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Discussion and Reply

Comment on "Permeability prediction from MICP and NMR data using an electrokinetic approach" (P. W. J. Glover, I. I. Zadjali, and K. A. Frew, 2006, GEOPHYSICS, 71, no. 4, F49–F60)

Discussion by A. Revil[1]

Glover et al. (2006) present a supposedly new permeability model that they call the RGPZ model. This model relates permeability to the mean grain size of a porous medium and the electric formation factor. They compare the prediction of this model with the predictions made with four other models—the Kozeny-Carman, Berg, Swanson, and van Baaren models (see Kozeny, 1927; Berg, 1970; Swanson, 1981; and van Baaren, 1979)—on different sets of permeability data covering glass bead packs and samples with various lithologies. This comparison reveals the improved accuracy of the RGPZ model compared with the four other models. The RGPZ model furthermore is used to interpret downhole measurements using the T_2 spectrum resulting from nuclear magnetic resonance (NMR) measurements.

The so-called RGPZ model was published earlier by Revil and Cathles (1999, see their equation 12) and is called the RC model in this comment. The RC model is also extended to sand/clay mixtures and applied to the interpretation of downhole measurements by Revil et al. (2002) and Rabaute et al. (2003). Rabaute et al. (2003) use a nonlinear inversion algorithm of borehole data to estimate the mineralogical composition of sandstone reservoirs and to estimate a permeability log using the RC model in clay-coated sandstone reservoirs. The RC model is extended by Revil (2002) to high-porosity granular materials and low-porosity granular materials with a percolation threshold, without relying on the assumption that $a = 2$ and $m^2 = 3$ in the permeability/porosity relationship. The derivation of the RGPZ model is provided by Revil and Cathles (1999, their Appendix A and equations A1–A4). [See also Revil (1999, sections 4 and 5) and Revil (2000, Appendix B), where the thermal formation factor f is defined.]

Glover et al. (2006) misinterpret the nature of the physical relationship between permeability and the electric parameters, such as the electrical formation factor or Archie's exponent used in the RGPG model. They claim in the title of their paper and in their abstract that this relationship is electrokinetic in nature. Electrokinetic effects are a class of phenomena involving a relative displacement between the diffuse layer of counterions around the mineral grains or solid particles in colloidal suspensions and the grains themselves (e.g., Revil et al., 1999). For example, the streaming potential is the electric field produced by the drag of the excess of charge contained in the pore water when water flows through the porous material [e.g., Revil (2002) and references therein]. However, the relationship between permeability, mean grain size, and electric formation factor developed by Revil and Cathles (1999) and Revil (2002) is not based on electrokinetic phenomena (e.g., Wildenschild et al., 2000). The RC permeability model is an application to granular media of previous works by D. L. Johnson, P. Sen, and coworkers at Schlumberger (e.g., Johnson et al., 1987a, 1987b), who relate the permeability and two electric parameters: the Λ-length scale and the electric formation factor defined in the DC-conductivity problem of porous rocks.

Several groups of researchers claim the RC model works successfully for a variety of applications concerning the evaluation of the permeability of granular media such as soils (e.g., Lienard et al., 2001; Wahyudi et al., 2002; Tuller and Or, 2003) and in hydrogeophysics (e.g., Slater and Glaser, 2003). It would have been more appropriate for Glover et al. (2006) to have acknowledged this point and to focus on the application of the RC model to downhole measurements using NMR information.

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Reply to the discussion

P. W. J. Glover[2]

The comment by Revil (2007, this issue) regarding a recent article in GEOPHYSICS (Glover et al., 2006) contains a number of interesting points. First of all, we confirm that some of the development of the theory in our paper is also contained in Revil and Cathles (1999). To be more specific, the comparison between equation A-8 in Glover et al. (2006) originally comes from the work of Bussian (1983),

$$\sigma = \frac{1}{F}(\sigma_f + m(F-1)\sigma_s), \tag{1}$$

and equation A-9 in Glover et al. (2006), originating from the work of Johnson and Sen (1988):

$$\sigma = \frac{1}{F}\left(\sigma_f + \frac{2}{\Lambda}\Sigma_s\right). \tag{2}$$

This leads directly to an expression for the length scale Λ,

$$\Lambda = \frac{R}{m(F-1)} \cong \frac{R}{mF} = \frac{d}{2mF}, \tag{3}$$

which is equation A-10 in Glover et al. (2006) and is equation A-4 in Revil and Cathles (1999). This relationship can be combined with a well-known relationship for hydraulic conductivity (e.g., Schwartz et al., 1989; Kostek et al., 1992; Bernabé and Revil, 1995),

$$k \approx \frac{\Lambda^2}{aF}, \tag{4}$$

to give the prediction equations found in Glover et al. (2006) as equation A-12:

$$k_{\mathrm{RGPZ}} \cong \frac{d^2}{4am^2F^3} = \frac{d^2\phi^{3m}}{4am^2} = \frac{3d^2\phi^{3m}}{32m^2}. \tag{5}$$

By comparison, Revil and Cathles (1999) arrive at a slightly different equation by taking a specific case in which $a = 2$ and $m^2 = 3$:

$$k_{RC} \cong \frac{d^2\phi^{3m}}{24}. \tag{6}$$

Those equations (A1–A7) that lead up to the comparison are fully and appropriately referenced in Glover et al. (2006), and the other equations in the paper are not found in Revil and Cathles (1999). We are happy to apologize to Revil and Cathles for the oversight that was caused by our not being aware that the critical comparison had been made already.

Revil claims that the Glover et al. (2006) article "misinterpreted the nature of the physical relationship between the permeability and the electrical parameters like the electric formation factor or Archie's exponent used in the RGPG [sic] model." The model is based on a comparison of coefficients between two models: one representing the flow of bulk and surface electric conduction in a granular porous medium and the other representing fluid flow in a like medium. The comparison does not rely on a mechanism that is currently formally described. However, it does link fluid flow with bulk and surface electric conductivity, and it is our implicit statement in the article that the link, when found, will be electrokinetic in nature. This being the case, perhaps it would be better to replace occurrences of "electrokinetic" with the form "possible electrokinetic" in the title and text of the original paper.

We are happy to acknowledge that several groups of researchers have found that the Revil and Cathles (1999) RC model works successfully for a variety of applications concerning the evaluation of the permeability of granular media such as soils or in geophysics. We hope that these applications continue. However, we feel it is too restrictive to use a model that assumes that $a = 2$ and $m^2 = 3$, when at least the cementation factor is often known. I also agree with Revil (2007, this issue) that this approach would be extremely useful if it could be applied routinely to nuclear magnetic resonance data. More work needs to be carried out; however, data sets of sufficient quality are hard to find.

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