# APPLICATION OF RESISTIVITY SOUNDING METHOD FOR OIL POLLUTION STUDY IN URBAN AND RURAL AREAS

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## Abstract

Resistivity sounding (VES) method is frequently used in environmental studies. During the last years a new faster and more detailed VES modification, named electrical resistivity tomography (ERT), has appeared which uses profiles with preliminary installations of great number of electrodes.

VES is effective method at oil pollution study. Low resistivities in oil-polluted zone, resulted from oil degradation under the influence of oil-transform bacteria, can be accurately localized by VES in area and with depth. There are several problems at VES studies of such objects. The first problem is, that oil pollution frequently takes place at industrial enterprises or in urban areas, where asphalt or concrete encloses a great part of surface. For realization of galvanic contacts it is necessary to drill some holes in concrete. In urban areas, the active (non-contact) measuring capacitative electrodes with low frequency resistivity instrument ERA can be used, making measurements simpler and faster. The identity of non-contact and traditional measurements has been proved experimentally.

The second one is the problem of separation between contaminated and non-contaminated areas on resistivity values. This problem can be solved by theoretical calculation of rock resistivity and by comparison with values measured in the field. The next problem is a geological noise (near-surface inhomogeneities) causes distortions of VES data. Geological noise can be canceled with the help of special field technology (AMN+MNB array) and data filtering. Practical examples of these improvements are presented in this report.

## Introduction

In many countries, the development of the oil industry has been accompanied by the contamination of different areas of exploitation, transportation, refining and distribution. Due to this, in last years a great interest has been focused on a study of the environmental impact from oil industry.

The geophysical methods are frequently used in the analysis of the environmental contamination of different nature (Daniels and Roberts, 1992; Bastianon et al., 2000).

Several investigations have demonstrated the efficiency of geoelectrical methods for the contaminants localization in area and with depth (Campbell et al., 1996; Nash, et al., 1997; Sneddon et al., 2000; Abdel-Aal et al., 2001). The resistivity method has shown being effective (Olhoeft, 1992; Abdel-Aal et al., 2001; Modin et al., 1997). Studies have demonstrated that the plume can be either resistive or conductive anomaly (Sauck, 1998). Recent spill presents a resistive anomaly. However, the oil pollution shows low resistivity after 1 to 4 months the spill has happened, in dependence of the geological characteristics of medium (Sauck, 1998, Shevnin et al., 2002).

First publications that expose the relation between oil contamination and the presence of low resistivity anomalies are relatively recent (Sauck and McNeil, 1994; Modin et al., 1997).

The contamination resulted in chemical reactions and variations of physical characteristics of the polluted medium. The conductivity anomaly is resulted from an increase of the Total Dissolved Solids

(TDS) level due the acid environ that creates the bacterial action in the inferior part of the vadose zone (Sauck, 1998; 2000; Atekwana et al., 2001).

In this work we present the results of VES application using ERA instrument (ERA Inc., St. Petersburg, Russia) for oil pollution study in the area Campo-10, in Poza Rica, Ver., Mexico.

We show the advantages of a modified technology that allows applying this method efficiently in urban zones where the terrain is covered with concrete or asphalt. We demonstrate how it is possible to separate contaminated and non – contaminated areas on the base of theoretical calculation of rock's resistivity.

## VES Method And Field Technology

VES measurement consists in passing electric current into a ground through two electrodes A and B, while electrodes M and N register the potential difference ΔU. This operation is repeated when the distance between A and B electrodes is increased, together with an increase of the study depth. A value of apparent resistivity is calculated in each distance AB on the formula:

$$\rho_a = k * \frac{\Delta U}{I}$$

where k is geometrical coefficient of the array.

ΔU- potential difference (mV) registered between M and N electrodes.

I- electric current (mA) passed into ground through A and B electrodes.

$\rho_a$ - apparent resistivity (Ohm-m).

Different arrays can be used for resistivity soundings (Schlumberger, Wenner, pole-dipole, dipole-dipole). Schlumberger and Wenner are the most popular. When the subsurface could be considered as 1D medium then Schlumberger or Wenner array can be applied due to simple field technology. When the subsurface structure is more complex due to near-surface inhomogeneities (NSI) (that is frequent in urban areas) it is necessary to use another configuration that allows correcting the observed data and eliminating the geological noise caused by NSI. We consider AMN+MNB array as the best for such situation.

***Two-sided pole-dipole (AMN-MNB) array***

In recent years, a new modification of VES called Electrical Resistivity Tomography (ERT) has appeared, being faster and more accurate, at using a great number of electrodes reconnected manually or automatically. In Moscow state university for ERT studies two-sided pole-dipole array (AMN-MNB, Fig. 1) was applied (Modin et. al., 1997). Its efficiency was proved with the help of the theory of VES data distortions, caused by NSI. From the data, measured with this array the effect of near surface inhomogeneities can be canceled with the special algorithm and software Median (Modin et. al., 1997; Ritz, Robain, Pervago, et al., 1999).

