RECENT ADVANCES IN CPT TECHNOLOGY

FOR ENVIRONMENTAL INVESTIGATIONS

by

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ABSTRACT

The cone penetrometer test has been widely accepted for use in geotechnical investigations, however the use of the cone in hydrogeological investigations and contaminant studies has been very limited. This paper provides a brief overview of CPT technology as applied to environmental investigations with the main focus on the resistivity cone test (RCPT). Basic hydrogeological parameters and contaminant plume delineation can be determined using the resistivity cone test. Also resistivity data is presented and some of the aspects of interpretation are discussed. In addition possible future developments in push-in technology are discussed.

Key Words: Electrical Resistivity, Push-In Technology Contaminant Plumes, Soil

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INTRODUCTION

With push-in instrumentation there are two approaches to contaminant detection, these are: 1) Direct Methods, such as pore fluid and gas retrieval probes. 2) Indirect Methods, the in-situ measurement of some property related to the presence of contaminants. Of the indirect methods, the best suited for contaminant detection are the measurements of the electrical properties of the soil and pore fluid. Presently this is accomplished by measuring the low frequency resistivity of the soil (bulk resistivity) or by measuring the pore fluid resistivity. In this paper the application of the resistivity piezocone to environmental site investigations and examples of resistivity cone profiles are discussed. In addition future developments in electrical techniques and other possible methods are presented.

EXISTING CONE PENETROMETER TECHNOLOGY

In addition to the basic piezocone extra additions developed for environmental investigations are:

1. The resistivity cone test (RCPT). The RCPT works on the principle of measuring the electrical resistivity of the soil. The resistivity of the soil is for the most part influenced by the resistivity of the pore fluid, which in turn is a measure of the groundwater quality. The RCPT has been used by Conetec, Fugro, Delft and UBC. An illustration of the ConeTec resistivity cone is shown in figure 1. The cone can do seismic, high resolution temperature and resistivity all in one sounding. The cone uses two electrodes with a 1000 Hz constant current source. The probe is microprocessor controlled and operates with 0.1% precision over ranges from 0 - 5 ohm-m up to 0 - 1000 ohm-m. For a more detailed description of a resistivity cone refer to Campanella and Weemees (1990).

2. The pore fluid conductivity cone (Chemi-Cone). While the resistivity cone measures bulk resistivity, a more direct, and accurate, way of determining groundwater quality is by measuring the pore fluid conductivity (conductivity being the inverse of resistivity). By measuring conductivity an approximate estimate of the total dissolved solids in the groundwater can be made, since there is a linear correlation between the amount of dissolved ions and the ability of the pore fluid to transfer current. The one disadvantage of the Chemi-Cone is that it does not provide a continuous profile of conductivity. Tests are carried out at specific locations thus requiring more time than a resistivity cone test.

