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Electrical methods in geological and engineering investigations of interglacial calcareous and organic sediments from Warsaw

Paweł Pietrzykowski

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The upper 15 meters of gyttja and other detritus mud was deposited in the Warsaw area during the Eemian interglacial (Eem, Mikuliński, Ipswichian, R/W). The length of the postglacial channel lake was over 12 kilometers and its width varied between 250 and 750 meters. The area where organic and calcareous sediments can be found is significant; therefore, their presence in construction grounds in the area of Warsaw repeatedly forced additional site and laboratory investigations of the geological and engineering conditions of soil. The interglacial lake sediments have been studied for more than 100 years; however, there are no known attempts of using electrical methods in the analysis of these sediments. The paper presents an assessment of their usefulness for determining the depth of occurrence of gyttja and lacustrine chalk as well as their value in estimating sediment thickness on the basis of field and laboratory research.

Key words: electrical cone, gyttja, lacustrine chalk, electric resistivity, electric conductivity

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Paweł Pietrzykowski. Institute of Hydrogeology and Engineering Geology, Warsaw University, Żwirki i Wigury 93, 02-089 Warsaw, Poland. E-mail: ppietrzykowski@uw.edu.pl

INTRODUCTION

A postglacial channel lake filled with the soil under analysis during the last interglacial period – 108000–125000 BP – determined by the TL (thermoluminescence) method (Lindner et al., 1992) occupied an area of approximately 12 km in length and a few hundred meters in width (Morawski, 1980). Nowadays, sediments from this palaeoaquifer with a roof 2 to 10 meters deep and up to 20 m thick (Frankowski, Wysokiński, 2000) are the ground base for engineering structures in Warsaw. On the basis of archival borehole profiles, the approximate shape of the palaeoaquifer was reconstructed (Fig. 1), but each new profile in the surroundings of the lake brings new information about its range. The neighbouring profiles often present a different geological structure, and it is impossible to present a reliable interpretation of the geological layers without additional drillings.

Compared to drillings, a cheaper and more timesaving method is geophysical research which exploits the electrical properties of the ground. Laboratory and field research demonstrated that the electrical cone method is the most valuable.

LOCATION AND STRATIGRAPHY

Based on the analysis of borehole logs presented in the database of the engineering and geological Atlas of Warsaw (Fig. 2), two districts of Warsaw were chosen for research: Bielany and Ochota. In Bielany district, lacustrine chalk and gyttja maximum 5.5 m thick and in the area of Ochota gyttjas over 15 m thick may be found. Samples of soil for tests were taken from the wall of underground line during deep excavations made for engineering purposes in Bielany district. For laboratory research, undisturbed samples of lacustrine chalk from the Eemian (Eem, Mikuliński, Ipswichian, R/W) interglacial were taken. For field investigations (Fig. 2), an area of approximately 0.05 square kilometres (~0.02 square miles) was selected, where interglacial calcareous sediments about 10 m thick can be found. Together with peat and detritus mud, the thickness of the lake sediments exceeds 15 m and reaches over 20 m below ground level.

Above gyttjas and lacustrine chalk, fine and silty eolian sands may be often found. At the bottom of organic and calcareous sediments there are Eemian fine sands or glacial tills of the Warta glaciation (Scale 3). Stratification of the ground presented on exemplary profiles of boreholes made it possible – with some limitations – to extract the analysed sediments (Fig. 2; 8).

LABORATORY EXPERIMENTS

Before the field research, the specific values of resistivity were determined during laboratory analysis. For this purpose, electrode configurations AB and MN were used (Fig. 3 a, b). They were

