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HYDROGEOLOGICAL PROPERTIES OF THE PODHALE FLYSCH (CENTRAL WESTERN CARPATHIANS, POLAND) IN THE LIGHT OF STUDIES ON WATER STORAGE CAPACITY

JÓZEF CHOWANIEC

Polish Geological Institute, Carpathian Branch, ul. Skrzatów 1, 31-560 Kraków, Poland; jchowan@pigok.com.pl

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Abstract: The paper presents an analysis of the variability in fissuring with depth in the flysch deposits of the Podhale Basin (Central Western Carpathians). Within the stratigraphic sequence of the Podhale Flysch of nearly 3000 m, a fractured and permeable 80–100 m thick, near-surface zone is very important for the water flow. The thickness of this zone varies and depends mainly on the lithologic development of the flysch deposits and on their morphological position. In the shaly Szaflary and Zakopane Beds (and also in the beds from Brzegi) its thickness reaches only 50 m, while in the Chochołów Beds, where sandstone predominates, it reaches 100 m. The obtained results are comparable to the regional statistical evaluation of data from the Outer Western Carpathians.

Key words: Central Western Carpathians, Poland, Podhale Flysch, water active exchange zone, hydrogeological parameters, water storage capacity, flysch.

Introduction

Examination of water storage capacity, which allows us to observe changes in permeability with depth, is an important task in hydrogeological investigations. The purpose of such studies is to evaluate the permeability of fractured rock masses around the sites of planned water dams. Studies on the water storage capacity in the flysch deposits of a near-surface zone were performed in Slovakia and the Czech Republic (e.g. Jetel 1985). Jetel (1985) found that in the majority of flysch regions the subsurface zone of fractured and decompressed rocks functions as the main aquifer. In the zone in question, on the regional scale, the mean permeability decreases regularly with depth, and the lower interface of the subsurface zone of fracturing is at the depth interval of 30–40 m on average. On the other hand, the lower interface of the continual system of open fractures facilitating circulation of ground water in the massifs built of flysch rocks usually does not exceed 100 m.

The purpose of this paper is to show the differentiation of permeability with depth in the subsurface zone of the Podhale Flysch deposits based on the examination of the water storage capacity.

Geological setting

The Podhale Flysch, Late Eocene–Oligocene in age, is the rock series lying above the *Carbonate Eocene*. Its largest thickness, 2996 m, has been recorded in borehole *Chochołów PIG-1*. The Podhale Flysch was subject to thorough studies initiated after 1945 (Gołąb 1959; Watycha 1959; Mastella 1975; Małecka 1981; Kępińska 1997). The profile of flysch deposits comprises, from bottom to top: the Szaflary, Zakopane, Chochołów and Ostrysz Beds (Figs. 1, 2).

The oldest Szaflary Beds are exposed on the surface in a narrow belt in the northern wing of the Podhale Basin along a contact with the Pieniny Klippen Belt. Based on the data from boreholes, it can be concluded that the Szaflary Beds extend relatively far southward into the flysch basin, but they do not reach the southern border of the Podhale Basin. The Szaflary Beds can be subdivided into lower, middle and upper parts. In