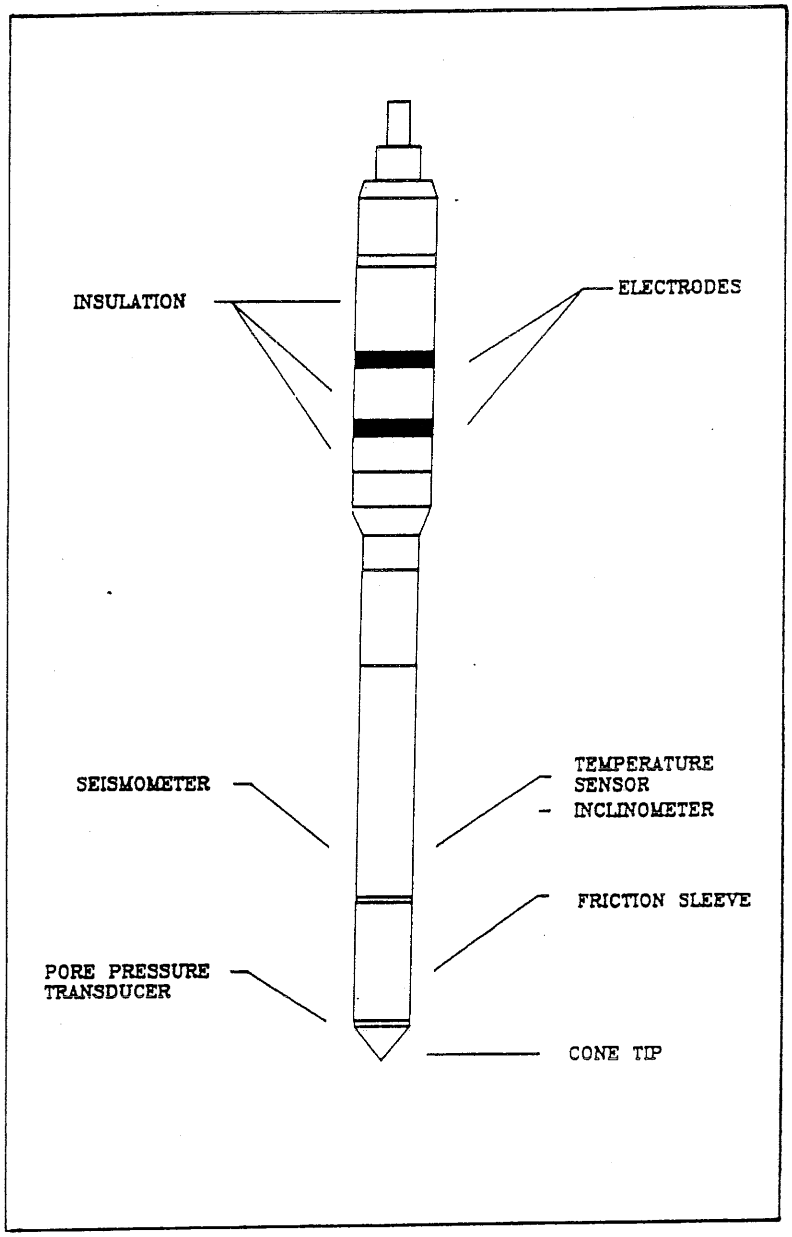

Figure 1. ConeTec Resistivity Cone.

3. High resolution temperature measurement. Very accurate temperature measurements are now possible using the cone penetrometer (± 0.2°C). Temperature measurements can be made in landfills to assess methane generation (Horsnell, 1988) and also used to map temperature anomalies extended beyond landfill boundaries (MacFarlane et al., 1983).

4. Vadose zone vapor probe (VZV Probe). The VZV probe is advanced into the ground in the same manner as a cone whereupon a gas sample is extracted from the ground and pumped to the surface. This probe has been used widely for gas station tank investigations (Horsnell, 1988).

SITE INVESTIGATIONS USING THE RCPT

When considering the use of push in tools at a site the suitableness of the site should first be considered. The cone can be advanced through most soils with the exceptions of gravels, soil layers with numerous cobbles or heavily cemented zones. (Robertson and Campanella, 1988) Narrow gravel stringers usually do not present a problem. If part of the soil profile is difficult the problem soil can be drilled out and the cone can be advanced again.

For a hydrogeologic investigation the cone can provide:

1. Very accurate determinations of lithological boundaries including the identification of very narrow layers.

2. Determinations of soil types from classification charts based on measured values of bearing, friction, and pore pressure (Robertson and Campanella, 1988).

3. Estimations of hydraulic conductivity either based on soil type classification or pore pressure dissipation measurements.

4. Estimations of porosity based on soil type classification and cone bearing relative density relationships

5. Equilibrium pore pressure values in nonplastic soils.

Under most circumstances cone penetration testing is a rapid and cost effective procedure. Thus in a short period a geological section across a site can be prepared, groundwater gradients can be determined on the basis of equilibrium pore pressure data. Also with estimates of hydraulic conductivity and porosity an initial rough estimate of advective ground water velocities may be calculated.

By measuring the resistivity vertical and horizontal mapping of conductive contaminant plumes may be made. This method should be ideal for identifying the maximum extent of contamination since the dissolved solids that create the resistivity contrast travel at or near the advective groundwater velocity. Figure 2 illustrates how discrete conductivity measurements were made to define the boundaries of a contaminant plume (MacFarlane, 1983). The resistivity cone test would be able to define the boundaries of the plume in the same manner, but would have done so more rapidly while also supplying lithological, geotechnical and hydrogeological information.