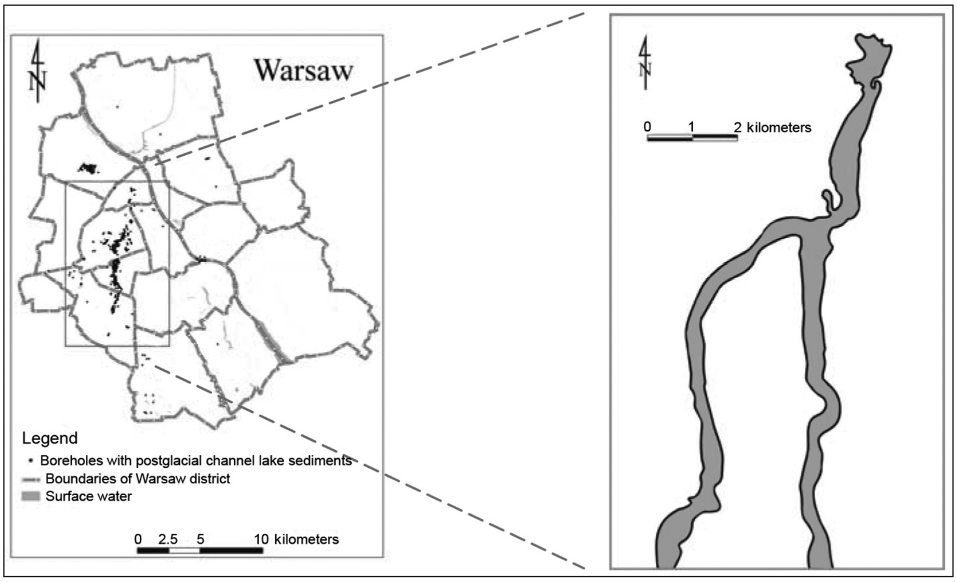

Fig. 1. A view map of research area with boreholes of analysed sediments (Frankowski, Wysokiński, 2000) and the shape of the postglacial channel lake in Warsaw (Morawski, 1978)

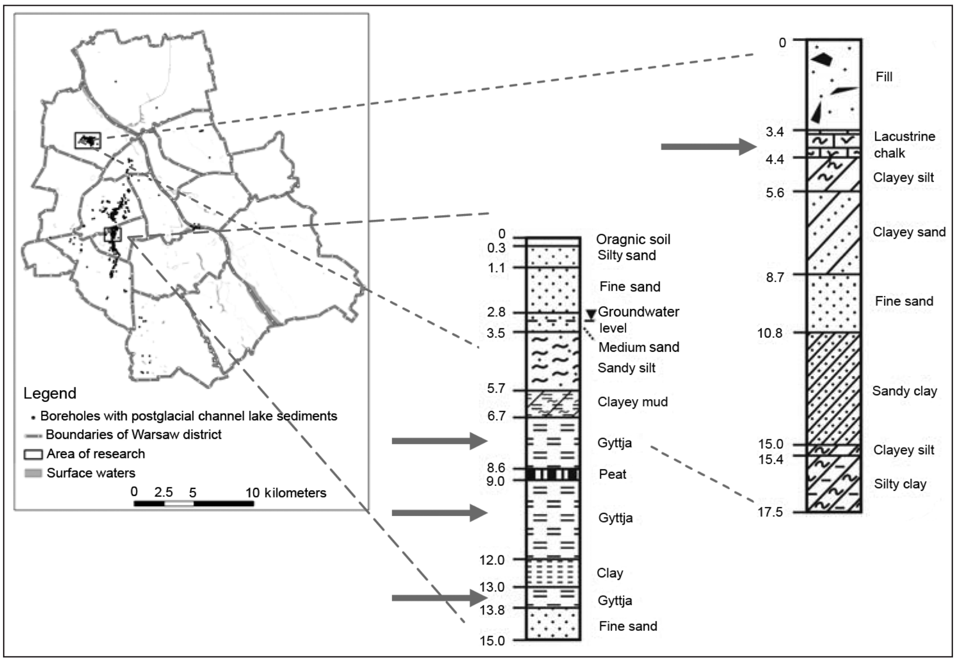

Fig. 2. Areas of research and typical profiles with indicated calcareous sediments (Frankowski, Wysokiński, 2000)

connected to a digital geoelectrical gauge for soil resistance reading to register the current in line AB (I) and the potential difference on MN electrodes (ΔV). Each measurement was carried out twice with a different current. The calculations were made (for device in Fig. 3a) according to a formula based on Ohm's law:

$$\rho = K\frac{\Delta V}{I},$$

where ρ is resistivity, ΔV is potential difference, I is the applied current, and K is a geometric factor based on electrode arrangement (Ward, 1990), and (for device in Fig. 3b) on the following formula:

$$\rho = \left(\frac{s}{l}\right)\frac{\Delta V}{I},$$

where ρ, ΔV, I are as above, s is the surface of the current electrodes A and B, and l is the distance between the potential electrodes (Fukue et al., 2001).

