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Filtration and geoelectrical investigations in the karst region of North Lithuania

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Water flow through sandy-clayey glacial sediments and weathered sulphurous-carboniferous rocks and their geoelectric parameters were investigated for estimating the intensity of karst processes and possible pollution of groundwater in Northern Lithuania. The modified Nesterov–Boldyrev infiltrometer and the Lita-5 permeameter were used for measuring the permeability. The construction of the instruments and the methods of measurements were elaborated at the Department of Hydrogelogy and Engineering Geology of Vilnius University. The geoelectric survey was done using electrical tomography, one of the newest geophysical methods.

Key words: karst development, infiltration, permeability, modified Nesterov–Boldyrev infiltrometer, electrical tomography, electric resistivity rocks

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INTRODUCTION

Karst processes with the related phenomena are rather widespread in the upper part of the lithosphere. Occurrence of a Middle and Upper Devonian massif of sulphatic gypseous deposits in the northern area of Lithuania is not an exception. In Lithuania, there are several karstified zones of different significance. The most important zone of active recent karst is in North Lithuania, where it covers the area of two administrative districts – Biržai and Pasvalys– with developed karst lakes, sinkholes of different size and other karst forms. Several state-protected areas lie in this area (Karajimiškis, Kirdonys–Tatula, Nemunėlis–Apaščia and Kirkilai). The scientific literature refers to this area as the Karst Region of North Lithuania, covering the area of about 1000 km^2 [2].

Studies on karst development in this region are not only of scientific but also of practical interest, because this area is densely populated not only in the country side also, but there are such towns as Pasvalys and Biržai. One of the sinkholes, formed recently, on 26 April 2003, 8 m deep and about 4 m in diameter, is called the Pit of Geologists.

The main objective of filtration investigations in the karst region was to establish the relationship between the intensity of karst processes, filtration and electrical parameters for till loam and sandy loam covering the karst deposits, as well as for karst deposits. To determine infiltration rate (coefficient of permeability) for the deposits in the aeration (vadose) zone, a modified Nesterov–Boldyrev infiltrometer and the methods elaborated at the Vilnius University Hydrogeology and Engineering Geology Department were used (Klizas, Lubas, 1990).

MATERIALS AND METHODS

The standard infiltrometer was supplemented with a set of five rings, their cross-section ranging from 0.0075 to 0.77 m^2, i. e. the device had seven rings in total. The infiltration studies performed on the rocks of different structure and grain-size showed that the reliable determination of infiltration rate requires application of rings in a certain combination. The standard infiltrometer can be used only for a narrow range of infiltration rate values. Thus, the system applied enabled to make several determinations of the infiltration rate in one pit at its different depths, because several combinations of rings were used depending on the lithology, grain-size and structural peculiarities of the deposits under study. In other words, such an approach to infiltration investigations enabled to assess the spatial range of filtration characteristics in a given profile. This is important to know when comparing the data obtained with the geoelectrical measurements.

Table 1. **Filtration and physical properties of soils in the aeration zone**
1 lentelė. **Aeracijos zonos uolienų filtracinės ir fizikinės savybės**

Pit No.	Humidity, %	Density, g/cm³	Porosity	Ring No.	Permeability, m/d
1	0.11	1.82	0.62	3–5	0.59
	0.12	1.89	0.61	3–5	18.22
2	0.09	1.98	0.50	3–6	6.07
	0.08	1.84	0.59	3–6	37.5
3	0.07	1.78	0.62	3–5	8.94
	0.07	1.71	0.66	3–5	34.4
4	–	–	–	3–5	11.4
	–	–	–	3–6	15.6

Table 2. **Laboratory data on filtration properties of the Middle-Upper Devonian deposits**
2 lentelė. **Viršutinio-vidurinio devono uolienų laboratorinių filtracinių tyrimų rezultatai**

