New shape of TEM: membrane polarization, mechanism and possible interpretation

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It is known that induced polarization (IP) effect affects the polarization process on a TEM sounding. Usually, it is an effect of electroosmosis type. Numerous formulae, which describe the IP-effect of electroosmosis type in geological media, are known. The most widely used IP model is described by the Cole-Cole formula (Cole and Cole 1941; Pelton et al. 1978). In our calculations, we use a simplified Cole-Cole formula, i.e.:

Frequency domain	Time domain
$\sigma(\omega) = \dfrac{\sigma_\chi}{1+\dfrac{\eta}{i\omega\tau+1}}$ (1)	$\sigma = \dfrac{\sigma_\chi}{1+\eta}\left[1-\eta\exp\left(-\dfrac{1+\eta}{\tau}t\right)\right]$ (2)

where ω represents angular frequency, η is the polarizability and τ is the decay constant.

This means that η is the ratio of surplus electrical conductance to the electrical conductance of the pore fluid. The values of polarizability η ranges from 0, for sediments with large pore spaces when the contribution of the electrical double layer (EDL) is negligible, to 1, in sediments such as some types of clay, where the pore spaces are very small.

Many TEM soundings are distorted by the IP effect but not all of the decay curves change in sign. However, equations (1) and (2) show that the amplitude of IP effect does not depend neither on amplitude of electrical current nor on the current pulses duration.

The theory of IP effect caused by constrictivity of pores, developed by Zadorozhnaya (2008), Zadorozhnaya and Hauger (2009) and Zadorozhnaya and Maré (2011), to explain non-linear electrical phenomena measured on saturated samples of porous rocks in laboratory, starts from observing that cations in narrow capillaries are more mobile (transfer more electrical charges) than anions because in narrow capillaries some anions are adsorbed by the EDL and are immobile. This means that the salinity of cations increases. The salinity of anions is increased by the same amount (in case of neutrality of solution). Obviously the excess of salinity at the boundary between pores depends on time of applied current. If pulse length is short, then the excess of the ions becomes small and time of levelling (discharging) is also short. Increasing length of current pulse entails that the membrane effect increases. The direction of ions accumulated at the boundaries is the same as the current flow (Kobranova 1986). On the other hand the direction of discharge is also the same as the direction of transient emf. That is why the resistivity of layers, where membrane IP effect occurs, show considerable decrease.

In 2012, the authors carried out a TEM survey in the Northern Apennines composed of 6 soundings above a subsurface mainly composed by clayey layers. The ZONGE equipment was used. All the 6 TEM soundings were registered using different length of current pulses (frequencies 32, 8 and 4 Hz). Very strange signals were collected. While all decay curves show a typical IP effect, three of them (TEMs 1, 2 and 3, acquired on the northern side of the investigated area) strongly depend on used exciting frequencies, while the remaining three on the south do not. In Fig. 1 TEM 3 and TEM 4 are shown as examples.

For interpretation of TEM soundings, a 1D modelling and inversion code, written in MATLAB by V. Yu. Zadorozhnaya was used. Results of interpretation are given in Table 1. At frequency 32 Hz (right model) the section contains relatively resistive (60 – 90 Ωm) first layer, then resistivity gradually decreases with depth. The resistivity of deep clay layers is about 0.5 Ωm.

This geoelectrical structure shows a good agreement with a 2D, DC resistivity inversion model obtained nearby TEM 3 (not reported here). However, the resistivity of clay considerably decreases when frequencies 8 Hz or 4 Hz have been used (left model). Obviously the resistivity

0.05 Ωm is too small to be a realistic value of any shallow formation, even for a submarine clay deposit. This effect can be explained if we accept that an additional type of IP effect occurs, due to different length of current pulses. We propose that membrane polarization occurring due to constrictivity of pores affects the shape of the TEM signals, which depend on the exciting current time-span.

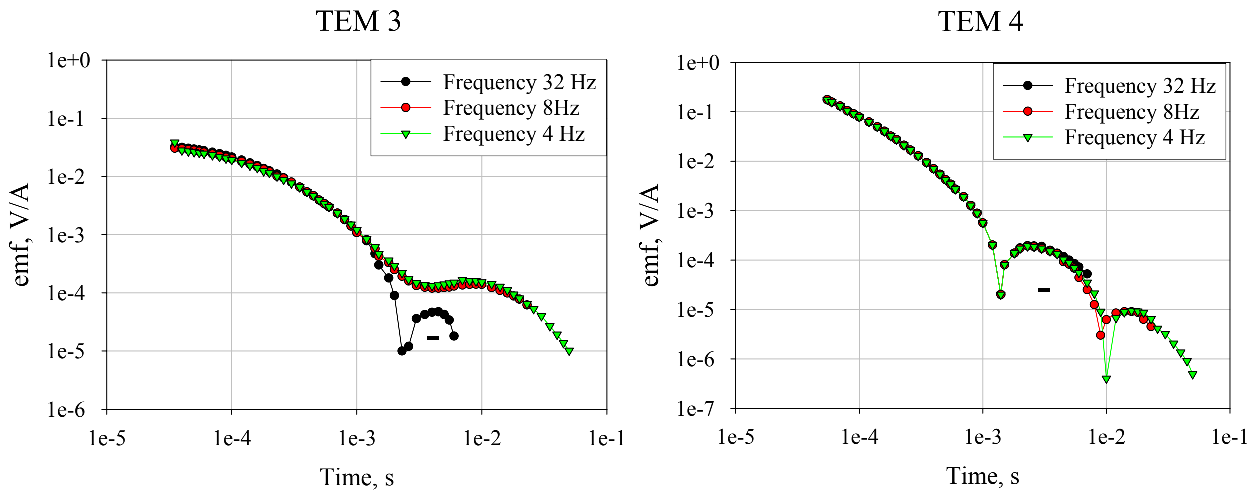

Fig. 1: Decay curves of TEM soundings 3 and 4.

Modelling of TEM 3. Frequency 4-8 Hz					Modelling of TEM 3. Frequency 32 Hz				
# of layer	ρ resistivity (Ω m)	h thick-ness (m)	η chargeability	τ decay constant (s)	# of layer	ρ resistivity (Ω m)	h thick-ness (m)	η chargeability	τ decay constant (s)
1	30	30	-	-	1	90	15	-	-
2	8	45	-	-	2	12	25	-	-
3	0.92	45	0.25	3e-3	3	2.3	19	-	-
4	0.05	45	0.99	3.5e-3	4	0.5	20	0.25	3.5e-3
5	0.05	45	0.99	3e-3	5	0.5	25	0.25	3e-3
6	0.05	45	0.99	3e-3	6	0.6	24	0.25	3e-3

Table 1: 1D models of TEM sounding 3 at 4-8 Hz (left) and at 32 Hz (right).

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