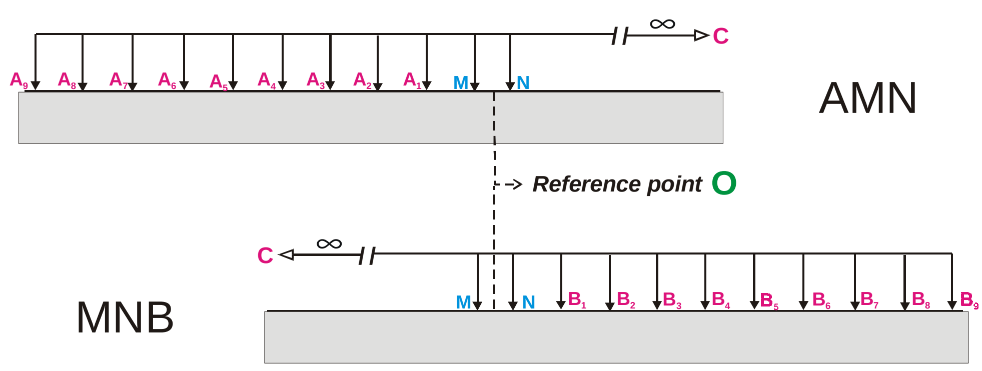

**Fig. 1. VES method with AMN-MNB array.**

To carry out ERT

survey many electrodes are placed along the profile with the equal step. The potential difference between M and N electrodes is measured while the current passes in turn through current electrode $A_1$, then $A_2$, $A_3$, $A_4$... $A_n$, while the current electrode C is placed in infinity. $\rho_a$ values for each position of the electrode A are calculated. All measurements are referred to MN center (point O between MN electrodes). Finally, $\rho_a$ curve for AMN sounding is obtained. The same procedure is repeated without moving the potential electrodes, for all positions of current electrodes $B_1$, $B_2$... $B_n$, determining $\rho_a$ values for each position of the current electrode B and receiving MNB sounding.

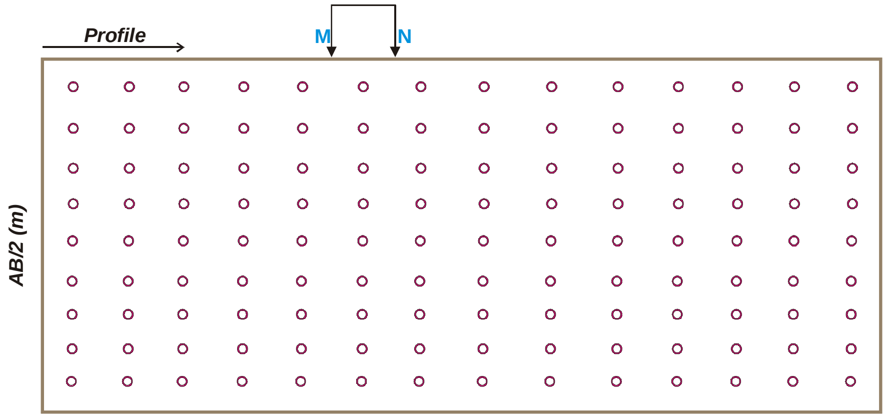

**Fig. 2. $\rho_a$ matrix resulted from VES measurements along profile.**

Afterwards, the MN dipole is moved to the next reference point and the process is repeated.

The final result consists in obtaining two $\rho_a$ matrixes for AMN and MNB arrays along the profile (Fig. 2) placing the referents points O along *x*-axis and the spacing values AO along *y*-axis.

This matrix allows us to obtain $\rho_a$ pseudo-cross-section for each profile whereas a set of profile in the area allows building $\rho_a$ map for each AO spacing. Both ways give good material for a visual qualitative interpretation (see figs.8-9).

In case of urban and industrial zones, the application of the ERT technique requires a great number of drills in concrete or asphalt cover for placing current and potential electrodes.

ERA company has developed active (capacitative) AC electrodes for measure of the electrical field at 5 or 625 Hz with its resistivity instrument. Active electrodes are placed on metal plates and connected by a cable to measuring unit (Fig. 3).

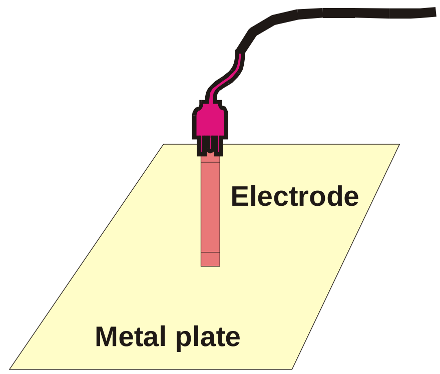

**Fig. 3. The view of an active electrode for ERA instrument.**

In order to check a similarity between measurements with active and grounded electrodes we made control measurements in urban area (Fig. 4). Selected area is characterized by the presence of an artificial ground (2 m thick) above resistive basement; the area contains underground pipes and electrical cables and has high level of EM noise (about 1 mV/m).

