Geoelectrical characterization of a site with hydrocarbon contamination as a result of pipeline leakage

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Summary

Resistivity method is used extensively in environmental impact studies. In this work, the results of the geoelectrical characterization of a hydrocarbons contaminated site are presented. Although the contamination grade of the study area is low, were mapped two contaminated zones into sandy aquifer. In addition, petrophysical parameters were estimated by recalculate of ground and water resistivity values in clay content, porosity and CEC values. Anomalous values of clay content, porosity and CEC indicate the presence of hydrocarbon contaminants. The correlation between geoelectrical results, petrophysical parameters and hydrocarbons contamination was verified in laboratory by electrical measurements made in pure and contaminated sand samples.

Introduction

Hydrocarbons are the most prevalent type of contaminants in geological media. During the last decade electrical and electromagnetic methods, especially resistivity method, were applied on the characterization of oil contaminated soils (Sauck, 1998, 2000). Oil contamination also can be studied with the help of georadar, self-potential, induced polarization, electromagnetic survey and vertical resistivity probe (Sauck, 1998).

Recent hydrocarbon contamination gives high resistivity anomalies, while mature oil contamination produces the low resistivity ones (Sauck, 1998). After several months after the spill has occurred, contamination creates a low resistivity zone (Sauck, 1998; 2000). The formation process of a hydrocarbon contaminated area was described in details, linked to chemical reactions and variations in the physical characteristics of the affected medium (Sauck, 1998; 2000; Atekwana et al., 2001). According to Sauck, the low resistivity anomaly is resulted of an increase of Total Dissolved Solids (TDS) due to the acid environment created by the bacterial action in the inferior part of the vadose zone or below Groundwater Level (GWL).

In this work the application of resistivity method for the characterization of a site with hydrocarbon contamination as a result of pipeline leakage is presented.

Study area

The study area has 9,100 m^2 approximately and it's located near Cárdenas City, México, where the agriculture is the main use of soil. Four pipelines cross the study area (Fig. 1).

In May of 2002 a hydrocarbon spill from pipeline leakage was registered. After having carried out an excavation around the spill point and recovered a great part of the poured hydrocarbons, we decided to realize a geoelectrical characterization to a final evaluation of the environmental impact.

Geoelectrical characterization

1. - Field-Works

<u>Location of pipelines and preparation of VES profiles</u>

By pipe locator equipment Fisher TW-6 was possible to locate the four pipelines. Taking into account pipes position, six parallel VES profiles (Fig. 1) were designed with a minimal distance from pipelines of 2.5 m. VES profiles 1 and 2 have 128 m and profiles 3 to 6 have 104 m of longitude. Step between VES was 4 m.

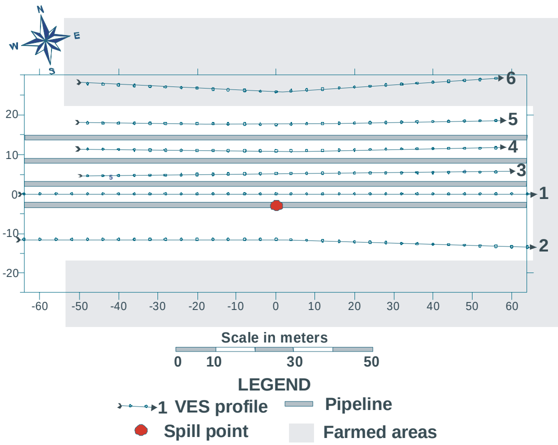

Figure 1: Scheme of the study area.

<u>VES measurements on profiles.</u>

One hundred seventy four VES points distributed in six profiles (Fig. 1) were measured. Due to low geological noise level Schlumberger array was used taking into account the advantage of its simplicity and high productivity.

For VES survey we used robust equipment development in our institute that includes a 4.88 Hz generator with stabilized current (10 to 100 mA) and a measuring instrument with intrinsic noise of $3*10^{-7}$ V. The attenuation of signals for 60 Hz is 10^{-6} and is more than 10^{-4} for frequencies below 0.1 Hz (rejection of fluctuations in self potential on the measuring electrodes).

