R/12

LADISLAV MELIORIS*

FACTORS INFLUENCING THE HYDROGEOLOGICAL CONDITIONS IN THE WESTERN TATRA MOUNTAINS

(Fig. 1—2)

Abstract: By their altitude above 2000 m the Western Tatra Mountains belong among the second highest mountain range in Czechoslovakia. In his paper the author points out to those natural factors which influence the retention and flow of ground water in this high and exposed mountain range formed by crystalline complexes. With regard to the fact that up to now no subsurface exploratory works have been carried out here, he also points out to the methods applied to hydrogeological investigation in the studied area. The knowledge the author has acquired from his exploratory work is stated in the cenclusion.

Резюме: Западные Татры, достигающие высот более чем 2000 м над уровнем моря, являются самым высоким горным районом в ЧССР. Автор в статье обращает внимание на природные факторы, которые имеют основные влияние на условия ретенции и движения подземных вод в горном районе, строенном кристаллическими породами. В рассматриваемом горном районе Западных Татр до настоящего времени отсутствуют техническо-гидрогеологические исследования. Таким образом автор обращает внимание на методику исследований, которая была использована для изучения гидрогеологических условий Западных Татр. В заключении статьи показаны достижения исследований.

Introduction

The preesent work gives new results and method of hydrogeological investigation of the Western Tatra, carried out in an area of about 200 km².

The aim of the paper is to point out mainly those natural factors which are of a decisive influence on the circulation and retention of ground waters in the Western Tatra crystalline complexes. The reason for selecting this area is the fact that nothing has been known so far on the hydrogeological conditions of any core mountain range in the Central West Carpathians. With regard to the fact that up to now no subsurface exploratory works within the studied area has been effected, the evaluation of hydrogeological conditions was carried out through indirect methods based on the recent meteorological and hydrological works. In order to realize this objective the solution mainly of the following problems was taken into consideration:

1. Complex hydrogeological mapping and study of the area of the Western Tatra covering approx. 200 km²;

2. Determination of space and time repartition of precipitation recorded for the period of years from 1963—1968;

3. Determination of evapotranspiration by means of various empirical and semi-empirical equations with regard to the fact that there are no gaging stations in this area;

4. Determination of those factors that are of main effect on the flow of ground water in the crystalline complexes and on their retention capacity;

---

* RNDr. L. Melioris, C. Sc., Department of Engineering Geology and Hydrogeology, Faculty of Natural Sciences of the Comenius University, Bratislava, Gottwaldovo nám. 2.

5. Process of formation of ground and surface water runoff and their regimen determination.

6. Modelling of the process of runoff formation from the Račkova Valley water basin.

The determination of hydrometeorological characteristics, from which precipitation represent the only natural source of ground water storage recharge in this area, was methodically connected with the fundamental complex hydrogeological investigation. Based on detail analysis of geological-petrographical, tectonical and geomorphological conditions and known hydrometeorological characteristics we determined the conditions of ground and surface water runoff. This method led us finally to the determination of retention capacity of rock complexes and to clarification of ground water regimen in the studied area as well as of runoff conditions in its individual water basins. The information about water regimen and runoff from the individual water basins acquired this way permitted finally modelling of runoff formation process from the Račkova Valley drainage basin in the hydraulic integrator of Lukjanov system at the Department of Engineering Geology and Hydrogeology, Faculty of Natural Sciences of the Comenius University.

Geological Conditions

The Western Tatra belong to the Tatride core mountain ranges of the Central West Carpathians. A young mountain range, formed by the Alpine folding, is mainly composed of granitoid rocks and crystalline schists. The Mesozoic groups are only cropping out in a small area in the Tomanovská Valley and at the end of the Tichá Valley.

The crystalline schists were formed by polymetamorphosis of the former, mainly sedimentary series. They are mainly represented by mica schists and mica schists gneisses, quartzite gneisses and gneisses, biotite and two-mica gneisses, and various types of amphibolites.

The granitoid rocks are represented by the late-tectonical and post-tectonical intrusion of tongue-like type. They are mainly formed of granodiorites to quartz diorites.

The Mesozoic groups are represented by the Tomanovská group and by the groups of the Červené vrchy fold.