AMN sounding was carried out using MN lines with grounded and active electrodes. Measurements were made at two frequencies (5 and 625 Hz) to compare results.

In Fig. 5, $\rho_a$ curves for both types of electrodes are shown. There is a similarity between $\rho_a$ values especially for the same frequency.

So, MN dipole with active electrodes can be used when terrain surface is covered by concrete or asphalt, increasing VES

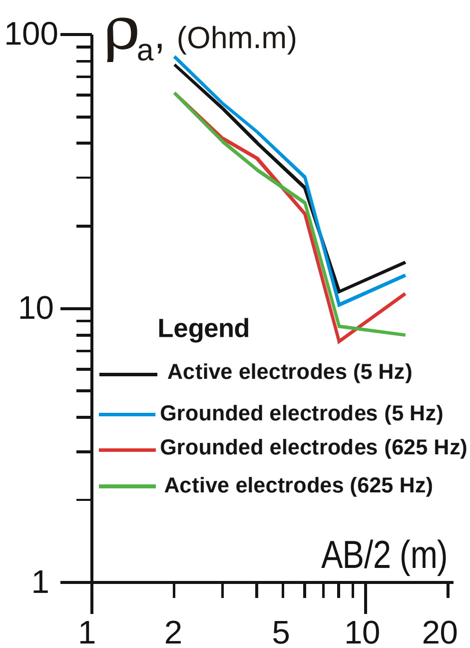

**Fig. 4. Comparison of $\rho_a$ curves for MN dipole with grounded and active electrodes.**

method productivity.

Availability of two ERT matrixes for AMN and MNB soundings with the same reference points, allowing eliminate geological noise from sounding data resulted from near-surface inhomogeneities (Modin et. al., 1997; Ritz, Robain, Pervago, et al., 1999).

In general at ERT application, we have one of three geological situations in a study area:

1. The whole ground surface (or its part) in urban area is covered with asphalt or concrete. Frequently, water or fuel pipes, cables, trenches or some other near-surface inhomogeneities (and EM noise) distort the geoelectrical information.

2. - Urban zone without concrete, but with high geological (and EM) noise's level, resulting from underground pipes or power cables, trenches, artificial ground, acting like near-surface inhomogeneities.

3. - Rural zone with low geological noise level.

Zones of the 1 and 2 types give strong distortion of resistivity measurements and need application of two-sided pole-dipole array and special data processing for canceling geological noise.

In fig.5 there are three examples of ERT data dispersion, estimated at Ex-oil-refining factory (Poza Rica-2000), at an area of oil-wastes utilization (Campo-10, Poza Rica-2001), and at Paredón-31 (Tabasco-2001) as zones with three levels of distortions. Figure 5 shows the dispersion graphs as AO function.

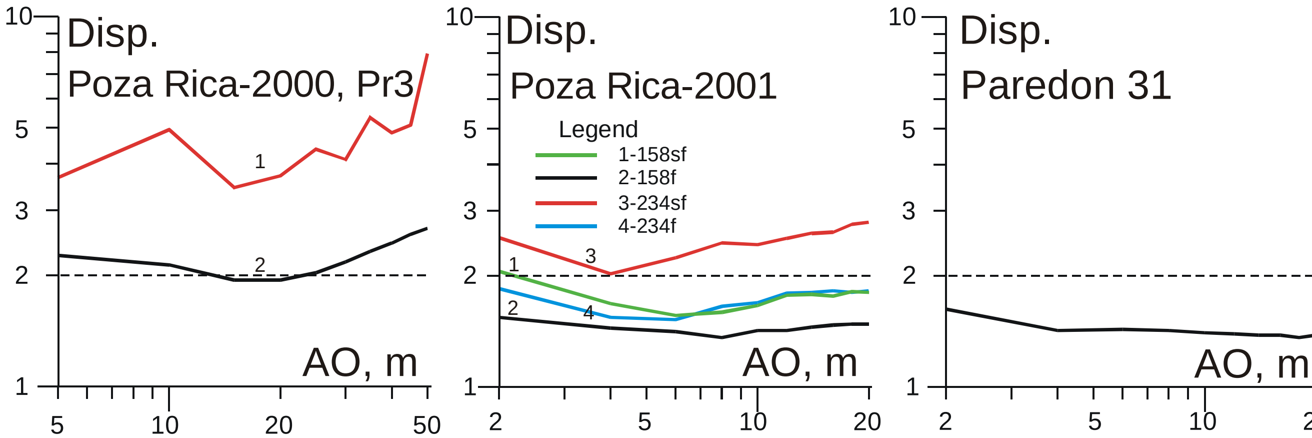


**Fig.5. Dispersion graphs as function of AO for three areas.**

In the first case (fig.5, left) the dispersion is maximal both before (1) and after (2) filtration with Median program. High dispersion in this case resulted from geological noise at oil refining factory and low measuring accuracy of the instrument Syscal Kid due to EM noise. After filtration dispersion become 2 times low (Shevnin et al., 2002).

