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Petrophysical Analysis of Resistivity Data

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SUMMARY

Ryjov developed forward problem of soil resistivity for sand-clay models. It uses 9 parameters (clay and sand porosity and capillary radii, water salinity and humidity, cation exchange capacity, temperature and clay content) to calculate soil resistivity. We applied these calculations for petrophysical analysis of sand clay soils using soil resistivity obtained from VES interpretation. It became clear that dependence of resistivity from clay content, porosity, cation exchange capacity, etc. allows solving inverse problem (estimation of petrophysical parameters on soil resistivity), that was fulfilled as algorithm and software in 2003. It is evident that we can t determine all 9 parameters by using only soil resistivity; we need to find and use some additional information to have quantity of known parameters more than unknown ones. Temperature and groundwater salinity can be determined in each field site. We take soil samples to measure soil resistivity versus pore water salinity in laboratory to obtain soil model and recalculate resistivity data (cross-sections and maps) into cross-sections and maps of petrophysical parameters: clay content, porosity, cation exchange capacity, filtration coefficient, etc. After 2003 this technology was probed at more than 20 field sites in Mexico and Russia and demonstrated its efficiency.

Introduction

Ryjov and Sudoplatov (1990) developed forward problem of soil resistivity for sand-clay models. They used 9 parameters (clay and sand porosity and capillary radii, pore water salinity and humidity, clay cation exchange capacity, temperature and clay content) to calculate soil resistivity in forward modeling. We applied these calculations for petrophysical analysis of sand clay soils using soil resistivity obtained from VES interpretation. It became clear soon that dependence of forward problem from clay content, porosity, cation exchange capacity of clay, etc. allows solving inverse problem (estimation of petrophysical parameters on soil resistivity), that was fulfilled as algorithm and software in 2003. It is evident that we can’t determine all 9 parameters by using only soil resistivity; we need to find and use some additional information to have quantity of known parameters more than unknown ones. Normally temperature and groundwater salinity can be determined in each field site. We also take soil samples to measure soil resistivity versus pore water salinity in laboratory and these data interpretation gives us soil model. With this information we can recalculate resistivity data (cross-sections and maps) into cross-sections and maps of petrophysical parameters: clay content, porosity, cation exchange capacity, filtration coefficient, superficial conductivity, etc. After 2003 this technology was probed at more than 20 field sites in Mexico and Russia, mainly on oil contaminated sites and demonstrated its efficiency.

1. General considerations

Before recalculation of site resistivity into petrophysical parameters we need to obtain soil model of the site. Special operation called petrophysical modeling was developed for that. Its purpose to verify consistency of all data of the site (VES data, groundwater salinity and soil samples resistivity) and specify the main factor, influenced on resistivity. According to this main factor one can discriminate site's soil model (lithological one, when change of lithology is the main factor of resistivity change; humidity factor, in the case of vadose zone with strong resistivity contrast; salinity factor, when changes of groundwater salinity mainly influence on resistivity). Of cause there are mixed types, when lithology and humidity together control resistivity changes. When we know the main factor (or factors) we can begin resistivity recalculation into petrophysical parameters tacking into account this main factor.

All forward and inverse problem calculations are fulfilled with the same software Petrowin. One can calculate solution resistivity for different salts and their concentrations, soil resistivity for any given petrophysical model, investigate the influence of some parameters (for example, humidity, clay content, cation-exchange capacity, etc.), perform interpretation of the soil sample curve (resistivity vs. salinity) to determine petrophysical model and recalculate cross-sections and maps of VES resistivity into cross-sections and maps of petrophysical parameters.