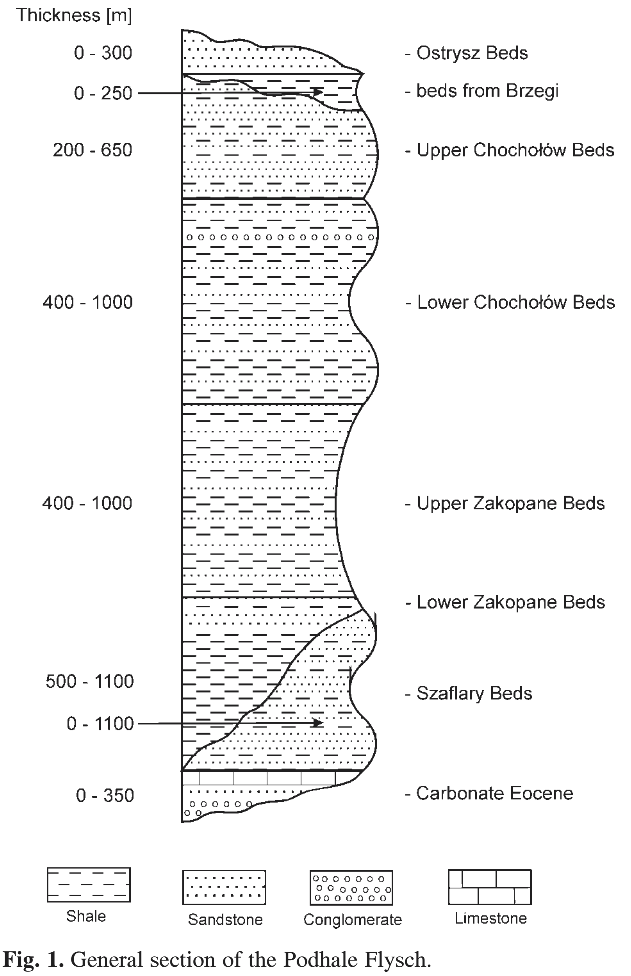

Fig. 1. General section of the Podhale Flysch.

