Steirische Beiträge zur Hydrogeologie
Jahrgang 1966/67 — Graz 1967

Karst Hydrogeology of the Polish Tatra Mts. Obtained by Colouring Methods

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Investigations on this subject have been carried on for four years in the Chair of Hydrogeology of the Warsaw University. In course of his field work in the Western Tatra Mts. the autor received help from Dr. J. RUDNICKI of the Geological Institute, Polish Academy of Sciences, and in the Eastern Tatra Mts. from Dr. J. GLAZEK, Laboratory of Dynamic Geology of the Warsaw University.

For the recognition of underground water flows, chemical (NaCl) and colour (fluoresceine) indicators have been used. The measurements of stream volume and capacity of springs were made by the dispersion of chemical indices method.

The karst processes in the Tatra Mts. develop mostly in limestones of the Middle Triassic, Jurassic and Lower Cretaceous of the high-tatric units (Fig. 1). Many caves have developed within those deposits: among others the Czarna Cave — 6000 m long, the Miętusia Cave — 4500 m long, the Zimna Cave — 4000 m long, the Snieżna Cave 640 m deep and the Ptasia Cave 350 m deep, etc.

A complete lack of surface drainage and dimensions of the caves, that once were the ways of underground karst water circulation — point to the presence of a well developed underground drainage in this area. Two types of underground karst circulation could be distinguished (Fig. 2):

1. exsurgences supplying long and deep water circulation,
2. underground karst flows of surface streams.

Exsurgence circulation

Exsurgences can be supplied in two following ways. One of them is infiltration of rain water into limestones in which the karst phenomena develop. Initially minute water rills join together within the limestone massif into underground streams leading to exsurgence.

The course of such streams can sometimes be traced in their parts within caves. This kind of supply is known from the exsurgences: the Lodowe, the Wołoszyńskie and in the Kraszewski's Gate (Fig. 1).

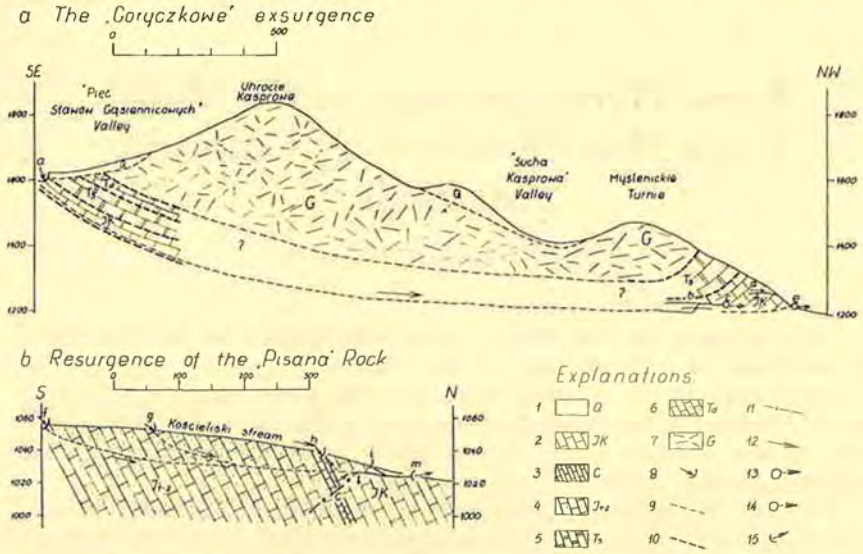


Fig. 1: Schematic Cross-section Through Alimentation System
(Geology after F. RABOWSKI)

1. Quaternary deposits; 2. Malm and Neocomian limestones; 3. Oxfordian limestones; 4. Liassic clastic calcareous deposits; 5. Middle Triassic dolomites and limestones; 6. Lower Triassic clastic deposits; 7. crystalline core of the Giewont Fold; 8. swallow-holes, a) in the Pięć Stawów Gąsienicowych Valley, f), g), h) in the Kościeliska Valley; 9. alimentation routes of the Goryczkowe exsurgence; 10. alimentation routes of resurgence from the Pisana Rock; 11. underground karst flow from the Kraków Ravine; 12. underground and surface water flow directions; 13. exsurgence; 14. periodical exsurgence; 15. resurgence, b) schematic cast of the Lower Kasprowa Cave onto the section plane, c) periodical exsurgence from the Lower Kasprowa Cave, d) schematic cast of the Goryczkowa Cave onto the section plane, e) the Goryczkowa exsurgence, i) dry entrance to the water cave under the Pisana Rock, 1) the water cave under the Pisana Rock, m) resurgence from the Pisana Rock.