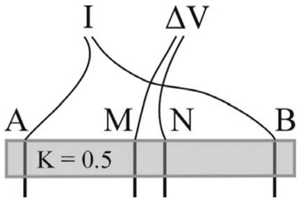

Fig. 3a. Resistivity equipment for undisturbed samples

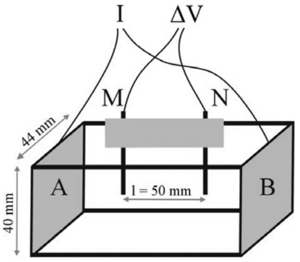

Fig. 3b. Resistivity equipment for slurries

The resistivity of soil depends on various components that form the sediments: carbonates, organic matter, mineral non-carbonate components, and pore water. In the research, especially pore water mineralization was taken into consideration, because the resistance of soil is first of all a function of the electrolyte contained in the pore spaces (Attewel, Farmer, 1976). Shallow-located soils in urbanized areas that have no natural or artificial insulation made of cohesive soils are exposed to potential contamination, which in this case was simulated by increasing the concentration of the solution.

The possibility of using electrical methods for detecting soil contamination has been shown by Campanella and Weemees (1990) (Fukue at al., 2001). The analysis of resistivity was conducted with a variable soil water content. The range of humidity between 40% and 70% is specific of the analysed soil in natural conditions. Figure 4 presents the values of resistivity and the initial water content of an undisturbed sample of lacustrine chalk from the pit. The value of resistivity ranges between 23 and 30 Ω-m.

On slurries, three kinds of tests were conducted, on their basis the influence of humidity, KCl solutions of different concentrations and organic matter were measured. The results of the research on slurries are presented by correlations shown in Fig. 5. Increasing humidity in the range of 49–56% by adding distilled water is not expressed by a linear decrease of resistivity. Except one measurement (25 Ω-m), changes in resistivity were not significant and oscillated around 1 Ω-m. When increasing the humidity of new slurries with KCl solutions (0.2%; 0.5%; 1.0% and 5.0%) a linear decrease of resistivity was observed. The lines on the chart present the order of carrying out the tests on slurries saturated with KCl solutions of various concentrations. The humidity of the slurries were gradually increased, and then the slurries were saturated with KCl solution (0.5%, 1.0% and 5.0%) and were dehydrated. The relation between resistivity and the content of organic matter was also tested. Together with milled peat, distilled water was added to the slurry. The influence of organic matter and 0.2% KCl solution on the resistivity was measured separately (Fig. 6).

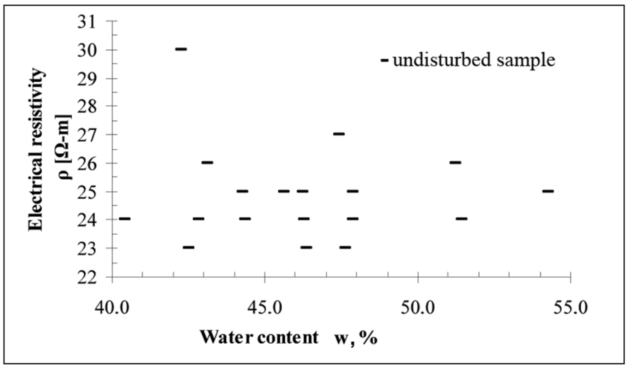

Fig. 4. Relation between water content (*w*) and electrical resistivity (ρ)