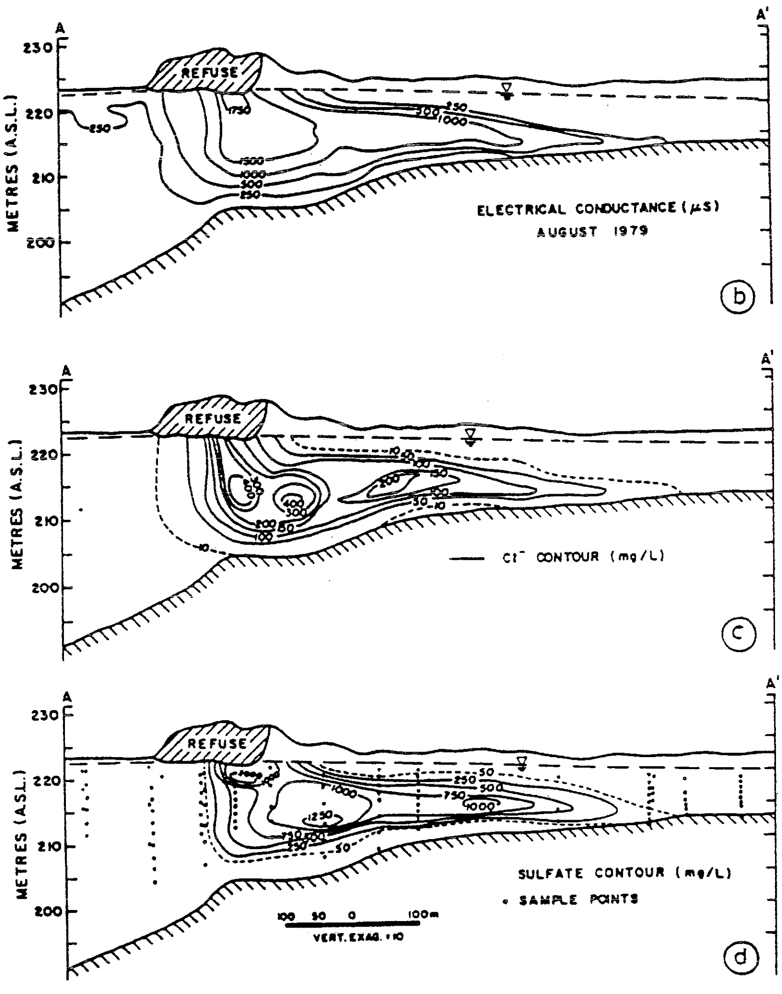

Figure 2. Electrical conductance, chloride, and sulfate contours at the Borden Landfill (after MacFarlane, 1983)

RESISTIVITY CONE TEST DATA

Following is resistivity cone data from four different sites with some general comments about the resistivity profiles and the applicability of the method.

Figure 3 illustrates a resistivity and soil profile from a site offshore of Richards Island, NWT in the MacKenzie Delta. The sand units in this profile have different resistivities which is most likely due to variations in pore fluid salinity. At locations where permafrost is present there is greater impedance to the flow of ions through the pore fluid thus increasing the resistivity.

Figure 4 is a resistivity cone profile at a site on parcel 2 of the Expo Site. This profile is part of a program carried out

