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Hydraulic Parameters of Sediments of the Inner Carpathian Paleogene in Eastern Slovakia

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Abstract:

In the presented paper the author evaluates hydraulic properties of the sediments of the Inner Carpathian Paleogene in a part of Eastern Slovakia. The sediments are divided into four lithostratigraphic units - the Borové, Huty, Zuberec and Biely Potok Formations. Their hydraulic properties are evaluated with the help of comparative parameters of transmissivity index - Y-, permeability index - Z -, from which the hydraulic parameters - transmissivity coefficient - T- and permeability coefficient -k- have been derived. The formations are classified according to the calculated -T- and -k- values in corresponding transmissivity and permeability classes. On the basis of general evaluation, the highest transmissivity, or permeability, showed the Borové Formation – tectonically affected homogeneous breccias and conglomerates formed of Triassic carbonate rocks, and the lowest by the Huty and Zuberec Formations (Tab. 1, 2, 3).

Key words: Inner Carpathian Paleogene, hydraulic parameters, transmissivity, permeability

(5 Figs., 3 Tabs.)

Introduction

Paleogene sediments form a considerable part of Slovakia. They emerge to the surface in the Eastern as well as Inner Carpathians. In the Inner Carpathians they are described as the Inner Carpathian Paleogene - the Subtatric Group. GROSS et al. (1984) distinguished here four Formations.

The base is formed of the Borové Formation, lying transgressively on the pre-Tertiary basement consisting mostly of Triassic limestones and dolomites. It consists of breccias, conglomerates, sandy limestones, passing towards the overlier into clayey limestones. Breccias and conglomerates are developed in two lithologic types. The first type consists of homogeneous breccias and conglomerates, the material of which comes from Triassic carbonates, and they are cemented with carbonaceous cement. The second type consists of heterogeneous breccias and conglomerates with polymictic material, formed mostly of non-carbonate rocks with clayey cement. Their age is estimated as Middle Eocene.

Above the Borové Formation is lying the Huty formation. It is formed of a thick and quite monotonous complex of calcareous claystones with sandstone beds. The ratio of sandstones vs. claystones is 1 : 4 to 1 : 10, sporadically even more. As far as its age is concerned, the formation belongs to the Upper Eocene.

The Zuberec Formation develops gradually from the Huty formation, the sandstone beds increasing and claystones decreasing in quantity, until it passes into a flysch development, with regularly alternating sandstones and claystones. According to its age it belongs to the middle part of the Upper Eocene.

The youngest formation of the Inner Carpathian Paleogene is the Biely Potok Formation, characterised by the development of heavy-bedded sandstones with sporadic non-calcareous claystone layers. The age of the formation is Lower Eocene.

Sediments of the Inner Carpathian Paleogene have been affected by germanotype tectonics. They are horizontal, or subhorizontal, only at the margin of basements the position is steeper.

The subject of the presented paper is regional evaluation of hydraulic properties of the subsurface zone of Inner Carpathian Paleogene sediments in Eastern Slovakia. The studied territory includes two regions – the Levočské vrchy Hills and Šarišská vrchovina Hills (Fig. 1), formed predominantly of the Biely Potok Formation. Other formations occur in their marginal parts (ZAKOVIČ, 1980 a,b)

