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title: **Hydrochemical evidences of hydraulic connection between crystallinic and carbonate aquifers (the Tatra Mts., East-Central Europe)**

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INTRODUCTION

The hydrogeology of fissured crystalline and karst rocks complexes remains one of the most difficult and not much developed areas of hydrogeology, both theoretically and practically.

Ground water circulation in the Tatra Mts. has been investigated mainly by J. Chowaniec (2009), T. Dąbrowski and J. Głazek (1968), D. Małecka (2003), K. Różański and M. Duliński (1988) and A. Zuber et al. (2008). They stated hydraulic connection between the aquifer in the High Tatra Mts. built of Paleozoic igneous rocks (granite) and the karst aquifer in the lower parts of the Tatra Mts. built mainly of the Mesozoic limestones, dolomites, quartzites and shales. Mesozoic formations are drained by vaucluse springs with high yield and very low mineralization which proves their crystalline rocks origin (Oleksynowa, Komornicki, 1996).

In spite of wide knowledge in hydrogeology of the biggest vaucluse springs in the Tatra Mts. (Małecka 1996, 1997; Małecka et al., 1998) there is no well recognized recharge of springs with considerable small yields. Hence, the aim of the research is investigation of recharging small springs, which are not common in this area. The project was designed to identify water circulation paths and water supply mechanism in the Olczyski Creek catchment in the Tatra Mts. — a highest range of the Carpathians in southern Poland. The paper presents preliminary results obtained by hydrochemical investigations.

AREA OF INVESTIGATION

The Olczyski Creek catchment is located in the northern part of the Polish Tatra Mts. (7.94 km^2). Mountain peaks surrounding the valley rise from 1200 to 1531 m a.s.l (Figure 1).

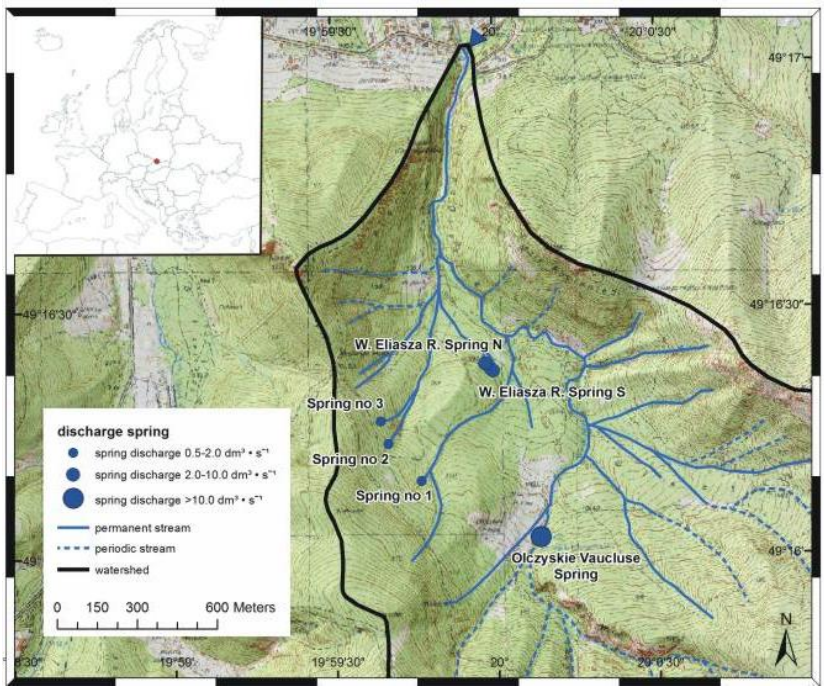

Figure 1. Location of the study area.

The geology of the catchment is dominated by nappe structures and the SW-NE tectonic thrusts. Most of the catchment lies within the temperate cool belt (to 1150 m a.s.l.) where amount of annual precipitation reaches 1200 mm and mean annual air temperatures amounts 4–6°C (the lower subalpine forest zone). The highest parts of peaks surrounding the valley lay in the cool climatic belt where amount of annual precipitation reaches 1500 mm and mean annual air temperature amounts 2–4°C (the upper subalpine forest zone).