FIELD EXPERIMENTS

The analysis of electrical resistivity was conducted with an electrical cone (Fig. 7) near an archival borehole 20 m deep (Fig. 8). The device was invented by Campanella and Weemes in 1990 (Fukue et al., 2001) in order to detect contaminated layers of groundwater and soil. The usage of the device is described in the following monographs: Campanella (1993), Fukue (1998, 1999), Fukue et al. (2001). There is also a possibility of using the electrical cone to measure the salinity of soil and marking pH levels (Brouwer, 2007) as well as to describe the micro-structures of clays (Fukue et al., 1999). Attempts were even made to determine the content of clay fraction in clays (Zawrzykraj, 2005). This very cheap and timesaving method is not commonly used for identification of soil types, although its usefulness has been noted by other researchers (Fukue et al., 2001; Zawrzykraj, 2005). To identify organic lake sediments in Warsaw, measurements were made of specific resistance of overlaying sands, the analysed gyttjas and interlaying peats, sands and clayey sediment. Calculations of resistivity were made according to the following formula:

$$\rho = \pi^2 \frac{\Delta V}{CI},$$

where *C* is the geometric factor based on electrode arrangement and the diameter of the cone (Fukue et al., 2001).

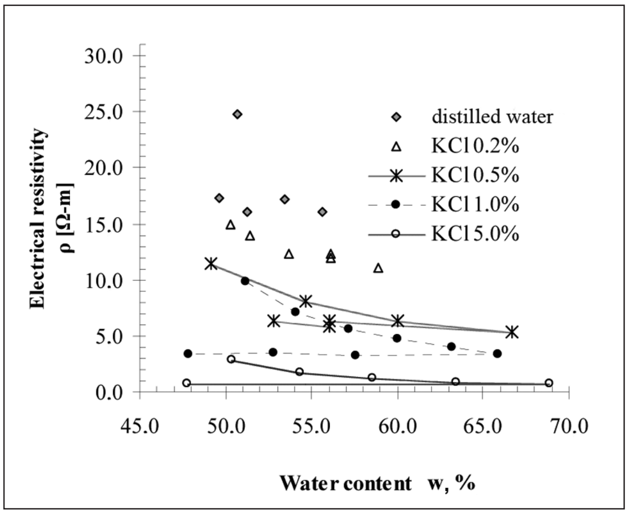

Fig. 5. Correlation between water content (*w*) and electrical resistivity (ρ) in terms of KCl concentration

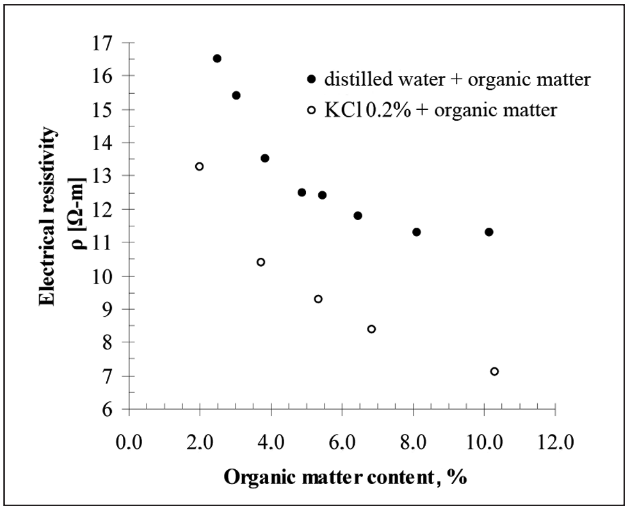

Fig. 6. Correlation between organic matter content and electrical resistivity (ρ) in terms of KCl concentration

The electrical cone was statically inserted into the ground using the equipment of the maximum force 50 kN into a previously prepared borehole of a smaller diameter. The difference of potentials was measured every 20 cm starting from the depth below the fill. The depth of penetration was 17 m. The results of the measurements are presented in Fig. 8.