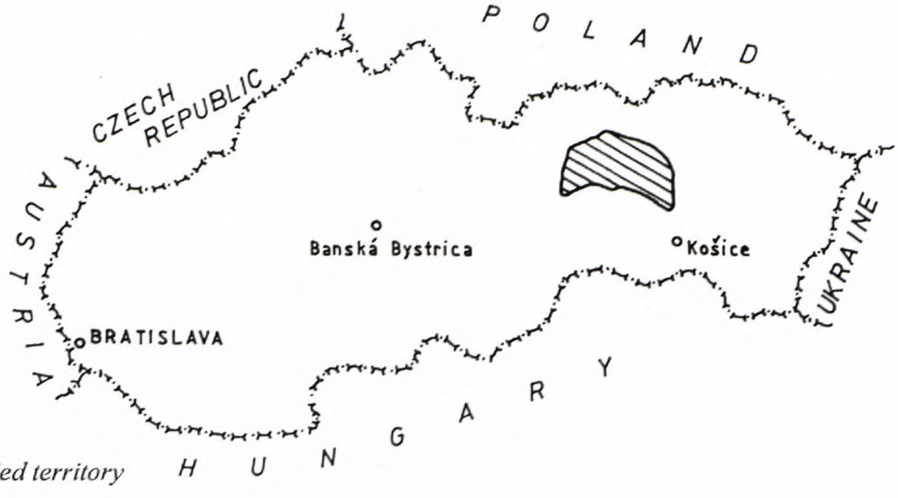


Fig. 1 Situation of the studied territory

Methods of data processing

The evaluation of hydraulic properties of sediments in the above lithostratigraphic units was based on the processing of comparative hydrogeologic parameters - the transmissivity index -Y-, permeability index -Z- - according to the method of regional evaluation of hydraulic rock parameters elaborated by JETEL (1985 a, b). The basic step was determining the transmissivity index -Y- and permeability index -Z- from values of specific yield -q-, derived from data provided by pumping hydrodynamic tests.

The values of hydraulic parameters – transmissivity coefficient -T- and hydraulic conductivity coefficient -k- are derived from the values of comparative parameters Y and Z with the help of logarithmic calculation difference -d- (JETEL, 1985 a) defined by the formula d = logT - logq, which, after its estimation or analytical derivation, is substituted into the calculation formulae (JETEL, 1985 a, b):

$$T\ (m^2/s) = \text{antilog}\ (Y + d - 9) = 10^{(Y + d - 9)} \quad (1)$$

$$k\ (m/s) = \text{antilog}\ (Z + d - 9) = 10^{(Z + d - 9)} \quad (2)$$

The degree of transmissivity and permeability in the studied lithostratigraphic units is expressed as medians Md(Y) and Md(Z) and arithmetic means M(Z) and M(Y). After substituting the estimations of calculation difference -d- into the formulae (1) and (2), we obtain respective estimations corresponding to the characteristics of middle level of transmissivity coefficient T and coefficient of hydraulic conductivity -k-, i.e. the medians Md(T) and Md(k) and the geometric means G(T) and G(k). As shown by the formulae (1) and (2), the comparative parameters Y and Z represent certain logarithmic transformations of the transmissivity coefficient -T- and permeability coefficient -k-. According to these relations, the arithmetic mean M of the values Y and Z corresponds to the geometric mean G of the values T and k:

$$G(T) = \text{antilog}\ M(Y + d - 9) = 10^{M(Y + d - 9)} \quad (3)$$

$$G(k) = \text{antilog}\ M(Z + d - 9) = 10^{M(Z + d - 9)} \quad (4)$$

Normal distribution of the values Y or Z indicates then lognormal distribution of the values -T- or -k- (JETEL, 1985 a,b).

As indicators of transmissivity and permeability variability in various lithostratigraphic units are used the values s_Y and s_Z, representing estimations of the standard deviation of the values Y and Z in the basic set.

The level of transmissivity is evaluated using the classification proposed by KRÁSNÝ (1986), for the level of permeability we use its eight-degree classification (JETEL, 1982).

Hydraulic parameters of lithostratigraphic units

Borové Formation

It is the lowermost lithostratigraphic unit of the Inner Carpathian Paleogene. Its hydraulic properties are characterised on the basis of data obtained from hydrogeologic drillholes. Trasmissivity and permeability of this formation is depending on its lithologic composition and tectonic reworking. Higher transmissivity and permeability classes are displayed by homogeneous breccias and conglomerates composed of Triassic limestone and dolomite pebbles, in contrast to heterogeneous conglomerates and breccias the pebble material of which consist besides Triassic carbonates of non-carbonate rocks, often cemented by clayey cement.

The characteristics of the distribution of transmissivity index Y, permeability index Z as well as estimations of transmissivity coefficients T and permeability coefficients -k- of the Borové Formation are presented in Tabs. 1, 2, 3, and Figs. 2, 3.

The transmissivity index in homogeneous conglomerates and breccias is lying in the range 4.7 - 6.8, about the median Md(Y) = 5.6 and arithmetic mean M(Y) = 5.7. The transmissivity coefficient T varies between 1.23×10^{-4} - 1.44×10^{-2} m^2/s, with a median of 8.51×10^{-4} m^2/s and geometric mean G(T) = 1.26×10^{-3} m^2/s.

According to the classfication of transmissivity, this formation is classed as a highly transmissive aquifer, with great variability of transmissivity (class II).