No.	Depth interval	Lithology and geological index	Natural humidity	Porosity	Pressure gradient	Coefficient of permeability, m/d • 10^{-6}
1	15.5–15.6	Dolomite D_3s-kp	0.082	0.29	66.89	0.43
2	36.5–36.6	Marl D_3j	0.023	0.23	37.59	1.3
3	36.5–36.6	Marl D_3j	0.023	0.23	75.19	1.5
4	36.5–36.6	Marl D_3j	0.023	0.23	112.78	1.4
5	19.6–19.8	Dolomite D_3s-kp	0.071	0.22	163.04	0.064
6	17.5–17.7	Marl D_3t	0.135	0.35	58.82	2.75
7	17.5–17.7	Marl D_3t	0.135	0.35	117.65	2.43
8	17.5–17.7	Marl D_3t	0.135	0.35	176.47	2.71
9	28.9–29.1	Dolomite D_3j	0.076	0.23	42.55	10.70
10	28.9–29.1	Dolomite D_3j	0.076	0.23	85.11	4.71
11	28.9–29.1	Dolomite D_3j	0.076	0.23	127.66	2.45
12	25.0–25.2	Marl claeyey D_3t	0.159	0.31	40.98	2.28
13	25.0–25.2	Marl claeyey D_3t	0.159	0.31	81.97	2.29
14	25.0–25.2	Marl claeyey D_3t	0.159	0.31	122.95	2.20

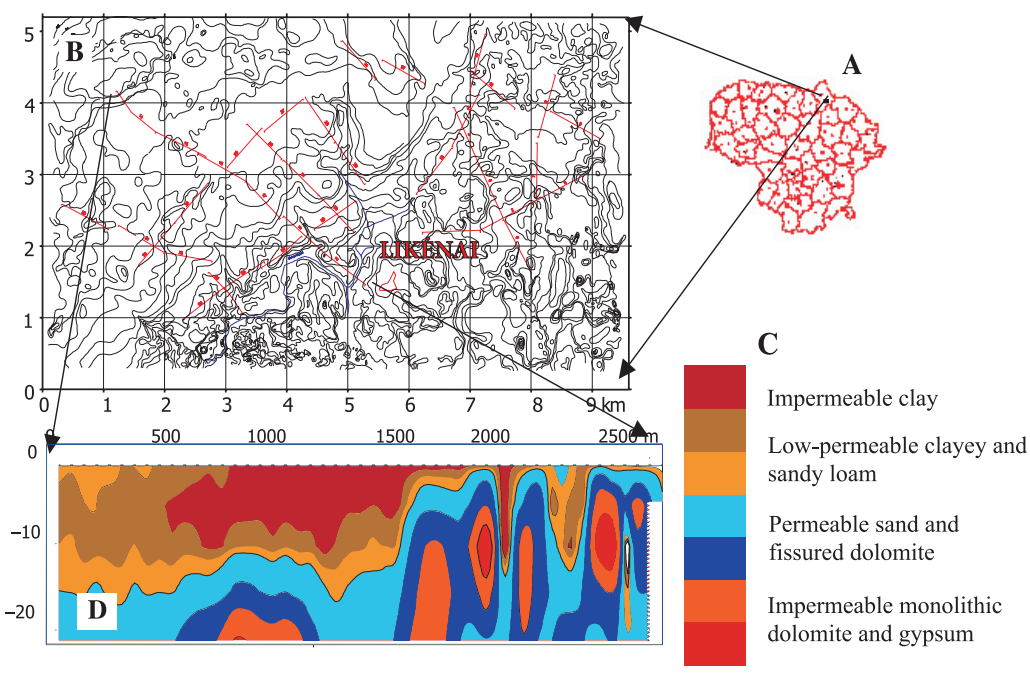

Fig. 1. Electrical tomography survey in Likėnai environs (Biržai District): *A* – location of the study area on the map of Lithuania; *B* – topographical map of area with measurement lines (red lines); *C* – coloured qualitative permeability scale of sediments; *D* – hydrogeological interpretation of geoelectric sections along lines 14–19

