# Regional Hydrogeological Characteristics of Mineral Water Aquifers in Slovakia

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**Abstract:** During inventory of mineral water sources in 1997-2000 1,687 sources were documented on the Slovak territory, 111 were not found, 297 disappeared and 30 were destroyed. Mineral water sources in Slovakia are characterized by quite a varied representation of chemical water types with a wide range of TDS, temperature and yield. The largest representation of mineral water in Slovakia is located within the Central Western Carpathians (43 %), of which account for most of the resources Inner Carpathian Palaeogene (24.1 %) and Mesozoic sediments of the Central Western Carpathians (15.2 %). The smallest number of sources accounted for metamorphic rocks (3.2 %) and magmatic rocks (1.5 %). The second most numerous sources of mineral water are from Neogene sediments (31.7 %). This structural-geological facies has the largest representation of mineral water sources that have been acquired through technical work (the number of wells far outscores the springs). The third and fourth most numerous sources of mineral water fall within Flysch Zone (13.3 %) and Neovolcanites (6.8 %). The lowest representation of mineral water falls on Klippen Belt (4.2 %). The territory of Slovakia is explored by a number of deep geological wells to verify the presence of mineral waters. Only a small part of them has set the hydraulic parameters of the aquifers. The most important aquifers from the viewpoint of formation of mineral waters in Slovakia are the Mesozoic sediments of the central zone of the Western Carpathian and the Neogene sediments, which fill up the basins. The Mesozoic aquifers (limestones and dolomites) of mineral waters have been verified by 79 hydrogeological boreholes (56 pumping tests) and the value of the geometric mean of transmissivity coefficient G(T) = 9.08 . $10^{-4}$ $m^2$ . $s^{-1}$. The drillings carried out in the Mesozoic carbonates are also reported for relatively large yield (Md Q = 12.4 l . $s^{-1}$/ Mn Q = 19.4 l . $s^{-1}$). Neogene sedimentary aquifers (sands, sandstones, conglomerates) of mineral waters have been verified by 58 hydrogeological boreholes (49 pumping tests) and the geometric mean value of the coefficient of transmissivity G(T) = 5.35 . $10^{-4}$ $m^2$ . $s^{-1}$. Drillings carried out in an environment of the Neogene sediments have achieved balanced yields (Md Q = 10.0 l . $s^{-1}$/ Mn Q = 10 . 5 l . $s^{-1}$).

**Keywords:** sources of mineral waters, coefficient of transmissivity, deep borehole, chemical type of water, Western Carpathians

## 1.1 Introduction

By 1999, 1,687 mineral water sources were registered in Slovakia. These sources are characteristic either of the content of 1,000 mg . $l^{-1}$ of dissolved solids or dissolved gases, $CO_2$ included (≥ 1,000 mg . $l^{-1}$ ), $H_2S$ (≥ 1,0 mg . $l^{-1}$) or they reach the ground surface temperature of more than 20 °C. The occurrence of mineral waters on the territory between the Tatras and the Danube and Tisza rivers reflects its geological and tectonic evolution. The presence of major regional aquifers of mineral waters that are affected tectonics of alpine or German types created the conditions for the formation of the mineral waters in the hydrogeological structure. In the past the ideas about the formation of mineral waters in the space of hydrogeological structures largely depended on knowledge of geological and tectonic structure, chemical composition of mineral waters and later of the isotopic composition of mineral waters. It has been the isotopic composition of mineral water that has contributed to the fact that the view of the nature of the hydrogeological structure of mineral water as such has changed from the hypothetical viewpoint to the real one. Determination of the isotopic composition of mineral waters in the hydrogeological structures provides information about the nature of the aquifer, where its chemical composition is formed over time. In some cases it is possible to determine the hydrogeological structures in which mixing of waters from multiple aquifers occurs. The knowledge of the geological and tectonic settings of the hydrogeological structure of the Western Carpathians, including the hydraulic parameters of aquifers and character of mineral water in terms of the chemical and isotopic composition, creates a closer correlation to define the conditions of formation of mineral waters. The data gained from deep boreholes in different parts of the hydrogeological structure provides valuable material that documents the evolution of monitored parameters towards the depth.

## 1.2 Geological and tectonic conditions of mineral waters genesis

The territory of Slovakia is situated within the Western Carpathians, which are part of the Alpine-Himalayan system with folded-Nappe structure. Formation of mineral waters takes place in the rock environment, which is liable to concentrate them, which is reflected in the quantity and quality. As the mineral waters are affiliated to the geological environment, which reflects the geological and tectonic setting of the area, we will describe these in relation to the structural-facies zone, which were earmarked by Andrusov (1958). In Slovakia there are these zones: 1. Flysch Zone, 2. Klippen Belt, 3. Central Western Carpathians, 4. Internal Neogene depressions, plains and volcanic rocks (Fig. 1.1).

The conditions favourable for the formation of mineral waters were outlined by Maheľ (1952) and supplemented by Franko (1975) as follows:

- the presence of large amounts of Mesozoic sediments, mainly the Middle and Late Triassic carbonates (limestone and dolomite) and evaporites in the Permian, Early and Late Triassic;

– Extensive Tertiary (Palaeogene and Neogene) marine and freshwater sediments, mostly pelites with aquifer layers of psephites and psammites. In the Miocene evaporites occurred;
– Tectonics of Alpine type within the Mesozoic formations created far reaching folds plunging from the mountain slopes into larger depths below the internal basins and lowlands;
– Tertiary sediments have tectonics of Alpine and German types;
– Longitudinal and transverse young faults;
– Deep faults among the blocks of the Earth's crust ($CO_2$);
– Young Tertiary volcanism ($CO_2$, favourable geothermal conditions);
– Favourable geothermal conditions (average geothermal gradient of 39 °C . km$^{-1}$, the average heat flow density – 82 mW . m$^{-2}$).

## 1.3 Distribution of mineral waters in structural-facies zones

Geological setting of the Western Carpathians, which build particularly the territory of Slovakia, is reflected in the abundance of mineral waters (Tab. 1.1, 1.2) and the diversity of their chemical types (Tab. 1.3). During the inventory of mineral water sources in the years 1997-2000 1,687 sources were documented in Slovakia. Of this number, there were 1,249 sources, 111 were not found, 297 disappeared and 30 were destroyed. Among the lacking sources there were 80 springs, 4 dug wells and 27 wells, of which there is no information on their destruction.

Affiliation of mineral water to the individual zones of the Western Carpathians is reflected in the frequency and variability of chemical water types.

### 1.3.1 Mineral waters of the Flysch Zone

The Flysch Zone is made of Cretaceous and Palaeogene alternating claystones and sandstones of marine origin. Of the total number of mineral waters in Slovakia, this share is 13.3% with five chemical types of waters (Tab. 1.3).

This zone is characterized by abundant representation of small springs of cold sulphane and carbonate, very weakly (up to 1 g . l$^{-1}$) and weakly mineralized water (1 – 5 g . l$^{-1}$) of the chemical type Ca-Mg-$HCO_3$, Na-$HCO_3$ with yield do 0.1 l . s$^{-1}$.

The best known are the cold strongly mineralized carbonated water with mixed mineralization from sources Cigeľka (Na-$HCO_3$-Cl) and Bardejov (Na-$HCO_3$) with yield up to 4 l . s$^{-1}$. In the area Bardejov – Stropkov there are important sources in Bardejov – Dlhá Lúka (Na-$HCO_3$-Cl), Mikulášová (Na-Cl-$HCO_3$) and Dubová (Na-$HCO_3$-Cl) with yield do 0.3 l . s$^{-1}$. Equally, the cold (springs, wells) and the thermal sources (well FPJ-1) of very high TDS strongly mineralized (35 – 50 g . l$^{-1}$) are iodine-bromine and water with thalassogenic mineralization of chemical type Na-Cl in Oravská Polhora with yield up to 1 l . s$^{-1}$. Structural-hydrogeological borehole FPJ-1 (Fig. 1.2) reached a depth of 2,417 m and it verified the sediments of Obidowa-Słopnice-Zboj unit in depth interval 1,298 – 2,417 m. The water temperature at the collar was 31.3 °C, available quantity at exploitation with free spill was set at 1.0 l . s$^{-1}$ (Zakovič et al., 1988).

Tab. 1.1 Status of mineral water sources as of inventory 1997 – 2000 (Zeman et al., 2000)

| | N | % representation | Spring | Piscine | Dug well | Borehole |
|---|---|---|---|---|---|---|
| exist | 1,249 | 74.0 | 690 | 7 | 138 | 414 |
| not found | 111 | 6.6 | 80 | | 4 | 27 |
| disappeared | 297 | 17.6 | 188 | 3 | 40 | 66 |
| liquidated | 30 | 1.8 | 17 | | 3 | 10 |
| ∑ | 1,687 | 100.0 | 975 | 10 | 185 | 517 |

Tab. 1.2 Representation of mineral waters sources in structure-geological facies

| No. | Structure-geological facies | N | % representation | Spring | Piscina | Dug well | Borehole |
|---|---|---|---|---|---|---|---|
| 1. | Flysch Zone | 225 | **13.3** | 158 | 0 | 20 | 47 |
| 2. | Klippen Belt | 71 | 4.2 | 53 | 0 | 4 | 14 |
| 3. | Magmatic rocks | 26 | 1.5 | 18 | 0 | 1 | 7 |
| | Metamorphic rocks – Early Palaeozoic | 30 | 1.8 | 30 | 0 | 0 | 0 |
| | Metamorphic rocks – Late Palaeozoic | 23 | 1.4 | 22 | 0 | 0 | 1 |
| | Mesozoic sediments of Central Carpathians | 256 | **15.2** | 159 | 1 | 14 | 82 |
| | Inner Carpathians Palaeogene | 406 | **24.1** | 305 | 0 | 31 | 70 |
| 4. | Neogene | 535 | **31.7** | 169 | 8 | 99 | 259 |
| | Neovolcanites | 115 | 6.8 | 61 | 1 | 16 | 37 |
| ∑ | | **1,687** | **100** | **975** | **10** | **185** | **517** |