Hydrometeorological Characteristic

From the hydrogeological point of view area forms part of the upper Váh river basin and is drained by the small streams of Belá, Smrečianka, the Žiar and partially the Jalovec creeks. The geographic watershed corresponds with the hydrogeologic one, excluding the area of Mesozoic groups occurrence.

The space and time repartition of precipitation and evapotranspiration were treated for the Belá and Račkova creeks water basin. This repartition of precipitation was effected on 8 ombrometric stations for the period of 1963 to 1968 and precipitation gradients, calcuted on the base of measured values during the period of 1951 to 1960.

The calculation of evapotranspiration was carried out according to method prepared by M. I. Budyko and L. I. Zubenok (1961). The method is based on simultaneous solution of equations of water and thermal balance.

Average values of precipiation, evapotranspiration and runoff conditions for the studied water basins are indicated in Tab. 1 (L. Melioris, J. Tomlain 1970).

Table 1. Water Balance for the Period of 1963—1968

	year			XI-IV			V-X		
	mm	mil. m^3	%	mm	mil. m^3	%	mm	mil. m^3	%
Belá River Basin from the Gaging Profile below the Town of Podbanské									
Precipitation	1588	146,956	100	619	57,296	39,0	969	89,658	61
Runoff	1189	110,018	74,9	320	29,606	26,9	869	80,412	73,1
Evapotranspiration	439	40,614	27,6	62	5,724	14,1	377	34,890	85,9
Difference (P-R-E)	— 40	— 3,657	— 2,5	237	21,968	14,9	— 277	— 25,644	— 17,4
Raćkov Creek Basin									
Precipitation	1643	59,079	100	643	23,135	39,1	1000	35,944	60,9
Runoff	1199	43,106	73	415	14,917	34,6	784	28,189	65,4
Evapotranspiration	407	14,615	24,8	60	2,148	14,7	347	12,469	85,3
Difference (P-R-E)	37	1,358	2,2	168	6,072	10,2	— 131	— 4,714	— 8,0

Hydrogeological Conditions

1. *The fundamental factors affecting hydrogeological conditions:* The evaluation of hydrogeological conditions of this important core range of the West Carpathians was very difficult. The Western Tatra (with maximum height above sea level of 2496 m in the Belá water basin) together with the High Tatra represent the highest range in the West Carpathians with a typical highmountain relief. Approx. 50 % of the total area is covered by forest predominantly of spruce trees.

In the fundamental study of hydrogeological conditions, the geological structure of the area and the extension of the main genetical-petrographical complexes which differ hydrogeologically from one another, were taken into consideration: the crystalline and the sedimentary mantle. Since the sedimentary rocks of the Mesozoic outcrop only in a small area (approx. 7 km^2) and their importance from the point of view of total hydrogeological conditions is negligible, the main attention was paid to the hydrogeological characteristic of granitoid rocks and crystalline schists.

The flow of ground waters in the crystalline rocks and their retention capacity are mainly affected by the following factors:

a) geological-genetical development and petrographic character of rocks,
b) tectonical development,
c) action of exogenous geological processes and formation of surficial deposits,
d) geomorphological conditions,
e) precipitation and infiltration conditions.

a) The crystalline schists and their tectonical derivatives were formed during various processes of metamorphosis which had completely wiped out and suppressed the former porous permeability of sandy-clayey sediments. The present permeability of these rocks is of fracture character, resulting from various forms of fracturing. Granitoid rocks were formerly compact rocks of intrusive character. The crystalline schists as well as the granitoids represent the rock environment in which the ground water circulation takes place. Therefore, it would be desirable to know their fundamental physical-mechanical properties which were and are of substantial affect on the course of processes of gradual disintegration of the rock mass compactibility (fractures, dislocations, weathering zones, etc.) and on the degree of water-bearing of these rocks as well. However, our knowledge in this sphere is so far poor. M. Matula (1968) gives for granitoids and paragneisses from various areas of Slovakia the following physical-mechanical values (maximum, average, minimum) — Tab. 2.

b) The view that earlier orogenetic phases in the Central West Carpathians were

Table 2

Rock	ρs	ρn	p	n	τfs	N
Paragneisses	2,82 2,74 2,61	2,76 2,71 2,61	4,65 1,99 0,10	3,00 0,56 0,10	1896 715	29
Granitoids	2,81 2,72 2,67	2,78 2,69 2,55	4,74 1,42 0,08	1,20 0,40 0,05	1913 860	83