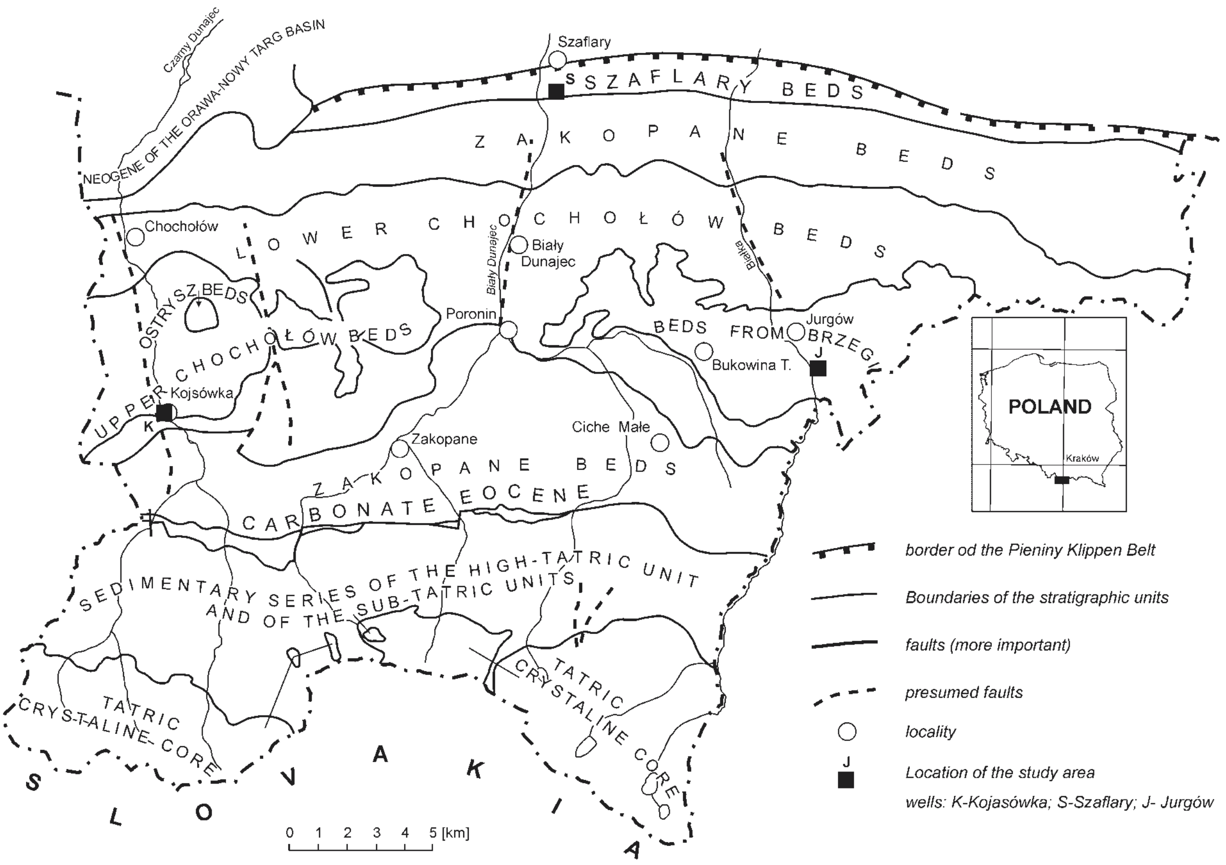

Fig. 2. Geological map of the Podhale region (without Quaternary deposits, after Chowaniec 1989 — simplified) and location of the study area.

the lower and upper beds, sandstones predominate, while shales and mudstones prevail in the middle part.

The Zakopane Beds form the thickest formation in the Podhale Flysch. They rest directly upon the *Carbonate Eocene* in the southern wing of the Podhale Basin, while in the northern wing they occur above the Szaflary Beds. Clay-shales and mudstones (lower Zakopane Beds), predominate in the lower part, while in the upper part sandstones (upper Zakopane Beds) are abundant.

The Chochołów Beds, which mainly form morphological elevations in the Podhale Basin, rest directly on the Zakopane Beds. Generally, in the Chochołów Beds, two members, upper and lower ones, are distinguished. Sandstones predominate in both the members of the Chochołów Beds. In the eastern part of the Podhale Basin, the beds of Brzegi are equivalents of the upper Chochołów Beds, and then its characteristic feature is predominance of clay-shales (Watycha 1959).

In the western part of the Podhale Basin, above the Chochołów Beds, the Ostrysz Beds (series of thick massive sandstones), the youngest flysch deposits, are distinguished in a relatively small area.

Water flow in the Podhale Flysch deposits

The water flow in the flysch aquifer runs in a system of connected fissures. It can be assumed (e.g. Małecka 1981) that the flysch permeability is controlled by fissuring while inter-granular porosity of rock masses is less important. Laboratory tests of the Podhale Flysch sandstones and conglomerates showed that their inter-granular porosity is low (Table 1).

Table 1: Porosity of sandstones of the Podhale Flysch.

Studied beds	Region	Porosity in %	Authors
1	2	3	4
Chochołów	Inter-basin area of Biały Dunajec and Białka rivers	0.60–6.61 (effective)	Małecka & Murzynowski (1978)
Zakopane	"	0.13–6.73 (effective)	"
Szaflary	"	1.17–5.33 (effective)	"
Flysch in general	Western Podhale	1.5–7.9	Bromowicz & Rowiński (1965)

For quantitative evaluation of the size and percent of fissures in the studied rocks the coefficient of fracturing is used (Liszkowski & Stochlak 1976). The measurements of the fissures, carried out by the author, allowed the conclusion that in the area formed by the Zakopane Beds (Nędzówka region) the mean fissuring is 0.8 % (inter-bed fissility has not been considered), while in the Chochołów Beds (Kościelisko) it is 2.4 % and locally above 4.0 % (Chowaniec 1978).

The thickness of sandstone layers of the Zakopane Beds is 15–30 cm and in the Chochołów Beds — 0.5–1.5 m. The coefficient of fracturing, 2.4 %, is twice as big as the value of the Magura sandstones of Śnieżnica region (Bober & Oszczypko 1964). Results of the studies by Małecka & Murzynowski (1978), performed in the area of the Podhale Flysch show that the values of this coefficient differ in a very wide range (Table 2).

Table 2: Results of fissuring measurements (after Małecka & Murzynowski 1978).