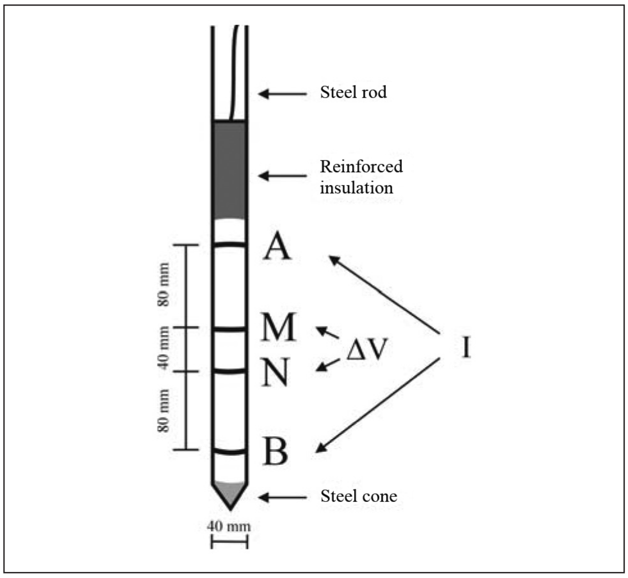

Fig. 7. Resistivity cone

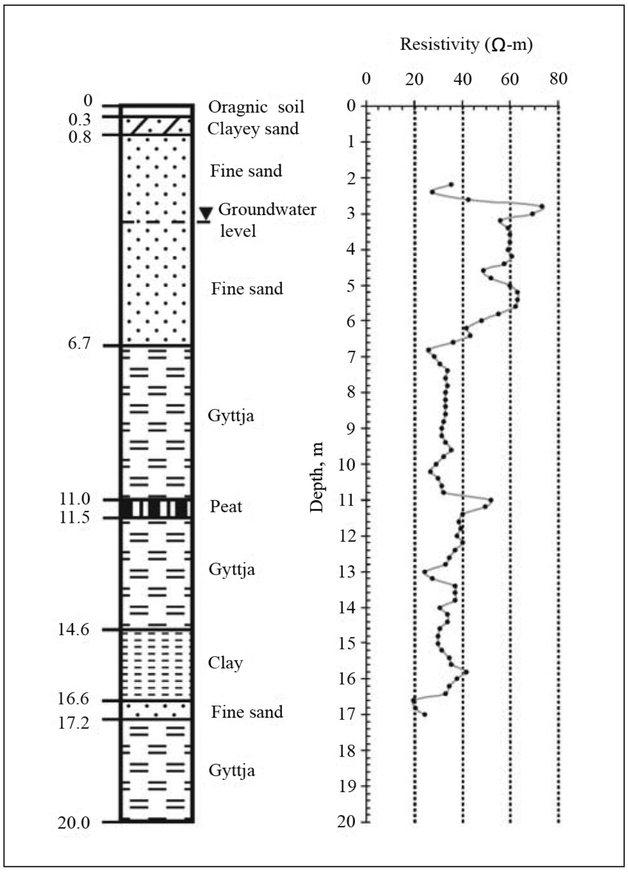

Fig. 8. Correlation between resistivity and soil profile

RESULTS AND DISCUSSION

Effects of KCl concentration and content on organic matter on resistivity measurements

The resistivity values obtained from all the laboratory measurements range from 0.8 to 30 Ω-m (Fig. 9) and do not exceed the specific values of resistivity described in monographs (Attewell, Farmer, 1976; Stein, 1983).

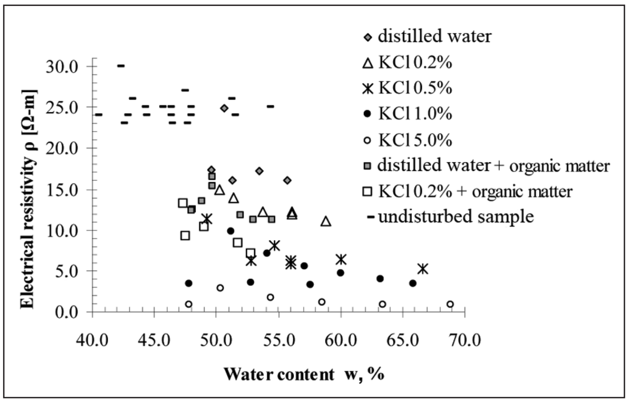

Fig. 9. Correlation between water content (*w*) and electrical resistivity (ρ) in terms of KCl concentration and the presence of organic matter