2. - Qualitative interpretation

Apparent resistivity sections

In Figure 2 the apparent resistivity section for the profile 1 show the near-surface geology with horizontal layers. A low resistivity covering, represented by clayish-sandy sediments, is observed above of a sand layer (aquifer). In profile 1 (Fig. 1) is possible to observe a conductive (clayish) basement in the first half of profile.

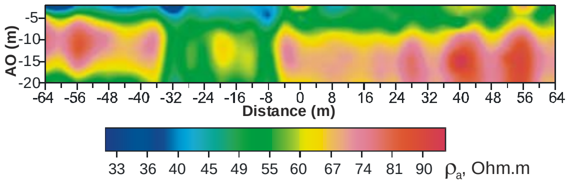

Figure 2: Apparent resistivity section for the profile 1.

In the interval -36 m to -8 m of profile 1 the apparent resistivity values for sand layer decrease (Fig. 3). This low resistivity area is associated with spill happened in pipe next to point 0 m.

Apparent resistivity maps

Apparent resistivity maps show a plan view of resistivity behavior for different study depth. In AO = 8m map (Fig. 3) is observed a horizontal change of the apparent resistivity. A low resistivity zone is observed crossing the area with east-west trend. This low resistivity zone can be the result of two main factors: removed soil by the four pipelines trenches and/or the presence of contaminants. Last factor can be the cause of the lowest local resistivity values.

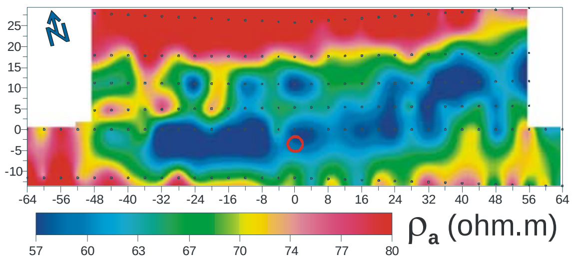

Figure 3: Apparent resistivity map for AO = 8 m.

3. - Evaluation of the trenches and pipelines effect in the geoelectrical measurements.

By solution of the forward problem it was possible to evaluate the effect of an isolated (resistive) pipeline (Ryjov and Shevnin, 2001) into a trench less resistive than background (Fig. 4). Model includes: the resistivity of trench varies from 1 up to 5 ohm.m, background resistivity is 10 ohm.m, giving the contrast from 0.1 up to 0.5.

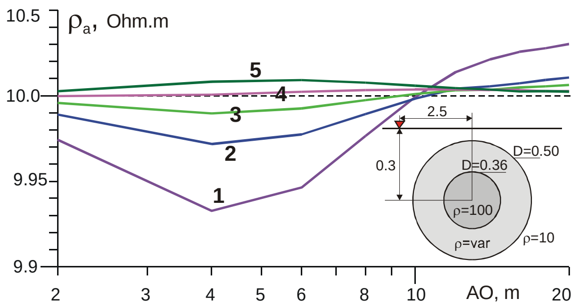

Figure 4: Influence of a conductive trench with diameter 50 cm and depth 30 cm. Inside trench is a pipe with resistivity 100 Ohm.m (i.e. insulated).

For trench resistivity 1-3 we have low resistivity anomaly, and for trench resistivity 4-5 ohm.m there is a small maximal as an influence of an insulated pipe inside the trench (Fig. 4). For actual resistivity contrast (for example contrast 0.3 and less) an influence of the trench with a pipe is about 0.1 %. Such influence can be neglected.

4. - Quantitative interpretation

Interpreted resistivity section

A two-dimensional interpretation process using RES2DINV (Loke and Barker, 1996) was applied to six geoelectrical profiles. In Figure 5 the interpreted section for the profile 1 is presented. A similar characteristic is observed in all sections: the first half of each profile is represented by three layers (superficial sandy clay, sand and clayish basement), while in the second half, clayish sand covering more resistive (80 ohm.m) than sandy-clay sediments (40 ohm.m), is added (Fig. 5).

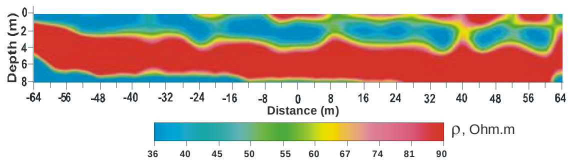

Figure 5: Interpreted resistivity section for the profile 1.