In the second case (fig.5, center) there is no concrete on the surface, but geological noise is rather high. Instrument ERA has perfect protection against EM noise. After filtration of geological noise the dispersion becomes 1.4-1.7 times smaller (see also Fig. 7).

In the third case (Paredon-31), in rural area there is no artificial cover or any cables, trenches or pipes in the ground and geological noise is low. There is no need in special measuring technology (AMN+MNB) and filtration procedure. Schlumberger array was used here (fig.5, right).

## RESULTS OF FIELD STUDY AT CAMPO-10

Campo-10 is a territory with oil unload tank for recovering oil wastes. There is also notable an active burner in the northwest part of the study area (Fig. 6).

The study area could be divided in two parts. The SE part corresponds to the zone, where the oil unload tank operated some time ago (oil unload ex-zone). This area was subjected to remediation process and is considered now like no-contaminated one. The NW part corresponds to active unload area, being considered like polluted.

The objective of this work is the geoelectrical study of the subsurface of Campo-10,

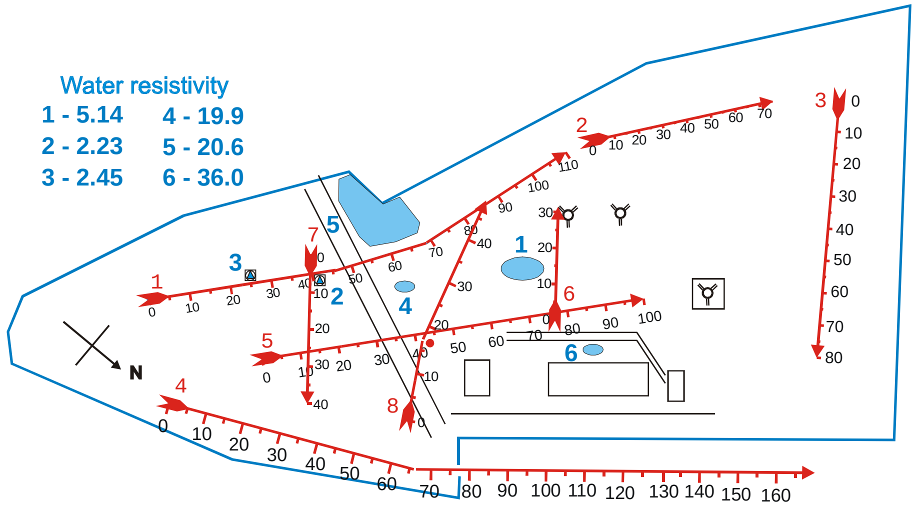

**Fig. 6. Scheme of the study area (Campo-10).**

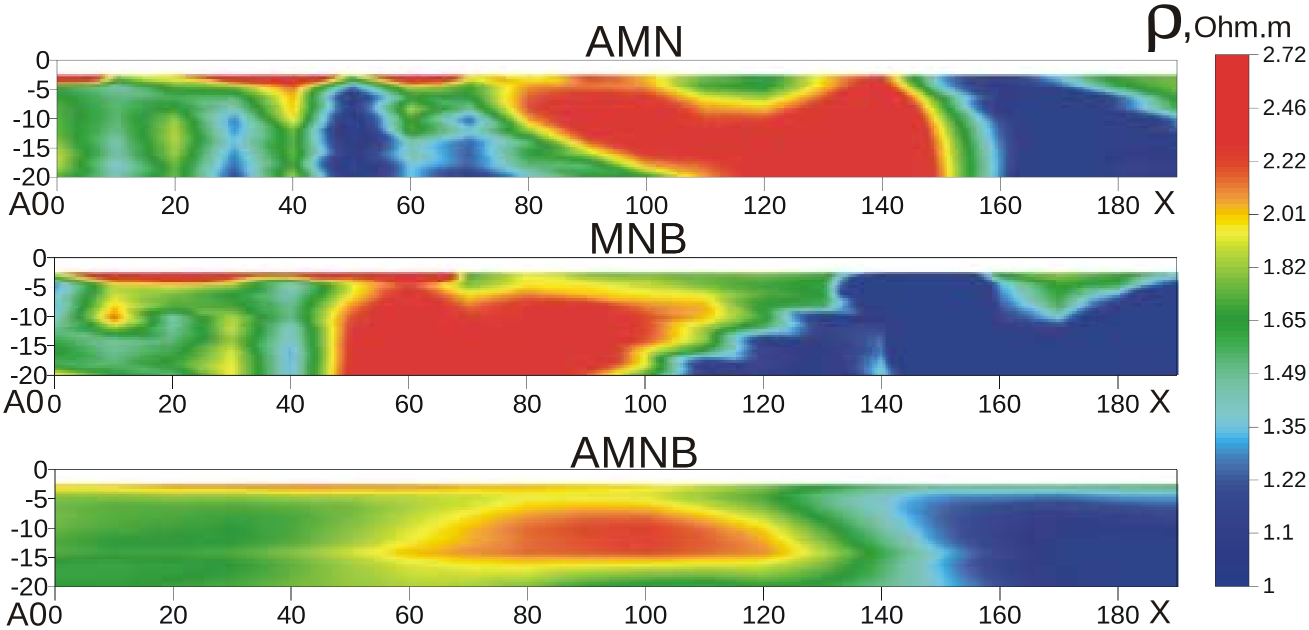

**Fig. 7. Pseudo-cross-sections for initial AMN, MNB arrays and then AMNB data after filtering. Poza Rica-2001, Campo-10, profile 2.**

localization of oil-polluted zones in area and on depth and estimation of their contamination degree.