The second type of supply occurs when streams flow out of a non-karstic area into a karstic one. The result is an escape of water out of the surface stream. In some cases it is complete and the stream cuts on the swallow-hole zone. These are the cases of the Pańszczyca and Pięć Stawów Gąsienicowych Valleys and the periodical stream of the Kamienne Cirque. Eight colourings have been made, that partly gave basis for the recognition of alimentation areas and of underground flows of some exsurgences. The results are presented in table 1.

Table 1

No.	Localization of swallow-holes or place of colouring	Altitude	Exsurgence or place of appearance of dye	Altitude	Date	Distance[1]	Velocity	Quantity of dye
		m (a. s. l.)		m (a. s. l.)		m	m/h	kg
1	the stream in the Snieżna Cave	1450	terminal siphon in the Snieżna Cave	1100	31.08.61	1000	167	8
	terminal siphon in the Snieżna Cave	1100	Lodowe exsurgence	987	31.08.61	4600	34	8
2	the stream in the Zimna Cave	1120	periodical exsurgence at the bottom of Kościeliska Valley	1000	25.04.62	400	67	1,5
3	the stream in the Czarna Cave	1350	a—periodical exsurgence on the slope of the Kościeliska Valley	1100	26.04.62	700	37	3
			b—Lodowe exsurgence	987		1200	57	
4	the stream in the Mroźna Cave	1100	exsurgence in the Kraszewski Gate	990	26.04.62	400	22	2,5
5	Kamienne Cirque	1600	a—Kraków exsurgence b—resurgence from the Pisana Rock c—resurgence from the Raptawicka Rock	1040	26.05.62	2000	111	5
6	swallow-holes in the Pięć Stawów Gąsienicowych Valley	1615	Goryczkowe exsurgence	1215	7.09.64	2500	109	8
7	swallow-holes in the Panszczyca Valley	1390	Olczyskie exsurgence	1075	14.09.64	3200	70	6
8	the stream in the Upper Wołoszyńska Cave	1150	a—the stream in the Lower Wołoszyńska Cave	1130	19.06.65	40	240	3
			b—Wołoszyńskie exsurgence	1100	19.06.65	550	156	3

[1] Distance between the swallow-holes zone and the exsurgences measuved along the straight line.

Observations made in Snieżna, Ptasia and other caves point to the fact that underground streams are characterized by large hydraulic gradients and nonbalanced profile in their initial course. The velocities are similar to those in surface streams in their upper course and they range within 150—200 m/h. Those streams flow then into a zone of numerous siphons and ponds, where the character of flow changes from a free flow into a flow under hydraulic-pressure. This part of underground flow is unattainable for direct observations. Occasionally it can be seen in lower parts of Lower Kasprowa Cave and Bystra Cave in dry season. The outflow from underground systems usually takes place in springs situated at bottoms of deeply cut valleys. Colourings and the geological structure of karst areas point that the maximum length of alimentation systems of exsurgences in the Tatra Mts. should not exceed 6000 m. Exsurgences supplied by systems less than 1000 m long are usually of a periodical character. Systems longer than 1000 m, though working constantly, exhibit changeable capacities. It is caused by short duration of water flow between the alimentation area and the exsurgence, that in Tatra does not exceed 6—10 days. The variability of capacity of major exsurgences is presented in the table 2.

