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On penetration electric sounding

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A comparison is made of a penetration resistivity log with a resistivity log measured in a drilled hole. From natural gamma ray and neutron porosity logs, clay content and porosity were estimated and then true resistivity was calculated on the basis of De Witte's shaly sand model and the Dual Water model. The approximation of the penetration resistivity log with the simulated true resistivity logs is acceptable.

Keywords: penetration sounding, resistivity log, Dual Water model, De Witte model

1. Introduction

A penetration geophysical complex consists of measurements of natural gamma ray, gamma-gamma density, neutron porosity, and specific apparent resistivity [FEJES, JÓSA 1990]. The last is a relatively new one because several technical difficulties had to be overcome to create the penetration electric sonde. A penetration electric sonde consists of ring shaped electrodes mounted on an insulating cylinder outside the steel penetration tube. Between the current and the voltage electrode there is a spacing of 5 cm, and the return current electrode is 20 cm from the current one. The reference electrode is on the surface. The whole length of the insulating cover on the steel tube is 30 cm. It can be supposed that the steel tube has a perturbation effect on the measured apparent resistivity, which probably depends on the length of the steel tube. Although theoretical modelling has not yet been used, there is evidence that the penetration measured apparent resistivity value differs only slightly from the true one.

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2. Comparison of penetration and borehole electric measurements

Penetration and borehole electric measurements took place in the same field: the borehole and the penetration site were some 10 m apart. The borehole was drilled with mud having an apparent resistivity of 5 ohmm. Two apparent resistivity log curves were measured in the borehole, the usual short normal and a shorter one — with spacings of 40 cm and 10 cm respectively. From these, the true resistivity curve was calculated, to eliminate the borehole effect. No processing was carried out on the penetration resistivity curve. Depth matching was necessary in order to compare the penetration and the true resistivity curves (shown in *Fig. 1*). By comparing the two curves, it is seen that the penetration resistivity curve is much more rugose than the borehole true resistivity curve, probably due to its shorter spacing. Another finding is the systematic difference between the curves: the penetration resistivity has higher values than the other one, and the difference increases with increasing depth. Nevertheless the shapes of the curves are very similar, the correlation coefficient value is 0.866. Regardless of the fact that the measurement sites were not the same but only close to each other, there are other reasons for the difference. In both cases the environment is changed but in a different manner. For borehole electrical log the invasion process may change the resistivity, during penetration the soil environment is more or less compressed in the near zone thereby causing porosity decrease and resistivity increase. Another factor is the effect of the steel tube which has not been taken into account.

3. Simulation of penetration resistivity from other logs

At another site, where the water was polluted by sodium hydroxide, several penetration soundings were performed. The measuring complex consisted of natural gamma rays, neutron porosity, and resistivity. The soil environment was modelled with fine grain components (clay and silt) and coarse grain components (sand and gravel). The remaining part of the soil is the effective pore space. The volume of the fine grain components and that of the porosity are denoted by v_{cl} and ϕ respectively. The pore space was completely saturated with polluted water up to the surface.