Spring density in the investigated catchment is equal 4 per km^2, however spatial distribution of springs is differentiated: most of them occur in the middle part of the catchment. Small springs belonging to VI-VIII Meinzer's classes of discharge prevail in the area.

Special attention was paid to the vaucluse Olczyskie Spring representing III Meinzer's class and W. Eliasz springs representing V Meinzer's class (W. Eliasz Spring South and W. Eliasz Spring North; Fig. 2). Their names are related to Walery Eliasz Radzikowski – the famous Polish painter which visited the valley in the XIX c. Three small springs representing V and VI Meinzer's classes were taken into consideration additionally (No 1, 2 and 3; Table 1).

Table 1. Elevation and types of investigated springs in the Olczyska Creek catchment.

Spring	Altitude [m a.s.l.]	Type of outflow, geology	Yield [$dm^3 \cdot s^{-1}$]	Type of spring (after Meinzer)
Olczyskie	1065	crevasses, dolomites	233	III
W. Eljasz South	1000	crevasses, quartzitic sandstones	7.11	V
W. Eljasz North	998	crevasses, quartzitic sandstones, spongolites	4.22	V
Spring no. 1(61)*	1030	seepage spring, quartzites, loamy shales	0.46	VI
Spring no. 2 (64)*	1080	debris, loamy shales, quartzites – trace	1.39	V
Spring no. 3 (65)*	1030	debris, loamy shales, quartzites – trace	0.22	VI

*numbering is according to Oleksynowa, Komornicki (1989).

a)

b)

Figure 2. Water outflowing from the South W. Eliasz (a) and North W. Eliasz (b) Springs (Photo. S. Wójcik).

FIELD OBSERVATIONS AND METHODS

Water samples from six selected springs and from the Olczyski Creek were collected once a month in 2009 during the weather conditions representing annual seasonality. The time interval between measurements varied between 2.5 and 5.5 weeks (Table 2). Chemical analyses were done in the laboratory at the Institute of Geography and Spatial Management, Jagiellonian

Univeristy using ion chromatography (DIONEX ICS-2000). Water temperature, electrical conductivity and pH were carried out in the terrain (Elmetron CX-401). The spring discharges were measured using volumetric method (except the vaucluse spring). Simultaneously, the water level in the Olczyski Creek were observed (Figure 1).

Table 2. Dates and weather conditions during a fieldworks and during a week before field works in the Olczyski Creek catchment.

Date	Mean air temperature during a week before field works *	The daily total precipitation in the week preceding the field studies*	Weather conditions during fieldworks
	°C	mm	
January 12, 2009	-9.6	3.3	Sunny, snow cover
February 9, 2009	1.7	2.0	Snow cover
March 9, 2009	1.4	23.9	Snow cover
April 20, 2009	8.7	1.0	Cloudiness, patches of snow
May 12, 2009	10.1	16.0	Rainfall
June 17, 2009	13.3	30.7	Sunny weather
July 2, 2009	16.2	70.6	Sunny
August 4, 2009	18.2	0.0	Little rainfall
September 7, 2009	13.1	28.7	Cloudiness
October 11, 2009	10.7	17.0	Rainfall
November 10, 2009	1.6	14.7	Rainfall
December 16, 2009	-4.6	10.4	Cloudiness , snow cover

*data from the Zakopane meteorological station; http://www.ncdc.noaa.gov/oa/wdc/index.php.

PRELIMINARY RESULTS AND DISCUSSION

The Olczyskie Spring and the W. Eliasz South and North springs joint discharge is considerable higher than the discharges of the rests of springs (Table 3). The mean values of the spring discharges in 2009 amounted from 0.22 to 233 $dm^3 \cdot s^{-1}$. The Olczyskie Spring are the main source of water in the Olczyski Creek (Oleksynowa, Komornicki 1989).