ρ_s = specific density (g. cm^{-3}); ρ_n = unit mass density (g. cm^{-3}), p = porosity (%), n = absorbtion capacity (%), τfs = uniaxial compressive strength — dry (kp. cm^{-2}), N = number of tests.

affected by Alpine-type phases to such a measure that they play no longer any rôle in the crystalline water-bearing (O. Hynie 1961) cannot be wholly accepted. An expressive structural element is represented by the mylonite fracture zones. Their study in the Western Tatra has shown that they are in no case Late Alpine ones, that their predisposition was already given by the Variscian tectonics. The Alpine-type tectonics gave rise to a dense network of tectonic joints in crystalline rocks, mainly in granitoids. These phases resulted in a substantial change of former very unfavourable collector properties of compact granitoid bodies. The network of joints that was created, still determines the flow of ground waters in these rocks. The systems of joints of transversal tectonics are more open, more permeable and probably reach greater depths.

Minor tectonics is of primary hydrogeological importance, i. e. tectonic elements reaching several tens of meters. It effects directly the permeability of crystalline rocks and is created by Alpine-type orogenetic phases.

Non metamorphosed crystalline rocks manifest a so-called cleavability of rock mass, which the rock mass acquires during its solidification phase and a splitting tectonics, which the rock mass acquires in its solid state (O. Hynie 1961). The systems of joints of transversal tectonics are a dominating element here: They are termed Cloose Q-planes. The wells of these joints are usually smooth and even, more dense and penetrate to greater deapths. The system of longitudinal joints, Cloose S-planes, is perpendicular to the direction of rock-forming pressure, therefore, perpendicular to the system of joints of transversal tectonics. The Cloose S-planes are less opened, rarely rock and ore veins are bound to them. This fact characterizes best the difference in permeability of systems of lonfitudinal and transversal joints.

The most open and most permeable joints in crystalline schists are represented by those joints which are opened by tensile components in the field of force of lateral rock-forming pressures. They are planes of discontinuity following the rock-forming pressure action. At some places they pass in to transversal faults. Foliation for the crystalline rock water-bearing is of no significance. It represents only the structural element which forms the system of approximately parallel planes of weakened homogeneity, but not planes of complete mechanical discontinuity.

c) From studies made in the Alps (U. Z i s c h i n s k y 1967) it is known at present that in deep cut valleys the horizontal stresses are released in the vicinity of steep slopes to a depth of several hundreds of meters. On release the jointed rock mass in general deforms slinghtly and individual joints widen in the direction of maximum release, i. e. roughly in a direction parallel with the slope (Fig. 1). At some places this process still continues. Loosening increases and assumes a small movement. These cases of gravitational deformation of slopes in the Western Tatra are described by A. N e m č o k and J. P a š e k (1969).

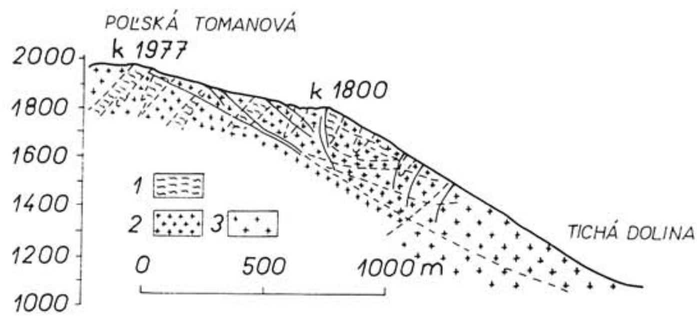

Fig. 1. Cross-section of south-west slopes of Poľská Tomanová (A. N e m č o k, J. P a š e k 1969). 1 — biotite and two-mica paragneisses (Proterozoic), 2 — quartz diorites to granodiorites, 3 — autometamorphosed leucocratic granitoids, aplites and pegmatites of the marginal fringe (Carbon).