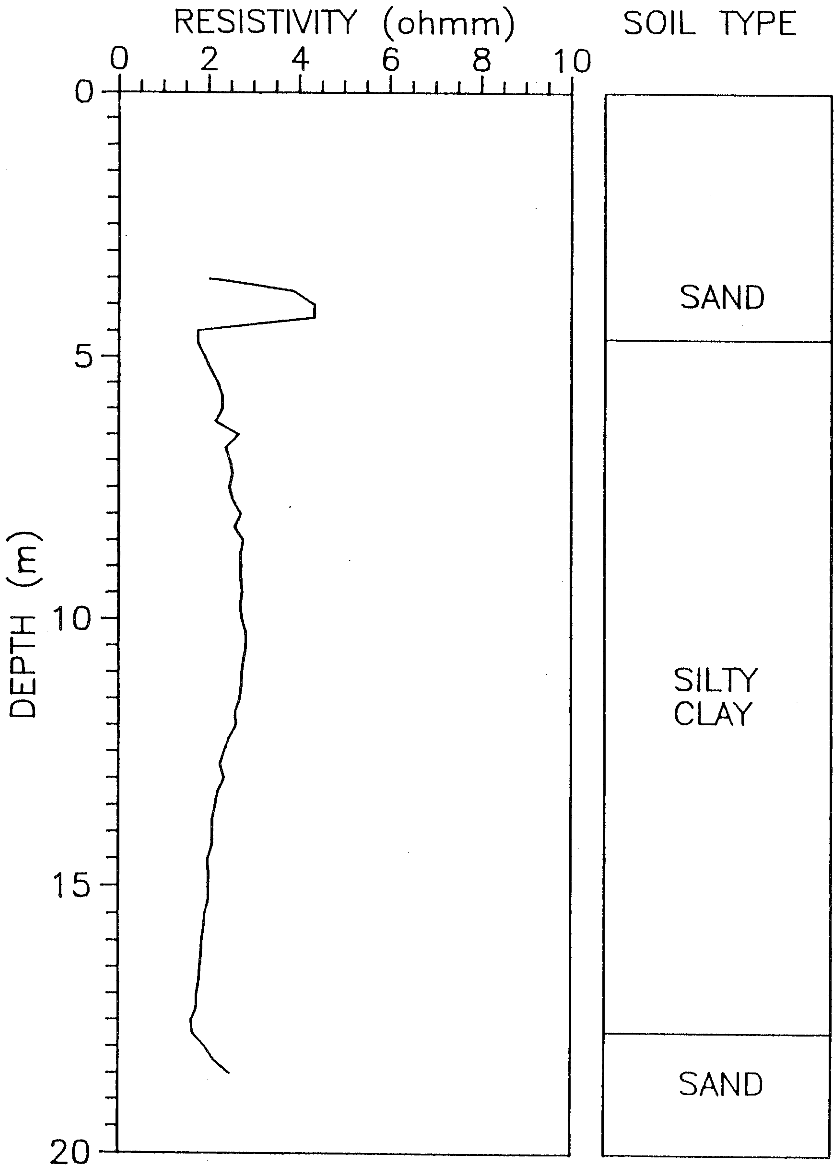

Figure 3 Resistivity and soil profile. MacKenzie Delta, N.W.T.