Table 3. Properties of investigated springs in the Olczyska Stream catchment in 2009.

Spring	SEC [$\mu S \cdot cm^{-1}$]	Mean water temperature [°C]	pH
Olczyskie	131.43	4.5	8.24
W. Eliasz South	173.72	5.3	8.09
W. Eliasz North	173.43	5.2	8.08
Spring no 1	205.79	6.1	7.99
Spring no 2	216.11	5.5	8.17
Spring no 3	261.29	5.1	8.26

The observed springs are characterized by snow-rain regime: maximum discharge in most of them occur in April and second one — in November (Figure 3a). The high water level in the Olczyski Creek has been prolonged to July, what is suitable for streams supplied by water from snow cover melting gradually from the lower to highest parts of the Tatra Mts. during spring and early summer months (Figure 3b). It represents typical mountain rivers flow regime described by I. Dynowska (1971), A. Dobija (1981) and W. Chełmicki et al. (1998–1999).

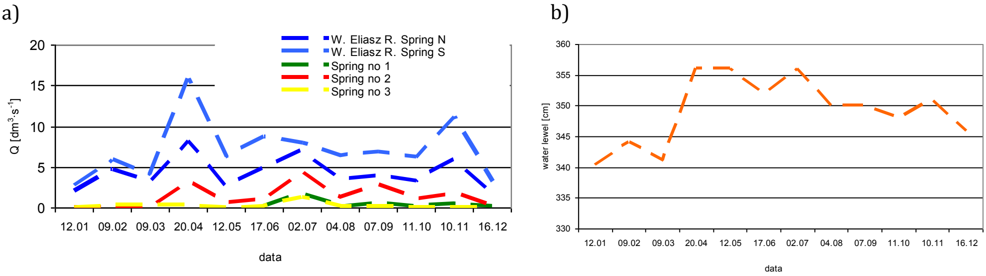

Figure 3. Discharges of springs (a) and water level in the Olczyski Creek (b) in 2009.

The mean annual water temperature of investigated springs is amounted from 4.5 to 6.1°C (Table 3). The mean water temperature of the Olczyski Creek amounts 4.6°C and approximates the Olczyskie Spring. The most differentiated temperature during the year represents the smallest springs — no 1 , 2 and 3 and the Olczyski Creek (Figure 4). Water temperature variability of the W. Eliasz R. Springs and Olczyskie Spring is considerable lower.

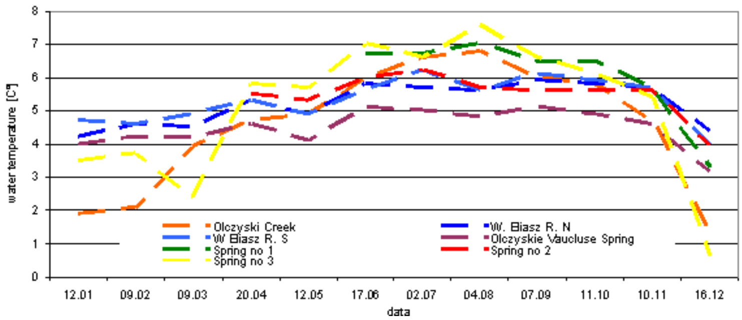

Figure 4. Water temperature of springs and the Olczyski Creek in 2009

Springs water alkalinity during investigations period (7.99–8.26 pH) can be easily explained by the dominance of calcium ion due to presence carbonate rocks in the catchment. The SEC of small springs (no 1, 2, 3) is considerably higher (205.79–261.29 $\mu S \cdot cm^{-1}$) than the Olczyskie and W. Eliasz springs (131.43–173.72 $\mu S \cdot cm^{-1}$) (Table 3).