Note: N – count of sources

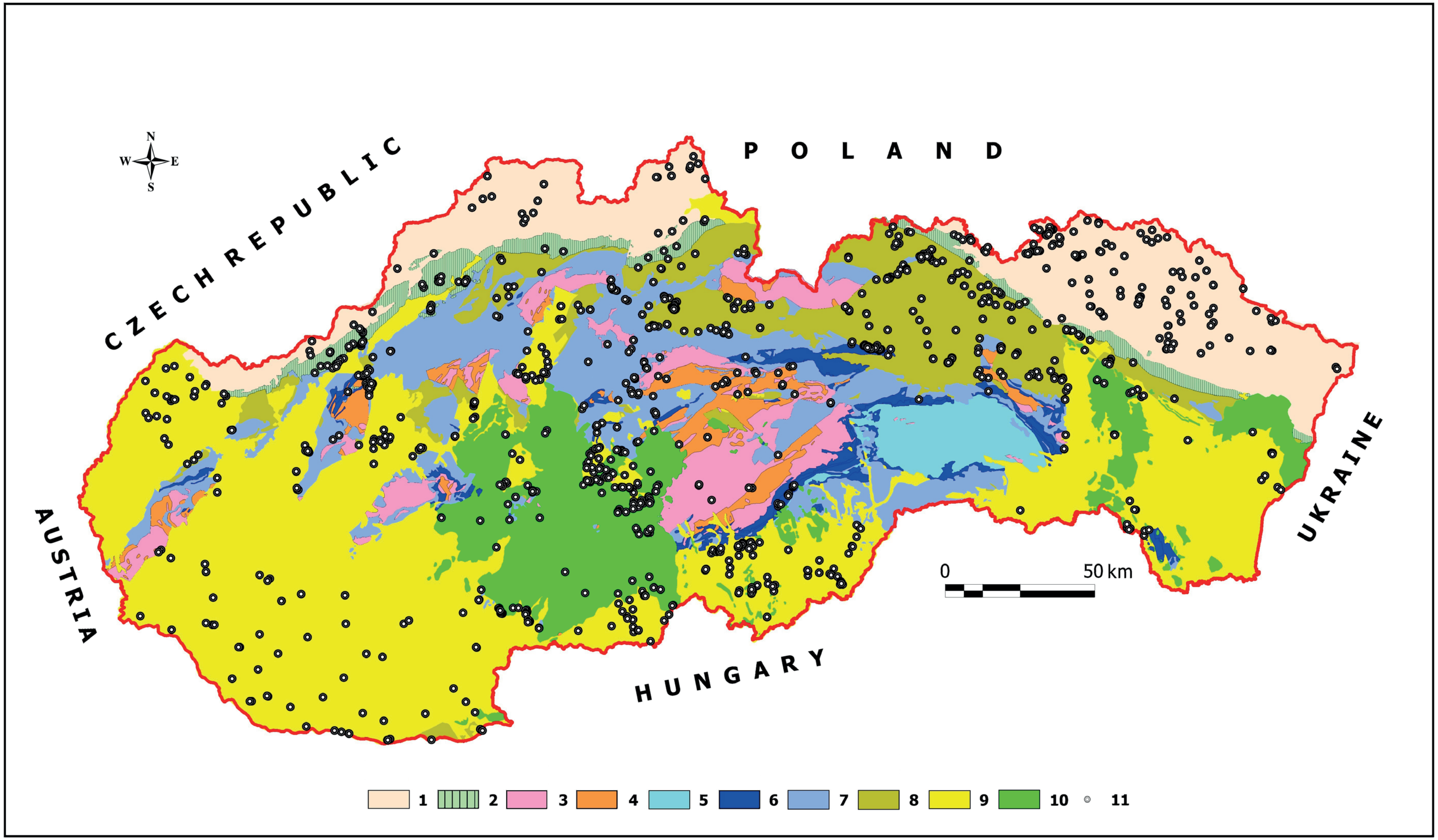


*Fig. 1.1 Mineral waters sources in structure – facies zones of Slovakia (based on Zeman et al., 2000; Biely et al., 1996)*
*Explanation: 1 – Flysch Zone, 2 – Klippen Belt, 3 – Crystalline/magmatic rock, 4 – Crystalline/metamorphic rock (phyllites to mica schists with metavolcanic intercalations, locally gneisses), 5 – Metamorphic rocks – Early Palaeozoic (metasandstones, paraconglomerates, phyllites), 6 – Metamorphic rocks – Late Palaeozoic (metamorphosed clastic sediments, mafic volcanics and volcanoclastics, scarce ultramafic fragments), 7 – Mesozoic sediments (predominantly carbonate rocks – limestones, dolomites), 8 – Inner Carpathians Palaeogene (sandstones, claystones, conglomerates, breccias), 9 – Neogene sediments (clay, sand, sandstones, claystones, conglomerates), 10 – Neovolcanites (volcanic and volcanoclastic rocks), 11 – sources of mineral waters*

Better known are sources with hydrosilicatogenic mineralization; they are mainly medium-mineralized, carbonic (5 – 10 g . l$^{-1}$) waters in Šarišský Štiavnik ($Na\text{-}Ca\text{-}HCO_3$) and Malý Sulín ($Na\text{-}Ca\text{-}HCO_3$).

Source of mineral water with polygenic mineralization of the chemical type $Mg\text{-}SO_4\text{-}HCO_3$ represents cold strongly mineralized water in Zbudzský Rokytov with the yield of up to 0.1 l . s$^{-1}$.

*Fig. 1.2 Wellhead of borehole FPJ-1 Oravská Polhora – Slaná voda (Photo: Teťák, 2012, in Teťák et al., 2016)*

### 1.3.2 Mineral waters of the Klippen Belt

The Klippen Belt is formed by numerous carbonate blocks of Triassic, Jurassic and Early Cretaceous age, which are encompassed within the marly Cretaceous and Palaeogene layers. The best known are the cold carbonic sources of weakly mineralized water in Nimnica ($Na\text{-}HCO_3$) with yield around 2 l . s$^{-1}$. Sources of thermal and cold (21 °C) weakly mineralized waters are known in Belušské Slatiny ($Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$) with yield up to 10 l . s$^{-1}$. In addition to these better-known water sources there occur occasional cold sources of carbonated and sulphane very weakly to weakly mineralized waters of chemical type $Ca\text{-}Mg\text{-}HCO_3$, $Ca\text{-}Na\text{-}HCO_3$, $Ca\text{-}Mg\text{-}Na\text{-}SO_4$ with yield up to 0.1 l . s$^{-1}$.

### 1.3.3 Mineral waters of the Central Western Carpathians

Zone of the Central Western Carpathians is built of crystalline fundament cropping out in the Core mountains and envelope. The Core mountains are split from each other by intermountain Young Tertiary basin. Volcanic mountains and lowlands are located in the southern part of the territory of Slovakia. The mineral and thermal waters are the most abundant in this zone.

To Crystalline there are mainly bound cold carbonic very weakly mineralized waters of the chemical type $Ca\text{-}Mg\text{-}HCO_3$ with yield up to 0.1 l . s$^{-1}$. Among the well-known we can state Starý Smokovec ($Ca\text{-}Na\text{-}HCO_3$), Mýto pod Ďumbierom ($Na\text{-}HCO_3\text{-}Cl$) and Jasenie ($Ca\text{-}HCO_3$). In the Crystalline the wells GVL-1 (Vlachovo) and RS-1 (Čučma) with depth of 1,201.3 m/1,379.6 m documented water of chemical type $Na\text{-}HCO_3$ with a temperature of 19 °C or 25 °C (Franko & Snopko, 1979).

To the *Triassic carbonates* (limestone and dolomite) of different tectonic units there are bound almost all significant sources of cold and thermal waters, which are used for spa treatment, recreation or for filling in consumer packaging.

On *sedimentary Tatricum envelope* are bound weakly mineralized thermal water with sulphatogenic mineralization in Piešťany ($Ca\text{-}SO_4\text{-}HCO_3$) and Trenčianske Teplice ($Ca\text{-}SO_4$). The yield of these sources is ranging within 20 – 40 l . s$^{-1}$ and water temperature is in the range 40 – 68 °C. The source Trajan in Piešťany (Fig. 1.3) is a dug well with a depth of 8.4 meters, which is deepened by two hydrogeological wells with ø 400 mm to a depth of 11.2 meters (Krahulec et al., 1977). The maximum yield by pumping equals to 1,200 m$^3$ . day$^{-1}$ (13.9 l . s$^{-1}$). The Triassic carbonates of the Tatricum envelope binds also cold carbonated weakly mineralized waters in Baldovce ($Ca\text{-}Na\text{-}Mg\text{-}HCO_3\text{-}SO_4$), Slatina ($Ca\text{-}Mg\text{-}Na\text{-}HCO_3\text{-}SO_4$, $Ca\text{-}Mg\text{-}Na\text{-}HCO_3\text{-}Cl\text{-}SO_4$) and Korytnica ($Ca\text{-}Mg\text{-}SO_4\text{-}HCO_3$). Their yield is ranging within 1 – 4 l . s$^{-1}$ and water temperature in the range 4.5 – 16.5 °C (Franko & Melioris, 2000).

*Fig. 1.3 Dug well Trajan in Piešťany Spa (Photo: Marcin, 2008)*

On the *Krížna Nappe* there are bound mainly thermal weakly mineralized waters with prevailing sulphatogenic mineralization. They are extended at the northern edge and amidst the Central Slovak neovolcanites. The best known are waters of chemical type $Ca\text{-}Mg\text{-}SO_4\text{-}HCO_3$ in Sliač, Kováčová, Sklené Teplice, Kremnica and Chalmová. In Turčianske Teplice the water is of chemical type $Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$. Yield of the above sites is ranging

Tab. 1.3 Mineral waters of Slovakia in structure-facies zones of the Western Carpathians (Franko & Melioris, 2000)

| Structure--facies zones | RU | TU | MWO | TDS [g . l$^{-1}$] | | $CO_2$ [g . l$^{-1}$] | | $H_2S$ [g . l$^{-1}$] | | Q [l . s$^{-1}$] | | t [°C] | Chemical type water prevailing > 20 meq . l$^{-1}$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | min | max | min | max | min | max | min | max | max | |
| 1. Flysch Zone | | | CM | 0.5 | 2.6 | 0.2 | 1.2 | 0.0 | 16.0 | 0.02 | 0.5 | 14 | Ca-Mg-$HCO_3$<br>Ca-$HCO_3$ |
| | | | HSiM | 0.4 | 25.0 | 0.02 | 2.5 | 0.0 | 30.4 | 0.01 | 0.3 | | Na-Ca-$HCO_3$<br>Ca-Na-$HCO_3$ |
| | | | TM | 14.0 | 47.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.01 | 2.5 | 47 | Na-Cl |
| 2. Klippen Belt | | | CM | 0.5 | 3.2 | 0.0 | 1.7 | 0.0 | 4.4 | 0.07 | 10.0 | 21.5 | Ca-Mg-$HCO_3$-$SO_4$ |
| | | | CM | | | | | | | 0.01 | 2.1 | 11.0 | Na-$HCO_3$ |
| 3. Inner Carpathian Palaeogene | CR | | SiM | 0.1 | 9.6 | 0.0 | 1.6 | 0.0 | 8.5 | 0.01 | 2.4 | 10.4 | Ca-Mg-$HCO_3$<br>Na-$HCO_3$ |
| | MS | TCU | CM | 3.1 | 8.4 | 2.0 | 2.2 | **St. | **St. | 0.4 | 1.5 | 16.5 | Ca-Na-Mg-$HCO_3$-$SO_4$,<br>Ca-Na-Mg-$HCO_3$ |
| | | | SuM | 2.7 | 3.6 | 0.2 | 2.9 | 0.0 | 12.0 | 1.0 | 56.6 | 69.5 | Ca-Na-Mg-$SO_4$-$HCO_3$ |
| | | KN | CM | 1.5 | 3.9 | 0.01 | 1.7 | 0.0 | 4.0 | 0.9 | 47.5 | 45.0 | Ca-Mg-$HCO_3$-$SO_4$ |
| | | | SuM | 0.5 | 3.9 | 0.1 | 1.4 | <0.6 | <0.6 | 7.1 | 37.0 | 53.0 | Ca-Mg-$SO_4$-$HCO_3$ |
| | | ChN | CM | 0.7 | 3.5 | 0.07 | 2.2 | 0.0 | 1.7 | 0.5 | 71.2 | 48.0 | Ca-Mg-$HCO_3$, Ca-Mg-$HCO_3$-$SO_4$ |
| | CPg | | CM | 0.5 | 2.6 | 0.04 | 1.2 | 0.0 | 11 | 0.01 | 10.0 | 10.5 | Ca-Mg-$HCO_3$ |
| | | | HSiM | 0.6 | 0.7 | 0.02 | 0.03 | 3.2 | 16.6 | 0.04 | 0.2 | | Ca-Na-Mg-$HCO_3$,<br>Na-$HCO_3$ |
| | | | TM | 8.7 | 12.4 | 0.0 | 1.27 | 0.0 | 0.0 | 0.2 | 0.6 | | Na-Cl-$HCO_3$ |
| 4. Neogene, Neovolcanites | | | CM | 0.2 | 2.7 | 0.7 | 2.5 | 0.0 | 0.0 | 0.01 | 0.2 | 13.5 | Ca-Mg-$HCO_3$ |
| | | | SiM | 0.12 | 9.6 | 0.0 | 2.0 | 0.0 | 2.61 | 0.1 | 5.1 | 36.6 | Ca-Mg-Na-$HCO_3$,<br>Na-$HCO_3$ |
| | | | TM | 1.9 | 41.6 | 0.0 | 0.5 | 0.0 | 0.0 | 0.08 | 25.0 | 91.5 | Na-Cl-$HCO_3$,<br>Na-Cl |
| | | | HM | 9.5 | 292.0 | 0.04 | 0.8 | 0.0 | 0.0 | 0.2 | 2.0 | 16.8 | Na-Cl |
| Western Carpathians* | | | MM | 0.8 | 28.8 | 0.04 | 2.5 | 0.0 | 10.8 | 0.25 | 5.0 | 54.0 | Na-Ca-Mg-$HCO_3$-Cl-$SO_4$,<br>Na-$HCO_3$-Cl |
| | | | PM | 1.6 | 25.0 | 0.0 | 0.4 | 0.2 | 700 | 0.2 | 2.2 | 21.5 | Na-Ca-Mg-$SO_4$-$HCO_3$-Cl,<br>Na-Ca-Mg-$SO_4$-$HCO_3$<br>Na-Mg-$SO_4$ |