The increase of water content caused by adding distilled water did not affect the increase of electrical conductivity. The increase of humidity, understood as a ratio between the weight of pore water and the weight of solid particles was the lowering of resistivity only after applying KCl solutions of various concentrations. The conductivity increasing because the soil was provided with more and more ions carried by water. The decrease of resistivity in the function of the increase of the concentration of the added solution was described for quartz sands and clays by Fukue (Fukue et al., 2001) who used KCl solutions (0.3% and 3.0%) among others. The obtained results of measurements for lacustrine chalk with the use of the same current intensity (1 mA) range between the results for sands and clays analysed in Japan (Fukue al., 2001) with a much higher water content (Table).

The results in the table confirm that even with a high mineralization of the electrolyte contained in pore spaces, the lithology is significant for the obtained values of resistance. To confirm that it is the quantity of ions the soil was provided with and not the humidity that determines the conductivity, the resistivity of dehydrated slurries was measured. Experimental results were

Table. **Comparison of resistivity for three kinds of soil in terms of similar KCl concentrations**

KCl, % Clay and sand*	KCl, % Lacustrine chalk	Resistivity, Ω-m		
		Quartz sand*	Warsaw lacustrine chalk	Kibushi clay*
0.3	0.5	~16 (w = 8%)	5.3–11.4 (w = 49–67%)	~2.8 (w = 31%)
3.0	5.0	~1.8 (w = 14%)	0.8–2.9 (w = 48–69%)	~0.35 (w = 37%)

* Data for clay and sand (Fukue et al., 2001).

similar to results obtained with the maximum humidity of the prepared slurry. Drying decreased the humidity without decreasing the amount of ions which affect the increase of conductivity. A slurry saturated with a 1% KCl solution was artificially dehydrated at a temperature of about 50 °C. The test sample shrinked, and even though it was almost devoid of water, it still displayed resistivity in the range 20–32 Ω-m.

The influence of organic matter in the soil on the decrease of resistivity was pointed out by Fukue (Fukue et al., 2001), but he did not present quantitative relationships. An experiment (Fig. 8) showed that even a small change in the contents of organic matter – from 2.5% to 10.2% – together with addition of distilled water significantly decreased the resistivity – from 16.5 to 11.0 Ω-m. A similar relationship occurred when adding organic matter together with a 0.2% KCl solution where a decrease of resistivity from 13.3 to 7.1 Ω-m and an increase of organic matter content from 2.0 to 10.3% were observed. An increase of water content while adding distilled water can be excluded as the reason for conductivity increase. It has been stated that it does not affect the decrease of resistivity. A change of distilled water by KCl relatively decreased the resistivity, but the retained tendency of an increase of conductivity is the effect of adding organic matter. It is best shown by a summary chart of the laboratory tests (Fig. 9) where it is possible to compare the correlation between resistivity in the function of humidity for slurry saturated with 0.2% KCl and slurry saturated with 0.2% KCl with organic matter added.

RESISTIVITY OF *IN-SITU* SOIL

The measurements of resistivity were ended at the depth of 17 m because of the presence of a dense sand layer. A correlation with the soil profile (Fig. 8) supplied information on specific resistivities for separate soil layers. The values of resistivity for sands in the unsaturated zone were 28 to 73 Ω-m. The groundwater level was clearly marked when the resistivity fell below ~ 60 Ω-m. The contact zone of sands with gyttja was also marked by a decrease in resistivity below 30 Ω-m. The contact zone of gyttjas and saturated sands has a higher plasticity, and a higher content of mineralized water increases the conductivity. Low-plasticity gyttjas in the upper part of the test profile are characterized by resistivity of 28–35 Ω-m with a modal score of 33 Ω-m. In the interlaying peats the resistivity increases to 50–52 Ω-m. It is also hard to separate gyttja from clay in the lower part of the profile based on values of resistivity. During this analysis the change in lithology was expressed by a decrease of resistivity from 34–37 Ω-m to 30–31 Ω-m. Low resistivity of values from 20 to 24 Ω-m are specific of saturated sands in the lower part of the profile.