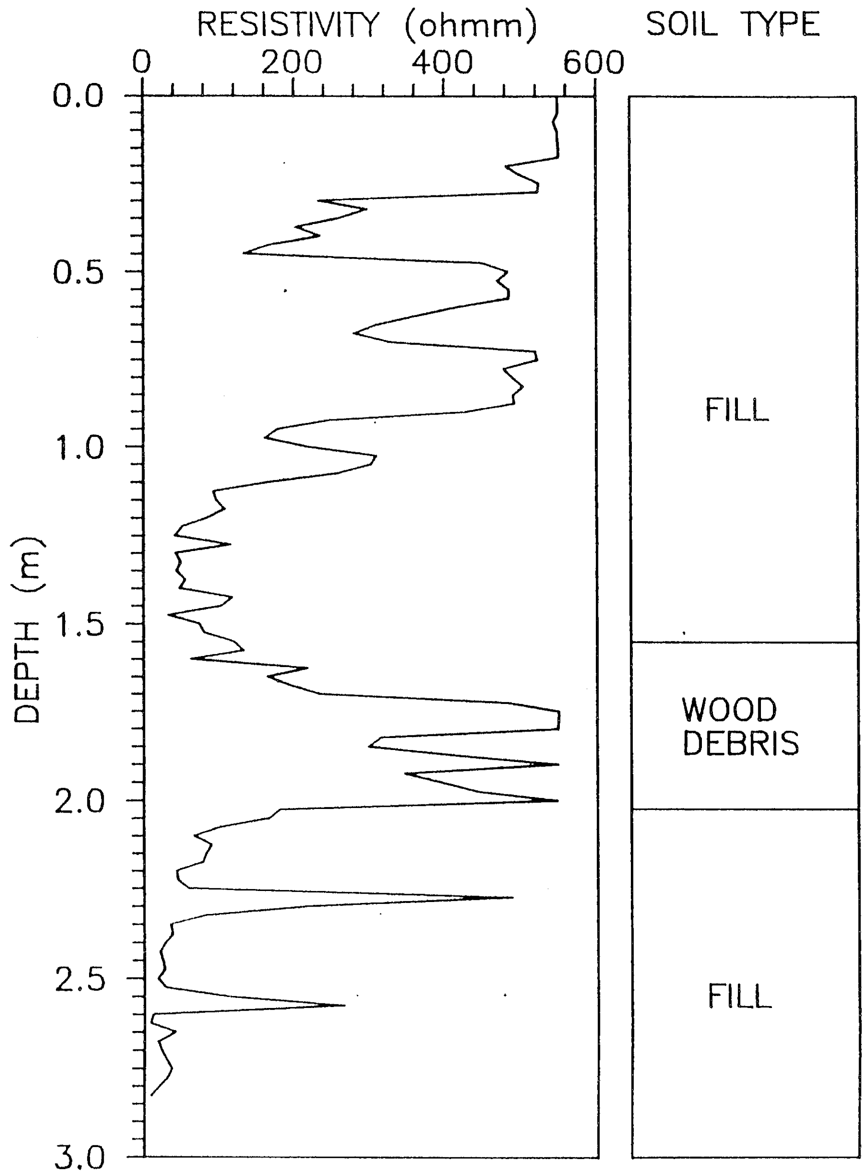

Figure 4 Resistivity and soil profile. Parcel #2 - Expo Site

using the UBC resistivity cone to determine if the resistivity cone could detect the presence of organic contaminants on the site (Kokan, 1990). Discontinous zones of wood fill have been mapped at the site. These zones are particularly important as not only are they the highest permeability units at the site, they also tend to selectively adsorb organic carbon substrate. Figure 4 shows a profile through a zone of wood waste where a large resistivity anomaly has been located. It is likely that the high resistivities are caused by poycylic aromatic hydrocarbons associated with the wood fill. The latter compounds were identified in soil samples taken adjacent to the resistivity sounding location.

Figure 5 presents a cone plot of a site adjacent to the Fraser River. The influence of more brackish water can be seen by the decreasing resistivity with depth. This type of salt water intrusion is a concern in coastal aquifers where active pumping takes place. It is important to note that the resistivity method works by detecting contrasts in resistivity due to differences between contaminant and natural pore fluid resistivity. Therefore contaminants from a landfill that may be quite conductive may not be detected if the natural groundwater is brackish. On the other hand insulating NAPLs would be easier to detect if the natural groundwater was brackish.

Figure 6 shows that variation in soil type also has an affect on the measured bulk resistivity. Typically sands will have a greater resistivity than soils containing clay minerals if the soils have pore water resistivities that are the same. This is because the clay minerals themselves are conductive. This difference becomes more pronounced as the resistivity of the pore fluid increases and a greater proportion of the conduction takes place along the surface of the clay minerals (Campanella and Weemees, 1990).

One other application of resistivity logging is the determination of corrosion potential of buried steel structures. The following standard has been adopted in the UK (QJEG Working Party, 1988).

resistivity (ohm-m)	soil corrosivity
<10	severe
10 - 100	moderate
>100	slight

FUTURE DEVELOPMENTS IN PUSH-IN TECHNOLOGY

Push-in technology in the geotechnical and groundwater field is developing rapidly. More sophisticated electrical logging instrumentation is the most likely avenue of improvement in in-situ testing equipment. Natural source gamma probes may also have some limited applications.