*Note:* ***Rock units /RU/:*** *CR – Crystalline rock, MS – Mesozoic sediments of Central Carpathians, CPg – Central Carpathians Palaeogene,*
***Tectonic units /TU/:*** *TCU – Tatricum Cover Unit, KN – Krížna Nappe, ChN – Choč Nappe,*
***Mineral waters accordance origin of chemical composition /MWO/: petrogenic mineralization*** *(CM – carbonatogenic dissolved solids, SuM – sulphatogenic dissolved solids, SiM – silicatogenic dissolved solids, HSiM – hydrosilicatogenic dissolved solids, HM – halitogenic dissolved solids, PM – polygenetic dissolved solids), TM* ***– thalassogenic mineralization****, MM –* ***mixed mineralization***
** – sources with mixed and polygenetic mineralization are distributed across the entire Western Carpathians, ** – traces of $H_2S$.*

within 4 – 40 l . s$^{-1}$ and water temperature in the range of 33 – 53 °C.

The carbonates of this Nappe bind thermal carbonic weakly mineralized water of chemical type Ca-Mg-$HCO_3$-$SO_4$ in Liptovský Ján, Vyšné Ružbachy, Banská Bystrica. The value of the yield of each site is within the range of 20 to 50 l . s$^{-1}$ and water temperature in the range of 20 – 45 °C. Source Kráter (Crater, Fig. 1.4) in Vyšné Ružbachy despite its name, has nothing to do with volcanic activity, but it is a karst-fissure spring. It has the character of a lake with travertine rim with a diameter of 20 m and a depth of 3 m. The yield reaches the value of 7.8 l . s$^{-1}$ (Krahulec et al., 1977).

In the basement of the Inner Carpathian Palaeogene in the northern Slovakia the wells Oravice OZ-1 and OZ-2 (Fig. 1.5), Plavnica PI-2, Poloma Šariš-1, Lipany L-1 and L-2 documented the presence of mineral water in the Mesozoic sediments of the Krížna Nappe close to the Klippen Belt. Drillings OZ-1 and OZ-2 were carried out to verify the presence of geothermal waters and wells (PI-2, Šariš-1, L-1 and L-2) in the north-eastern part of Slovakia aimed to verify the hydrocarbon potential of the area. The mentioned wells have documented the presence of both polygenetic mineral waters with mineralization in the Oravice area and also strongly carbonated mineral water mixed with mineralization in the north-eastern part

*Fig. 1.4 Karst-fissure spring "Kráter" in Spa Vyšné Ružbachy (Photo: Marcin, 2008)*

of Slovakia. Different chemical composition of water in these areas is due to nature of groundwater circulation and the remoteness of the remote catchment. While in the case of Oravice the infiltration area is close (about 2 km – NE slopes of the altitudinal point Osobitá), for the north-eastern part of Slovakia the aquifers do not crop out directly onto the surface of the potential catchment, but they are covered by sediments of Palaeogene. For potential area may be assumed the slopes of the Branisko Mts., which are located at a distance of approximately 10 – 15 kilometres.

Mineral waters of the Choč Nappe and higher units are typical of acratotherms presence (water with a very weak TDS and temperatures above 20 °C) of chemical type Ca-Mg-$HCO_3$. Well-known sources of this chemical type are in Rajecké Teplice, Bojnice, Malé Bielice. The Choč Nappe binds also thermal mineral waters with polygenetic mineralization of chemical type Ca-Mg-$HCO_3$-$SO_4$ in Kalinčiakovo and Vyhne. The yield of the sources in these areas reaches a value of 50 l . $s^{-1}$ and 10 l . $s^{-1}$. The water temperature ranges from 26 °C to 35 °C (Krahulec et al., 1977).

Besides the above waters the carbonates of the above units bind also carbonated weakly mineralized waters, e.g. in Trenčianske Mitice (Ca-Mg-$HCO_3$), Gánovce (Ca-Mg-$HCO_3$-$SO_4$) and Lipovce (Ca-Mg-$HCO_3$), Santovka (Ca-Mg-$HCO_3$) and Šafárikovo (Ca-Mg-$HCO_3$, Silica Nappe). Yield of the above waters is ranging within 1 – 15 l . $s^{-1}$ and water temperature in the range of 10 – 27 °C.

On carbonates of the Hungarian Central Highlands are bound waters of the sources in Patince (Ca-Mg-$HCO_3$) and Štúrovo (Ca-Mg-$HCO_3$-$SO_4$). The yield of the sources of these areas is ranging within 29 – 70 l . $s^{-1}$ and water temperature is in the range of 20 – 40 °C.

*Palaeogene sediments of the Inner Carpathian Palaeogene* overlay the older tectonic units of the Western Carpathians. These rocks of marine facies have a character of flysch turbidites, which constitute both the filling of Intermountain depressions, but also they build up mountains close to the Klippen Belt: Súľovské vrchy, Skorušinské vrchy, Levočské vrchy, Spišská Magura, Bachureň, Šarišská vrchovina Mts.

Mineral waters of the Inner Carpathian Palaeogene are linked to conglomerates and sandstones, and are similar to

*Fig. 1.5 Wellhead of borehole OZ-1 (left) and OZ-2 (right) Oravice (Photo: Marcin, 2013)*

waters of the Flysch Zone. Cold hydrogen sulphide very weakly mineralized waters of chemical type Ca-Mg-$HCO_3$ and Na-$HCO_3$ are in prevail, with yield up to 0.1 l . $s^{-1}$. In smaller quantities there are present cold carbonated low-mineralized water chemical type Ca-Mg-$HCO_3$ with similar yield. The most famous sources include Nová Ľubovňa (Ca-Mg-$HCO_3$, Ca-Mg-Na-$HCO_3$) with yield 10 l . $s^{-1}$. Also known are the sources of mineral water in Konská (Na-$HCO_3$), Slatvina (Ca-Mg-Na-$HCO_3$-Cl) and Vojkovce (Na-Mg-Ca-$HCO_3$-Cl) with yield do 0.1 l . $s^{-1}$.

### 1.3.4 Mineral waters of sedimentary Neogene

Neogene sediments fill up intermountain depressions and the Vienna, Danube, Southern and the East Slovakian Basins. Neogene mineral waters are tied to the position of the basal clastic rocks, sand and sandstone which alternate with pelites. Neogene mineral water sources are of the highest yield (10 – 20 l . $s^{-1}$) and the water temperature ranges from 40 to 90 °C. The waters are bound to sandy sediments of Dacian, Pontian and Pannonian of the Central Depression of the Danube Basin (Franko & Bodiš, 1989).

Depressions in Slovakia filled with Neogene sediments are characterized by hydrogeochemical zonation of mineral water in vertical and horizontal directions. In the near-surface zone and on the edges of the depressions there are present cold and thermal very weakly to weakly mineralized waters of chemical type Ca-Mg-$HCO_3$ (e.g. Diakovce borehole – Di-3, Dubové – Spring at Municipality Office, Hodejov – Kúpeľný prameň, Trubín – Medokýš, Horné Plachtince – Medokýš), Na-$HCO_3$ (e.g. Diakovce – borehole Di-1, Dolná Strehová – borehole M-4, Valaliky – KAH-5) and the same is valid also for chemical types Na-Ca-$HCO_3$, which attain a temperature of 22 °C and TDS 0.3 g . $l^{-1}$ (e.g. Dolná Strehová-Hámor – borehole S-107) or temperature of merely 12 °C and high TDS 8.5 g . $l^{-1}$ (Martin-Záturčie – Fatra). Change in the nature of mineral waters from Neogene depends on the depth and position of aquifers and their distance from the edge of the basin, but also on the presence of $CO_2$. Depthwards and more distant from the edge of the basin occur thermal moderately to strongly mineralized water of chemical type Na-Cl (Gbely – borehole at the swimming pool, Báhoň – borehole B-1, Dunajská Streda – borehole DS-1, Nesvady – borehole K-3, Nová Vieska – borehole NV-1, Číž – well Hygiea, Buzica – Slaný vrt). Sources with the highest yield (10 – 20 l . $s^{-1}$) and temperature (40 – 90 °C) have open sections in the sands of Dacian, Pontian and Late Pannonian of the Central Depression of the Danube Basin (Franko et al., 1989).

Sources of mineral waters of the sedimentary Neogene with halitogenic mineralization reach a value of TDS from 1.3 to 292 g . $l^{-1}$ (Plavecký Peter – sources Vajcovka, Prešov-Solivar – Leopold Shaft). The largest representation of mineral water with this kind of mine- ralization is located in the East Slovakian Basin, where Karpatian and Badenian sediments contain halite.