The values of permeability index in the Borové Formation vary in the range Z = 4.2 - 5.9, about the median Md(Z) = 5.1 and arithmetic mean M(Z) = 5.0. This range of Z values corresponds to estimates of coefficient of hydraulic conductivity G(k) = 2.51×10^{-4} m/s, the M(Z) value corresponds to an estimate of geometric mean of the coefficient of hydraulic conductivity G(k) = 2.51×10^{-4} m/s. According to permeability, homogeneous breccias and conglomerates are classified as permeability class III - relatively strongly permeable, with great variability of permeability (ZAKOVIČ et al., 1993).

In contrast to this, the Borové Formation formed of heterogeneous breccias and conglomerates, or tectonically unaffected homogeneous conglomerates, displays one class lower transmissivity and permeability. For example, JETEL – VRANOVSKÁ (1990) mentioned for the Borové Formation in the Hornádska Basin transmissivity coefficients in the range 1.1×10^{-5} - 9.0×10^{-3} m^2/s, about the median 3.7×10^{-4} m^2/s and permeability coefficient in the range 1.2×10^{-7} - 3×10^{-4} m/s, with the geometric mean 9.5×10^{-6} m/s. This corresponds to the transmissivity class four (medium transmissivity).

Flysch formation

Above the Borové Formation there are flysch sediments – the Huty, Zuberec and Biely Potok Formations.

Groundwater forms in flysch sediments either by infiltration of precipitation, or by surface water penetrating into the rock environment. The principal hydrogeologic aquifer is the near-surface zone. The predominant part of the infiltrated precipitation water is flowing off more or less conformably with the surface terrain, in small depth below the surface. On more steep slopes, the near-surface zone, especially in its most permeable section, after interrupted influx of precipitation, it is very rapidly drained off and the table of the first groundwater body descends into less permeable parts of the rock environment. The movement of water table in the near-surface zone, with permeability and transmissivity decreasing with depth, is the reason for considerable variability of drainage from the territory. The greatest part of the groundwater flowing off in the near-surface zone passes into surface drainage by the way of disseminated transition into Quarternary alluvia and surface streams, and only a small part reaches the surface in the form of springs. Average yield of springs flowing off the flysch sediments is relatively low. Relatively abundant are springs with Q up to 0.51 l/s. An exception are springs at tectonic zones fed from the above- or underlying lithostratigraphic members, or springs occurring in the closure of valleys filled with a thicker cover of debris.

A smaller part of groundwater descends into greater depth in the direction of inclination of aquifer rocks as well as along vertical fault zones and it participates in the formation of springs flowing off on these faults or reached by hydrogeologic drilling.

Huty Formation

It is formed by grey, dark-grey claystones with varying calcareousness, with layers of sandstones. Its hydraulic properties are characterized on the basis of results obtained from hydrogeologic drill-holes.

The characteristics of the distribution of transmissivity index -Y-, permeability index values -Z-, transmissivity coefficients T and permeability coefficients -k- are presented in Tabs. 1, 2, 3 and on Figs. 2, 3. The transmissivity of the Huty Formation is characterised by the range of transmissivity index values Y = 4.3 - 5.2 with Md(Y) = 4.7, M(Y) = 4.7 and standard deviation s_Y = 0.50. This corresponds to estimates of the range of transmissivity coefficients T = 3.3×10^{-5} m^2/s and G(T) = 7.5×10^{-5} m^2/s.