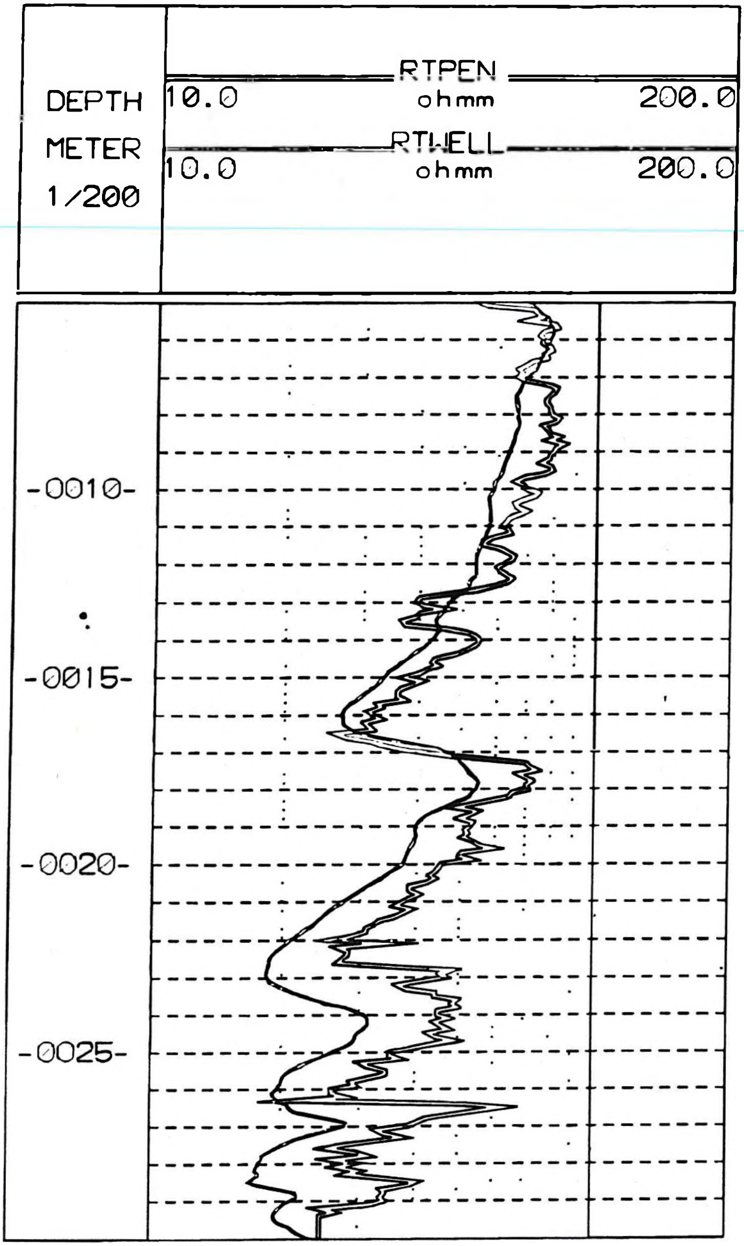

Fig. 1. Comparison of penetration (RTPEN) and borehole (RTWELL) resistivity logs
1. ábra. Penetrációs (RTPEN) és fúrásban mért (RTWELL) fajlagos ellenállás szelvények összehasonlítása

As is known, gamma ray logs are sensitive to clay, and the clay content can be estimated from gamma ray logs as follows:

$$v_{cl} = \frac{GR - GR_s}{GR_{cl} - GR_s} \tag{1}$$

where GR_{cl} and GR_s are the gamma ray activities of clay and sand respectively.

The neutron porosity (ϕ_N) log measures the soil's total hydrogen concentration, which comes from the movable free water and the bound water of clay. The neutron porosity of the clay is denoted by ϕ_{Ncl}:

$$\phi_N = \phi + v_{cl}\phi_{Ncl} \tag{2}$$

In the shaly-sand resistivity model of De Witte [SERRA 1984 p. 458] the free water and the electrically conducting clay are regarded as two components of a mixture of electrolytes that fill the generalized pore space ($\phi+v_{cl}$). From this model the following formula is deduced for the resistivity R_t of the shaly sand when the pore space is totally saturated with water:

$$R_t = F\left(\frac{q}{R_{cl}} + \frac{1-q}{R_w}\right)^{-1} \tag{3}$$

where F is Archie's formation resistivity factor relating to the generalized pore space and q the relative clay content:

$$q = \frac{v_{cl}}{\phi + v_{cl}} \quad . \tag{4}$$

R_{cl} and R_w are the resistivities of the clay and the water respectively.