Studied beds	Village	Coefficient of fracturing [%]
1	2	3
Ostrysz	Dzianisz	6.4
Ostrysz	Witów	4.2
Chochołów	Gliczarów Białka Ciche	8.1 8.1 1.8
Szaflary	Szaflary Murszyna	9.3 11.1
Zakopane	Zakopane Poronin	8.9 5.1

In the studies that have been performed until now, due to the lack of hydrogeological drillings (Pokorski 1965; Boretti-Onyszkiewicz 1968; Mastella 1975), the permeability of the flysch deposits used to be determined at the surface, based on fissuring measurements. The boreholes in the region of Kojsówka, Szaflary and Jurgów in the 1960s allowed the determination of the permeability of a certain section of the profile based on examination of water storage capacity.

Examination of water storage capacity

Water storage capacity obtained at the pressure of 0.2 MPa is used as a standard according to the BN-75/8950-07 Polish Branch Standard chart. Specific water storage capacity, of the value of 0.01 dm^3/min/m/0.01 MPa is accepted as the threshold for impermeability of the orogen. Oszczypko et al. (1981) and Chowaniec et al. (1983) have determined the variability in water-storage capacity with depth in the Magura and Krosno Beds and have reported differences in the storage capacity of these beds. The authors have found evidence that the thickness of the permeable zone of the Krosno Beds in the Central Carpathian Depression reaches 40 m, which is only half of the thickness of this zone in the Magura Beds. The filtration coefficient of the Krosno Beds to the depth of 20 m is usually 1.4×10^{-6} m/s, while in the depth interval of 20–40 m — it is 2.4×10^{-7} m/s. Permeability in both the depth intervals of these beds is one order of magnitude smaller than the permeability of the Magura Beds. The permeability of the Krosno Beds in the entire Carpathian Depression was studied earlier by Dziewański (1962).

In the region of Kojsówka, the substratum is built of medium and massive sandstones with intercalations of clayey-marly shales belonging to the Lower and Upper Chochołów Beds. That is a fragment of the southern limb of the so-called Ostrysz Syncline dipping northward according to Gołąb (1959).

In the course of the planned siting of dam in Kojsówka, 18 boreholes have been drilled to depths of 40–75 m to examine water storage capacity. The results have been interpreted by numerous authors (Michalik 1963; Monkiewicz 1966; Niedzielski 1974). Table 3 presents specific water storage capacity at particular depths.

In the region of Kojsówka no major dislocations have been stated, however, the rock massif is strongly fractured, especially on the left slope. Following mining works, 2–20 cm wide fractures, reaching to the depth of 6 m, have been detected. Fractures (1–3 cm wide) reach at least 10 m in depth. This finding has been confirmed by water storage capacity tests. According to the data presented in Table 3, it is apparent that the impermeable zone has not been reached in each borehole. The impermeable zone in the bottom of the valley and on the right slope has been reached at a depth of 70–75 m. Thus, a thick zone of water holding rocks is observed here, especially in the bottom of the valley, which is evidence of a deep infiltration range.

The author of this paper has performed a statistical analysis of the results of the water storage capacity of 18 boreholes drilled in the Chochołów Beds near Kojsówka. The set of data amounted to 293 (Table 4; Chowaniec 1989). Variability in water storage capacity with depth has been approximated by a logarithm function and by a polynomial function of n = 1–3 order (Fig. 3). The straight line reflects only a general trend in the zones from which the majority of the data originate. The

Table 3: Specific water storage capacity of the Chochłów Beds near Kojsówka (after Monkiewicz 1966).

Depth [m]	Specific water storage capacity (average)		
	left slope	valley floor	right slope
1	2	3	4
< 15	-	0.1202–1.870 (0.907)	0.024–0.0900 (0.527)
15–20	0.503–1.398 (0.822)	0499–1.190 (0.859)	0.204–0.630 (0.393)
20–30	0.096–1.200 (0.504)	0.412–1.132 (0.731)	0.0099–0.538 (0.344)
30–40	0.072–0.694 (0.377)	0.067–1.350 (0.607)	0.004–0.851 (0.320)
40–50	0.033–0.376 (0.175)	0.039–0.230 (0.523)	0.000–0.315 (0.159)
50–60	0.009–0.710 (0.270)	0.000–0.589 (0.344)	0.001–0.289 (0.118)
60–70	0.004–0.398 (0.144)	0.000–0.600 (0.240)	0.012–0.210 (0.113)
70–75	-	0.009	0.051

Table 4: Statistical characteristics of specific water storage capacity.