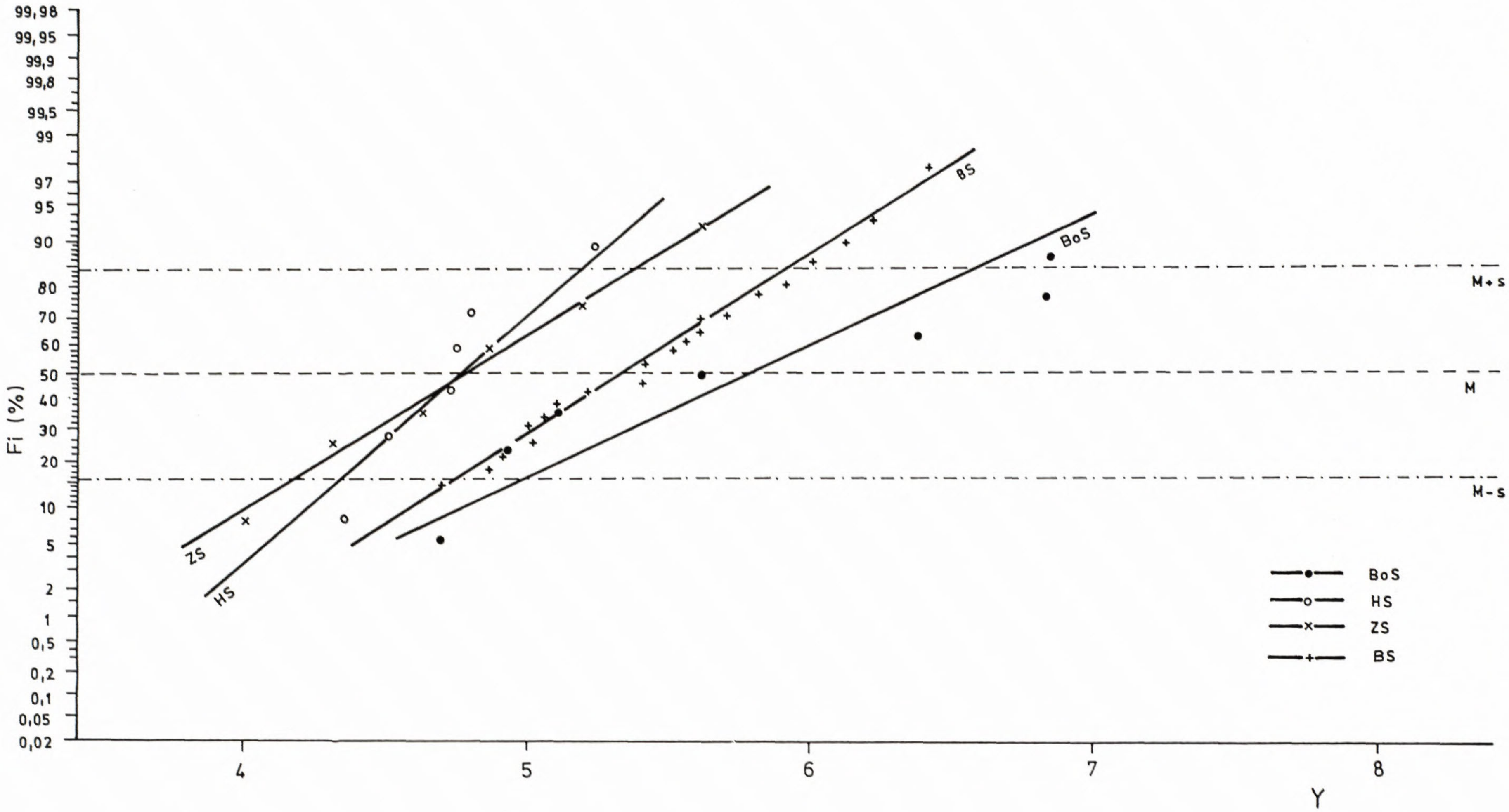


Fig. 2: Quantile graph of the transmissivity index (Y) for the studied lithostratigraphic units
BoS – Borové Formation, HS – Huty Formation, ZS – Zuberec Formation, BS – Biely Potok Formation.
On the vertical axis there are relative cumulative frequencies, M = arithmetic mean, s = estimate of standard deviation of the basic set