180 soundings distributed in eight profiles were carried out in the study area (Fig. 6). The distance between profiles was between 25 and 50 m, while a sounding step along profile was 4 m. We applied AMN-MNB technology because of proposed considerable geological noise level.

Profiles of AMN and MNB soundings (or data matrixes) were filtered with Median program in order to cancel the geological noise. After filtering AMN and MNB sounding curves were united into AMNB curves for 1D interpretation and also for visualization of pseudo-cross-sections and apparent resistivity maps. Figure 7 shows the result of this processing for profile 2. AMN and MNB pseudo-cross-sections show a high geological noise level, while AMNB presents a filtered pseudo-cross-section.

Cross-sections corresponding to the profiles 1-8 are presented in Fig. 8. In general view significant differences are observed. In the cross-sections 1, 5, 7 and 8 a more resistive medium is presented than in the cross-sections 2, 3, 4 and 6.

In Fig. 9 there are four maps for different spacings (2, 4, 8, 20 m), reflecting different depths of study. In the shallow part an electrical resistivity is higher that in deeper part. A near-surface layer with resistivity value 5 Ohm-m covers the top part of medium. At the depth the NW part has lower resistivity than the SE area, proposing that NE part is a more polluted area.

From fig.8 and 9 we conclude that the more evident oil pollution is concentrated near profiles 2, 3, 4. That is why we made statistical analysis of VES data, separately for two groups (profiles 2-4 and profiles 1, 5-8).

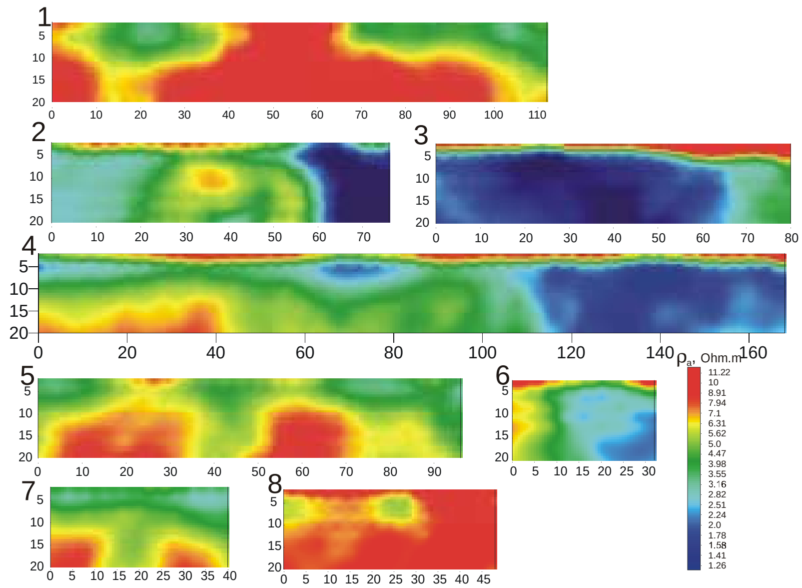


**Fig. 8. Resistivity pseudo-cross-sections for profiles 1-8.**

Fig. 10 presents the mean VES curves after statistical data processing for profiles 2, 3 and 4 (curves 3-4 with strong oil pollution) and profiles 1, 5-8 (curves 1-2 with weak or absent pollution). Curves 1 and 3 are mean geometrical curves while curves 2 and 4 are median curves. All curves are of H-type with a minimum.

Fig. 11 and 12 are statistical VES images in values of frequencies for the same groups of profiles as Fig. 10. Noticeable feature is observed in Fig. 12 – two different mean curves for proposed more weak or absent and for strong pollution.