These phenomena are important from the point of view of evaluation of hydrogeological conditions of a rock mass, since the released zone in the slopes is simultaneously representing the zone of increased permeability and retention with an expressive anisotropic character of permeability. The author assumes that the relatively highest water-bearing of a rock mass in this zone is conditioned also by the fact that the joint system of the release zone relates to systems of joints of transveral tectonics, which are decisive for the flow of ground waters in a given rock mass.

Of considerable importance for a correct evaluation of hydrogeological conditions in the Western Tatra are cover, but mainly Pleistocene formations. Originally one of the widespread types of these sediments were represented by the morainic deposits. They suffered strong erosion and transportation after the last glaciation, as a result of which they were partly transformed to fluvioglacial sediments. Granulometric properties of individual moraines differ from each other by the degree of rounded edges of individual block rocks, by the representation of blocks and their gravel, sand and silt fractions. Their grain composition conditions directly their permeability. According to M. L u k n i š (1959) even moraines composed of the smallest talus grain size at the foot of the Tatras are sufficiently coarse grained as to allow a rapid flow and exchange of waters. Moraines of the High Tatra in their frontal parts are composed of ungraded materials of all fractions beginning from claey through silty, sandy, through minute slightly ground rock rubble and of gravel blocks reaching considerable dimensions. The differences in grain size are big at short distances. Important is the degree of inclination to mechanical disintegration, or the degree of mechanical, resp. chemical disintegration of individual fragments, rounded boulders of these formations. According to resistance and degree of weathering M. L u k n i š (1959) classifies granitoid rocks in stone debris and alluvial formations at the foot of the Tatras in six groups. The thickness of these sediments reaches several tens of metres (for example the trough bottom of the Kôprová Valley).

Of great importance from the hydrogeological point of view are also slope débris and landslides. Their extension in the Western Tatra is considerable. Rapid development of these forms is conditioned mainly by the periglacial climate with a very effective frost weathering and slopes undetermined by glacial erosion.

d) The geometrical boundaries of rough forms of the surface of the area corespond with young, relatively intensive upheaval of the Tatras. In Neogene an asymetrical uparching of the Tatras occured along the „Podtatranský Fault" with a moderate overthrust to the South. Retrogressive erosion articulated together with Neogene and Pleistocene upheval the fault slope into a system of facets. The height of this upheaval is valued to at least 1400 m (M. L u k n i š 1956).

By the asymetric uparching one can also explain the fact that streams flowing to the south present a much bigger gradient than those flowing to the north. Meanwhile the main valleys are of a radial character with regard to the arch, the detailed shape of the mountain range relief reflects a tectonic disruption of the rock mass.

The actual relief of the Western Tatra is due to a considerable extent the result of morphological processes of glacial-nival and periglacial morphological cycle in glacial periods.

e) Pleistocene sediments (glacial, fluvial, glaciofluvial formations and periglacial forms) are factors affecting considerably hydrogeological-hydrological conditions in the crystalline rock of the Western Tatra and elsewhere as well. These sediments cover up to 50 % of the area (frequently even more) of upper parts of the individual water basins. They are mainly predominating in higher altitude above 1600 m, where average totals of precipitation attain the highest values. As a consequence of their areal extension, petrographic composition and unsorting of the material, they represent a very good environment for infiltration of precipitated waters. The predominant part of precipitations which falls on their surface, infiltrates directly. Part of the water accumulates in these formations. In periods following immediately precipitation these waters form the major part of the surface runoff. The permeability of the surficial deposit formations is very heterogeneous, high as a whole (to which corresponds the rapid decrease of flow lines immediately after precipitation till it reaches the minimum value — approx. 2 weeks) and it is expressed in the coefficient of filtration k within the range of 1.10^{-3} and 1.10^{-1} m/s.