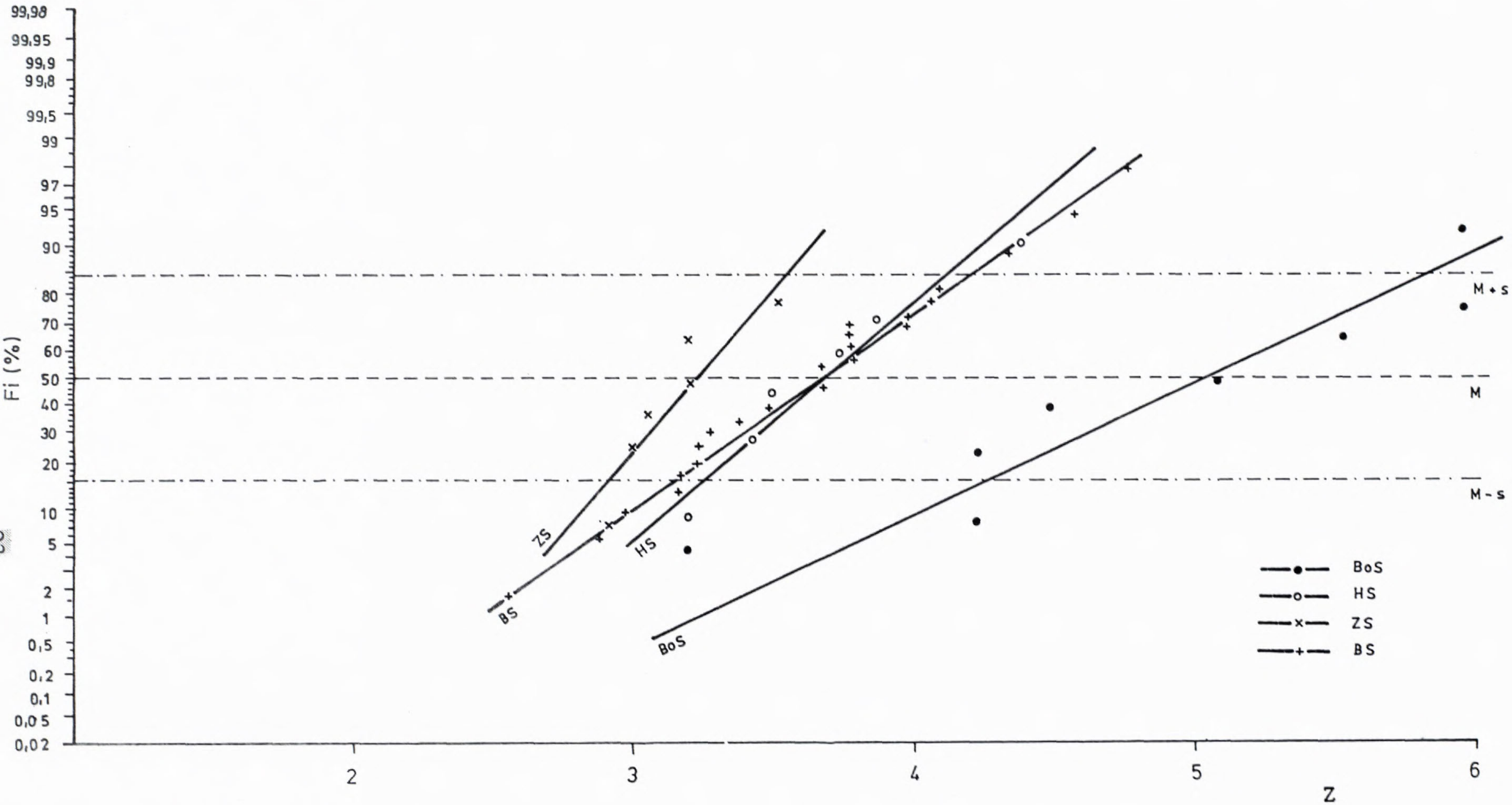


Fig. 3 : Quantile graph of the permeability index (Z) for the studied lithostratigraphic units. Explanations – see Fig. 2

Tab.1 Characteristics of the distribution of transmissivity index Y and permeability index Z values in the studied lithostratigraphic units

Lithostratigraphic unit	n	Y	Md(Y)	M(Y)	s_Y	Z	Md(Z)	M(Z)	s_Z
Biely Potok Formation	25	3,9–6,4	5,4	5,3	0,54	2,6–4,8	3,7	3,6	0,55
Zuberec Formation	7	4,0–5,6	4,7	4,7	0,62	1,5–5,4	3,7	3,7	0,84
Huty Formation	6	4,3–5,2	4,7	4,7	0,50	3,2–4,3	3,5	3,6	0,44
Borové Formation	7	4,7–6,8	5,6	5,7	0,80	4,2–5,9	5,1	5,0	0,78

n = number of data, Md(Y), Md(Z) = medians of the values Y and Z, M(Y) and M(Z) = arithmetic means of the values Z and Y, s_Y, s_Z = standard deviation estimates of the basic set for the values Y and Z

Tab. 2 Distribution of estimates of transmissivity coefficient T derived from transmissivity index Y

Formation	n	R(T)(m^2/s)	G(T)	Transmissivity class
Biely Potok Formation	25	$1,5.10^{-5}$– $4,4.10^{-3}$	$3,8.10^{-4}$	III. Medium Transmissivity
Zuberec Formation	7	$1,4.10^{-5}$–$5,7.10^{-4}$	$8,3.10^{-5}$	IV. Low Transmissivity
Huty Formation	6	$3,3.10^{-5}$–$2,4.10^{-2}$	$7,5.10^{-5}$	IV. Low Transmissivity
Borové Formation	7	$1,2.10^{-4}$–$1,4.10^{-2}$	$1,2.10^{-3}$	III. High Transmissivity

n = number of data, R(T) = range of transmissivity coefficient values, G(T) = geometric mean of transmissivity coefficient

