Membrane polarization from molecular to rock scale in dynamic regime

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In recent years V. Zadorozhnaya measured in laboratory a strong non-linear behaviour of electrical resistivity and chargeability in fresh-water saturated samples of several porous rock types. In particular she observed a general increase of resistivity and decrease of chargeability with injected current, together with an increase of both parameters also with time of electric current circulation, (Zadorozhnaya 2008; Zadorozhnaya and Hauger 2009; Zadorozhnaya and Maré 2011).

Based on Fick equation, a model of membrane polarization was developed at pore level, which successfully explained the results (*ibid.*). In particular, the model links the above non-linearity to Pore Size Distribution (PSD) and thus it allows to predict PSD from specifically designed measurements (at least 3 resistivity measurements at 3 different current intensities), in satisfactory agreement with PSD measured using the well-known Hg porosimeter test.

As is known, PSD is linked, although in a heuristic way, to hydraulic conductivity of a porous rock (e.g. Schoen 2004), so that recording a non-linear electrical response should allow predicting hydraulic conductivity through estimation of PSD. Of course, observing the same non linearity in the field by using conventional, or at most specifically adapted, resistivity and induced polarization methods should be of utmost importance for water resources exploration, as an information of strong hydrogeological impact could then be added to the estimation of effective porosity based on the well-known Archie's relationship (Archie 1942).

Electrical non linearity violates the well-established Ohm's law. Such non linearity was never reported in the geophysical literature, at authors knowledge, from usual field measurements. On the other hand, although today the IP response is taken for granted as linear, in the early times of testing the IP method, researchers were aware about possible non linearity associated to circulation of very intense electrical current (Bleil 1953; Iliceto et al. 1982): this non linearity was interpreted as a "saturation" effect, without any further investigation.

Authors also calculated and analysed the shape of induced polarization signals if arbitrary current pulse is to be applied to the sample (dynamic regime of transient IP). The results are very similar to laboratory experiments provided by Swanson et al. (2012).

In fact, laboratory samples are crossed by current densities which are fairly greater than those usually available in the field. As a matter of fact, electric currents of the order of 1 A or less are usually injected into the ground by currently available geo-resistivity-meters both for safety reasons and for portability of equipment. With so small current intensities at injecting electrodes, current density becomes very weak with increasing investigation depth, which is very far from laboratory measuring conditions.

In this work a field test is described, which was carefully planned, selecting a site where a saturated porous aquifer, of the same type as those had shown non linearity in the laboratory was possibly outcropping, to reduce decay of current density with depth of investigation. At the selected site (Northern Apennines, Italy), the porous saturated formation was sandstone, while the aquiclude was clay. Several shallow wells for collecting fresh water for drinking uses are present and were producing water at moment of measurements (May 2013). A commercial geo-resistivity-meter was used, to get measurements in a tomographic way, repeating the acquisition at two fixed and fairly different intensities of injected current, of 50 and 500 mA respectively. The equipment was the model SAS4000 by ABEM Instruments (Sweden), which is built as a current generator, so that injected current is under the control of electronic circuitry embedded in it. A profile of 25 electrodes, spaced 3 m was laid out, allowing for a maximum investigation depth of about 12 m.

The datasets were inverted by using a commercial two-dimensional inversion code and the resistivity models are shown in Fig. 1. The geological interpretation is simple: dark areas indicated by "C" are associated to clay formation, while the grey to dark areas indicated by "A" to saturated sandstone. A fair increase of resistivity associated to the resistive bodies, i.e. saturated sandstone, is observed, centred at abscissae 31 m and 55 m respectively. Also chargeability models (not shown here) exhibit a behaviour which is quite similar to that observed on lab samples, i.e. a strong decrease with increasing current intensity.

The authors are aware that the field results shown here are so unusual that they need an indispensable validation, both by extending measurement at the test site and by repeating them in other sites, possibly of similar hydrogeological characteristics

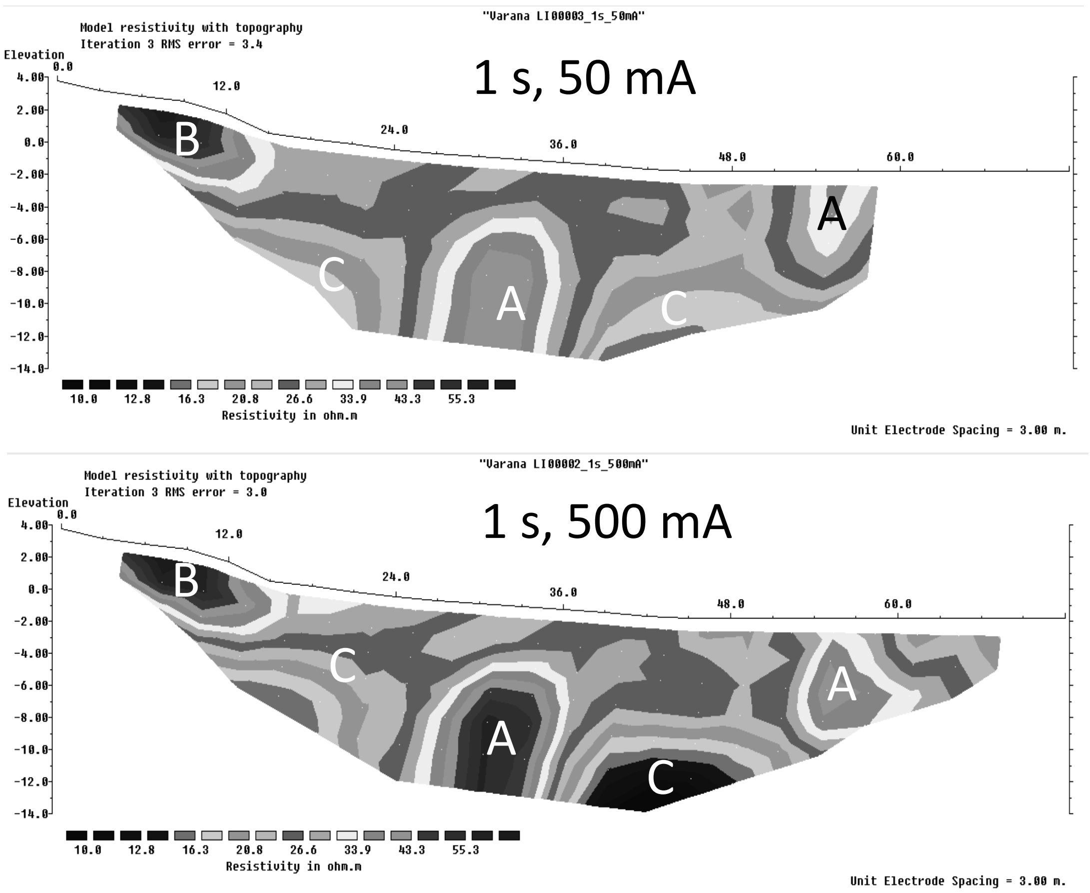

Fig. 1: 2D resistivity model obtained at 50 mA of injected current (above) and at 500 mA respectively (below), 1 s of injection time. A: aquifer bodies; B: drained debris.

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