New Ways in Detecting LNAPL Plumes in Granular Sediments Using Geophysical and Atmogeochemical Methods

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Abstract: During last years, a series of papers was devoted to possibilities of geophysical methods in detecting long time residing LNAPL plumes in the granular sediments. Sauck (2000) developed a new conceptual geophysical model for this case taking into account geochemical processes caused by bacterial biodegradation of hydrocarbons. The existence of low resistivity zone below the LNAPL plume is the only chance to estimate the extent of the plume by resistivity survey (multielectrode measurements, vertical electrodes) and ground penetrating radar. We combined the geophysical techniques with the soil vapour survey using the new method and instrumentation (ECOPROBE 5) based on the combination of total PID and selective IR analysers. The efficiency of this approach is documented on materials from an abandoned military area in the Cretaceous of Bohemia.

Long time residual hydrocarbons of the LNAPL type (light non-aqueous phase liquids) in permeable formation are exposed to microbial biodegradation, which changes the original natural ground water geochemistry and the distribution of gaseous components in the vadose zone. Baedecker, et al. (1993) described in detail the geochemical processes connected with hydrocarbon degradation in the vadose zone, as well as in the upper part of the saturated zone. The most important features of these processes is the creation of organic acids, the enrichment of ground water with Fe^{2+} and Mn^{2+} cations, outgassing of CO_2 and CH_4 into the vadose zone. Organic acids and the carbonic acid attack rock minerals and extract from them further cations like Ca, Mg, etc. All these geochemical changes have as a consequence the changes in physical properties of ground water below the spill and of the rock medium beneath the groundwater table.

Based on the geochemical studies, Sauck (2000) developed a new conceptual geoelectrical model for the rock medium influenced by hydrocarbon spill. The most important features of the new geoelectrical model are:

a) the existence of high conductive zone 1-2m thick observed at the bottom of the vadose zone and in the upper most part of the saturated zone at all sites with long time residence of the LNAPL in a form of free product. The extent of high conductive zone corresponds to the extent of the free hydrocarbon product exceeding it only in the direction of the groundwater flow. The high conductive zone has no sharp lower boundary due to the diffusion process, the aquifer resistivity slowly increases to normal conditions (part of the aquifer with uncontaminated ground water). The reason of high conductive zone is the leachate from the acid environment created by the intense bacterial action on the residual hydrocarbons near the base of the vadose zone.

b) The nature of the free product on the groundwater table has a character of a zone saturated only partially (less than 50 %) by hydrocarbons, the rest of the space being saturated by water or by water and air.

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The existence of the free hydrocarbon products is usually checked and its thickness measured in scarce situated monitoring wells. There is a question how atmogeochemical and geophysical survey can contribute to mapping the hydrocarbon plume in relation to above described geochemical situation and geoelectrical model. They have the following chances:

- The extent of the free product zone can be indirectly determined according to the extent of the high conductive zone below the water table. It is detectable by multielectrode resistivity survey, by ground penetrating radar and by vertical resistivity probes (Sauck, 2000).
- The extent of the contaminated zone can be directly determined by the soil vapor analyser ECOPROBE 5. The following components of soil air are measured: total concentration of common petroleum products, CH_4 concentration, CO_2 concentration, all in ppb levels.
- The existence and the thickness of the free hydrocarbon product zone is detectable by static cone penetration tests combined with logging (neutron logging, density logging, permittivity logging, gamma-ray logging).

A complex geophysical and atmogeochemical survey has been conducted in the abandoned Soviet military area Ralsko-Hradcany in the Cretaceous of Bohemia.

Geological situation: The test site has an extent $2000 m^2$. The first 3 m thick layer isformed by Quaternary alluvial sediments of the river Ploucnice. Deeper, the Middle Turonian well-sorted sandstones with clay content lower than 5 % have been found. The free water level is in the depth 3.5 m below surface with small fluctuations during the year.

Pollution history: The test site is situated in the area of the railway terminal, where the hydrocarbon products have been transferred from tank wagons to underground storage tanks. The leakage of tubes and bad insulated high volume tanks - getting rusty during the 30 years long period and finally being perforated - caused serious LNAPL pollution of ground water with first meters of the kerosene at the water table, with vadose zone pollution and traces of dissolved hydrocarbons in groundwater. The remedial activities (pumping fluids from clean-up wells situated in the dense network 10x10m, bioventing, venting) are running continuously from 1993 under the supervision of the KAP Company. Under present conditions the light heating oils and kerosene still contaminate irregularly the upper part and the base of the vadose zone, and the top part of the saturated zone. Free hydrocarbon product can be found in monitoring wells especially in the western part of the test site (Fig. 1).

Geophysical survey: The test site is covered with 5 parallel profile lines 100 m long with mutual distance 5 m. Following geophysical methods were applied on all profile lines: multielectrode resistivity survey (multicable system ME100 with basic electrode distance 2m - combined with measuring and controlling unit RESISTAR 100, product of Geofyzika Brno Com., for results see Fig. 2), resistivity survey using vertical resistivity probes (length of the probe 6 m, electrode distance 0.5 m), ground penetrating radar GPR (pulse EKKO - 100A, antenna 200 MHz, T - R distance 2 and 4 m, antennae orientation PR-BD, product of the Company Sensors and Software) with the step of measurements 0.5 m, cone penetration tests CPT combined with gamma-ray, formation density, neutron porosity, conductivity and permittivity logging.