Another part of the infiltrated waters seeps as deep as the joint sytem of the release zone, weathering zone. This deeper flow of ground waters in the rock mass forms the groundwater storage which mainly in winter period and in long rainless period permanently forms the groundwater surface in water streams of the studied area. The discharge of ground water from this zone behaves hydraulically as dischange from an aquifer with inclined underlier, approximately parallel with the surface (joints of the zone of release are parallel with the surface) of the area. The hydraulic gradient of the groundwater level is then approximately constant, what in its turn is also manifest by a constant minimum discharge of water from the water basin in periods when the retention storage of surficial deposits were exhausted (Fig. 2). A minimum runoff from the water basins formed this way characterizes the extent of disrupted rock mass in the zone of release. The minimum specific runoff from 1 km^2 is represented by the underground discharge from the zone of release and weathering zone. What regards the Ráčkov stream basin this minimum specific runoff is represented by the value of 5,63 $1/s/km^2$ and for the Belá stream basin 4,97 $1/s/km^2$. The high values of minimum specific runoff hint at the considerable retention capacity of the rock environment of granodiorites and crystalline schists of these water basins, which is caused by the considerable depth of the zone of release and weathering zone. This confirms simultaneously the assumption of A. N e m č o k and J. P a š e k (1969) that the thickness of the zone of release attains several hundreds of meters. The fact that groundwaters participate in the water supply of surface streams helped us to point out indirectly the retention capacity of the rock mass in the weathering and release zone by the hydrological method of delineation of underground discharge on the flow line (L. M e l i o r i s and J. T o m l a i n 1970). It is that part of waters, of which flow duration curve is not dependent on the course of foregoing precipitation and is relatively constant in rainless periods (Fig. 2).

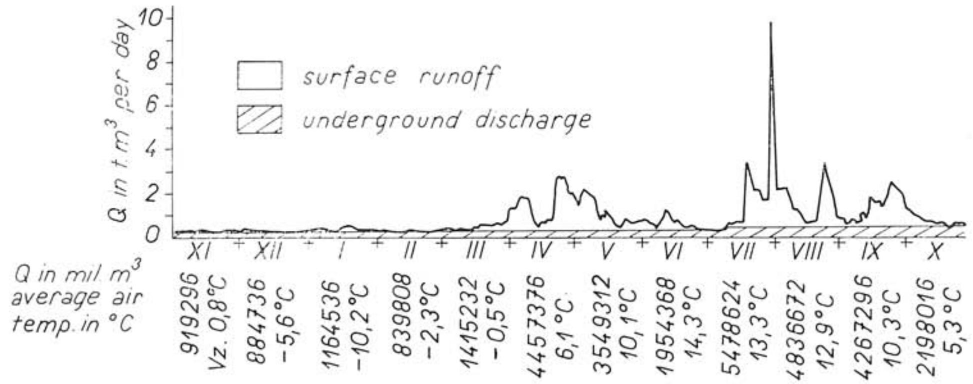

Fig. 2. Diagrammatic delineation of underground discharge on the flow Boundary of the Račkov creek in the Western Tatra according to E. E. F o s t e r s.

The third part of infiltrated waters is discharged immediately after precipitation in the form of slope débris springs. If the surficial deposits are superficially limited and isolated, the yield of springs is small. However, if surficial deposits of larger areal extension are drained, the yield of springs reaches higher values, several tens of litres per second (concentration spring below Baranec in the Žiar Valley with a discharge Q = 25—30 l/s). The final part of atmospheric waters forms the surface runoff, if the intensity of run-in is less than the intensity of precipitation, or if the retention capacity of rock is saturated.

Fluvial and glaciofluvial sediments filling the valley bottoms represent a fairly permeable environment. The permeability expressed by the coefficient of filtration k is assumed within the range of 1.10^{-4}—1.10^{-2} m/s.

A total of 367 springs were evaluated. Their heights above sea level vary from 790—1940 m. All natural water issues belong to three types of springs representation of which is the following one: 248 natural water issues are represented by the slope débris spring. 111 by the joint type of spring and 8 by the stratum type of spring.

The discharge of the most numerous — slope débris springs fluctuated from minimum discharges to discharges attaining several tens of litres. dependently on the amount of precipitation and their morphologic position. The highest discharges are attained by the slope débris springs flowing out from huge surficial deposits at the end of valleys — to 30 l/s. The discharges of most slope débris springs are. however. much smaller. maximum Q = 1—2 l/s.

Joint springs have smaller values of discharge — maximum 2 l/s. but their regimen is more stable. the discharges are not showing such a fluctuation as slope débris springs. Interesting is the fact that joint springs are predominantly situated in greater heights a. s. l.

At the southern tectonical boundary of the Western Tatra. several tectonic outliers — islands of the Mesozoic Group out. to which streams of relatively high discharges are related (for example Suchý Hrádok — 27.9 l/s.).