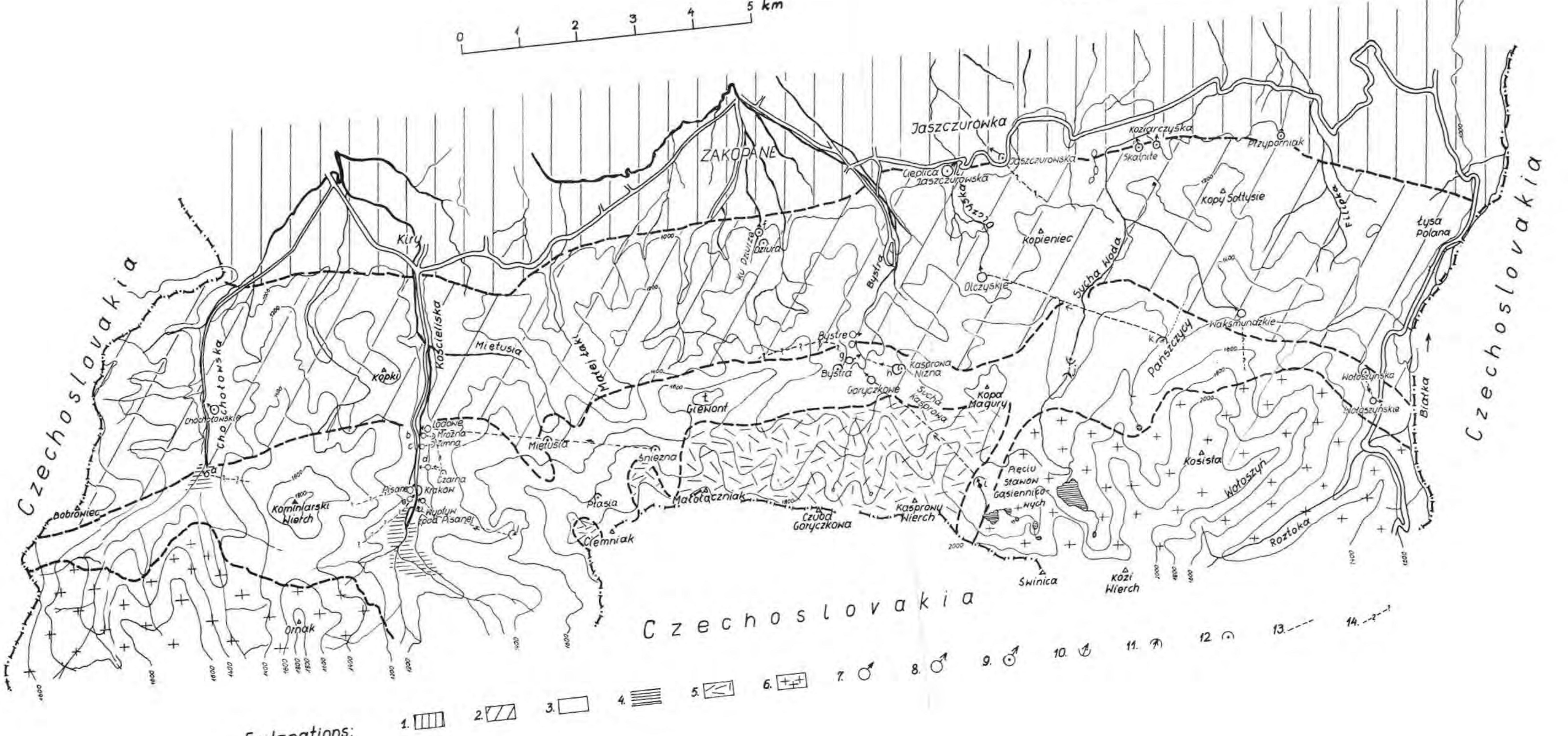
Table 2

No.	Exsurgence	Q_{max} l/s	Q_{min} l/s	$R = \frac{Q_{max}}{Q_{min}}$
1	Lodowe	3500	70	50
2	Bystra	2800	110	25
3	Olczyskie	2000	150	13
4	Goryczkowe	2000	300	7

Maximum capacities are noted during spring thaws in high parts of mountains (April-May) and minimum ones at early autumn (September-October).