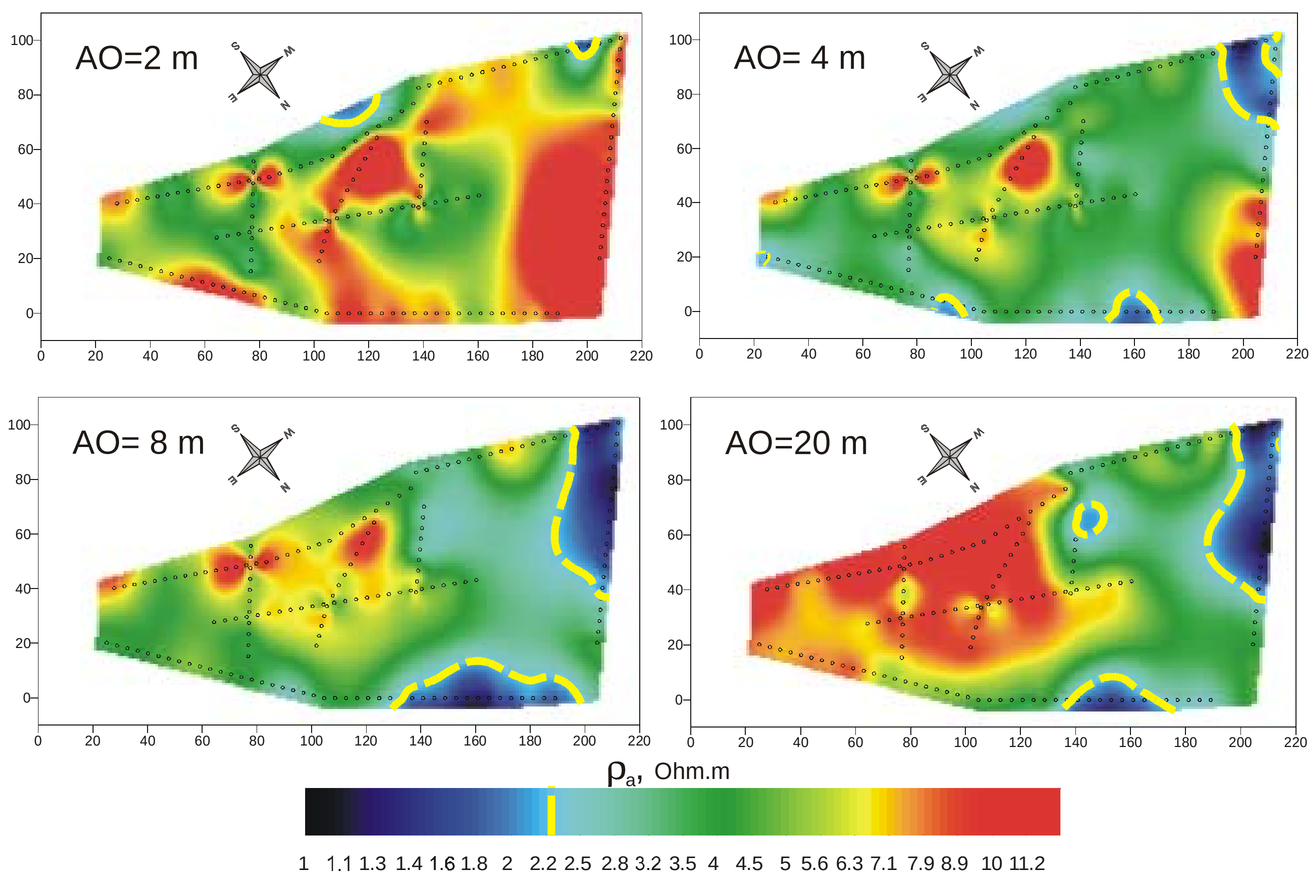


**Fig. 9. Apparent resistivity maps for AO = 2, 6, 12 and 20 m. Black points mark the soundings location.**

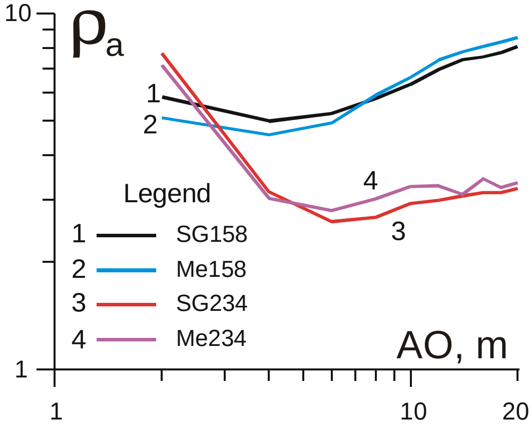


**Fig. 10. Mean VES curves.**

The next problem is separation of polluted and non-polluted areas. For the decision of this problem we used our experience of analogical problems decision at the other area of Poza Rica (Shevnin et al., 2002). A theoretical calculation of rock resistivity for the frequent lithological types (sand, clay, their mixtures and pore water) was made with the help of the program Petrofiz (Ryjov and Shevnin, 2002). Fig. 13 shows the relationship between resistivity and salt concentration for different types of lithology according to the clay content in rock. The curve 1 corresponds to pure sand, while the curve 10 to pure clay.