Tab. 3 Distribution of hydraulic conductivity coefficient estimates derived from permeability index Z

Formation	n	R(k)	G(k)	Permeability class
Biely Potok Formation	25	$7,6.10^{-7}$–$1,2.10^{-4}$	$1,7.10^{-5}$	IV. medium
Zuberec Formation	7	$1,1.10^{-6}$–$9,1.10^{-6}$	$3,2.10^{-6}$	V. relatively low
Huty Formation	6	$2,2.10^{-6}$–$1,9.10^{-3}$	$7,0.10^{-6}$	V. relatively low
Borové Formation	7	$3,5.10^{-5}$–$1,9.10^{-3}$	$2,5.10^{-4}$	III. relatively high

n = number of data, R(k) = range of coefficient of hydraulic conductivity values, G(k) = geometric mean of coefficient of hydraulic conductivity

The values of permeability index vary here in the range Z = 3.2 - 4.3, about the median Md(Z) = 3.5 and arithmetic mean 3.6, with an estimate of standard deviation of the basic set s_Z = 0.44. This range of Z values corresponds to estimates of the coefficient of hydraulic conductivity k = 2.26×10^{-6} - 3.5×10^{-5} m/s, the value of M(Z) corresponds to the estimate of geometric mean of coefficient of hydraulic conductivity G(k) = 7.0×10^{-6} m/s.

According to the eight-degree permeability classification of JETEL (1982), average permeability of the near-surface zone in the Huty Formation corresponds to class V (relatively weak permeability and transmissivity) – IV (low transmissivity).

Zuberec Formation

The Zuberec Formation consists of grey, weakly calcareous claystones and clayey siltstones, with layers of gradation-bedded sandstones, which sometimes reach a thickness of 2 or more meters.

Hydraulic parameters of the Zuberec Formation are evaluated on the basis of 7 data obtained from hydrogeologic drillholes. The transmissivity index is in the range Y = 4.0 - 5.6, with a median of Md(Y) = 4.79, arithmetic mean M(Y) = 4.76, at standard deviation s_Y = 0.62. This corresponds to estimates of transmissivity coefficient T = 1.45×10^{-4} m^2/s and G(T) = 8.32×10^{-5} m^2/s. According to these values, the Zuberec Formation is characterised as aquifer with low transmissivity (class IV).

Values of permeability in the near-surface zone of the Zuberec Formation vary in the range Z = 2.9 - 3.8, Md(Z) = 3.2 and M(Z) = 3.25 at standard deviation of 0.31. This range of Z values corresponds to estimates of coefficient of hydraulic conductivity k = 1.14×10^{-6} m/s and G(k) = 2.57×10^{-6} m/s. The near-surface zone of the Zuberec Formation is thus according to average permeability classified as relatively weakly permeable aquifer with low variability of permeability (permeability class V).

Biely Potok Formation

The youngest formation of the Inner Carpathian Paleogene is the Biely Potok Formation. It is formed predominantly of sandstones, with minor occurrences of claystones and microconglomerates. In the studied territory it attains the greatest areal extent.

Hydraulic properties of this formation may be characterised on the basis of 25 data obtained from hydrogeologic drillholes. The characteristics of the distribution of transmissivity, permeability index and transmissivity and permeability coefficient values are presented in Tabs. 1, 2, 3 and on Figs. 2, 3 (ZAKOVIČ et al., 1993)

The transmissivity index of the Biely Potok Formation has a range of 3.9 - 6.4, Md(Y) = 5.4, M(Y) = 5.3 at standard deviation of 0.54. The transmissivity coefficient may be estimated from the above values - T = 1.52×10^{-5} - 4.48×10^{-3} m^2/s, G(T) = 3.82×10^{-4}. According to transmissivity values, the Biely Potok Formation may be classified as medium transmissivity aquifer (transmissivity class III).

The permeability of the studied sections of the Biely Potok Formation is characterised by values of permeability index -Z- (Tab. 1). The Biely Potok Formation has a permeability index of Z = 2.6 - 4.8, Md(Z) = 3.7, M(Z) - 3.6 and standard deviation s_Z = 0.55. These values correspond to estimates of k = 7.6×10^{-7} - 1.2×10^{-4}, G(k) = 1.74×10^{-5}. The near-surface zone of the Biely Potok Formation is classified according to average permeability as medium-permeable aquifer ranked with permeability class IV.