Plate I: Schematic Hydrogeological Map of Karst in the Tatra Mts.:

1. nonkarst areas (the Podhale Flysch deposits); 2. area of fissure and fissure-karst water circulation (the sub-tatric units); 3. karst area (the high-tatric units); 4. places of appearance of underground karst flows of streams; 5. crystalline cores of high-tatric folds; 6. granites of the Tatra Massif; 7. exsurgences, a) in the Upper Chochołowska Gate (the Chochołowska Valley), b) in the Kraszewski Gate (the Kościeliska Valley), e) under the Raptawicka Rock (the Kościeliska Valley); 8. periodical exsurgences, c) at the bottom of the Kościeliska Valley, d) on the slope of the Kościeliska Valley, g) the Upper Bystra exsurgence, h) out of the Lower Kasprowa Cave; 9. fissure or fissure-karst springs, f) in the bottom of Ku Dziurze Valley, l) Jaszczurówka-term; 10. resurgences; 11. swallow-holes, i) in the Pięć Stawów Gąsienicowych Valley, k) in the Pańszczyca Valley; 12. caves; 13. circulation ways of karst waters; 14. supposed circulation ways of karst waters, j) underground flow of the stream in the Sucha Woda Valley partly within alluvial deposits and partly in karst channels.



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Skalnite
Przyporniak
Kopy Sołtysie
Kopieniec
Łysa Polana
Filipka
Sucha Woda
Olczyskie
Olczyska
Bystra
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Dziura
Kościeliska
Chochołowska
Chochołowskie
Kopki
Miętusia
Małe Łąki
Bystre
Bystra
Kasprowa Niżna
Goryczkowe
Sucha Kasprowa
Kopa Magury
Giewont
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Zimna
Czarna
Pisana
Kraków
Wypływ spod Pisanej
Śnieżna
Kominiarski Wierch
Bobrowiec
Ornak
Ptasia
Ciemniak
Małołączniak
Czuba Goryczkowa
Kasprowy Wierch
Pięciu Stawów Gąsienicowych
Świnica
Kozi Wierch
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Resurgence circulation

Underground karst flows of streams have developed in two valleys in the Western Tatra — the Kościeliska V. and Chochołowska V. in their gorge parts (Plate I).

The longest and best developed is the resurgence system from the Pisana Rock. It is connected with the system of resurgence from the Raptawicka Rock, situated on the opposite side of the Kościeliski Stream (Fig. 2). This connection is developed beneath the stream bed. Both these resurgences are supplied by stream water disappearing in several swallow-holes zones situated in stream bed.

The resurgences described above are entrances of caves, with corridors exhibiting large dimensions near their outflows. Hence the great receptiveness of the nearby swallow-holes. Farther from the outflow the corridors narrow. Simultaneously numerous ponds and siphons appear in their beds. The flow in such system is free and very similar to that in the surface stream. Velocities between subsequent swallow-holes and the resurgence are differentiated. It is due to the fact of various dimensions of underground channels. Average velocities range from 300 to 600 m/h. Lower than 100 m/h and higher than 1500 m/h velocities occur sporadically in dry periods and during floods.

The velocities of the Kościeliski Stream measured in the section where the underground karst flows are developed, range from 200 to 2500 m/h. Capacities of resurgences are variable and depend on the level of surface waters.

The variability of capacity of major resurgences is presented in the table 3.

Table 3

Resurgence	Q_{max} l/s	Q_{min} l/s	$R = \frac{Q_{max}}{Q_{min}}$
Kościeliska Valley			
resurgence from the Pisana Rock	588	45	13
resurgence from the Raptawicka Rock	135	5	27
Chochołowska Valley			
resurgence from the Rybia Cave	70	18	4

Waters from deep karst circulation appear also in resurgences. The measurements of the receptiveness of swallow-holes supplying the resurgence from the Pisana Rock gave the result 240 l/s. At that time the capacity of resurgence was 260 l/s. The difference of 20 l/s between these two measurements is caused by the inflow of karst waters from the area of the Krakow Ravine (Fig. 2). It has been confirmed by the colouring of water.