The chemical composition of stream and springs water represents bicarbonatic-calcian-magnesian type except the spring no 2 which represents bicarbonatic-calcian type. The share of ions Ca^{2+}, HCO_3^- and SO_4^- is differentiated and two groups of springs may be identified: 1st group with high concentration of Ca^{2+} and HCO_3^- (springs no 1, 2, 3) and 2nd group with lower concentration of Ca^{2+} and HCO_3^- (Olczyski Creek, Olczyskie and W. Eliasz springs) (Table 4).

Table 4. Mean ion contents in the water in the Olczyski Creek catchment in 2009.

Object	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{-}	Hydrochemical type of water, number of type (after Shtsukariev and Priklonski)
	mval·dm^{-3} mg·dm^{-3}								
Olczyski Creek	0.97 19.55	0.59 6.97	0.04 0.87	0.01 0.31	1.41 86.69	0.16 7.83	0.01 0.44	0.03 1.95	HCO_3–Ca^{2+}–Mg^{2+} (18)
W. Eliasz R. Spring South	1.33 26.54	0.57 7.06	0.04 0.87	0.01 0.46	1.80 109.77	0.17 8.31	0.02 0.59	0.03 1.67	HCO_3–Ca^{2+}–Mg^{2+} (18)
W. Eliasz R. Spring North	1.34 26.74	0.57 7.01	0.04 0.82	0.01 0.42	1.81 110.74	0.16 8.04	0.01 0.54	0.03 1.68	HCO_3–Ca^{2+}–Mg^{2+} (18)
Olczyskie Spring	0.83 16.83	0.56 6.95	0.03 0.78	0.01 0.34	1.26 77.49	0.14 7.03	0.01 0.42	0.03 2.03	HCO_3–Ca^{2+}–Mg^{2+} (18)
Spring no. 1	1.57 31.55	0.72 8.70	0.03 0.78	0.01 0.50	2.06 125.79	0.22 1064	0.02 0.72	0.03 1.69	HCO_3–Ca^{2+}–Mg^{2+} (18)
Spring no. 2	1.99 39.84	0.43 5.25	0.03 0.76	0.01 0.44	2.05 125.06	0.34 16.28	0.02 0.77	0.04 2.55	HCO_3–Ca^{2+}(9)
Spring no. 3	2.16 43.29	0.77 9.32	0.03 0.71	0.02 0.60	2.37 144.81	0.47 22.50	0.03 1.05	0.09 5.51	HCO_3–Ca^{2+}–Mg^{2+} (18)

CONCLUSIONS

On the base of hydrological research conducted in 2009 in the Olczyski Creek catchment one may state, that springs water differs in the degree of mineralization, chemical composition, pH and several other parameters. It proves the existing a complicated hydrogeological system favoured by variuos geology and existing tectonic thrusts and faults.

The properties of the vaucluse Olczyskie Spring confirm that the most important alimentation area is located beyond the topographic catchment what was discovered by T. Dąbrowski and J. Głazek and investigated by D. Małecka and W. Humnicki (1989).

The present study proved a complicated hydrological system, featuring three connected subsystems: granitic fissured, carbonate karst and quartzites fissured ones. Karst subsystem plays the role of semi-drain that collects water infiltrating from granitic rock formation occured in the High Tatra Mts.

Hydrochemical properties of small springs (no 1, 2, 3) show that these springs drain mainly the local groundwater aquifers: the carbonate karst complex one and — in minority — another one — quartzitic sandstones with alternating loamy shales, which are visible around the outflow.

The properties of the W. Eliasz springs are considerable different and they are more related to the vaucluse Olczyskie Spring, which may indicate partially the same alimentation area (High Tatra Mts.) and bigger share of water coming from local basin aquifer. It may be assumed, that relatively small discharge of the W. Eliasz springs is limited by system of narrow fissures in quartzitic sandstones.

It may be also probable another scenario: the W. Eliasz springs drain local aquifers within the topography catchment — ie. quartzitic sedimentary fissured rocks and — in minority — carbonate karst complex. For complete explanation of groundwater circulation in the Olczyski Creek catchment, the authors recommend further and additional investigations involving tracers methods.

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