From the total number of 367 registrated springs. 25 attain a higher discharge than 1.5 l/s. 33 springs 0.5—1.5 l/s. 83 springs 0.15—0.5 l/s and 226 springs have a discharge lower than 0.15 l/s. The total discharge value of all 367 springs in the studied area represents a value of approx. 290—320 l/s.

2. *Physical and chemical properties of ground waters.* Ground waters of the studied area have good physical properties. Their temperature measured at the natural issues varies from 1 °C to 14 °C. They are very cold (0—3 °C). to cold waters (3—20 °C).

The temperature of waters in the springs of the Western Tatra is affected by the following factors: air temperature. soil surface temperature. spring position. spring situation. a. s. l. height and spring discharge.

The chemism of ground waters in the Western Tatra is conditioned mainly by the mineralogical composition of the rock environment. represented by granitoids and crystalline schists. The principal minerals of granitoids are plagioklases. quartz. biotite. feldspars (mainly potash feldspars) and muscovites. Since fundamental rock-forming minerals of crystalline schists in the studied area are also plagioklases. quartz. muscovite. biotite and feldspars. the chemism of ground waters genetically bound to these rocks does not practically differ from the chemism of ground waters bound to granitoid rocks. The same holds for the chemism of ground waters of surficial deposits with regard to petrographic composition of their material which is formed exclusively by crystalline rocks. A dominant position in the salt content of waters (60—80 mval $^0/_0$) in most ground water samples is held by the calcium-bicarbonate component part.

As it has already been stated we meet with a joint regimen of ground water flow in the granitoid rocks and crystalline schists. Part of the infiltrated atmospheric waters gets through the surficial deposits into the regimen flow of the release and „weathering zone".

The precipitation representing the main sources of ground water storage in the Western Tatra is also the main factor conditioning the chemical weathering of rocks. The chemical action of rain waters on the rocks is preceded by mechanical disintegration of rock-forming minerals and rocks.

The total mineralization of waters bound genetically to granodiorite rock mass varies from 0,30 to 0,73 g/l. All water samples represent one type of waters — calcium-bicarbonate. The coefficient values of Mg/Ca vary within the limit of 0,05 to 0,38. The Ca content fluctuates from 6,0 to 14,8 mg/l, HCO_3 from 12 to 40 mg/l. The increased content of SO_4 was detected only in one case, spring No. 206 situated „Pod Smrečinami". The water contains 10,7 mg/l of SO_4 (as against 12,55 mg/l of HCO_3).

The total mineralization of waters bound genetically to crystalline schists varies from 0,22 to 0,54 g/l. Even in waters bound genetically to these rocks the predominant type of waters is calcium-bicarbonate one. The Mg-Ca coefficient fluctuates from 0,0 to 0,33. The highest content at cations is attained by Ca — maximum 19,55 mg/l, at anions of HCO_3 — 3,15 to 21,95 mg/l. The chemism of waters bound genetically to crystalline rocks shows, however, a certain instability and changes occur in the ratio of single cations and anions. In some waters there is an increased content of Na (4,2 to 4,4 mg/l, representing 40,3, or 44,2 mval %) and Cl (4,35 to 4,95 mg/l, representing 19,84, or 53,46 mval %). Singly there is also an increase of sulphates — max. 7,8 mg/l.

Waters of surface streams have chemism similar to samples of ground waters taken from the springs of this water basin. The total calcium-bicarbonate mineralization of stream waters ranges within the limits of ground waters. With regard to the fact that samples were taken at low water level, we may also state that the low discharges of these waters basins are the result of ground water discharge mainly from thes release and „weathering zone".