Atmogeochemical survey: Soil vapor analysis (3 above given components) using ECOPROBE 5.0 system, product of RS Dynamics Ltd. (see Fig. 3). The distance of holes for soil air sampling was 2.5 m, depth of holes 0.5 m.

Results of geophysical and atmogeochemical survey: The extent of the low resistivity zone relating to the depth 6 m (Fig. 2) corresponds well with the extent of polluted area according to atmogeochemical survey (Fig. 3) and correlates principally with the area characterised with the free hydrocarbon product on the water table according to sampling of monitoring wells (Fig. 1). In the last case, much smaller density of sampling points must be considered not comparable with the density of points for geochemical and geophysical survey. Moreover, the results of atmogeochemical survey bring information on the activity of the hydrocarbon degrading microorganisms (e.g., CH_4 content, product of biodegradation).

Acknowledgement: The research has been supported financially by the Grant Agency of the Czech Republic (project No. 205/98/1164). We deeply appreciate the collaboration with KAP Com. especially with F. Hercik and S. Proksova supporting us with necessary field data.

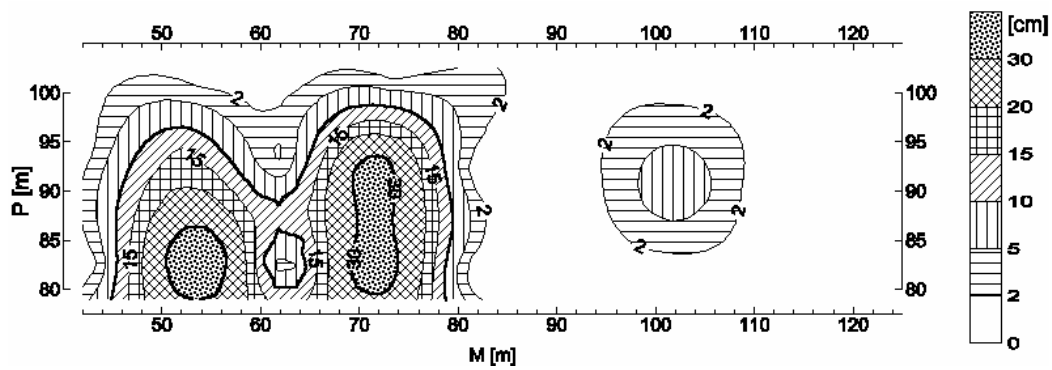

Figure 1 – Thickness of the free hydrocarbon product in monitoring wells.

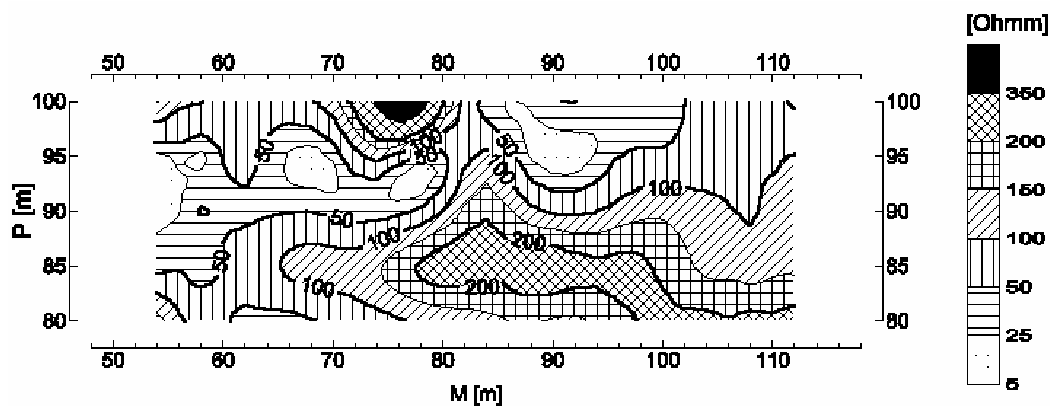

Figure 2 – Resistivities of the aquifer relating to the depth 6 m.

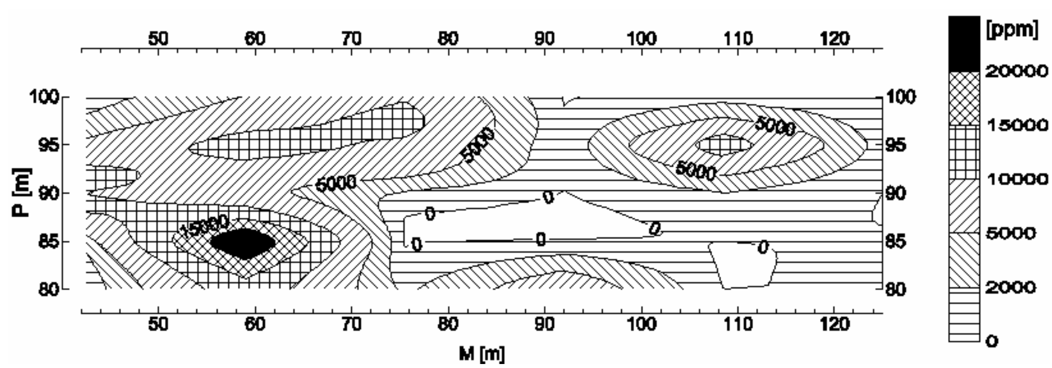

Figure 3 – Concentration of the total petrol vapors in the soil air.

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