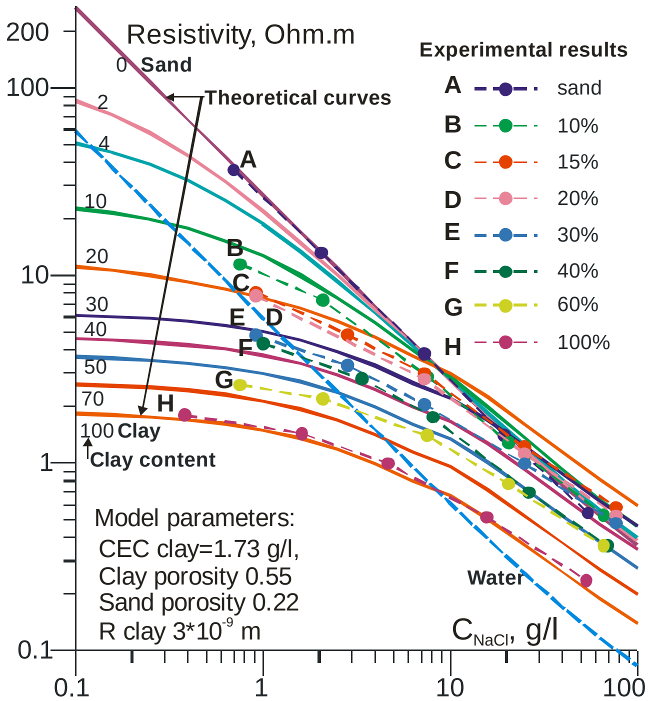

Figure 1. Comparison of theoretical and experimental curves of resistivity vs. salinity for different clay contents in samples.

We worked mainly with VES data (multi-electrodes technology and 2D interpretation), but one can use resistivity data obtained from other methods (electromagnetic profiling, frequency sounding, MTS, transient electromagnetic, resistivity logs, etc.). We applied in the same areas EM profiling together with VES and have a number of successful examples of EMP data recalculation into petrophysical parameters (Shevnin et al., 2005).

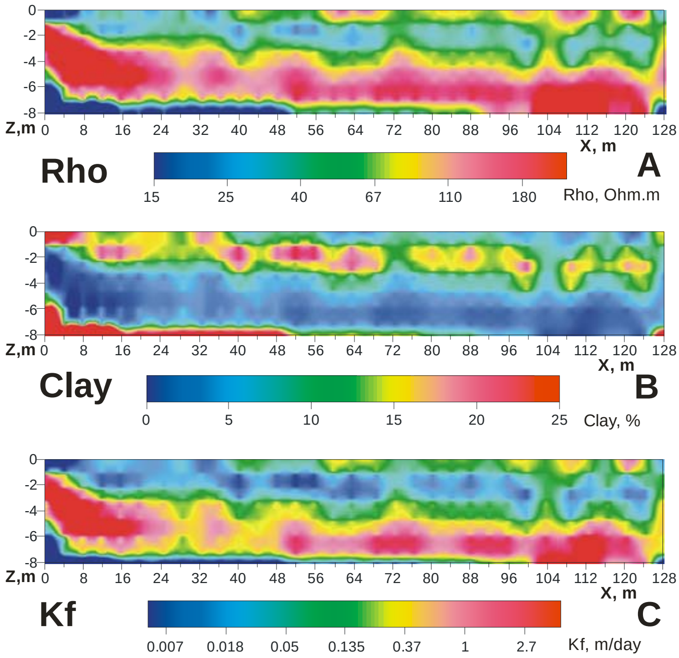

Figure 2. Cross-section of resistivity determined on VES (A) and calculated from it clay content (B) and filtration coefficient (C).

2. Examples of technology application.

2.1. Determination of clay content in samples

We checked our technology by using pure sand and pure clay (montmorillonite) components mixing then in different proportions (0, 10, 15, 20, 30, 40, 60 and 100% of clay). Comparison with theoretical curves of resistivity vs salinity shows satisfactory agreement with them (Fig.1) (Shevnin et al., 2007).

2.2. Example of lithology changes in cross-section of the site – km 42

In this site geological situation includes four layers: sandy loam cap (only in the east part of the site), loam, sand and then clay as the deepest layer). These four layers are clear visible in resistivity cross-section (Fig.2, A) and in petrophysical calculations (Fig.2, B - clay content and C - filtration coefficient). Clay content in sandy aquifer is between 0 and 4% of clay and Kf is more than 1 m/d. Kf was determined on clay content (Shevnin et al., 2006a)