Investigations of electrical properties of soil and fluid over a

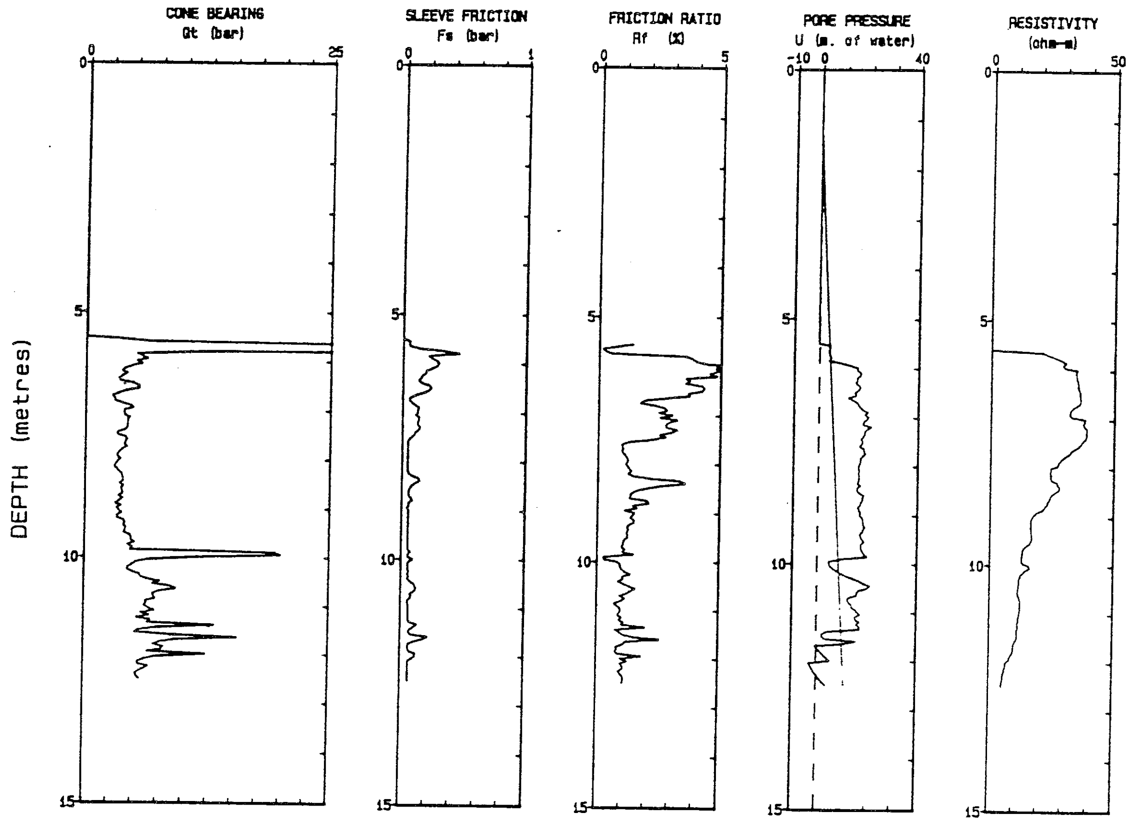

Figure 5 Resistivity Cone sounding near to Fraser River

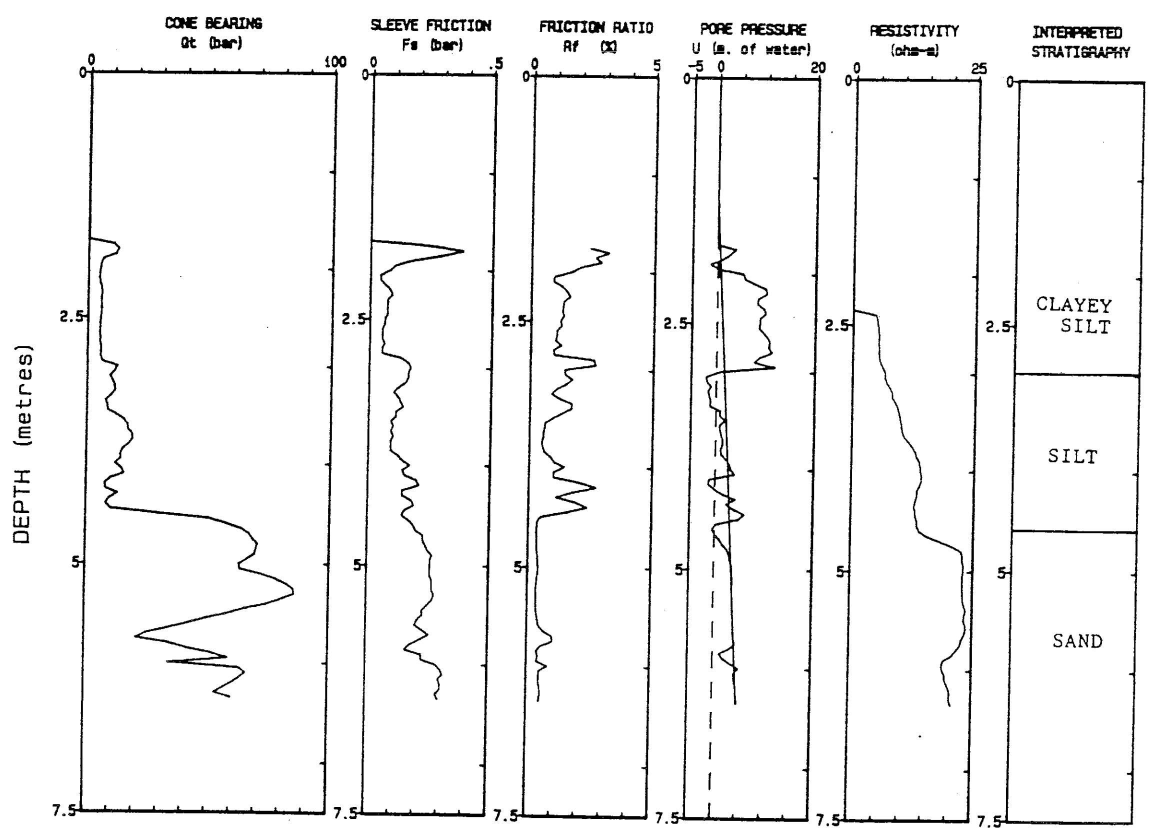

Figure 6 Resistivity Cone Sounding Richmond, B.C.

wide range of source frequencies have been carried out by a number of researchers. In the low frequency range Olhoeft (1985) examined the effect of contaminants on the ion exchange capacity of clays, which results in changes in resistivity at different frequencies. The most interesting applications are at frequencies greater than 100MHz. At these frequencies electromagnetic wave propagation due to displacement currents (a function of the dielectric properties of the soil-water mixture) dominate conduction currents. The implication of this being that the measurement of the dielectric constant of the soil is proportional to the water content of the soil. It may also be possible to detect the presence different contaminants due to unique differences in electrical properties at high frequencies. Promising research in this field has been presented by Yong and Hoppe (1989).

Natural source gamma logging tools note the occurrence of gamma rays from the decay of potassium 40, uranium-radium series, and thorium series. Typically this tool is used for the detection of clayey soils. For environmental investigations a natural gamma logging would be useful in detecting radioactivity in leachate. An example where this may be applied would be mapping leachate from uranium mine tailings.

CONCLUSIONS

The resistivity cone penetrometer test can rapidly provide lithological, hydrogeological, and geotechnical information in addition to information regarding the extent of contamination. The resistivity method depends on contrasts between the conductivity of contaminants and the natural groundwater. Therefore it works well in detecting leachate from landfills and acidic mine tailings. The method does not work for detecting small quantities of toxic organic pollutants. However, these organic pollutants may be associated with other products which may be present in large enough quantities to be detected by the resistivity method. Further work in this area is necessary to determine what lower limits of contamination can be detected using this method.

Other tools which are used in environmental assessment are the Chemi-Cone, which operates on similar principles to the resistivity cone and the VZV probe which is well suited for the detection and monitoring of the volatilization of light non-aqueous phase liquids (LNAPLs). Further developments in electrical logging methods hold the promise of directly measuring water content and the presence of different contaminants.

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