CONCLUSIONS

The research confirmed that resistivity depends mostly on the type of soil (Fig. 8) and the concentration of ions in pore water (Fig. 5).

The content of organic matter and mineralization of pore water influence the increase of conductivity in laboratory conditions. The observed relations between the decrease of resistivity and the content of organic matter (Fig. 6) are not enough to evaluate it quantitatively on the basis of geoelectrical measurements. The reasons for the decrease of resistivity cannot be clearly stated. Based on geoelectrical research, it is impossible to unquestionably indicate the factor responsible for resistivity changes.

Calcareous sediments from Warsaw are characterized by too large a range of resistivity to definitely identify those soils in the profile on the basis of field geoelectrical research. The accuracy of measurements of the electrical cone allows to mark even thin interlayers in a profile, but on the basis of measured resistivity values it is impossible to determine soil type. It is a useful device for identification of soils characterized by varied resistivities, but for identification of calcareous sediments in Warsaw it needs a correlation with profiles of research drillings.

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References

1. Attewell P., Farmer I. W. 1976. Principles of Engineering Geology. New York: John Wiley & Sons. INC.
2. Brouwer J. J. M. 2007. *In-situ* Soil Testing. Gardline Lankelma, Book online, http://www.conepenetration.com/online-book/.
3. Frankowski Z., Wysokiński L. 2000. Atlas geologiczno-inżynierski Warszawy 1 : 10000. Warszawa: Arch. PIG.
4. Fukue M., Minato T., Horibe H., Taya N. 1999. The microstructures of clay given by resistivity measurements. *Engineering* Geology. ***54***. 43–53.
5. Fukue M., Minato T., Matsumoto M., Horibe H., Taya N. 2001. Use of resistivity cone for detecting contaminated soil layers. *Engineering Geology*. ***60***. 361–369.
6. Lindner L., Lamparski Z., Madeyska T., Marks L., Różycki S. Z. 1992. Czwartorzęd. Osady. Metody badań. Stratygrafia. Warszawa: PAE.
7. Morawski W. 1978. Szczegółowa Mapa Geologiczna Polski. Arkusz Warszawa Zachód (523) 1 : 50000. Warszawa: Wydawnictwa Geologiczne.
8. Morawski W. 1980. Objaśnienia do Szczegółowej Mapy Geologicznej Polski (523) 1 : 50000. Warszawa: Wydawnictwa Geologiczne.
9. Różycki S. Z. 1929. Interglacjał Żoliborski. Odbitka ze Sprawozdań z posiedzeń Towarzystwa Naukowego Warszawskiego. Warszawa.
10. Stein J. 1983. Przewodnik do ćwiczeń z geofizyki geologicznej. Warszawa: Wydawnictwa Uniwersytetu Warszawskiego.
11. Ward S. H. 1990. Resistivity and induced polarization methods. In *Geotechnical and Environmental Geophysics*. ***1***. Ed. S. H. Ward. Society of Exploration Geophysicists. Tulsa. Okla. 147–189.
12. Zawrzykraj P. 2005. Przydatność nowej sondy geoelektrycznej do charakterystyki litologicznej iłów warwowych z Plecewic k. Sochaczewa. *Przegląd Geologiczny*. ***53***. 677–681.

Paweł Pietrzykowski

GEOELEKTRINIŲ METODŲ TAIKYMAS EŽERINIŲ ORGANINIŲ IR KARBONATINIŲ GRUNTŲ INŽINERINIUOSE GEOLOGINIUOSE TYRINĖJIMUOSE VARŠUVOJE

Santrauka

Straipsnyje pateikiami geoelektrinių tyrinėjimų paleorinoje rezultatai. Tyrinėti sapropelis ir kreida, susiklostę rinos tipo ežere, Varšuvos miesto teritorijoje.

