Hydrology and Earth System Sciences Discussions

Interactive
Comment

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 for his/her constructive comments of our manuscript. All the comments made the referee have been followed.

1. The Referee wrote: "*1. After noting that the values of m are quite low relative to the value reported by Revil et al. (2005), the authors state that the presence of micro-cracks caused a decrease in m. This statement needs to be reworded. While it is not unreasonable to conclude that micro-cracks may have caused a decrease in m, additional evidence would be required to establish a clear cause and effect. Also, it is not clear why the m value from Revil et al. (2005) is used as benchmark to assess whether or not the optimized m values are of the correct magnitude. This value is for water-saturated argillite. It seems entirely possible that values of m obtained using*

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the new model (with variable saturation) might differ from the m value for a saturated sample. Why is this not considered as a possible explanation for the "low" values? Can this be ruled out? Insofar as the data in Figure 3 include values of thermal conductivity at saturation, I encourage the authors to consider using this subset of the data to estimate m values using approach of Revil et al. (2005). This would allow for an assessment of the effect of micro-cracks on the parameter m that is independent of the new model."

This comment is very interesting and has been the subject of many discussions during the article writing. Our work is based on the use of electrical parameters to characterize the pore space geometry of the medium and the geometry of the water phase. In saturated conditions, we used the thermal conductivity model developed by Revil (2000) and more precisely the thermal formation factor f (see Eq 2) calculated from the m exponent. This Archie's first exponent is determined from first Archie's law for electrical conductivity: $\sigma = \phi^{-m}\sigma_f$ in clay-free rocks, where σ and σ_f are the medium and the pore water conductivity, respectively. Considering unsaturated conditions, Archie second law is $\sigma = \phi^{-m}s_w^n\sigma_f$, where s_w and *n* are the saturation and the saturation index, respectively. Since *m* or the electrical formation factor $F = \phi^{-m}$ are fundamental textural property of the medium, they should be the same in saturated and unsaturated conditions (see Yaramanci et al. 2002, Kruschwitz and Yaramanci 2004, Linde et al. 2006). The exponent *n* takes into account the water phase geometry. Following all these approaches, *m* is in principle the same in saturated and unsaturated conditions except in the case where irreversible damage occurs during dessication. The effect of microcracks can explain the low value of *m*. Heating argillites samples yields to the formation of microcracks (Montes et al. 2004, Cosenza et al. 2007). Heating was used by Homand et al (1998) to dry their samples. Such textural changes have been observed by Scanning Electron Miscroscopy (see Montes et al., 2004), and they show that the medium do not recover its initial properties when resaturated.

The cementation exponent *m* provides a quantification of the pore space geometry. We

consider that if *m* decreases, the "tortuosity" of the medium decrease also. For example in sand *m* = 1.3, while in consolidated clay *m* > 2 (see Archie 1942, Lesmes and Friedman, 1984). Microcracks can only decrease the tortuosity by creating shortcut in the consolidated medium, that is why we consider the low values of *m* is explained by the presence of microcracks during the heating of the samples. We have modifield our manuscript to explain this point.

2. The Referee wrote: "*2. In the Conclusions the authors suppose that m = 2 could be used for undisturbed argillites. No basis for this supposition is presented. The authors argue that the m values between 1.37 and 1.52 for the argillite samples are low due to the presence of micro-cracks, but they present to no evidence to support the supposition that this parameter would increase to the particular value of m = 2 for undisturbed (i.e., no micro-cracks) argillites.*"

We agree with the referee on the fact that there is not enough electrical measurements on COx argillites in general. The value of *m* = 1.95 comes from the only electrical measurements we had for saturated COx argillites (published by Revil et al. 2005). Revil and Linde (2006), determinate the value of *m* values from diffusion experiments (see also Jougnot et al., in press in Geochimica et Cosmochimica Acta). This approach for undisturbed saturated COx argillites yields a cemetation exponent close to 2. Leroy and Revil (submitted in Journal of Geophysical Research) used Arulanandan (1969) data on fully saturated Mancos Shale (clays-rocks very similar to the COx argillites) and have found *m* = 2.2. In the revised version of our paper, we will add these new results in order to justify why we think that *m* = 2 seems to be a fairly good assumption for saturated COx argillites.

3. The Referee wrote: "*3. In light of the previous comment, and the fact that a value of n is reported for damaged (i.e., disturbed) argillites only, it is premature to conclude that the thermal conductivity of undisturbed formations can be obtained by non-intrusive imaging. The experimental results do not support this conclusion. Additional testing is needed to verify that the approach has merit.*"

We agree with the referee and we have removed this statement in the conclusion of the revised manuscript.

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