### 1.3.5 Mineral waters of neovolcanites

Complex of neovolcanic rocks builds up central part of Slovakia (Štiavnica, Stratovolcano, Stratovolcano in the Kremnické vrchy Mts., stratovolcanoes Poľana, Javorie, Lysec, Čelovce, eroded stratovolcanic relics from the area of Tisovec and Rimavská kotlina Basin) and in the eastern part of Slovakia it is a line of stratovolcanoes of the Slanské vrchy Mts. (stratovolcanoes Šebastovka, Zlatá Baňa, Makovica, Strechov, Bogota, Milič and Bradlo) and Vihorlat (stratovolcanoes Kyjov, Sokolský potok, Morské oko, Diel and Popriečny). Neovolcanite rocks complex is also involved in the sedimentary infill of the Žiarska kotlina Basin, Danube Basin and the East Slovakian Basin. In terms of abundance of mineral water the neovolcanites have the largest representation of resources from the central regions of Slovakia.

Mineral waters of Neovolcanites (Badenian andesites) were explored by deep wells in the Danube Basin (Rusovce – HGB-1, Šurany – S-1) with documented presence of mineral water of chemical type Na-Cl, TDS with 18.6 g . $l^{-1}$ and water temperature of 28 °C. Yield at the collar was 0.1 l . $s^{-1}$ (Bondarenková et al., 1977). Geological exploration well S-1 in Šurany reached the andesite tuffs and andesites at a depth of 1,750 – 2,700 m and documented the presence of mineral water of chemical type Na-Cl with TDS 32.5 g . $l^{-1}$.

In the Banská Štiavnica the 910 m deep borehole documented flow of mineral water of chemical type Na-Ca-$SO_4$-$HCO_3$, which had the TDS of 2.4 g . $l^{-1}$ and water temperature of 46 °C (Remšík et al., 2007). Inflow of mineral water occurred from altered vein filling in andesites.

On the western outskirts of Žiarska kotlina Basin and the Vtáčnik mountain range with a presence of faults of the N-S direction 8 carbonic mineral water springs have been documented. In Bukovina there are three springs of mineral water of chemical type Ca-Mg-$HCO_3$ with TDS of 1.4 g . $l^{-1}$ to 3.4 g . $l^{-1}$. North of the village Dolná Ždaňa surges mineral water of chemical type Ca-Mg-Na-$HCO_3$ in four springs and one well. The TDS of the water amounts to 0.6 g . $l^{-1}$ to 0.9 g . $l^{-1}$. West of Zvolen is spring Červený medokýš whose carbonated mineral water is of chemical type Na-Ca-Mg-$HCO_3$ with TDS of 2.7 g . $l^{-1}$ and $CO_2$ content of 2.5 g . $l^{-1}$. Yield of mineral springs is usually up to 0.1 to 0.2 l . $s^{-1}$, rarely as in the case of the resources in the Medokýš in Dolná Ždaňa it can reach 0.5 l . $s^{-1}$ (Krahulec et al., 1978).

## 1.4 Characteristics of mineral waters aquifers

Aquifers of mineral waters in Slovakia are characterized by lithological and age diversity, reflecting the geological and tectonic setting of the Western Carpathians.

In the individual structural-facies zones of the Western Carpathians in Slovakia there are aquifers, which are located in such a position and having a hydraulic characteristics that are favourable conditions for the accumulation of mineral waters. The amount of mineral waters concentrated in the accumulation area of individual structures of mineral waters is, firstly, depending upon the very nature of the hydrogeological structure (open, closed), secondly it also depends on the extent of the aquifers, the thickness and depth of the deposit.

### 1.4.1 Aquifers of mineral waters in the Flysch Zone

The Flysch Zone is characterized by the presence of aquifers with dominant fissure permeability. The lowermost unit, whose aquifer has been documented by means of boreholes, was Obidowa-Słopnice-Zboj unit which in the territory of Slovakia was encountered in four wells Oravská Polhora FPJ-1, Zborov Z-1, Smilno S-1, Zboj-1 in the basement of the Magura Nappe. Zboj tectonic breccias and sandstones constitute the principal aquifer of the mineral waters which have been documented in this unit. Hydraulic parameters of this aquifer were obtained only from the well-FTJ 1 where the value of transmissivity coefficient T = 3.87 . $10^{-7}$ $m^2$ . $s^{-1}$ (Zakovič et al., 2009).

In the Magura Nappe the most important aquifers of mineral water are Magura formation of the Krynica lithofacies-tectonic unit, Tvarožec Sandstone in the subsoil of Bialowieza Fm. of the Bystrica lithofacies-tectonic unit and Zlín Fm. (Makovica sandstone) of the Rača lithofacies-tectonic unit.

The Magura Fm. (Čergov Mb. – mostly sandstone facies) builds bulk of the Čergov Mts. and there were realized 23 hydrogeological wells here. Of these, 4 hydrogeological drillings verified the near-surface zone of disintegration (depth of wells up to 50 meters). Estimated coefficient of transmissivity T reached 1.28 . $10^{-5}$ to 2.84 . $10^{-4}$ $m^2$ . $s^{-1}$. Hydrogeological massif was documented by 19 wells. The depth of these wells ranged from 100 to 205 meters. The length of the open sections ranged from 38.1 m to 165 m. The lower part of the open section of wells was located at a depth of 75 m to 187 m from the ground surface. The upper part of the open section was located at a depth of 5.9 m to 20 m from the ground surface. Estimates of the coefficient of transmissivity T reached 5.64 . $10^{-5}$ to 1.59 . $10^{-3}$ $m^2$ . $s^{-1}$. The estimate of the coefficient of transmissivity for the near-surface zone of the hydrogeological massif Čergov has lower values compared to the hydrogeological massif. In the drillings verifying the hydrogeological massif decline was observed in measuring the yield of individual wells with their increasing depth and increasing length of the open section (Marcin et al., 2005).

Makovica and Tvarožec sandstones are characterized by the fact that the hydrogeological drillings carried out in these complexes have the highest transmissivity coefficient T in a zone of intense disturbance along the tectonic lines and near-surface zone of disintegration of sandstone complexes up to a depth of 100 m. The geological environment of this nature reaches a value of T 9.8 . $10^{-4}$ $m^2$ . $s^{-1}$ to 9.1 . $10^{-3}$ $m^2$ . $s^{-1}$. With increasing depth of wells the disturbance of hydrogeological massif fades out along with the value of transmissivity coefficient (Zakovič in Nemčok et al., 1990).

### 1.4.2 Aquifers of mineral waters in the Klippen Belt

The Klippen Belt is characterized by the occurrence of more resistant, especially limestone cliffs – klippens, protruding from the generally less resistant marly flysch strata forming Klippen envelope. The Klippen Belt consists of several units that were thrust over each other and from the North these are: Czorsztyń unit, Kysucká unit, Pruské unit, Klapy unit, Orava unit, Manín unit.

Aquifers of mineral waters in this zone are Jurassic limestones (Czorsztyń radiolarian limestone) and limestones of Jurassic to Cretaceous (crinoidal limestone, Pieniny limestone, Rogoznica Mb. Gregorian breccia). In the Klippen Belt of the Ľubovnianska vrchovina Highlands these sediments were assessed using hydro-chemical method on 12 in descending sources at estimated aquifer thickness of the near-surface zone of 50 m. Due to the nature of the ground (karst-fissure permeability) this estimate of the average coefficient of transmissivity should be taken only indicatively. According to this analogy, the interval of estimated coefficient of transmissivity T is from 1 . $10^{-4}$ $m^2$ . $s^{-1}$ to 3 . $10^{-4}$ $m^2$ . $s^{-1}$ (Jetel, 1999).

Sedimentary envelope of the Klippen Belt in the Čergov Mts. was evaluated based on seven hydrogeological wells. Of these wells three wells have verified Proč and Jarmuta Palaeogene formations in near-surface zone of disintegration (within 50 meters) and four wells the hydrogeological massif. Estimates of the coefficient of transmissivity for the near-surface zone of disintegration reached T from 1.58 . $10^{-5}$ to 1.74 . $10^{-4}$ $m^2$ . $s^{-1}$. The depth of exploration wells verifying the hydrogeological massif ranged from 100 m to 133 m. The length of the open section ranged from 81.30 m to 123 m. The lower part of the open section of the wells was located at a depth of 100 m to 133 m from the ground surface. The upper part of the open section was located at a depth of 7.0 m to 10 m from the ground surface. Estimates of the coefficient of transmissivity reached from T 1.11 . $10^{-5}$ to 2.60 . $10^{-4}$ $m^2$ . $s^{-1}$ (Marcin et al., 2005).

The Upohlava Fm. of the Klapy unit of the Klippen Belt made up of calcareous sandstones, marlstones and claystones of Albian to Cenomanian was documented by shallow wells in the area of Nosice – Nimnica. The estimated coefficient of transmissivity of these wells was of the order T = 2.8.$10^{-7}$ $m^2$ . $s^{-1}$. Hydrogeological wells with a depth of 160-662 meters verify faulted zones of the Upohlava Fm with mineral water, the value of TDS ranged from 3,741 to 3,960 mg . $l^{-1}$ and water temperature was from 11 °C to 12 °C. The coefficient of transmissivity in these wells T reached from 4.7 . $10^{-6}$ to 9.38 . $10^{-5}$ $m^2$ . $s^{-1}$. During hydrodynamic tests the following yields/drawdowns were documented: Q = 0.15 l . $s^{-1}$/s = 54 m; 1.0 l . $s^{-1}$/s = 32 m; 2.3 l . $s^{-1}$/s = 34 m (Urban et al., 1962; Rebro et al., 1978; Rebro et al., 1989).

### 1.4.3 Aquifers of mineral waters in zone of the Central Western Carpathians

Central Western Carpathians zone is made up of aquifers, which are located in the crystalline, Triassic carbonates of the tectonic units and Inner Carpathian Palaeogene.

The *crystalline rocks* do not contain significant mineral water aquifers although at several sites their sources are present. The most favourable conditions for accumulation of cold mineral water can be found on the tectonic zones of regional character (e.g. Sub-Tatric Fault, Čertovica Line).

For the crystalline rocks of the Central Western Carpathians the presence of mineral water with temperatures exceeding 20 °C is not typical, so it was a little surprise when the implementation of structural geological wells in Spiš-Gemer Ore Mountains detected their presence. During the implementation of wells GVL-1 (Vlachovo) and RS-1 (Čučma) with depth of 1,201.3/1,379.6 meters waters were documented of chemical type $Na\text{-}HCO_3$ with a temperature of 19 °C or 25 °C. Inflows of thermal nitrogen poorly mineralized water into the well GVL-1 were located at depths of 701 m, 723 m in the zone of metasomatic limestone surrounded by phyllites of the Gelnica Series. In the borehole RS-1 the inflows of very weakly mineralized water were met in the depth interval of 565-647 m in the contact of greisen zone with the phyllites of the Gelnica Series underlain by a granitoid body. Yield at the collar of the borehole GVL-1 stabilized at 2.15 l . $s^{-1}$ and at the borehole RS-1 at 1 l . $s^{-1}$. Static water pressure at the well head GVL-1 reached the value 0.6 MPa and in the borehole RS-1 it was 0.3 MPa. Based on these results a new hydrogeochemical province of mineral water – nitrogen acratotherms of the Spiš-Gemer Ore Mts. (Franko & Snopko, 1979) has been allocated in the Central Western Carpathians. Metasomatic limestones surrounded by phyllites of the Gelnica Series documented in the borehole GVL-1 had a value of transmissivity coefficient $T = 1.15 . 10^{-3}$ $m^2 . s^{-1}$.