Pasirenkama prielaida, jog šios nuosėdos yra Eemio amžiaus. Laboratoriniais ir *in situ* tyrimais nustatyta organinėms karbonatinėms nuosėdoms būdinga elektros varža. Laboratoriniuose tyrimuose buvo naudojami grunto monolitai bei grunto pastos. Elektros varža mėginiuose buvo matuojama keičiant KCl tirpalo bei organinės medžiagos (smulkintos durpės) koncentraciją grunto pastoje. Gręžinyje nustatyta elektros varža buvo palyginta su litologiniu profiliu. Elektros varža buvo matuota kas 20 cm. Šiais matavimais galima nustatyti gruntinio vandens lygį, smėlio, sapropelio ir durpių kontaktus. Deja, neužfiksuotas elektros varžos verčių skirtumas tarp sapropelio ir molio. Tyrinėjimai patvirtino elektrinio kūgio, naudojamo kartu su CPT, tinkamumą gruntų rūšims nustatyti. Gruntams, kurių laidumas elektrai panašus, šis metodas taikomas ribotai.

Paweł Pietrzykowski

OCENA PRZYDATNOŚCI METOD GEOELEKTRYCZNYCH DO BADAŃ GEOLOGICZNO-INŻYNIERSKICH ORGANICZNYCH I WĘGLANOWYCH OSADÓW JEZIORNYCH Z WARSZAWY

Streszczenie

Ponad 15 metrów gytii i innych osadów jeziornych zostało zdeponowane na obszarze Warszawy podczas ostatniego interglacjału. Długość ówczesnego jeziora wynosiła ponad 12 kilometrów, a szerokość wahała się od 250 do 750 metrów. Obszar występowania osadów organicznych i węglanowych jest zatem znaczny, a ich obecność w podłożu budowlanym na terenie Warszawy niejednokrotnie wymuszała dodatkowe badania polowe i laboratoryjne w celu ustalenia warunków geologiczno-inżynierskich. Badania interglacjalnych osadów jeziornych są prowadzone od ponad 100 lat. Nie są znane jednak próby zastosowania metod geoelektrycznych do badań tych osadów. Artykuł przedstawia ocenę ich wykorzystania do określania głębokości występowania stropu gytii i kredy jeziornej oraz szacowania ich miąższości na podstawie własnych badań laboratoryjnych i polowych.

Павел Пиетшиковски

ОЦЕНКА ГЕОЭЛЕКТРИЧЕСКИХ МЕТОДОВ ПРИ ИНЖЕНЕРНО-ГЕОЛОГИЧЕСКИХ ИЗЫСКАНИЯХ ОЗЕРНЫХ ОРГАНИЧЕСКИХ И КАРБОНАТНЫХ ГРУНТОВ В ВАРШАВЕ

Резюме

Представлены результаты геоэлектрических исследований, выполненных в палеорытвине. Исследовались сапропели и мел, отложенные в озере рытвинного типа на территории Варшавы. Эти отложения относятся к эемскому периоду. Выполнены лабораторные и полевые исследования с целью установить характерное для этих отложений электрическое сопротивление. Лабораторные исследования проведены на монолитах и пастах грунтов. Электрическое сопротивление измеряли, изменяя в образцах пасты концентрации раствора KCl и органического материала (измельченных торфов). Установленное в скважине сопротивление сравнивалось с литологическим разрезом. Электрическое сопротивление измерялось через каждые 20 см. На основе измерений точно установлены уровень грунтовых вод, контакты песков с сапропелями и торфом. Однако не удалось зафиксировать разницу между значениями сопротивления у сапропеля и глины. Исследования подтвердили возможность использовать электрический конус при статическом зондировании, даже идентификации вида грунта в разрезе. Данный метод ограничен по применению в грунтах со схожими значениями электропроводимости.