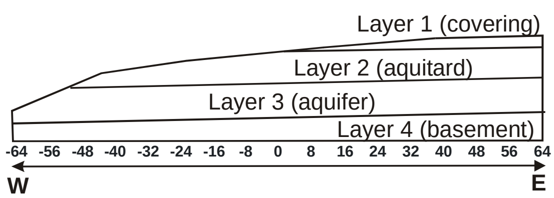

Figure 6: Structural section for the study area.

Geoelectrical characterization of a site

A structural section is presented in Figure 6. Resistive covering correlates with the local topographical characteristics where the height terrain increases in 1-1.5 m in the interval -64 m to 0 m, from west to east, appearing the resistive covering in the superficial portion of the interval 0 m to 64 m (Fig. 7).

<u>Interpreted resistivity map of superficial sandy clay (aquitard)</u>

From six interpreted resistivity sections was possible to make the resistivity map for the layer 2 (Aquitard) (Fig. 7) and to observe the horizontal resistivity variations in the local aquitard.

In Figure 7 some low resistivity anomalies are mainly located close to spill point (red circle) and in the northern and western parts of the study area. These anomalies probably indicate the increase of clay content or some presence of contaminants in the aquitard. In addition, the prevalence of high resistivity anomalies is evident in the Eastern part of the study area (Fig. 7), where the presence of a more permeable layer (layer 1) is known by geological information. Small permeable zones (red rhombuses) located around the spill point can be considered as geological windows that facilitate the infiltration of contaminants to the sandy aquifer.

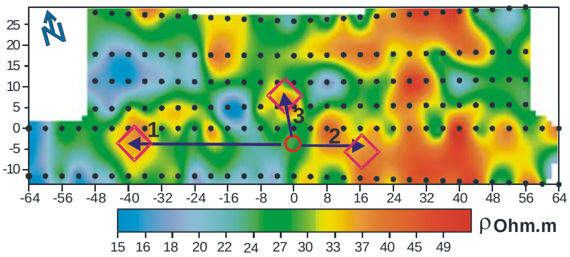

Figure 7: Resistivity map for aquitard.

<u>Estimation of petrophysical parameters to locate of contaminated zones</u>

Modeling algorithm allows recalculating ground resistivity and water salinity values into petrophysical parameters (clay content, porosity and cation exchange capacity (CEC)) (Ryjov and Shevnin, 2002)

In Figure 8 the clay content map for aquitard is observed. The minimal clay content zones correspond with the presence of the permeable windows which facilitates the infiltration of contaminants to the aquifer surrounding of the spill point. On the other hand higher clay content zones allow the retention of contaminants, as it probably occurs in the defined low resistivity zones of the Figure 7.

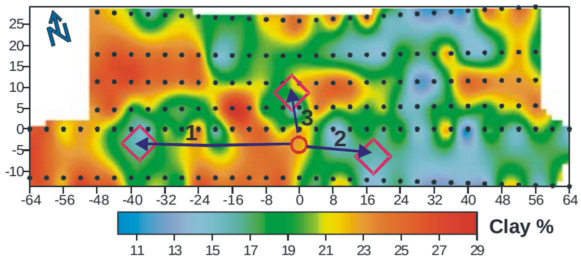

Figure 8: Clay content map for aquitard

A similar analysis was made for the sandy aquifer. In Figure 9 the resistivity map, as well as petrophysical maps (clay, porosity and CEC) are shown. In Figure 9A the resistivity map is similar to the apparent resistivity for AO =8 m. Two main anomalous areas are observed: first area extends from the spill point (X = 0 m, Y = -2 m) until X = -40 m, the second anomalous zone is located to East with coordinated X = 40 – 50 m and y = 8 - 15 m. The origin of the second anomaly is not clear. It probably can be due to migration and accumulation of contaminants from the spill point or to be the consequence of a second spill from another pipeline belonging to the study area.

Clay content (Fig 9B), porosity (Fig. 9C) and CEC (Fig. 9D) maps present a good correspondence with resistivity map (Fig. 9A). According to our experience, in uncontaminated zones the petrophysical parameters have true values. In contaminated zones these three parameters have anomalous values. For example, taking into account the geological information, clay content is 2%, but in the clay content map (Fig. 9B) we have values up to 6% in anomalous zones. These anomalous values do not reflect actual changes in clay content, but they reflect changes in the geoelectrical properties due to contamination.