*Triassic carbonates* (limestone and dolomite) of different tectonic units represent significant aquifers, to which cold and thermal waters are bound. Mineral water sources identified in these rock complexes achieved relatively high yield and belong along with the sources documented in the Neogene sediments among the most important in terms of productivity. Given the nature of the Triassic sediments (limestones and dolomites) in each nappe the following aquifers can be distinguished.

*In the sedimentary envelope of the Tatricum* unit major aquifers are Gutenstein and Ramsau Dolomites. *In the Křížna Nappe* the most *important* aquifers are Gutenstein Limestone, Ramsau Dolomite and Haupt Dolomite in the overlying Lunz Mb. The aquifers *of the Choč Nappe and higher units* are represented by Gutenstein Limestone, Ramsau Dolomite, Reifling Limestone, Wetterstein Limestone, Haupt Dolomite in the overlying Lunz Mb., Dachstein Limestone. *The Silica Nappe* as one of the higher units contains the aquifers represented Guteinstein Limestone, Steinalm Limestone, Schreyeralm Limestone, Wetterstein Limestone, Tisovec Limestone, Hallstatt Limestone, Dachstein Limestone. Hydraulic parameters of hydrogeological units in Slovakia have been processed through the wells database. Of this database 25,323 hydrogeological boreholes were involved, which enabled to obtain data on the reinterpretation 16,729 pumping tests. Group of the Mesozoic sediments contained 767 pumping tests (Malík et al., 2007). The values of the coefficient of transmissivity and filtration of the Triassic carbonates, without distinction of tectonic affiliation documents Tab. 1.4. Among those assessed drillings were mostly shallow wells and fewer consisted of data from deep wells.

Transmissivity coefficient values were obtained from the hydrodynamic tests in deep wells in promising geothermal areas of Slovakia. Documented aquifers parameters for mineral waters are listed in the Tab. 1.5. The total number of wells was 147 and 141 of them identified presence of mineral waters and provided information on the nature of the hydrogeological aquifer. Of these, data are available from 77 wells documenting Mesozoic sediments, 58 wells of Neogene sediments and two wells of Neovolcanites complexes. Transmissivity coefficient values were available from 56 wells verifying the Mesozoic sediments, the 49 Neogene sediments and 2 the Neovolcanites complexes.

Mesozoic carbonates in Slovakia are the most important aquifers of mineral waters, delivering a geometric mean of transmissivity coefficient $G(T) = 9.08 . 10^{-4}$ $m^2 . s^{-1}$ at standard deviation of log value $\sigma \log T = 0.90$ (Tab. 1.6). In terms of classification Krásný (1993) these aquifers attain a moderate transmissivity (Class III) and very high variability (Class E), which represents very significantly non-uniform geological environment. Drillings carried out in the environment of Mesozoic carbonates are also reported to reach relatively large yields (Md Q = 12.4 l . $s^{-1}$/Mn Q = 19.4 l . $s^{-1}$); the most productive is the borehole OZ-2 in *Oravice* (Q = 100 l . $s^{-1}$ Tab. 1.5).

The highest value of transmissivity coefficient T for Mesozoic carbonates in terms of wells has been documented in the Upper Nitra Basin (Chalmová – HCH-1), Rimavská kotlina Basin (Tornaľa – HM-5) and Žilinská kotlina Basin (Stráňavy – HZK-1). In evaluating the aquifers of each prospective geothermal areas of Slovakia based on the value T among the all wells of the areas (condition over 3 wells in the area) as Upper Nitra Basin, Komárno high block and Rimavská kotlina Basin appear to be the most favourable. Drillings carried out within these areas are mainly located in the discharge areas of the hydrogeological structures and the obtained data of the of the transmissivity coefficient T exhibit considerable variability. Their depth ranged from 158 m to 600 m (Tab. 1.7).

The lowest value of the transmissivity coefficient T for Mesozoic carbonates in terms of wells has been documented in the Topoľčany Embayment and Bánovská kotlina Basin (Topo*ľč*any – FGTz-1) of the Central Neovolcanites – NW part (Lukavica – LKC-4) and Liptovská kotlina Basin (Pavčina Lehota – FGL-1). In evaluating the aquifers of each prospective geothermal area of Slovakia on the basis of available data of the transmissivity coefficient T of all the wells the least favourable appears the Komárno marginal block, Liptovská kotlina Basin, Topoľčany Embayment and Bánovská kotlina Basin (Tab. 1.7). Drillings carried out in these areas were located mainly in the accumulation zones of the hydrogeological structures, except for Bešeňová boreholes, Malé and Veľké Bielice.

*Inner Carpathian Palaeogene sediments* in Slovakia are located around the Klippen Belt area; from the west, they comprise Myjava-Hričov Group. Its sedimentation was followed by Sub-Tatric Group. Aquifers of mineral waters in the Myjava-Hričov Group is the Súľov Fm. In the Sub-Tatric Group – Orava-Podhale section there are

Tab. 1.4 Values of standard specific capacities and geometric means ***G(T)*** and ***G(K)*** of derived values of transmissivity and hydraulic conductivity coefficients, calculated for different aquifer types in Slovakia (Malík et al., 2007)

| No. | Description | Origin and classification | Group | n | M[$^1$q] | Md[$^1$q] | G[T] | σ log T | G[K] |
|---|---|---|---|---|---|---|---|---|---|
| **83** | Cellular dolomites, dolomitic breccias, rauhwackes | Tectonically reduced carbonate rocks | MZ | 6 | 0.309 | 0.372 | 5.53 . 10$^{-4}$ | 0.51 | 4.05 . 10$^{-6}$ |
| **84** | Metamorphic limestones, carbonates | Metamorphic sediments of Triassic | MZ | 5 | 0.603 | 0.331 | 9.32 . 10$^{-4}$ | 0.66 | 8.47 . 10$^{-6}$ |
| **85** | Limestones, quartzitic limestones, nodular limestones, limestones with cherts | Sediments of Middle and Late Triassic | MZ | 34 | 1.622 | 3.236 | 3.52 . 10$^{-3}$ | 0.81 | 1.91 . 10$^{-4}$ |
| **86** | Sandstones, shales, variably beds or intercalations of limestones, dolomites, evaporites, metatuffs, silicites | Sediments of Middle and Late Triassic | MZ | 20 | 0.234 | 0.182 | 3.41 . 10$^{-4}$ | 0.93 | 1.34 . 10$^{-5}$ |
| **87** | Limestones | Sediments of Middle and Late Triassic | MZ | 238 | 0.339 | 0.407 | 6.19 . 10$^{-4}$ | 1.06 | 1.06 . 10$^{-5}$ |
| **88** | Limestones and dolomitic limestones, dolomites | Sediments of Middle and Late Triassic | MZ | 3 | 24.547 | 40.738 | 4.64 . 10$^{-2}$ | 0.47 | 6.00 . 10$^{-4}$ |
| **89** | Dolomites | Sediments of Middle and Late Triassic | MZ | 438 | 0.575 | 0.589 | 1.04 . 10$^{-3}$ | 0.86 | 2.37 . 10$^{-5}$ |
| **90** | Dolomites with intercalations of shales | Sediments of Middle and Late Triassic | MZ | 23 | 0.724 | 0.676 | 1.43 . 10$^{-3}$ | 0.71 | 2.57 . 10$^{-5}$ |

*Explanation of abbreviations:* ***n*** *– number of interpreted hydraulic tests on hydrogeological boreholes and wells;* ***M($^1$q)*** *– arithmetic mean of the standard specific capacity* ***$^1$q*** *[l . s$^{-1}$ . m$^{-1}$];* ***Md($^1$q)*** *– median value of the standard specific capacity* ***$^1$q***; ***G(T)*** *– geometrical mean of the transmissivity coefficient* ***T*** *[m$^2$ . s$^{-1}$];* ***σ log T*** *– standard deviation of the transmissivity coefficient logarithm values;* ***G(K)*** *– geometrical mean of the hydraulic conductivity coefficient* ***K*** *[m . s$^{-1}$];* ***MZ*** *– group of Mesozoic sediments.*

Borové and Biely Potok formations and in the Spiš-Šariš section it is Šambron Mb. In southern Slovakia, between Kravany and Štúrovo extend the Palaeogene sediments of Buda facies protrude from the south, which overlay the carbonates of the Hungarian Central Highlands. These sediments together with Cretaceous sediments form an insulator for Triassic carbonate aquifers of the Komárno block (Brodňan & Nemsilová, 1960).

Hydraulic parameters of the aquifers Inner Carpathian Palaeogene and Buda Palaeogene were evaluated in the Slovak territory through the database of hydrogeological wells, from which data were available on the pumping tests. Group sediments of the Inner Carpathian and Buda Palaeogene involved 703 pumping tests (Malík et al., 2007). The transmissivity coefficient and coefficient of hydraulic conductivity values of the above sediments documents Tab. 1.8. Among those assessments were used mostly shallow wells and fewer were obtained from deep wells.

Most famous sources of mineral waters are in the Inner Carpathian Palaeogene of the Ľubovňa Spa at Nová Ľubovňa and in Malé and Veľké Bielice near Partizánske. Originally, in the Ľubovňa Spa there were located 5 sources of mineral carbonic water that reached yield of 0.1 l . s$^{-1}$ (Krahulec, 1978). Larger quantities of mineral water have been obtained by realization of hydrogeological well LZ-6 in the area of the spring (Zakovič et al., 1993). The borehole reached a depth of 176.1 m and verified inflows of mineral water from graded-bedded coarse-grained sandstones of the Šambron Mb. in the interval from 17.0 to 21.0 m – Q = 1.0 to 1.5 l . s$^{-1}$, and in the interval from 96.0 to 111.0 m – Q = 22 l . s$^{-1}$. After the final incorporation of the borehole there followed a three-month trial, which documented an average yield of 11.4 l . s$^{-1}$ with a water temperature of 9 °C. Water from this source started to be bottled (Zakovič et al., 2006).

Hydrogeological drillings MB-1 (Malé Bielice) and VB-3 (Veľké Bielice) encountered the thermal water in the discharge area in the elevation of the fundament. Wells with a depth of 160 m and 102 m verified Palaeogene breccias of the Borové Fm. The value of transmissivity coefficient T in these sediments was 2.81 . 10$^{-3}$ m$^2$ . s$^{-1}$ and 3.11 . 10$^{-3}$ m$^2$ . s$^{-1}$, which significantly exceeds the value of G (T) = 3.58 . 10$^{-4}$ m$^2$ . s$^{-1}$ obtained from the evaluation of 60 pumping tests.