The other model considered is the Dual Water shaly sand resistivity model (Schlumberger Document 1987, p.114), in which the conductance effect of the clay is taken into account as a consequence of the exchange cations close to the particle surfaces; these cations cause an increase in the conductivity of the bound water. The resulting conductivity C_{we} of the electrolyte in the pore space is the weighted average of the conductivities C_{wb} and C_w of the bound water and the free water respectively. The amount of bound water on a saturation scale is S_{wb}. By applying Archie's law and supposing that the pore space is totally saturated with water, the conductivity of the shaly sand is:

$$C_t = \phi_t^m C_{we} \tag{5}$$

where ϕ_t is the total porosity which includes the volume of bound water and free water and m is the cementation exponent. Without going into detail, the conductivity of the soil will be:

$$C_t = \phi_t^m (C_w + S_{wb}(C_{wb} - C_w)) \tag{6}$$

In order to calculate the conductivity one needs to know the values of ϕ_t, C_w, C_{wb} and S_{wb}. Neglecting the effect of the mineralogical composition of the soil on neutron measurement, as a first approximation:

$$\phi_t = \phi_N \tag{7}$$

$$C_{wb} = \phi_{Ncl}^m C_{cl} \tag{8}$$

and

$$S_{wb} = v_{cl}\phi_{Ncl} / (\phi + v_{cl}\phi_{Ncl}) \quad . \tag{9}$$

Rewriting Eq. (6) by applying Eqs. (7), (8) and (9) one arrives at:

$$R_t = C_t^{-1} = \phi_N^{-m} \left\{ \frac{1}{R_w} + \frac{v_{cl}\phi_{Ncl}}{\phi_N} \left(\frac{1}{\phi_{Ncl}^m} \frac{1}{R_{cl}} - \frac{1}{R_w} \right) \right\}^{-1} \quad . \tag{10}$$

Now there are two equations (Eq. (3) and Eq. (10)) depending on different earth models to calculate the resistivity of the soil from the neutron and the gamma ray logs. In addition to these, other quantities have to be known, viz. the constants or zone parameters. These are: GR_{cl}, GR_s, ϕ_{Ncl}, R_w, R_{cl}, R_{wb} and m. The value of R_w is known from direct electrolyte resistivity measurement, its value was 4.6 ohmm. The values of the other constants were determined first from the minimum and maximum log readings and then refined in order to reach a fairly good approximation between the synthetic and measured resistivity curves. The results are shown in *Fig. 2*. In the first track are the measured gamma ray and neutron porosity logs; the other two tracks contain the pairs of measured penetration resistivity logs and synthetic resistivity logs for the two model cases. There is a visual similarity between the synthetic and measured logs. On calculating the correlation coefficient we found the following values: 0.902 for De Witte's model and 0.884 for the Dual Water model.