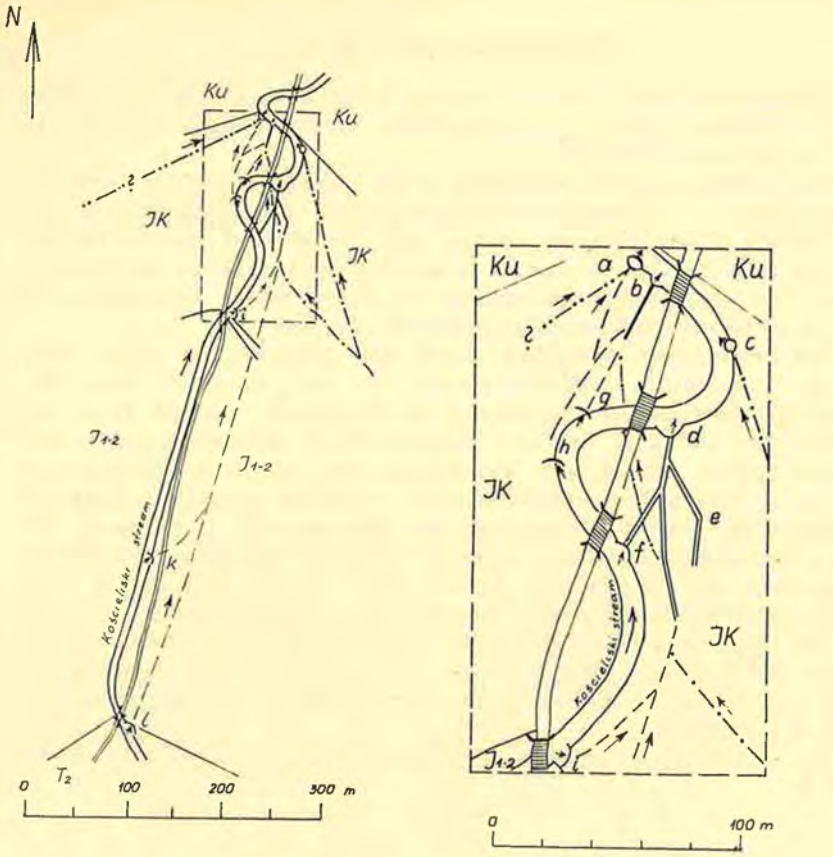

Fig. 2: Underground Karst Water Flows of the Kościeliski Stream in the Area of Raptawicka and Pisana Rock

(Geology after F. RABOWSKI)

1. Urgonian limestones; 2. Malm and Neocomian limestones; 3. Oxfordian limestones; 4. Liassic clastic calcareous deposits; 5. Middle Triassic dolomites and limestones; 6. exsurgences, a) under the Raptawicka Rock, c) Kraków exsurgence; 7. resurgences, b) from the Raptawicka Rock, d) from the Pisana Rock; 8. alimentation routes of the resurgences; 9. underground karst flow from the Kraków Ravine; 10. supposed circulations routes of karst water from the area of Kominiarski Wierch; 11. underground and surface water flows directions; 12. swallow-holes, g), h) of the resurgence system from the Raptawicka Rock, i), k), l) of the resurgence system from the Pisana Rock, e) schematic east of the water cave under the Pisana Rock, f) dry entrance to the water cave under the Pisana Rock.

In the resurgence from the Raptawicka Rock this inflow is greater — 70 l/s. In this case it was impossible to determine the derivation of those waters by means of colouring in the Smytnia Valley. Despite of the negative result of colouring it could be supposed that this water comes from the Kominiarski Wierch massif.

Ways of underground karst stream flows are developed along the N-S line. Simultaneously within the same high-tatric units the waterways supplying the exsurgences, exist that reveal the NW-SE direction. These directions point to the flow of karst waters toward major depressions in the crystalline massif of the Tatra Mts. These ways are not coincident with the directions of surface waters and frequently cross them. The flows under the beds of the Sucha Woda Valley and the Miętusia Valley proved by colouring can serve as examples.

The high-tatric units are covered by the sub-tatric ones. Those are composed mostly of dolomites and clastic deposits. The karst phenomena develop within locally occurring thin limestone intercalations. Only two caves, longer than 50 m are known in this area. They are situated in the Ku Dziurze Valley.