2.3. Model with humidity changes as the main factor

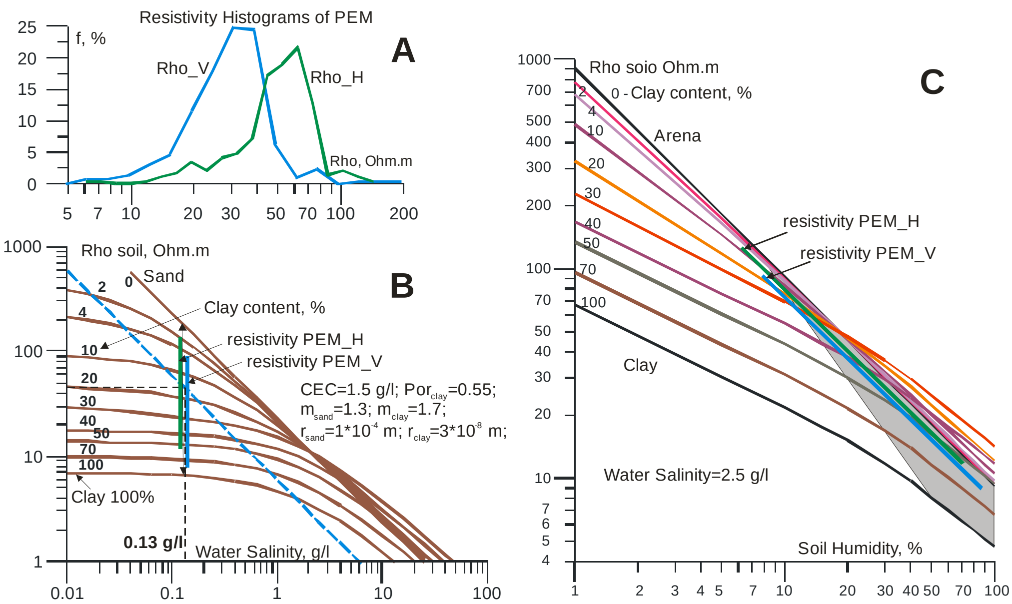

Figure 3. A – resistivity histograms for EMP; B – site model with lithology change, constant salinity and 100% humidity; C – site model with change of humidity, constant lithology and salinity.

This site was mapped only with electromagnetic profiling (EM31) and is an example of humidity influence. According to resistivity histogram (Fig.3, A) and one measurement of groundwater salinity (0.13 g/l) resistivity changes show possible wide spectrum of soil lithology (Fig.3, B) from sand to clay. But soil sample, which was received later, shows that we have pure coarse-grained sand in this place. That shows that water sample was from rainy pool and doesn't represent water of the site; real groundwater salinity is higher (more than 2 g/l); and resistivity changes were produced by changes of groundwater depth (surface topography) and humidity change (between 6 and 100% of humidity) in vadose zone (Fig.3, C). In reality this place is situated in sandy beach zone near Pacific coast of Mexico (in the state Michuacan) and there is no lithology change in the study depth interval.