<u>Petrophysical analysis of contaminated and uncontaminated sand samples.</u>

In Figure 10 are observed two curves with petrophysical modeling results corresponding to uncontaminated (red curve) and contaminated (gray curve) sand. The petrophysical results obtained for clean sand were: Clay content: 0 %, Porosity: 32 % and CEC: 0 g/l.

After that the sand was placed in a reactor tank where nutrients, bacteria and petroleum were added. After 45 days of biodegradation process the contaminated sand sample gave the next parameter: Clay content: 10 %, Porosity: 26 % and CEC: 3 g/l. Amplitude changes of each parameter is similar to that found in sandy aquifer (Clay content 2 to 6%, Porosity 34 to 32% and CEC 1.5 to 3.5 g/l), demonstrating that the anomalous values of clay, porosity and CEC in the Figures 8 and 9 correspond to hydrocarbons contaminated zones. So, we found an important effect that allows locating contaminated zones.

Conclusions

Resistivity sounding method is effective at geoelectrical characterization of contaminated zones, allowing future geochemical study with an optimized wells location and drilling depths.

The contamination of the study area is low. Only two zones have notice anomalies: the first one associated with spill point and the second one located in the Eastern portion of the study area.

The local aquifer (sandy layer) is protected of the contamination by a superficial clayish layer. Nevertheless, in areas where the clay content decrease or trenches related with pipelines the vulnerability is increased, facilitating the infiltration of contaminants to aquifer, as it happened in the interval X = -36 to -8 m of profile 1.

Changes of soil properties in the sandy aquifer and in the reactor tank were very similar.

Recalculation of petrophysical parameters from VES resistivity and groundwater salinity helps characterizing clean areas and estimating contaminated areas.

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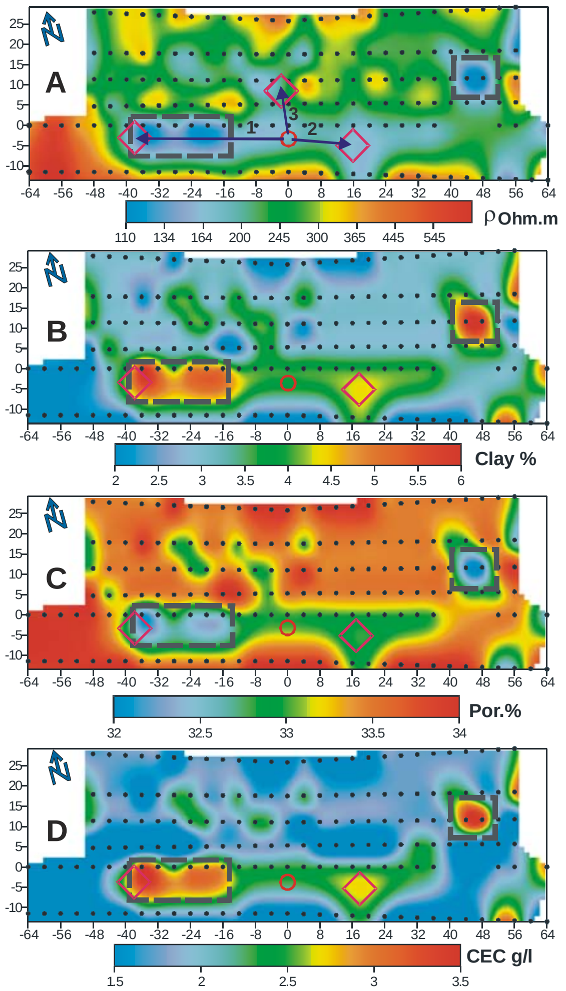

Figure 9: Comparative maps of the (A) resistivity, (B) clay content, (C) porosity and (D) CEC for sandy aquifer.

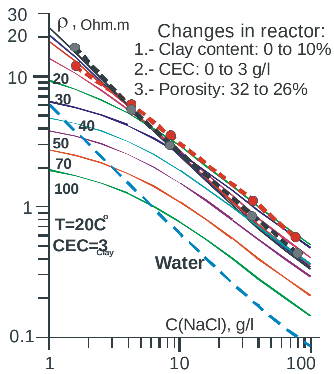

Figure 10: Calculation of petrophysical parameters for sand (before and after contamination)