1 pav. Elektrinės tomografijos profiliai Biržų rajono Likėnų apylinkėse: *A* – tyrimų rajono vieta, *B* – situacinis topografinis žemėlapis ir profilių linijos, *C* – uolienų skvarbumo vandeniui kokybinė skalė, *D* – geoelektrinio pjūvio hidrogeologinė interpretacija išilgai 14–19 profilių linijų

Table 3. **Lithology, structure, resistivity and permeability of Quaternary and Devonian sediments**

3 lentelė. **Kvartero ir viršutinio devono uolienų savitosios elektrinės varžos ir filtracijos koeficiento vertės**

Lithology, structure	Resistivity, Ohm•m	Permeability
Clay	20–30	Impermeable
Clayey till	30–50	Very low-permeable
Sandy till, clayey sand, dolomitic flour	50–80	Low-permeable
Sand, fissured dolomite, marl	80–200	Permeable
Weak fissured dolomite	200–500	Low-permeable
Monolithic dolomite, gypsum	>500	Impermeable

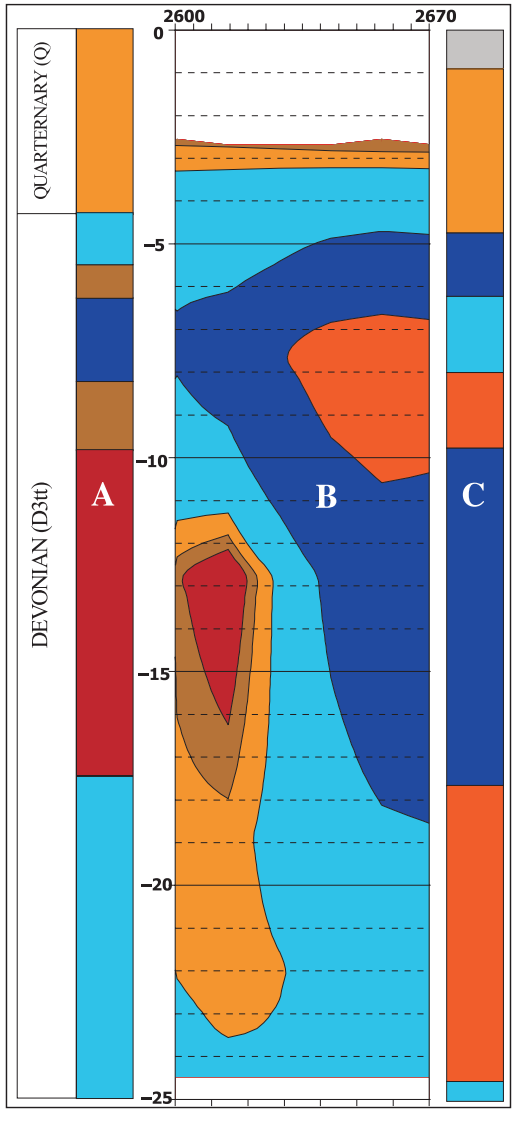

Fig. 2. Fragment of interpreted geoelectric section along lines 14–19 (interval 2600–2670) (B) between two borehole cross-sections (*A* and *C*). Colours mean the same as in Fig. *1C*

2 pav. Geoelektrinio pjūvio išilgai 14–19 profilių interpretuota atkarpa (intervalas 2600–2670 m) (*B*) tarp dviejų gręžinių pjūvių (*A* ir *C*). Spalvų reikšmė tokia pat kaip ir 1 pav., *C*

Field measurements were treated using equations proposed by N. Girinsky. The relationship determined for the flowrate (Q) flow from an internal ring is

$$Q = k\frac{5.4H_0 + 1.1d}{d + 2p}S, \quad H_0 = h_0 + h_k, \qquad (1)$$

where d and s mark the diameter and area of the internal ring in the combination used; h_0 is water depth in the infiltrometer; h_k is the height of capillary rise; k is the coefficient of permeability, and p is the depth of the infiltrometer pressed into the ground.

For a more convenient use of equation (1), V. Shestakov proposed to link changes in the hydraulic slope with water absorption during infiltration. If the volume of percolated water is V, then equation (1) turns into:

$$v = k + \frac{k\mu S(h_0 + h_k)}{V}, \qquad (2)$$

where v is the infiltration rate and μ is the coefficient of water yield.