### 1.4.4 Aquifers of mineral waters in sedimentary Neogene

Neogene sediments in Slovakia are significant aquifers, delivering a geometric mean of the transmissivity coefficient G (T) = 5.35 . 10$^{-4}$ m$^2$ . s$^{-1}$ at standard deviation σ log T = 0.51 (Tab. 1.9). In terms of classification by Krásný (1993) the aquifers are of moderate transmissivity (Class III) and higher variability (Class C), which represents rather inhomogeneous geological environment. Drillings carried out in an environment in Neogene sediments achieved relatively balanced yields (10.0 l . s$^{-1}$ – Mn Q = 10.5 l . s$^{-1}$), the most productive are the wells FGG-2 and FGG-3 in Galanta (Q = 25 l . s$^{-1}$).

The highest value of transmissivity coefficient T for the Neogene sediments among the wells has been documented in the Central Depression of the Danube Basin (Veľký Meder – C-2), Diakovce – Di-3, Želiezovce – HGŽ-1). The wells with the highest documented values

Tab. 1.5 Deep boreholes verifying the parameters of mineral water aquifers in Slovakia

| Locality | Borehole | Year of realization | Deep of borehole [m] | Open interval of borehole [m] | Age of aquifer | Lithology of aquifer | Yield [$l . s^{-1}$] | T [$m^2 . s^{-1}$] | Temperature at well head [°C] | Heat power [MWt] | TDS [$g . l^{-1}$] | Chemical water type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Central Depression of the Danube Basin | | | | | | | | | | | | |
| Rusovce | HGB-1 | 1974 | 1,493 | 1,067-1,493 | Badenian | andesites | 0.1 | $1.14.10^{-5}$ | 28 | - | 18.6 | Na-Cl |
| Chorvátsky Grob | FGB-1 | 1974 | 1,232 | 971-1,150 | Badenian | base clastics | 1.9 | $4.17.10^{-5}$ | 47 | 0.26 | 1.9 | Na-Cl-$HCO_3$ |
| Chorvátsky Grob | FGB-1/A | 1975 | 500 | 276-299 | Pontian | sands | 3.5 | $1.43.10^{-4}$ | 24 | 0.13 | 0.5 | Na-Mg-Ca-$HCO_3$ |
| Kráľová pri Senci | FGS-1 | 1974 | 810 | 430-570 | Pontian | sands | 0.3 | $8.47.10^{-5}$ | 23 | 0.01 | 3.6 | Na-Mg-$HCO_3$ |
| Kráľová pri Senci | FGS-1/A | 1974 | 1,500 | 910-1,370 | Pontian-Pannonian | sands | 13 | $3.52.10^{-4}$ | 52 | 2.01 | 7.7 | Na-$HCO_3$-Cl |
| Kráľová pri Senci | VMK-1 | 1992 | 804.5 | 439-572.5; 601-784 | Pontian | sands | 1.2 | $1.5.10^{-4}$ | 30 | 0.07 | 2.8 | Na-Mg-HCO3 |
| Senec | BS-1 | 1981 | 1,350 | 928-1,181 | Pontian | sands | 12 | $7.88.10^{-4}$ | 49 | 1.71 | 2.5 | Na-$HCO_3$-Cl |
| Topoľníky | FGT-1 | 1975 | 2,501 | 1,394-2,487 | Pontian | sands | 23 | $1.6.10^{-3}$ | 74 | 5.68 | 2.2 | Na-$HCO_3$-Cl |
| Čilistov | FGČ-1 | 1979 | 2,500 | 1,195-1,549 | Pannonian | sandstones | 15 | $1.99.10^{-3}$ | 52 | 2.32 | 6.9 | Na-$HCO_3$-Cl |
| Dvory nad Žitavou | FGDŽ-1 | 1980 | 2,500 | 1,024-1,607 | Pontian | sands | 7.2 | $4.71.10^{-4}$ | 62 | 1.42 | 3.4 | Na-$HCO_3$-Cl |
| Sládkovičovo | FGG-1 | 1975 | 1,990 | 1,212-1,670 | Pontian | sands | 10.8 | $5.14.10^{-4}$ | 62 | 2.13 | 3.2 | Na-$HCO_3$-Cl |
| Galanta | FGG-2 | 1983 | 2,100 | 1,706-2,032 | Pannonian | sands | 25 | $2.3.10^{-3}$ | 80 | 6.8 | 4.9 | Na-$HCO_3$-Cl |
| Galanta | FGG-3 | 1984 | 2,102 | 1,731-1,999 | Pannonian | sands | 25 | $4.85.10^{-4}$ | 77 | 6.49 | 5.9 | Na-$HCO_3$-Cl |
| Tvrdošovce | FGTv-1 | 1978 | 2,406 | 1,362-1,637 | Pontian | sands | 20 | $3.79.10^{-4}$ | 70 | 4.6 | 2.5 | Na-$HCO_3$ |
| Horná Potôň | FGHP-1 | 1978 | 2,500 | 1,394-1,804 | Pontian | sands | 20 | $1.2.10^{-3}$ | 68 | 4.43 | 4.7 | Na-Cl-$HCO_3$ |
| Horná Potôň | VHP-12-R * | 1987 | 2,100 | 1,380-1,832 | Pontian | sands | 22.3 | $1.7.10^{-3}$ | 68 | 4.94 | 4.3 | Na-$HCO_3$-Cl |
| Dunajská Streda | DS-1 | 1971 | 2,500 | 2,183-2,432 | Pontian | sands | 15.2 | $2.42.10^{-4}$ | 91 | 5.82 | 6.9 | Na-Cl-$HCO_3$ |
| Dunajská Streda | DS-2 | 1985 | 1,600 | 1,190-1,549 | Dacian-Pontian | sands | 23 | $2.83.10^{-3}$ | 55 | 3.85 | 1.6 | Na-$HCO_3$ |
| Čiližská Radvaň | ČR-1 | 1986 | 2,513 | 1,614-2,430 | Pontian-Pannonian | sands | 6 | $3.76.10^{-4}$ | 82 | 3.3 | 1.6 | Na-$HCO_3$-Cl |
| Čiližská Radvaň | VČR-16 | 1990 | 1,800 | 1,390-1,745 | Pontian | sands | 14.5 | $1.26.10^{-3}$ | 64 | 2.93 | 0.8 | Na-$HCO_3$ |
| Zlaté Klasy – Eliášovce | VZK-10 | 1987 | 1,800 | 1,331-1,457 | Pontian | sands | 12.5 | $7.72.10^{-4}$ | 65 | 2.6 | 8.3 | Na-Cl-$HCO_3$ |
| Veľký Meder | Č-1 | 1972 | 2,502 | 1,573-1,791 | Pontian | sands | 10 | $1.11.10^{-4}$ | 79 | 2.59 | 1.1 | Na-$HCO_3$ |
| Veľký Meder | Č-2 | 1983 | 1,503 | 1,037-1,439 | Pontian | sands | 18.2 | $6.93.10^{-3}$ | 57 | 3.2 | 0.9 | Na-$HCO_3$ |
| Šaľa | HTŠ-1 | 1982 | X | | | | $0.2^{+}$ | | 22 | | | |
| Šaľa | HTŠ-2 | 1983 | 1,200 | 880-1,169 | Pontian | sands | 3.1 | $3.0.10^{-4}$ | 42 | 0.36 | 1.5 | Na-$HCO_3$ |
| Šaľa | HTŠ-3 | 1983 | 290 | 73-282 | Dacian | sands | $5^{+}$ | $5.5.10^{-4}$ | 18 | 0.06 | 0.5 | Na-$HCO_3$ |
| Šaľa | GTŠ-1 | 2010 | 1,800 | 1,481-1,786 | Pannonian | sands, sandstones | $15^{+}$ | $6.04.10^{-4}$ | 69 | 3.39 | 4.9 | Na-$HCO_3$-Cl |
| Poľný Kesov | BPK-1 | 1980 | 847 | 387-737 | Neogene | sands | 1 | $1.44.10^{-4}$ | 26 | 0.15 | 1.1 | Na-Ca-$HCO_3$ |