Number of borehole	Number of data	Specific water storage capacity dm^3/min/m/0.01 MPa		
		Average	Minimum	Maximum
18	293	0.329	Not obtained	2.175

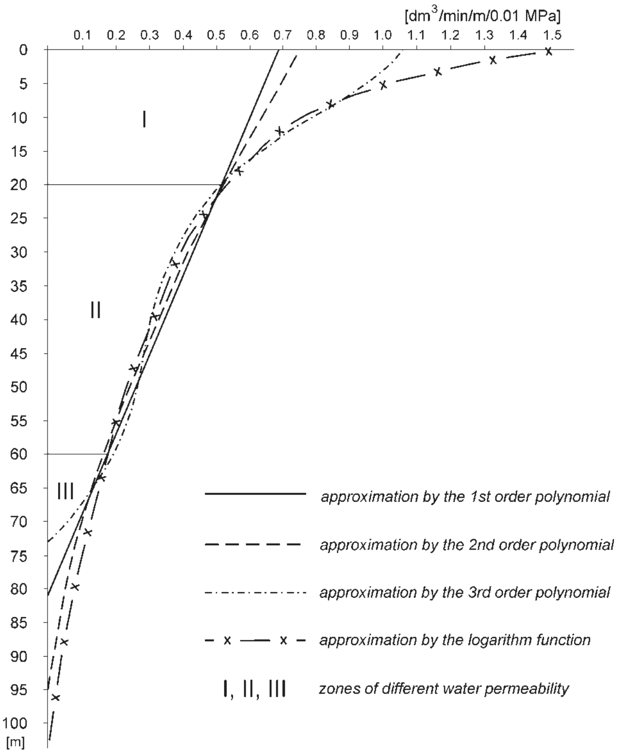

Fig. 3. Specific water storage capacity versus ground water depth in the Chochołów Beds in the region Kojsówka under the pressure of 0.2 MPa.

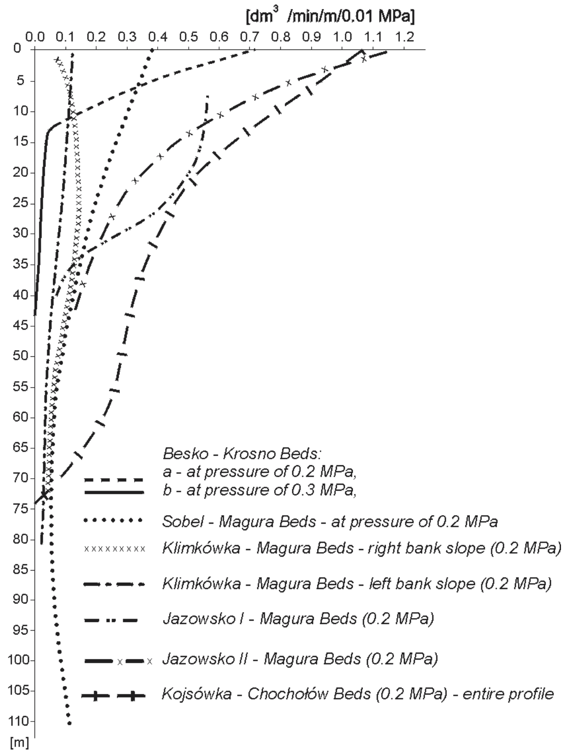

Fig. 4. Specific water storage capacity versus ground water depth — the 3rd order polynomial approximation (after Chowaniec 1989).

logarithmic curve is the most sensitive to any changes, thus, it is the best approximation for changes in water storage capacity with depth.