2.4. Monitoring of the site km 124: change of lithology, humidity and contamination

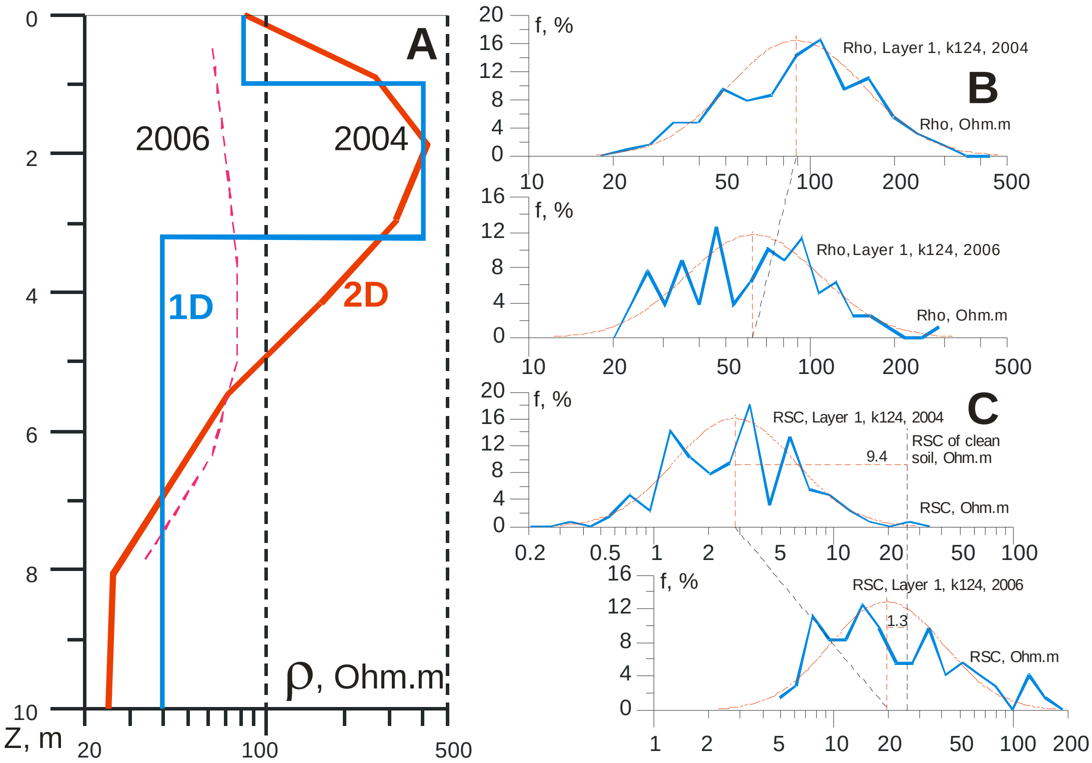

Figure 4. Monitoring of resistivity and RSC changes for two years in contaminated site.

This site was studied twice in 2004 and 2006 as the area with hydrocarbon contamination due to pipeline accident. Gas survey was performed here to have direct evidence of contamination. In 2004 geoelectrical study was made in dry period and groundwater level (GWL) was at the depth 2.3 m. Humidity in vadose zone was 10% (sand with no more than 6% of clay). Contamination was determined on resistivity values and on petrophysical maps including superficial conductivity (or its inverse value - RSC) as the most evident parameter of contamination having highest resolution in this case (Shevnin et al., 2006b). Superficial conductivity is estimated on clay content, groundwater salinity and clay conductivity. Clay conductivity depends on clay cation exchange capacity. Anomalous clay content reflects an increase of internal surface area, whereas anomalous cation exchange capacity reflects an increase of surface charges at the mineral grain - electrolyte interface. In the process of biodegradation of oil contamination, bacteria activity increases mainly superficial conductivity (Abdel Aal et al., 2004). In 2006 the study was performed in rainy period, when soil had 100% humidity until the day surface. We estimated on superficial conductivity values that oil contamination practically disappeared in two years (Fig. 4) and this was confirmed with direct chemical analyses.

2.5. The case of groundwater salinity change – site Karasor.

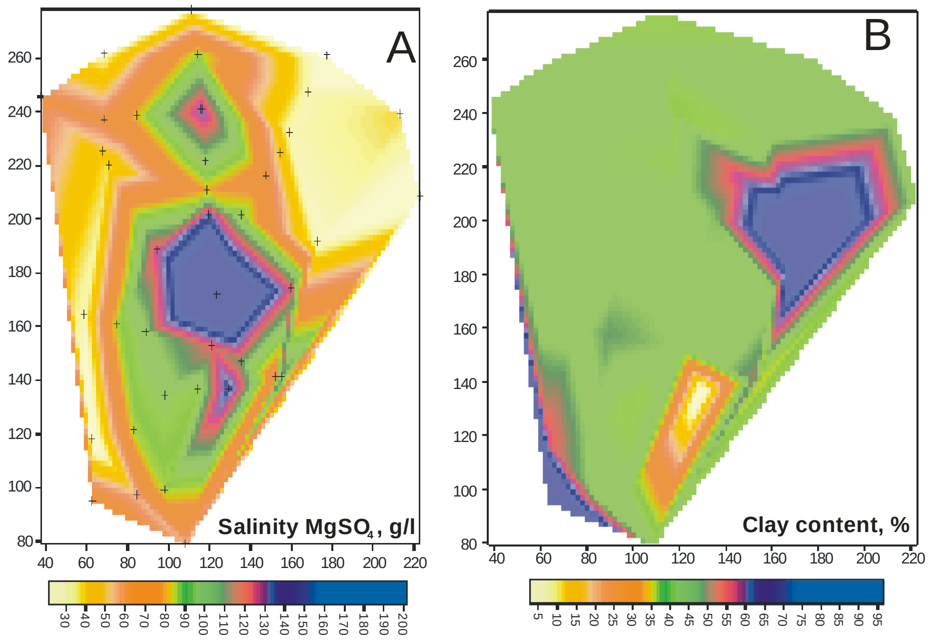

Figure 5. Karasor maps for 2 m depth. A - Salinity distribution; B - Clay content in soil.

This site is situated in semi-desert area. In the center of the site there is artificial pond to discharge brine water (200 g/l) from borehole. Electrical resistivity measurements were performed to control humidity and salinity distribution. These maps (Fig. 5) were received for 2 m. depth. Different position of clay and salinity maxima shows that petrophysical technology can separate these two factors influence.

Conclusion

Petrophysical analysis of resistivity data is a useful instrument of sites characterization and layers identification, which helps in lithological and petrophysical properties determination.

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