| Locality | Borehole | Year of realization | Deep of borehole [m] | Open interval of borehole [m] | Age of aquifer | Lithology of aquifer | Yield [l . s$^{-1}$] | T [m$^2$. s$^{-1}$] | Temperature at well head [°C] | Heat power [MWt] | TDS [g . l$^{-1}$] | Chemical water type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Poľný Kesov | BPK-2 | 1981 | 1,200 | 1,089-1,189 | Neogene | sands | 4 | $9.21.10^{-5}$ | 49 | 0.6 | 1.8 | Na-$HCO_3$ |
| Lehnice | BL-1 | 1985 | 1,500 | 1,031-1,455 | Dacian-Pontian | sands | 23.2 | $2.1.10^{-3}$ | 54 | 3.78 | 2.2 | Na-$HCO_3$ |
| Diakovce | Di-1 | 1962 | 3,303 | 720-810 | Pontian-Pannonian | sands | 4 | | 38 | 0.39 | 0.5 | Na-$HCO_3$ |
| Diakovce | Di-2 | 1982 | 1,551 | 1,416-1,536 | Pontian-Pannonian | sands | 12 | $1.7.10^{-3}$ | 68 | 2.66 | 2.1 | Na-$HCO_3$-Cl |
| Diakovce | Di-3 | 1983 | 306 | 215-275 | Dacian | sands | 15 | $5.0.10^{-3}$ | 19 | 0.25 | 0.6 | Ca-Na-$HCO_3$ |
| Vlčany | FGV-1 | 1982 | 2,500 | 1,244-1,852 | Pontian | sands | 10 | $1.8.10^{-4}$ | 68 | 2.22 | 2.1 | Na-$HCO_3$ |
| Gabčíkovo | FGGa-1 | 1982 | 2,582 | 1,122-1,926 | Pontian | sands | 10 | $2.01.10^{-3}$ | 52 | 1.64 | 1.1 | Na-$HCO_3$ |
| Boheľov | GBP-1 ** | 1982 | 2,800 | - | - | - | - | | - | - | - | - |
| Ňárad (Topoľovec) | VTP-11 | 1988 | 2,500 | 1,533-2,482 | Pontian-Pannonian | sands | 14.6 | $7.50.10^{-4}$ | 74 | 3.6 | 1.2 | Na-$HCO_3$-Cl |
| Zlatná na Ostrove | VZO-13 | 1990 | 1,650 | 1,089-1,625 | Pontian-Pannonian | sands | 7.5 | $2.8.10^{-4}$ | 51 | 1.25 | 7.5 | Na-Cl |
| Zemianska Olča | VZO-14 | 1990 | 1,849 | 1,555-1,839 | Pontian | sands | 10 | $3.2.10^{-4}$ | 74 | 2.51 | 2.7 | Na-$HCO_3$-Cl |
| Dunajský Klátov | VDK-15 | 1990 | 2,240 | 1,425-2,222 | Pontian-Pannonian | sands | 15.4 | $5.80.10^{-4}$ | 74 | 3.75 | 2.4 | Na-$HCO_3$-Cl |
| Nové Zámky | GNZ-1 | 1983 | 1,506 | 1,236-1,473 | Pontian | sands | 4.5 | $2.69.10^{-4}$ | 59 | 0.83 | 3.2 | Na-$HCO_3$-Cl |
| Nesvady | GN-1 | 2008 | 1,505 | 1,283-1,494 | Pontian | sands, sandstones | 2.7 | $1.36.10^{-4}$ | 60 | 0.5 | 2.9 | Na-$HCO_3$ |
| Šurany | GŠM-1 | 1989 | 1,500 | 892-1,400 | Pontian | sands | 3.5 | $2.2.10^{-4}$ | 49 | 0.5 | 3 | Na-Cl-$HCO_3$ |
| Komárno | M-2 | 1971 | 1,060 | 771-1,025 | Pontian-Pannonian | sands | $4.5^{+}$ | | 42 | 0.51 | 3.9 | Na-$HCO_3$-Cl |
| Komárno | FGK-1 | 1976 | 1,970 | 904-1,082 | Pontian-Pannonian | sands | 4 | $9.2.10^{-5}$ | 45 | 0.5 | 2 | Na-$HCO_3$-Cl |
| Sereď | SEG-1 | 2011 | 1,800 | 1,505-1,779 | Pannonian | sandstones | $9^{+}$ | $2.11.10^{-4}$ | 66 | 1.94 | 5.1 | Na-$HCO_3$-Cl |
| Komárno high block | | | | | | | | | | | | |
| Patince | SB-1 | 1959 | 226 | 130-160 | Triassic | limestones | 29.1 | | 26 | - | 0.7 | Ca-Mg-$HCO_3$ |
| Patince | SB-2 | 1972 | 160 | 129-146 | Lias-Triassic | limestones | 45 | | 27 | 2.26 | 0.7 | Ca-Mg-$HCO_3$ |
| Patince | SB-3 | 1982 | 170 | 132-167 | Triassic | limestones | 29.4 | | 26 | 1.35 | 0.7 | Ca-Mg-$HCO_3$ |
| Virt | JRD | 1973 | 260 | | Triassic | limestones, dolomites | 6.6 | | 26 | 0.3 | 0.7 | Ca-Mg-$HCO_3$ |
| Virt | HVB-1 | 1973 | 241 | 139-233 | Triassic | limestones, dolomites | $10^{+}$ | $2.76.10^{-3}$ | 26 | 0.46 | 0.7 | Ca-Mg-$HCO_3$ |
| Virt | vrt VŠE | 1976 | 280 | 155-263 | Triassic | limestones, dolomites | $18.3^{+}$ | $2.07.10^{-4}$ | 24 | 0.69 | 0.7 | Ca-Mg-$HCO_3$ |
| Štúrovo | FGŠ-1 | 1975 | 210 | 77-128 | Triassic | dolomitic limestones | 70 | $2.56.10^{-2}$ | 40 | 7.33 | 0.8 | Ca-Mg-$HCO_3$-$SO_4$ |
| Štúrovo | VŠ-1 | 1988 | 125 | 65-113 | Triassic | dolomites, limestones | 49 | $1.36.10^{-2}$ | 39 | 4.86 | 0.7 | Ca-Mg-$HCO_3$-$SO_4$ |
| Obid | FGO-1 | 1979 | 1,000 | 736-1,000 | Triassic | dolomites, limestones | 2.1 | $5.0.10^{-3}$ | 20 | 0.05 | 0.8 | Ca-Mg-$HCO_3$ |
| Kravany | FGKr-1 | 1979 | 1,021 | 723-920 | Triassic | dolomites, limestones | 5.5 | $2.04.10^{-4}$ | 20 | 0.12 | 0.8 | Ca-Mg-$HCO_3$ |
| Komárno marginal block | | | | | | | | | | | | |
| Komárno | M-1 | 1967 | 1,221 | 1,140-1,221 | Mesozoic | limestones, dolomites | 1.6 | | 42 | 0.18 | 2.2 | Na-Ca-Mg-$SO_4$-$HCO_3$-Cl |

| Locality | Borehole | Year of realization | Deep of borehole [m] | Open interval of borehole [m] | Age of aquifer | Lithology of aquifer | Yield [$l . s^{-1}$] | T [$m^2 . s^{-1}$] | Temperature at well head [°C] | Heat power [MWt] | TDS [$g . l^{-1}$] | Chemical water type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Komárno | M-3 | 1976 | 1,184 | 1,139-1,184 | Jurassic, Triassic | dolomitic limestones | 5 | $1.4.10^{-4}$ | 51 | 0.75 | 3.1 | Ca-Na-Mg-$SO_4$-Cl-$HCO_3$ |
| Komárno | FGK-1 | 1976 | 1,970 | 1,696-1,964 | Triassic | limestones, dolomites | 3.3 | $1.5.10^{-4}$ | 64 | 0.67 | 2.9 | Ca-Na-Mg-$SO_4$-Cl |
| Marcelová | GTM-1 | 1987 | 1,763 | 1,037-1,761 | Neogene, Triassic | conglomerates, limestones | 6 | $1.7.10^{-4}$ | 56 | 1.02 | 90 | Na-Cl |
| Levice block | | | | | | | | | | | | |
| Podhájska | Po-1 | 1973 | 1,900 | 1,155-1,740 | Badenian, Triassic | conglomerates, limestones | 53 | | 80 | 14.42 | 19.6 | Na-Cl |
| Podhájska | GRP-1* | 1986 | 1,470 | 995-1,365 | Badenian, Triassic | conglomerates, dolomites, limestones | 28 | $1.97.10^{-3}$ | 69 | 6.32 | 19.2 | Na-Cl |
| Dubník Depression | | | | | | | | | | | | |
| Bruty | VTB-1 | 1990 | 1,927 | 1,599-1,905 | Badenian | sandstones, conglomerates | $15^{+}$ | | 75 | 2.4 | 30 | Na-Cl |
| Svätý Peter | PTG-11 | 1990 | 1,856 | 972-1,321 | Neogene | sand | 6 | | 50 | 0.88 | 5.3 | Na-Cl |
| Želiezovce | HGŽ-1 | 1972 | 350 | 100-234 | Neogene | sands, sandstones | $13.5^{+}$ | $3.05.10^{-3}$ | 18 | 0.17 | 1.6 | Na-Ca-$HCO_3$ |
| Želiezovce | HGŽ-3 | 1990 | 916 | 342-900 | Badenian | clastics | $1.5^{+}$ | | 52 | 0.25 | 10 | Na-$SO_4$-Cl |
| Komjatice Depression | | | | | | | | | | | | |
| Komjatice | G-1 | 1989 | 1,830 | 1,509-1,700 | Pannonian | sands, sandstones | 12 | | 78 | 2.5 | 20.1 | Na-Ca-Cl-$HCO_3$ |
| Topoľčany embayment and Bánovce Basin | | | | | | | | | | | | |
| Malé Bielice | MB-3 | 1974 | 160 | 80-100 | Palaeogene | carbonatic breccias | 8.5 | $2.81.10^{-3}$ | 40 | 0.89 | 1.1 | Ca-Mg-$HCO_3$ |
| Veľké Bielice | VB-3 | 1983 | 102 | 27-90 | Palaeogene | carbonatic breccias | $8.3^{+}$ | $3.11.10^{-3}$ | 39 | 0.83 | 0.8 | Ca-Mg-$HCO_3$ |
| Brodzany | HGT-9 | 1982 | 160 | 133-139 | Triassic | carbonates | $1.7^{+}$ | $1.16.10^{-4}$ | 32 | 0.12 | 1.5 | Ca-Mg-$HCO_3$-$SO_4$ |
| Topoľčany | FGTz-1 | 1985 | 2,106 | 1,512-1,917 | Triassic | carbonates | $2.0^{+}$ | $6.70.10^{-6}$ | 55 | 0.33 | 5.9 | Na-$HCO_3$-$SO_4$ |
| Partizánske | FGTz-2 | 2004 | 998 | 401-970 | Triassic | dolomites, limestones | $12.5^{+}$ | $3.55.10^{-3}$ | 33 | 0.94 | 0.7 | Ca-Mg-$HCO_3$ |
| Partizánske | HGTP-1 | 2000 | 500 | 265-474 | Triassic | carbonates | $18.8^{+}$ | $7.83.10^{-3}$ | 20 | 0.37 | 0.7 | Ca-Mg-$HCO_3$ |
| Bánovce nad Bebravou | BnB-1 | 1984 | 2,025 | 2,000-2,025 | Triassic | dolomites | $17^{+}$ | $6.37.10^{-5}$ | 40 | 1.78 | 0.7 | Ca-Mg-$HCO_3$-Cl |
| Trnava embayment | | | | | | | | | | | | |
| Koplotovce | KB-1 | 1976 | 118 | 78-108 | Triassic | dolomites | 14.5 | $6.87.10^{-3}$ | 24 | 0.55 | 2.52 | Ca-Mg-$HCO_3$-$SO_4$ |
| Piešťany embayment | | | | | | | | | | | | |
| Nové Mesto nad Váhom-Zelená Voda | GZV-1 | 2008 | 1,206 | 985-1,155 | Mesozoic | carbonates | 10 | $1.82.10^{-4}$ | 19.4 | 0.18 | 1.41 | Mg-Ca-$SO_4$ |
| Vienna Basin | | | | | | | | | | | | |
| Šaštín-Stráže | RGL-2 | 1983 | 2,605 | 2,005-2,570 | Eggenburgian, Triassic | conglomerates, limestones | 12 | $2.61.10^{-4}$ | 73 | 2.91 | 10.9 | Na-Cl |