The graphical solution of equation (2) shows that the infiltration rate is in a linear relationship to the magnitude that is inverse to the volume of percolated water and that cuts a magnitude on X axis equal to the value of the infiltration rate. The second graphical interpretation of the equation (2) is the straight in the coordinates of vV and V with the slope equal to k (Šečkus, Dobkevičius, 1983).

RESULTS AND DISCUSSION

Data on the infiltration and physical features of rocks within the limits of the Karajimiškis Geological Reserve are disted in Table 1.

In order to determine the filtration properties of calcareous and sulphatic aquiclude deposits as well as of condensed rocks of the aquifers by means of direct filtration via a sample matrix, we have elaborated, designed and tested an experimental device, Lita-5 (Mikšys, Klizas, 1984). Its tests have shown that it enables to reach a reliable determination of infiltration rate in a rather wide range of values: from 10^{-3} to 10^{-9} m/d.

Investigations carried out for Middle-Upper Devonian and overlying Quaternary deposits in the karst region of Lithuania and adjacent areas showed that their values ranged widely – from $5.1 \cdot 10^{-4}$ to $5.4 \cdot 10^{-8}$ m/d for deposits of different lithology (Table 2).

The lowest values of infiltration rate were obtained for condensed monolithic marl and dolomite in the Jara and Suosa–Kupiškis beds of the Middle-Upper Devonian. The highest values were obtained for clayey sandstone notable for a high pore permeability. Variations in infiltration rate values are small for coeval rocks of the same lithology, identical fissuring and karstification. Comparison of the filtration properties of Devonian and Quaternary deposits, obtained in the laboratory testing of sample matrices, as well as field data collected during trial pumping enabled to assess the level of fissuring and karstification of deposits in the karst region of North Lithuania.

Experimental geoelectric field works were carried out in the vicinity of the balneological resort Likėnai (Biržai District), prominent in its curative mud and mineral water (Fig. 1A).