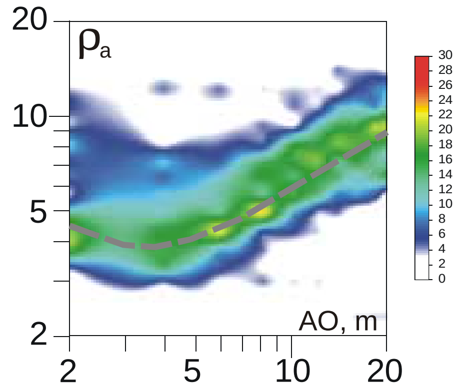


**Fig. 11. Statistical image of VES for profiles 1, 5-8.**

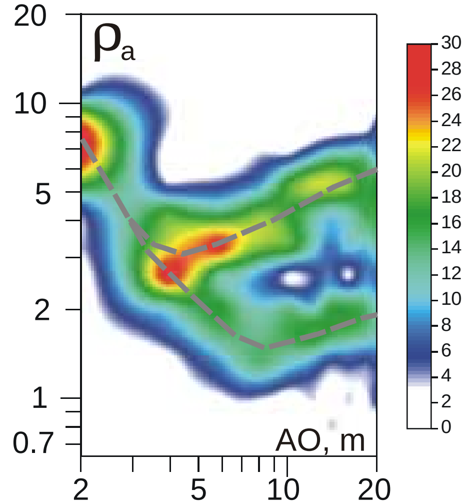


**Fig. 12. Statistical image of VES for profiles 2, 3 and 4.**

We also measured water resistivity in all accessible points (see fig.6). Water resistivity was measured in A and B wells (fig.6) giving a mean value of 2.3 Ohm-m. Tap water in the area has resistivity 36 Ohm.m. In two ponds on the territory we estimated resistivity value 20 Ohm-m. In Fig. 13 these values were used for placing vertical lines restricted possible salt concentrations range for our study area. For water resistivity value in 20 Ohm.m a lithological legend was created, that was used for lithological estimations of non-polluted rocks in the area. Resistivity values in lithological legend lower then 2.5 Ohm-m were considered as values for a contaminated medium, (Shevnin et al., 2002).

Thus, on the base of theoretical rocks' properties calculation VES data interpretation was made. The highest ρ values in Fig. 8 and 9 characterize a resistive basement (ρ > 10 Ohm-m) visible on cross-sections after VES data interpretation (Fig. 14) at the depths from 2 to 14 m. The mostly conductive layer is the second one placed above the basement and below GWL (ρ<2.3 Ohm-m, Fig. 14). Position of GWL according to VES interpretation and to wells A and B is at the depth about 1.5 m. The conductive second layer is common in all profiles. The first layer corresponds to loose rocks above GWL. For more definite conclusions about pollution we made a map of the second layer resistivity, estimated from VES data interpretation (Fig.15). There are two zones of minimal resistivity (polluted zones) in upper and lower parts of fig.15, separated by a more resistive zone in the middle. This anomaly pattern could be explained by the existence of some lithological structure controlling the behavior of

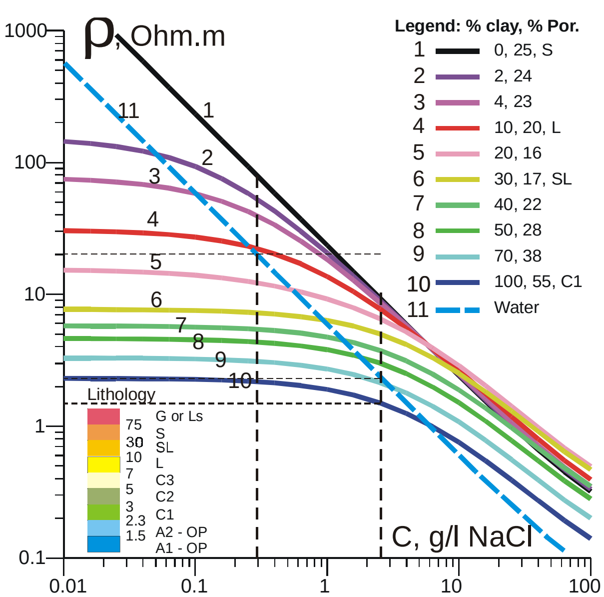


**Fig. 13. Theoretical dependence of rock resistivity from salt concentration for different clay content.**

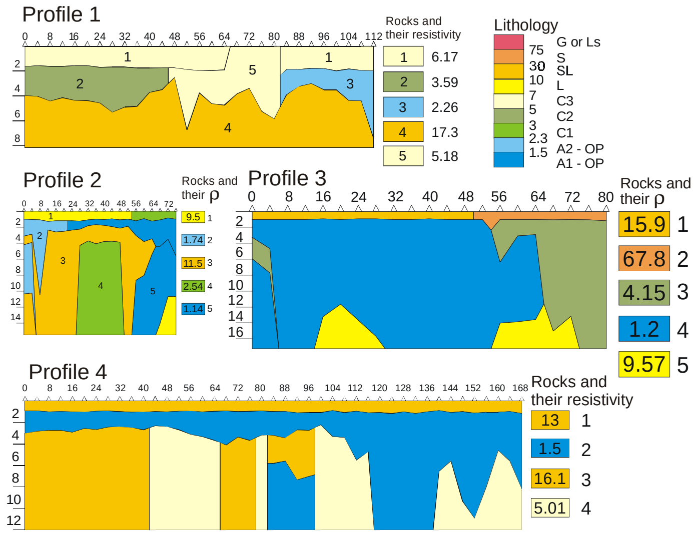


**Fig. 14. Resistivity cross-sections for profiles 1 - 4.**

local groundwater flow. The general direction of the groundwater flow in this area of Poza Rica is NW-SE. We can suppose that this lithological structure is a kind of paleo-valley with more coarse-grain sediments in the middle and more clayish sediments in peripherical parts. Oil pollution is concentrated in clayish sediments. This fact was considered in our report (Shevnin et al., 2002).