In the case of the logarithmic function the curve with the maximum (1.674) at the surface and minimum below 100 m deep has been obtained. For the linear relationship, a straight line crossing the ordinate axis at 81 m has been obtained. The polynomial of 3rd order has the minimum at the depth of 73 m. The zone to the depth of 20 m is the most permeable. Specific water storage capacity in this zone is above 0.5 dm^3/min/m/0.01 MPa. The zone at the depth of 20–60 m, whose specific water storage capacity decreases from 0.5 to 0.2 dm^3/min/m/0.01 MPa, is also well permeable. The third zone can be identified at the depth of 60–100 m (Fig. 3).

The occurrence of these zones can be characterized by the values of filtration coefficients, derived form water storage capacity, calculated according to the formula of Wieczysty (1970) (Table 5).

The results obtained from statistical analysis have been compared with the results of the studies performed for the Magura and Krosno Beds of the Central Carpathian Depression. The thickness of the permeable zone of the Chochołów Beds (80–100 m) is similar to that of the permeable zone of the Magura Beds and twice as thick as in the case of the Krosno Beds (Fig. 4). In Kojsówka the permeable zone features a much stronger fissuring. The obtained results are similar to the results for the sandstones of the Slovak Carpathian Flysch reported by Jetel (1985). Here, in Kojsówka, the slightly larger values for the permeable zone when compared to the Magura Beds are likely to be related to the tectonics of the Podhale Flysch and the corresponding fissuring. In Podhale the joint planes intersect the layers almost vertically and their number increases in the zones of numerous faults.

Table 5: Mean filtration coefficient calculated on the basis of water storage capacity.

Depth [m]	Filtration coefficient [m/s]
0–20	1.88×10^{-5}
20–60	6.08×10^{-6}
60–100	1.74×10^{-6}
0–100	5.71×10^{-6}

Table 6: Thickness of the permeable zone in the Podhale Flysch deposits based on the studies of water storage capacity.

Village	Studied beds	Thickness of permeable zone [m]	Mean filtration coefficient k [m/s]	Number of boreholes
Kojsówka	Chochołów Beds	80–100	5.71×10^{-6}	18
Szaflary	Szaflary Beds	Impermeable (at 0.2 MPa)	6.21×10^{-8}	1
		30 (at 0.5 MPa)	3.19×10^{-6}	
Jurgów	upper Chochołów Beds (from Brzegi)	15 (at 0.2 MPa)	2.43×10^{-6}	1
		20 (at 0.5 MPa)	2.43×10^{-6}	

Much lower values of water-storage capacity and a smaller thickness of the permeable zone have been stated in the regions of Szaflary (Drath et al. 1964; Oszczypko 1966) and Jurgów (Bober et al. 1964). That is associated with the nature of the deposits in these regions — that is with the predominance of shales in the Szaflary Beds and in the beds from Brzegi (Table 6).

Conclusions

For the flow of water in the flysch rocks the fractured and permeable zone, with a maximum thickness of 100 m, is very important. The thickness of this zone varies and depends mainly on lithological development of the flysch deposits and on their morphological position. This zone is thin (only 20–50 m), in the clay-shale of the Szaflary and Zakopane Beds, and it is thicker in the sandstones of the Chochołów Beds (80–100 m). An increased fissuring of the rock massif is observed especially in the zones of discontinuous dislocations, which are preferable routes of water circulation, transport the largest amount of water and play a draining function with respect to water circulating in small fissures. Numerous joints and a strong fissuring of the rocks results in a diversified water flow rate.

By hydraulic analogy between water-injection into a borehole and a well pumping, the following conclusions can be drawn based on the obtained results. The average depth of the wells drilled in a search for water should not exceed 50 m in the shaly Szaflary and Zakopane Beds, and 100 m in the sandstone-shaly Chochołów Beds. Deeper wells can be drilled only in strongly tectonized areas, where a thinner aquifer is expected. Similar conclusions have been reported earlier on the basis of Jetel's (1985) studies performed in other parts of the Carpathains.

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