referee wrote: "*p. 2414, l. 6: Texture or structure?*" We have used the word "Structure" in the new version of the manuscript.

16. The referee wrote: "*p. 2414, l. 7: I do not understand the part about the galleries. Please rephrase. Should that information really be given at this location in the paper?*" This information has been removed.

17. The referee wrote: "*p. 2415, l. 1-7. Does this belong in Materials and Methods? You use present tense here, but you seem to report how you did things; is the simple past tense not better suited for that?*" We agree with the referee and we used the past tense in the new version of the manuscript.

18. The referee wrote: "*p.2415, l. 12: What was the correlation coefficient of the*

S2753

*"quite good correlation"*" The value of the correlation coefficient is now given in the text explicitly.

19. The referee wrote: "*p. 2416: I find the conclusions not too convincing. You speculate that the method works in disturbed samples and undisturbed material, but you show no proof. Also, the scale issue involved in upscaling to much larger in situ scales is not addressed. If you rewrite the Introduction and the objectives, you should rephrase the conclusions too, I think.*" These changes have been followed and the manuscript corrected accordingly.

20. The referee wrote: "*Technical corrections proposed by the referee : Explain variables on first occurrence and specify their dimensions.*" Done

21. The referee wrote: "*p. 2415, bottom paragraph: single and past tense used inconsistently.*" Corrected.

22. The referee wrote: "*p. 2410, Abstract: parameters should be in italics. p. 2410, l. 8: two times "first"*" Done

23. The referee wrote: "*p. 2410, l. 12: a phase cannot have a variable saturation: ...at different water saturations.*" We agree and this has been corrected

24. The referee wrote: "*p. 2411, l. 5 and elsewhere: Gruescu et al.: (2007) or (2006)?*" This is Gruescu et al. (2006) and the change has been done accordingly in the manuscript.

25. The referee wrote: "*p. 2411, Eq. (1): there are nested ( ) in the equation; please use the prescribed order of nested brackets. p. 2412, l. 1: remove typo. p. 2412, l. 12: add space before n. p. 2412, l. 22: exponents and the verbs should be plural. p.2412, l. 24: experimentally observed...and the corresponding N calculated values.... p. 2413, top paragraph: past tense seems better.p. 2413, l. 14: ...a completely connected porous skeleton.. p. 2413, l. 15: ...material is granular. p. 2414, l. 5-6: ...required to let the water evaporate...p. 2414, l. 12: ...first discuss...p.2414, l. 20: prior -> priori*" We

S2754

have followed all these corrections. We thank the referee for the time he spent on our manuscript.

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