The pollution sources could be defined in the areas of minimal resistivity in Fig. 15 (zones of maximal contamination). These zones are:

- Unload tank (near point 160 m of profile 4) and,
- Right-upper end of study area (near crossing point of profiles 2 and 3). Near this place there are some fuel tanks, belongings to PEMEX but out of our study area. This zone is approximately 70 m NW outside of Campo-10.

At resulting scheme (Fig. 16) areas of contamination, zones of maximal contamination and pollution sources are shown.

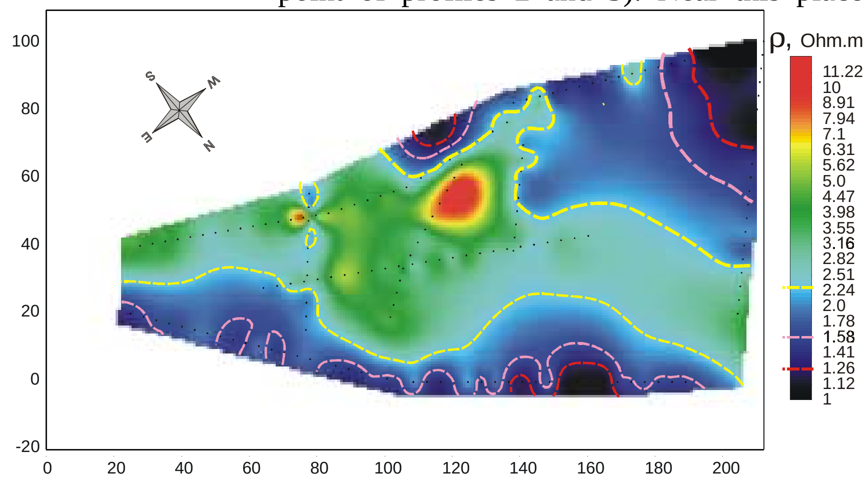


**Fig. 15. Map of the second layer resistivity. Dashed lines mark different levels of resistivity and pollution.**

## CONCLUSIONS

1. - The efficiency of the resistivity sounding method with ERA instrument for the geoelectrical characterization of contaminated subsurface was confirmed, correlating the areas of oil pollution with zones of low resistivity. Geological noise from sounding data was canceled (filtered) before data visualization and interpretation. Grid of several profiles in study area allows drawing vertical cross-sections along each profile and also resistivity maps for study area.

2. – In Campo-10 polluted zones and their relations with the underground water flow were established. Oil unload tank was identified as

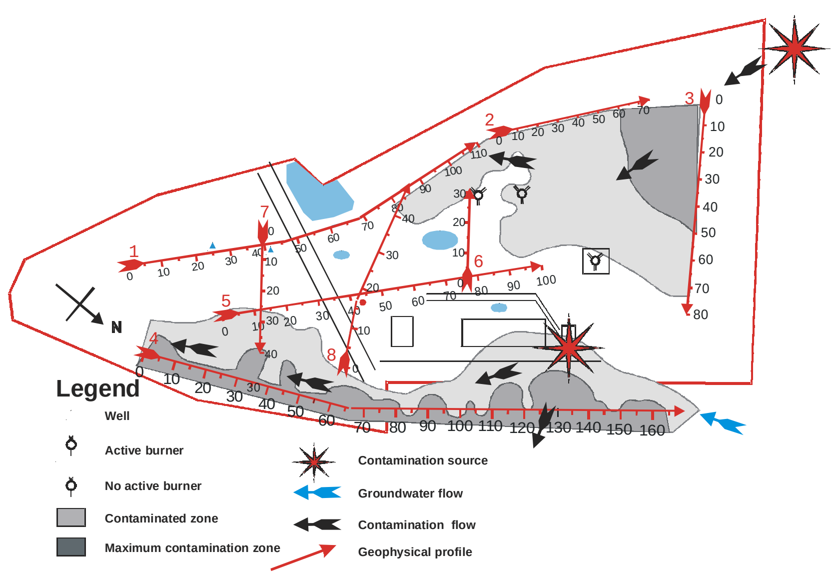


**Fig. 16. The resulting scheme of study area.**

pollution source, besides was proposed the existence of a second source near the right-upper end and outside of the study area.

3. - Similar results in resistivity soundings with active and grounded potential electrodes were obtained experimentally. Thus, it is possible to use this type of electrodes in urban or industrial zones avoiding make additional drills in concrete or asphalt for placing MN electrodes and increasing VES method productivity.


## ACKNOWLEDGMENTS

The authors would like to thank sincerely Dr. Luis Fernandez-Linares and M.C. Hector Zegarra-Martínez for their help in organization and participation in the fieldwork at Campo 10.


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