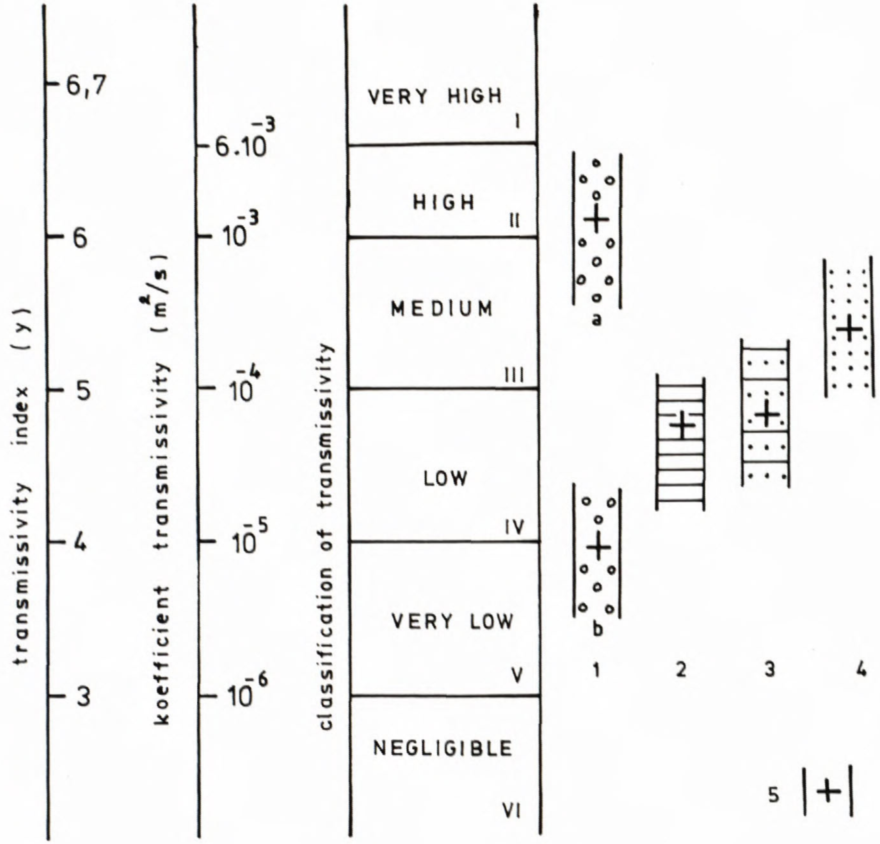
Summary comparison of transmissivity and permeability of lithostratigraphic members of the Inner Carpathian Paleogene

As indicated by Tabs. 1–3, Figs 2–3, providing an overview of the characteristics determined in the near-surface zone of the studied members, average permeabilities and transmissivities determined for these members on the basis of pumping tests differ relatively little from each other. The highest transmissivity is displayed by the Borové Formation - tectonically affected homogeneous breccias and conglomerates consisting of Triassic limestone and dolomite pebbles. They belong to class II – high transmissivity (Fig. 4).

The Biely Potok Formation belongs into transmissivity class three - medium transmissivity (T = 1×10^{-4} - 1×10^{-3} m^2/s).

The Huty and Zuberec Formations belong into transmissivity class four – low transmissivity (T = 1×10^{-5} - 1×10^{-4} m^2/s).

The Borové Formation, formed of heterogeneous breccias and conglomerates, is on the bound-