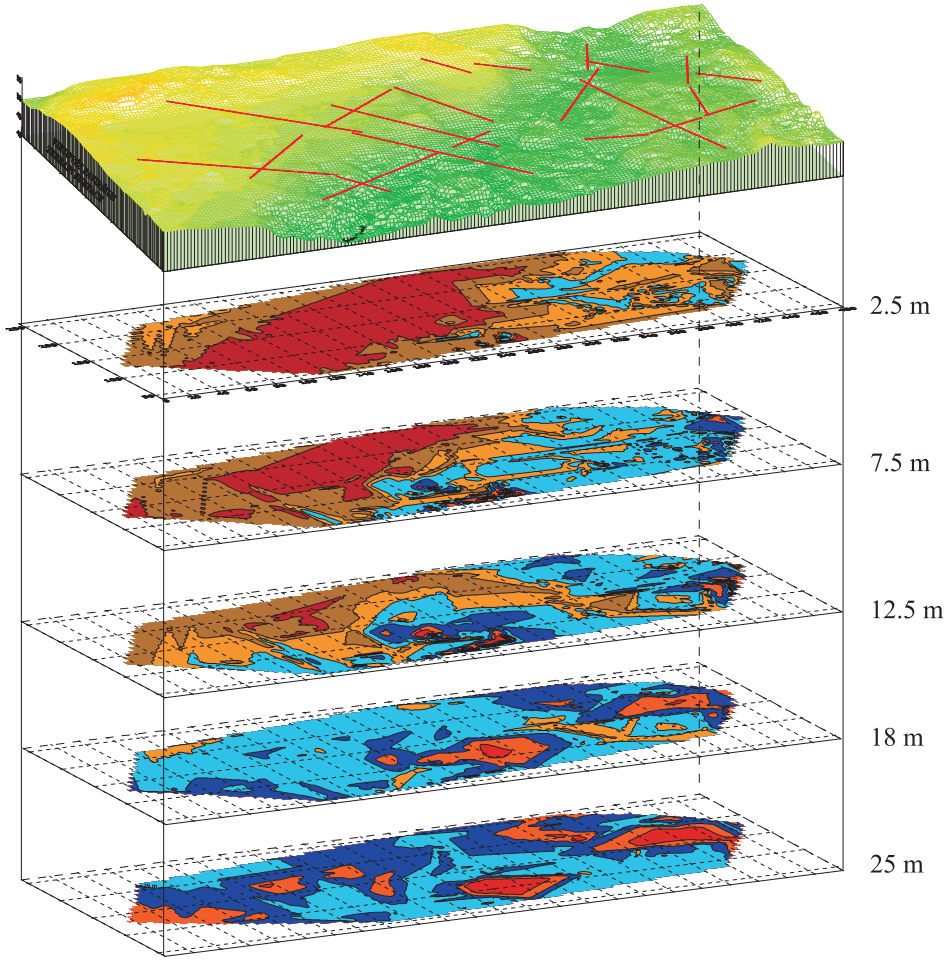

Fig. 3. The 3-D filtration model. Conventional signs: relief of the area with the lines of measurements is given in the upper part of the figure; lower – sections showing changes in filtration properties at a depth of 2.5, 7.5, 12.5, 18 and 25 m

3 pav. Trimatis filtracinis modelis. Viršutinėje paveikslo dalyje – reljefas su profilių linijomis, žemiau – pjūviai, rodantys filtracinių savybių kaitą 2,5; 7,5; 12,5; 18 ir 25 m. gyliuose

In the area of 30 km^2, electrical tomography was performed along 38 single profiles 0.5 km long (Fig. 1B) using the CAMPUS Resistivity Imaging System and the 50-electrode Wenner array 500 m long. Data obtained at single profiles located along one line were joined before the further treatment. Inversion of apparent resistivity values was performed by the Res2Dinv software (Loke, Barker, 1995). In accordance with the inversion results, the geoelectric sections were drawn and interpreted later to attain a hydrogeological meaning (Fig. 1D).

The hydrogeological interpretation was based on drilling data (Fig. 2) and on the relationship between the electric resistivity and filtration rate for sandy-clayey and calcareous rocks, as many authors had determined (Ogilvy, 1990; Seckus, 1998).

The results of experimental laboratory and field investigations of rock filtration properties in the karst region enable to confirm presence of such relationship. According to these data, impermeable rocks are notable for either very low (20–50 Omm) or very high (>500 Omm) resistivity, while the moderate values are characteristic of filtrating sandy-clayey quaternary and fissured calcareous Devonian rocks. Since the data available are not sufficient to determine a strict quantitative relationship between the infiltration rate and electrical resistivity, the deposits of a given area were divided into three classes according to their filtration properties: impermeable, very low-permeable, low-permeable and permeable (Fig. 1C, Table 3). The lithology, electrical resistivity and permeability of rocks are given in Table 3.

The same data were used to create a spatial model presented in Fig. 3. According to changes in the values of electrical resistivity on a given area, the sections were constructed and zones of different water filtration capacity were singled out. Figures 1D, 2 and 3 show that filtration properties were changing both in area and in depth. The upper part of the section contains two zones, the western and the eastern, obviously seen in Fig. 2. The western part of the study area was found to have a relatively thick layer of clayey deposits lying as deep as 0–12.5 m. Infiltration of surface water here is greatly hampered, while the upper part of the eastern zone is composed of sand and sandy loam, as well as of fissured calcareous rocks. This is confirmed by numerous soil collapses, karst sinkholes and lakelets. Taking into account the flat relief of the area, groundwater pollution in the zone of the area where Likėnai with its mineral water sources is situated is highly possible, and this is really dangerous.

The area of the aquifer is increasing with depth, as the sections show at a depth of 2.5–25 m. Monolithic dolomite and gypsum, which were not dissolved, lie below the level of 12.5 m in an increasingly growing area.