Low mineralized aggresive waters (maximum content of aggresive CO_2 according to H e y e r — 19,8 mg/l) of crystalline rocks and surficial deposits acquire their salt content (namely Ca, Mg, Na) mainly by hydrolythic dissolution of various silicates. The presence of CO_2 (maximum 15,4 mg/l) is acting in two ways. The carbonic acid formed in water by dissolution adds the necessary ions M^+ by partial dissociation of reactions. The simultaneously formed HCO_3 ions are of preventing affect to greater pH changes towards the alcalic sphere. The pH shift towards the acid sphere (pH of the studied waters in the studied area attains the values of 5,1—7,0) and results probably in increased and accelerated affect of waters on silicates. However, the problem of hydrolythic dissolution of silicates has not yet been solved and the opinions of various authors on the course and importance of these reactions diverge (C. W. C o r r e n s 1940, J. D. H e m 1959). As a result of relatively short water contact with a rock environment, the chemical reactions of the phase boundary rock-water cannot reach the stage of saturation equilibrium. This is why part of the aggresive CO_3 which was not used up during dissolution remains in water (maximum content of aggresive CO_2 according to H e y e r — 19,8 mg/l). Chlorides in ground waters are mainly derived from micas and amphibolites. The source of increased sulphate content in waters genetically bound mainly to crystalline schists is the pyrite oxidation, resp. other sulphides of low-thermal veins found in mylonite zones, representing the type of ore mineralization particular to this area. Beside fundamental cations and anions there were, in the ground water samples, sporadically detected also Li, Mn, Fe^+ and NO_3. The total hardness of ground waters in this area expressed in °N ranges within 0,65—5,6 — Tab. 3.

Table 3. Chemical Analysis of Some Selected Spring Waters in the Western Tatra

Source No. Name	Rock Type		Total miner. mg/l	Total hard °N	Free CO_2	Na	K	Mg	Ca	Cl	SO_4	HCO_3	Mg/Ca
96, Jam. Valley	granitoids	mg/l mval/l	53,05	1,64	5,94	2,4 0,104	0,6 0,015	1,5 0,123	9,35 8,466	4,35 0,123	6,6 0,137	28,25 0,463	0,26
326 Pod Vývratom	granitoids	mg/l mval/l	47,35	1,45	0,00	1,05 0,046	1,2 0,031	0,45 0,037	9,65 0,481	1,15 0,032	9,45 0,197	24,4 0,400	0,077
134 Pod N. Magurou	granitoids	mg/l mval/l	73,45	2,28	3,9	2,6 0,113	0,6 0,015	0,9 0,074	14,8 0,738	5,05 0,142	8,65 0,18	40,85 0,67	0,1
21, Pod Úbočou	granitoids	mg/l mval/l	43,75	1,32	3,1	1,7 0,074	0,3 0,077	0,3 0,023	9,0 0,449	3,6 0,101	3,7 0,077	25,15 0,412	0,051
37, Pod Barancom	crystalline schists	mg/l mval/l	22,1	0,65	3,9	2,2 0,096	0,2 0,005	0,45 0,037	3,95 0,1097	4,35 0,123	7,8 0,162	3,15 0,052	0,19
88, Pod Jedlinami	crystalline schists	mg/l mval/l	43,55	1,30	5,94	2,6 0,113	0,6 0,015	1,4 0,116	7,05 0,352	4,35 0,123	6,6 0,137	21,95 0,36	0,33
55, Pod Barancom	crystalline schists	mg/l mval/l	34,1	0,73	4,75	5,2 0,183	0,4 0,01	0,45 0,037	3,95 0,112	4,5 0,224	4,95 0,103	15,65 0,257	0,165
43, Pod Úbočou	crystalline schists	mg/l mval/l	30,5	0,65	9,1	4,4 0,192	0,1 0,1	tr. —	3,6 0,101	4,65 0,232	4,95 0,103	12,50 0,206	0
167, in Valley	Mesozoic Liptov bas.	mg/l mval/l	143,35	4,8	0,00	1,8 0,078	1,3 0,033	6,95 0,57	22,85 0,14	2,15 0,06	10,7 0,223	97,6 1,6	0,5
214, Sur. Hrádok	Mesozoic Liptov bas.	mg/l mval/l	121,2	4,03	11,5	3,3 0,143	0,6 0,015	4,10 0,337	22,4 1,118	3,6 0,101	8,65 0,18	78,56 1,288	0,3
262, Pod Úplazom	Mesozoic	mg/l mval/l	159,65	0,35	0,0	0,8 0,035	1,3 0,033	6,35 0,523	28,24 1,41	1,65 0,46	11,5 0,239	109,8 1,80	0,37

Chemical analyses of natural spring waters from the Western Tatra area were carried out at the D. Štúr's Geological Institute laboratory in Bratislava and at the laboratories of the Department of Engineering Geology and Hydrogeology, Faculty of Natural Sciences of the Comeinus University, Bratislava.