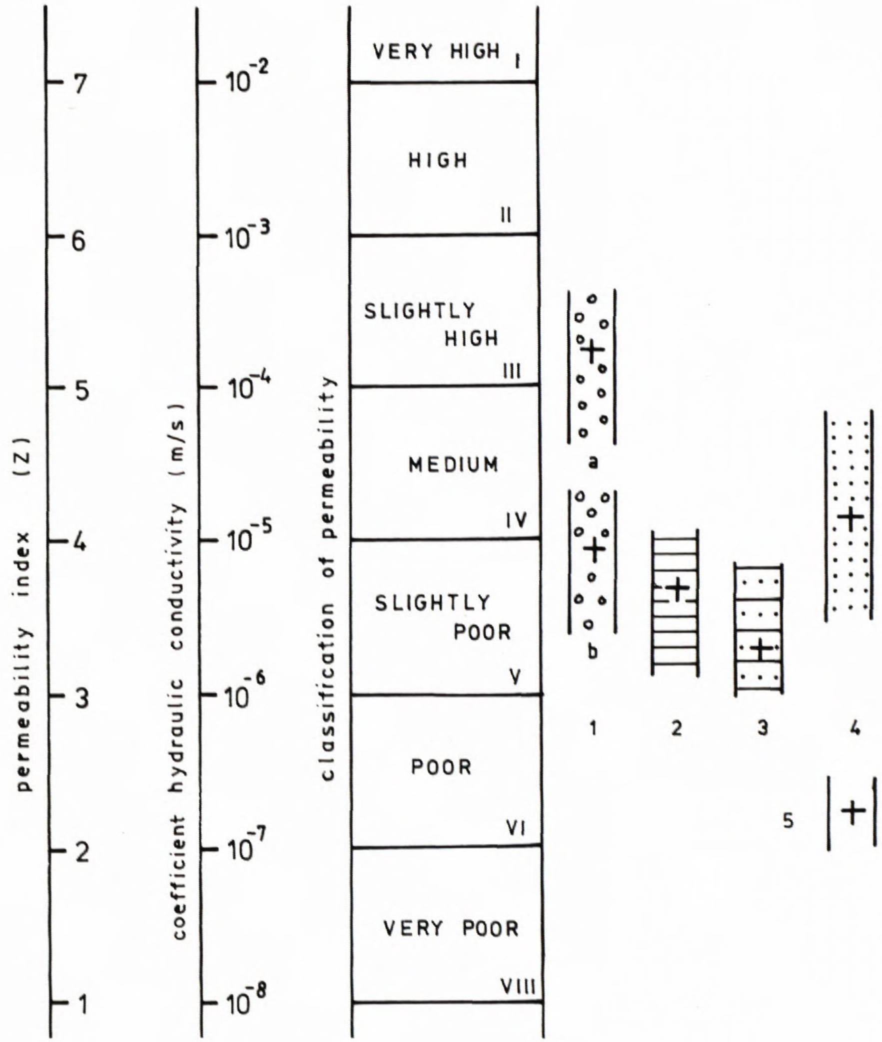


Fig. 4 : Comparison of the characteristics of transmissivity for the studied lithostratigraphic units
1 – Borové Formation: a) homogeneous conglomerates and breccias, tectonically affected, b) heterogeneous conglomerates and breccias, 2 — Huty Formation, 3 – Zuberec
Formation, 4 – Biely Potok Formation, 5 – average value of the transmissivity coefficient

Fig. 5: Comparison of the characteristics of permeability for the studied lithostratigraphic units. Explanations - see Fig. 4.

ary of classes four and five (low to very low transmissivity).

Similarly we can characterise the lithostratigraphic units according to permeability (Fig.5). The highest average permeability is displayed by the tectonically affected Borové Formation. It is classified in the permeability class three - relatively strong.

The Biely Potok Formation belongs into the permeability class four – medium permeability (k = $1x10^{-5}$ - $1x10^{-6}$ m/s).

The Borové Formation formed of heterogeneous breccias and conglomerates is lying on the boundary of classes four and five.

The Huty and Zuberec Formations belong into the permeability class five - relatively weak (k = $1x10^{-6}$ - $1x10^{-5}$ m/s).

Conclusion

When applying the determined characteristics of transmissivity and permeability of Inner Carpathian Paleogene lithostratigraphic units to practice, we must take into consideration the fact that due to spatial non-uniformity of the near-surface zone, these characteristics correspond to near-surface zone in depressions of the territory - valleys and lower parts of slopes. The majority of hydrogeologic drillholes, which provided data for determining the hydraulic parameters, is situated predominantly in valleys, and thus they yield information above all on transmissivity values of the valleys. Jetel (1990) pointed out that in the majority of terrains formed of flysch sediments, four quantitatively different transmissivity categories must be distinguished, relative to the position of the studied part of the territory in the relief of the surface, i.e. transmissivity of the near-surface zone in the bottom of valley and at foot of hills, slope transmissivity of the near-surface zone in slopes, transmissivity of deeper parts of the rock massif (except fissure zones) and transmissivity of fissure zones (tectonically affected zones), the differences between the transmissivity of these categories may reach even several orders in the same environment. Therefore it is necessary to bear in mind that the near-surface zone in slopes will have lower average transmissivity than above presented results from hydrogeologic drillholes.

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