CONCLUSIONS

Geoelectrical investigations show that the dense network of electrical tomography profiles and a relationship between the geoelectrical and filtration properties of deposits enable to con-

struct spatial filtration models. Such models can be used in further hydrogeological investigations, e. g., choosing the sites for new wells, constructing mathematical hydrogeological models, planning groundwater extraction, etc.

The filtration investigations performed in the present study enabled to make the following conclusions. High values of infiltration rate for the cover rocks cause an active development of karst in the Tatula gypsum-containing deposits due to an intense infiltration of rainwater. Where the cover deposits are not thick, or their sealing properties are low, karst sinkholes are formed on the surface. Groundwater in the karst region is not protected from surface pollution because of the high infiltration rate of sandy quaternary soils and fissured calcareous Devonian rocks.

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Petras Klizas, Rimantas Šečkus

UOLIENŲ FILTRACINIŲ IR GEOELEKTRINIŲ SAVYBIŲ TYRIMAI ŠIAURĖS LIETUVOS KARSTINIAME RAJONE

Santrauka

Atlikto darbo tikslas – nustatyti Biržų rajono Likėnų apylinkių moreninio priemolio, priesmėlio, užkarstėjusių sulfatinių-karbonatinių uolienų storymės lauko ir laboratorinių tyrimų filtracines ir geoelektrines savybes bei jų tarpusavio sąsajas. Geofiltraciniams tyrimams buvo naudojamas patobulintas Nesterovo-Boldyrevo infiltrometras „Lita-5“. Konstrukciniai sprendimai ir tyrimų metodika buvo sukurta Vilniaus universiteto Hidrogeologijos ir inžinerinės geologijos katedroje. Geoelektriniams tyrimams panaudotas geofizikos tyrimų metodas – elektrinė tomografija.

Regione tirtų skirtingų litologinių uolienų kompleksas pagal ryšį tarp filtracinių ir geoelektrinių savybių suskirstytas į 6 grupes: 1) molis; 2) priemolis; 3) priesmėlis, molingas smėlis, dolomitiniai miltai; 4) smėlis ir plyšiuotas dolomitas bei mergelis; 5) mažai plyšiuotas dolomitas; 6) monolitinis dolomitas ir gipsas. Filtracijos koeficiento verčių kitimo intervalas – 10^{-1}–10^{-8} m/d, o elektrinių varžų – nuo 20 omm I grupės iki >500 omm VI grupės. Pagal elektrinės tomografijos duomenis sudarytas trimatis filtracinis modelis leidžia įvertinti filtracinių savybių kaitą erdvėje.

Пятрас Клизас, Римантас Шечкус

ФИЛЬТРАЦИОННЫЕ И ГЕОЭЛЕКТРИЧЕСКИЕ ИССЛЕДОВАНИЯ В КАРСТОВОМ РЕГИОНЕ НА СЕВЕРЕ ЛИТВЫ

Резюме

Цель настоящей работы – оценить фильтрационные и геоэлектрические параметры перекрывающих моренных суглинков, супесей и карстующихся сульфатно-карбонатных толщ Биржайского района в окрестностях поселка Ликенай на севере Литвы.

Для определения фильтрационных параметров использованы модифицированный инфильтрометр Нестерова–Болдырева и прибор „Lita-5“. Конструкторские решения и методика таких исследований были разработаны на кафедре гидрогеологии и инженерной геологии Вильнюсского университета.

Геоэлектрические исследования проводились с использованием нового метода геофизической разведки – электрической томографии.

Проведенные исследования на данной территории позволили весь комплекс литологических разновидностей по связи между фильтрационными и геоэлектрическими параметрами разделить на 6 групп: 1) глина; 2) суглинок; 3) супесь, глинистый песок, доломитная мука; 4) песок, трещинный доломит, мергель; 5) слаботрещиноватый доломит; 6) монолитный доломит, гипс. Коэффициент фильтрации меняется с 10^{-1} до 10^{-8} м/сутки, а удельное электрическое сопротивление с 20 Ом в первой группе до >500 Ом в шестой группе. Трехмерная модель, построенная по данным электрической томографии, позволила оценить изменения фильтрационных свойств четвертичных и девонских отложений в пространстве.