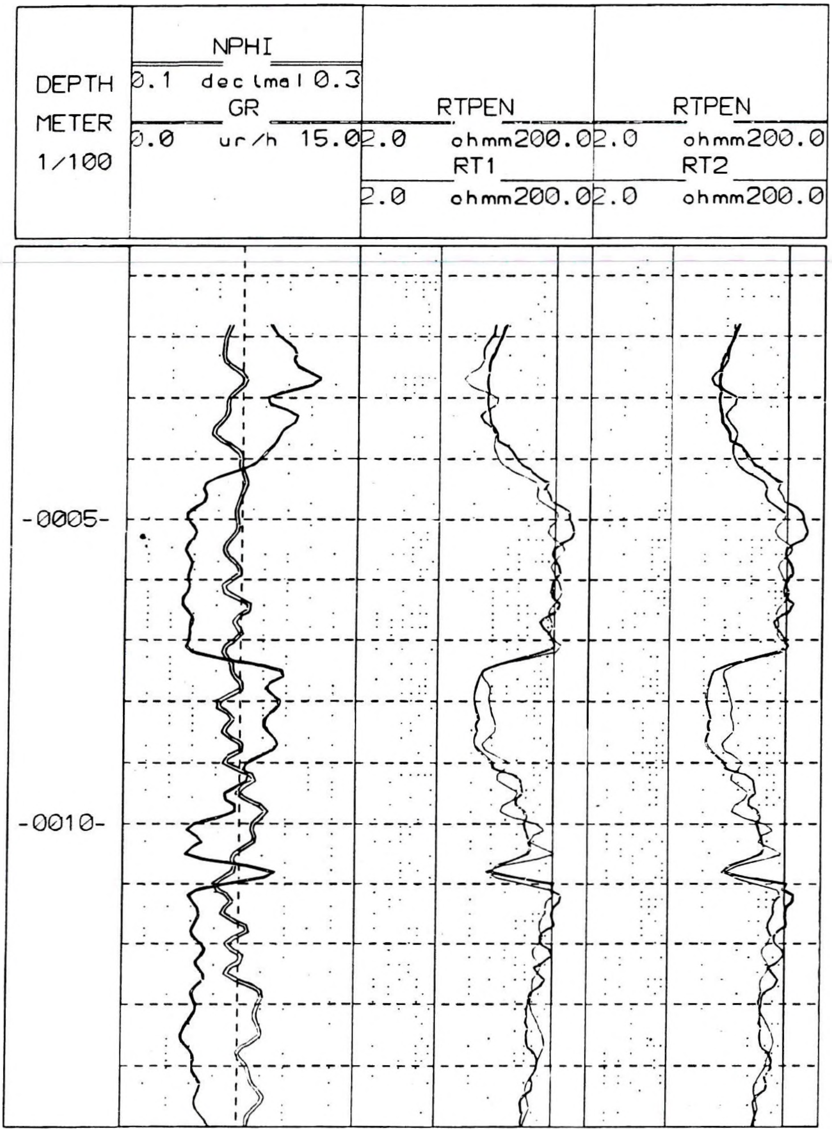

Fig. 2. Comparison of penetration resistivity (RTPEN) and simulated true resistivity logs RT1 and RT2 which were calculated from De Witte's and from the Dual Water model respectively. The other logs are neutron porosity (NPHI) and gamma ray(GR).

2. ábra. Mért penetrációs fajlagos ellenállás szelvény (RTPEN) összehasonlítása természetes gamma (GR) és neutron (NPHI) szelvények alapján számított fajlagos ellenállás szelvényekkel. A számított szelvények:
RT1: De Witte modell alapján számított fajlagos ellenállás szelvény,
RT2: Dual Water modell alapján számított fajlagos ellenállás szelvény

4. Conclusion

Direct comparison of penetration and borehole resistivity measurements show convincing similarity, and the effect of the steel tube does not mask the effect of the soil environment. But if the magnitude of the tube effect is unknown, the answer is in theoretical modelling. The good approximation of the penetration resistivity log by shaly sand models proves their applicability in a soil environment and also proves that the penetration apparent resistivity is close to the true soil resistivity.

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A mérnökgeofizikai elektromos szondázásokról

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A dolgozatban bemutatunk azonos területen fúrásban mért és penetrálás során fölvett fajlagos ellenállás szelvényeket, amelyek — kisebb eltérésektől eltekintve — hasonlóságot mutatnak. Egy másik kutatási területen a penetrációs mérés során természetes gamma szelvény és neutronporozitás szelvény is készült, amelyekből porozitást és agyagtartalmat határoztunk meg. Ezek alapján szintetikus fajlagos ellenállás szelvényt számítottunk az agyagos homokkő modellekre vonatkozó De Witte és Dual Water modellek alapján. A szintetikusan előállított ellenállás szelvények jól megközelítik a mért penetrációs fajlagos ellenállás szelvényt.

ABOUT THE AUTHOR

Dezső Drahos graduated as a geophysicist from the Eötvös Loránd University, Budapest in 1967. He received his Ph.D. degree from the Hungarian Academy of Sciences in 1989. From 1967 to 1970 he worked as a scientific assistant at the Eötvös Loránd Geophysical Institute where he was involved in theoretical and experimental modelling of logging sondes. Since 1970 he has been at the Department of Geophysics of Eötvös Loránd University initially as a lecturer and, since 1991, as associate professor. Besides his teaching activities he is interested in geophysical inversion, well logging and petrophysics. He is a member of the Association of Hungarian Geophysicists, and also a member of SEG and SPWLA.