Also some short caves only about 20 m long exist within the sub--tatric units. These are characterized by a well developed surface and subsurface drainage. Numerous streams and large springs such as Chochołowskie, Skalnite, Koziarczyska and Jaszczurówka-term may serve as examples. Lithology and weak development of karst phenomena point to the fact, that these springs are of a fissure or a fissure-karst type. Their capacities are large — up to 2500 l/s in Chochołowskie Spring.

The colourings, the aim of which was to determine the alimentation areas of those springs did not provide satisfactory results. The volume of streams which have been coloured equalled 3—12 l/s. They disappeared completely in fissures in Middle Triassic dolomites. Despite of small distances between swallow-holes and springs (500—700 m) and large quantities of dye used for the measurement it was impossible to find the connection between swallow-holes and springs.

It points to the existence of a dense network of fissures conducting water within the massif. Most probably these fissures do not join together. Simultaneously it confirms the presence of far and deep circulation routes of waters. The latter fact was used as an explanation of the occurrence of springs of higher temperature at the contact of sub-tatric series with the Podhale Flysch (e. g. Jaszczurówka-term).

North from sub-tatric series there occur Eocene deposits. These are mostly limestones (at the base) and conglomerates. The small Jaszczurówska Cave is developed within these limestones. The water flowing along its corridor most probably comes from the area of Kopieniec, built of sub-tatric deposits.

The karst regions of the Tatra Mts. despite of a small area are characterized by very complicated hydrogeological conditions. The

alimentation areas of particular exsurgences do not coincide with those of surface flows, e. g. Olczyskie, Goryczkowe and Lodowe exsurgences.

The colouring executed in exsurgences of the Kościeliska Valley point to the fact that the circulations routes are superimposed one over another. Their flow direction cross each other but never join. Similar conditions are observed in karst flow under the stream valley floors. It allows to state that in the highland karst in the Tatra Mts. there is no uniform level of karst waters that could be connected with surface waters. Each exsurgence has its own alimentation system in which the state of water level depends on the rainfall. The karst springs in the Tatra Mts. are characterized by great variability of capacity. The ratio $R = Q_{max} : Q_{min}$ ranges from 4—50. The exsurgences are usually more productive (up to 3500 l/s) than resurgences which do not exceed 600 l/s. This difference results from the kind and size of the alimentation areas of these types of springs.

The karst waters of the Tatra Mts. are weakly mineralized. The total hardness of water oscillates from 1.4 to 3.0 mval/l. The dry residue does not generally exceed 200 mg/l. These waters belong to the bicarbonate-sulphate-calcium-magnesium-type of waters.

Zusammenfassung

Im polnischen Tatragebirge gehen die Verkarstungsprozesse hauptsächlich in mitteltriassischen und jurassischen Kalken vor sich, die den tektonischen Einheiten der Hohen Tatra angehören. Viele Höhlen, wie z. B. die Czarna (Die Schwarze), etwa 6000 m lang, oder die Snienza (Die Schneehöhle), etwa 640 m tief, beweisen die intensive Verkarstung dieser Gegend.

Untersuchungen der Zirkulationssysteme des Karstwassers, die mit Hilfe von Färbemethoden seit 1961 durchgeführt wurden, sowie Quellenuntersuchungen haben zu einer teilweisen Klärung der Karsthydrogeologie des Tatragebirges beigetragen. Es wurde das Vorhandensein zweier von einander unabhängiger, hochentwickelter Typen der Karstwasserzirkulation festgestellt.

Résumé

Dans la Montagne de Tatra en Pologne, les procès de karstification ont lieu surtout dans des calcaires mésotriasiques et jurassiens, faisant partie des unités tectoniques de la Haute Tatra.

De nombreuses cavernes, telles que la Czarna (La Noire), à peu près 6000 m de long, ou la Snieza (La Caverne de Neige), ayant à peu près 640 m de profondeur, témoignent de la karstification intense de cette région.

Des recherches portant sur les systèmes de circulation des eaux karstiques effectuées à l'aide de méthodes de coloration depuis 1961 ainsi que des exames de sources, ont contribué à éclairer partiellement l'hydrogéologie de Karst de la Montagne de Tatra. On a constaté l'existence de deux types indépendants, très développés de la circulation des eaux karstiques.