Conclusion

A complex hydrogeological investigation of the Western Tatra territory (approx. 200 km^2) is the first carried out in a crystalline mountain range territory of the Central West Carpathians. The fissure waters are bound to „weathering zone“ and to the zone of release of rock environment of granodiorites and crystalline schists. The extraorinary importance of Pleistocene sediments in the hydrogeology of the Western Tatra was established.

What regards the type of ground water supply dependently on climatic conditions, there exists an annual supply in the Western Tatra (with preferred spring snow melting).

The ground water regimen and its retention in the rock environment form the storage of ground waters, which form the total runoff from the water basin in winter season and during long rainless periods. The total yieald of springs of all types represents an amount of approx. 300 l/s.

Factors of principal affect on ground water flow and retention in crystalline rocks of the Western Tatra were discussed. We pointed out the substantial influence of exogenous geological processes and surficial deposits on the subsurface runoff and of tectonical as well as geological-genetical development of the territory on the underground runoff.

The values of minimum specific runoff from 1 km^2 is represented by the underground runoff from the release and „weathering zone“. Its high values also point to the considerable retention capacity of rock environment formed by granodiorites and crystalline schists of the Western Tatra.

The chemism of ground waters of crystalline rock environment of the Western Tatra is product of hydrolythic splitting reactions of silicate minerals of granodiorites and crystalline schists. The small intensity of these reactions, caused by a short contact of water with the rock environment, relatively low average annual temperatures as well as relatively lower pressures result in a very low total mineralization of ground waters, fissure regimen of which is bound to release and „weathering zone“ of the Western Tatra. It is simultaneously the cause of only little changes — modifications in the cation as well as anion composition of ground waters in this area.

REFERENCES

ANDRUSOV, D., GOREK, A., 1959: Geologická mapa Vysokých Tatier. Manuscript, Bratislava.

BUDYKO, M. I., ZUBENOK, L. I., 1961: Opredelenija isparenija s poverchnosti suši. Izv. AN. SSSR, ser. geogr. 6, Moskva.

CORRENS, C. W., 1940: Die chemische Verwitterung der Silikate. Naturwissenschaft *28*, Berlin.

GOREK, A., 1959: Prehľad geologických a petrografických pomerov kryštalinika Vysokých Tatier. Geol. sborn. Slov. akad. vied *10*, 1 Bratislava, p. 13—88.

HEM, J. D., 1959: Study and interpretation of the chemical characteristics of natural water. Geol. Surv. Water, Supply Paper *1473*, Washington.

HYNIE, O., 1961: Hydrogeologie ČSSR I. Prosté vody. Edit. ČSAV, Praha.

LUKNIŠ, M., 1956: Náčrtok geomorfológie Tatier. Príroda Tatranského národného parku. Martin.

LUKNIŠ, M., 1959: Reliéf a roztriedenie kvartérnych útvarov vo Vysokých Tatrách a na ich predpolí. Geol. sborn. Slov. akad. vied *10*, 1, Bratislava, p. 233—268.

MATULA, M., 1968: Náčrt regionálnej inžiniersko-geologickej klasifikácie hornín Slovenska. Acta geol. et geogr. Univ. Com., Geologica *16*, Bratislava, p. 47—90.

MELIORIS, L., 1966: Hydrogeologické pomery na listoch Nižná a Bystrá. Záverečná správa „Základné geol. mapy, listy Nižná a Bystrá 1 : 50 000". Geofond Bratislava, p. 317—331.
MELIORIS, L., TOMLAIN, J., 1970: Príspevok k riešeniu problematiky režimu podzemných vôd v Západných Tatrách. Sborn. ref. V. hydrogeol. konferencie, Gottwaldov, p. 265—291.
NEMČOK, A., PAŠEK, J., 1969: Deformácia horských svahov. Geol. práce, Správy *50*, Bratislava.
ZICHINSKY, U., 1967: Bewegungsbilder instabiler Talflanken. Mitt. Ges. Gel. Bergbaustud. *17*, Wien.

Review by A. PORUBSKÝ.