| Locality | Borehole | Year of realization | Deep of borehole [m] | Open interval of borehole [m] | Age of aquifer | Lithology of aquifer | Yield [l . s$^{-1}$] | T [m$^2$ . s$^{-1}$] | Temperature at well head [°C] | Heat power [MWt] | TDS [g . l$^{-1}$] | Chemical water type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lakšárska Nová Ves | RGL-1 | 1984 | 2,100 | 1,242-2,065 | Eggenburgian, Triassic | conglomerates, limestones | 25 | $2.58.10^{-3}$ | 78 | 6.59 | 6.8 | Na-Ca-Cl-$SO_4$ |
| Ilava Basin | | | | | | | | | | | | |
| Belušské Slatiny | BHS-3 | 1990 | 1,761 | - | - | - | - | | - | - | - | - |
| Žilina Basin | | | | | | | | | | | | |
| Rajec | RK-22 | 1974 | 1,308 | 1,064-1,308 | Triassic | carbonates | 22 | | 26 | 0.6 | 0.5 | Ca-Mg-$HCO_3$ |
| Stráňavy | HŽK-2 | 1990 | 600 | 335-500; 500-559 | Palaeogene--Triassic | sandstones, dolomites | 22 | $3.03.10^{-2}$ | 24 | 0.84 | 0.4 | Ca-Mg-$HCO_3$-$SO_4$ |
| Kamenná Poruba | RTŠ-1 | 1991 | 1,831 | 1,370-1,830 | Triassic | carbonates | 13.4 | $7.3.10^{-4}$ | 42 | 1.51 | 0.5 | Ca-Mg-$HCO_3$ |
| Žilina | HŽK-10 | 1993 | 2,258 | - | - | - | - | | - | - | - | - |
| Horná Nitra Basin | | | | | | | | | | | | |
| Laskár | Š-1-NB II | 1980 | 1,851 | 1,677-1,851 | Triassic | carbonates | 22 | $2.78.10^{-3}$ | 59 | 4.08 | 0.8 | Ca-Na-Mg-$HCO_3$-$SO_4$ |
| Chalmová | BCH-3 | 1983 | 150 | 30-120 | Triassic | carbonates | $5.0^{+}$ | | 39 | 0.5 | 1.9 | Ca-Mg-$SO_4$-$HCO_3$ |
| Chalmová | HCH-1 | 1992 | 200 | 50-194 | Triassic | carbonates | $13.4^{+}$ | $9.25.10^{-2}$ | 33 | 1.01 | 1.3 | Ca-Mg-$SO_4$-$HCO_3$ |
| Handlová | FGHn-1 | 2002 | 475 | 370-430 | Palaeogene-Triassic | breccias, dolomites | $2.5^{+}$ | | 19 | 0.05 | 0.4 | Ca-Mg-$HCO_3$ |
| Handlová | RH-1 | 2010 | 1,201 | 862-1,179 | Permian-Mesozoic | sandstones, carbonates | $15^{+}$ | $2.02.10^{-4}$ | 37.5 | 1.41 | 1.06 | Ca-Mg-$SO_4$-$HCO_3$ |
| Turiec Basin | | | | | | | | | | | | |
| Turčianske Teplice | TTK-1 | 1977 | 56 | 46-56 | Mesozoic | carbonates | 3.5 | | 27 | 0.18 | 1.5 | Ca-Mg-$HCO_3$-$SO_4$ |
| Diviacky Háj | HM-2 | 1989 | 403 | 90-140 | Mesozoic | carbonates | $4^{+}$ | $5.68.10^{-3}$ | 42 | 0.45 | 1.6 | Ca-Mg-$HCO_3$-$SO_4$ |
| Diviacky Háj | TTŠ-1 | 1988 | 1,503 | 810-1,124 | Triassic | carbonates | 12.4 | | 54 | 2.02 | 2.5 | Ca-Mg-$HCO_3$-$SO_4$ |
| Martin | ZGT-3 | 1990 | 2,461 | - | - | - | - | | - | - | - | - |
| Skorušina Basin | | | | | | | | | | | | |
| Oravice | OZ-1 | 1979 | 600 | 342-561 | Triassic | dolomites | 35 | $3.21.10^{-3}$ | 28 | 1.09 | 0.8 | Ca-$HCO_3$ |
| Oravice | OZ-2 | 1991 | 1,601 | 950-1,565 | Triassic | dolomites | 100 | $3.08.10^{-3}$ | 56 | 17.2 | 1.3 | Ca-Mg-$HCO_3$ |
| Liptov Basin | | | | | | | | | | | | |
| Pavčina Lehota | FGL-1 | 1977 | 2,129 | 1,315-1,570 | Triassic | carbonates | $6^{+}$ | $3.19.10^{-5}$ | 32 | 0.43 | 0.5 | Mg-Ca-$HCO_3$-$SO_4$ |
| Bešeňová | ZGL-1 | 1987 | 1,987 | 1,540-1,987 | Triassic | dolomites | 27 | $1.16.10^{-4}$ | 62 | 5.3 | 3 | Ca-Mg-$SO_4$-$HCO_3$ |
| Bešeňová | FBe-1 | 2006 | 400 | | | | 5.4 | | 25 | 0.23 | 3.6 | Ca-Mg-$HCO_3$-$SO_4$ |
| Bešeňová | FGTB-1 | 2011 | 1,833 | 1,623-1,814 | Mesozoic | carbonates | 32 | | 66 | 6.83 | 3 | Ca-Mg-$SO_4$-$HCO_3$ |
| Liptovská Kokava | ZGL-3 | 1990 | 2,373 | 1,475-2,365 | Triassic | carbonates | $20^{+}$ | $1.82.10^{-3}$ | 43 | 2.39 | 4.4 | Ca-Mg-$HCO_3$-$SO_4$ |
| Liptovský Trnovec | ZGL-2/A | 1992 | 2,500 | 1,624-2,486 | Triassic | carbonates | 31 | $1.02.10^{-3}$ | 60 | 5.18 | 4.7 | Ca-Na-Mg-$HCO_3$-$SO_4$ |

| Locality | Borehole | Year of realization | Deep of borehole [m] | Open interval of borehole [m] | Age of aquifer | Lithology of aquifer | Yield [l . s$^{-1}$] | T [m$^2$. s$^{-1}$] | Temperature at well head [°C] | Heat power [MWt] | TDS [g . l$^{-1}$] | Chemical water type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Levoča Basin W and S part | | | | | | | | | | | | |
| Vrbov | Vr-1 | 1982 | 1,742 | 1,493-1,734 | Triassic | dolomites | 28.3 | $2.40.10^{-3}$ | 56 | 4.86 | 4 | $Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$ |
| Vrbov | Vr-2 | 1989 | 2,502 | 1,539-1,983 | Triassic | carbonates | 33 | $6.38.10^{-4}$ | 59 | 6.08 | 4 | $Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$ |
| Letanovce | HKJ-4 | 1989 | 607 | 408-589 | Triassic | carbonates | 8 | $8.80.10^{-4}$ | 25 | 0.33 | 0.6 | $Ca\text{-}Mg\text{-}HCO_3$ |
| Arnutovce | HKJ-3 | 1990 | 1,133 | 489-1,133 | Triassic | carbonates | 11.8 | $1.40.10^{-3}$ | 31 | 0.79 | 1.4 | $Ca\text{-}Mg\text{-}HCO_3$ |
| Poprad | PP-1 | 1994 | 1,205 | 634-1,128 | Triassic | dolomites | 61.2 | $6.54.10^{-3}$ | 48 | 6.6 | 2.8 | $Ca\text{-}Mg\text{-}SO_4\text{-}HCO_3$ |
| Stará Lesná | FGP-1 | 1995 | 3,616 | 1,431-2,092 | Triassic | dolomites | 22 | $5.41.10^{-4}$ | 58 | 3.95 | 3.2 | $Ca\text{-}Mg\text{-}HCO_3$ |
| Veľký Slavkov | VSČ-1 | 2007 | 2,400 | 1,877-2,353 | Mesozoic | dolomites, limestones | 27 | $3.10.10^{-4}$ | 57 | 4.75 | 3.5 | $Ca\text{-}Mg\text{-}HCO_3$ |
| Danišovce | DH-1 | 1997 | 1,000 | 800-1000 | Permian, Mesozoic | breccias, sandstones, shales | - | | - | - | - | - |
| Veľká Lomnica | GVL-1 | 2006 | 2,100 | | Triassic | carbonates | 35 | | 62 | 6.88 | | |
| Levoča Basin NE part | | | | | | | | | | | | |
| Plavnica | Pl-1 | 1988 | 3,500 | 2,306-3,360 | Palaeogene, Triassic | sandstones, carbonates | 5 | | 65 | 12 | 10 | Na-Cl |
| Plavnica | Pl-2 | 1989 | 3,500 | 2,500-3,010 | Palaeogene, Triassic | sandstones, carbonates | 4 | | 53 | 0.57 | 12.3 | Na-Cl |
| Lipany | L-1***** | 1978 | 4,000 | 3,184-3,390 | Triassic | dolomites | 10 | $1.87.10^{-4}$ | 85 | 2.93 | 9.4 | $Na\text{-}HCO_3\text{-}Cl\text{-}SO4$ |
| Lipany | L-2 | 1981 | 3,500 | 3,176-3,245 | Triassic | dolomites | 4.5 | | 51 | 0.68 | 8.7 | Na-Cl |
| Košice Basin | | | | | | | | | | | | |
| Valaliky | KAH-3 | 1976 | 190 | 158-171 | Neogene | sandy clay | $7.2^{+}$ | $7.27.10^{-4}$ | 21 | 0.18 | 2.2 | Na-Cl |
| Valaliky | KAH-5 | 1976 | 160 | 124-148 | Neogene | gravels, sands | $14.3^{+}$ | $1.19.10^{-3}$ | 21 | 0.36 | 0.7 | $Na\text{-}HCO_3$ |
| Šebastovce | KAH-6 | 1976 | 164 | 45-149 | Neogene | gravels, sands | $10^{+}$ | $2.44.10^{-3}$ | 18 | 0.12 | 3.6 | $Na\text{-}Ca\text{-}Cl\text{-}HCO_3$ |
| Košice | G-4 | 1982 | 310 | 72-273 | Triassic-Permian | dolomites, palaeoandesites | $4.9^{+}$ | $1.91.10^{-3}$ | 26 | 0.22 | 4.5 | $Na\text{-}Ca\text{-}Mg\text{-}HCO_3\text{-}Cl$ |
| Ďurkov | GTD-1 | 1998 | 3,210 | 2,109-3,155 | Triassic | dolomites | 56 | $2.09.10^{-4}$ | 125 | 25 | 30 | Na-Cl |
| Ďurkov | GTD-2*** | 1998 | 3,151 | 2,600-3,104 | Triassic | dolomites | 50 | $1.34.10^{-4}$ | 129 | 24 | 30 | Na-Cl |
| Ďurkov | GTD-3*** | 1999 | 2,252 | 2,223-2,246 | Triassic | dolomites | 65 | | 123 | 29 | 31 | Na-Cl |
| Humenne ridge | | | | | | | | | | | | |
| Sobrance | TMS-1 | 1975 | 823 | 487-625 | Neogene | sands. sandstones | 4 | $3.80.10^{-4}$ | 29 | 0.25 | 11.9 | $Ca\text{-}Na\text{-}Cl\text{-}SO_4$ |
| Kaluža | GTH-1 | 2005/2013 | 600/940.1 | 454-594; 600-836; 847-938 | Mesozoic | dolomites, limestones | $4^{+}$ | $4.15.10^{-5}$ | 39.4 | 0.41 | 13.9 | Na-Cl |
| Central Slovakian Neogene volcanics NW part | | | | | | | | | | | | |
| Kremnica | KŠ-1**** | 1976 | 531 | 476-531 | Mesozoic | carbonates | 23.2 | $7.71.10^{-4}$ | 47 | 3.1 | 1.5 | $Ca\text{-}Mg\text{-}SO_4\text{-}HCO_3$ |
| Vyhne | H-1 | 1967 | 92 | 19-78 | Triassic | limestones, dolomites | 5 | $5.73.10^{-3}$ | 36 | 0.44 | 1.1 | $Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$ |

| Locality | Borehole | Year of realization | Deep of borehole [m] | Open interval of borehole [m] | Age of aquifer | Lithology of aquifer | Yield [l . s$^{-1}$] | T [m$^2$. s$^{-1}$] | Temperature at well head [°C] | Heat power [MWt] | TDS [g . l$^{-1}$] | Chemical water type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vyhne | HGV-3 | 2009 | 64 | 46-54 | Mesozoic | limestones | 5.5 $^{+}$ | 2.05.10$^{-2}$ | 29 | 0.32 | 0.9 | Ca-$HCO_3$ |
| Zlatno | R-3 | 1975 | 710 | 660-710 | Neogene, Triassic | palaeoandesites, dolomites | 10 | | 35 | 0.84 | 5 | Ca-Mg-$SO_4$-$HCO_3$ |
| Lukavica | LKC-4 | 1980 | 876 | 792-851 | Triassic | carbonates | 10 | 1.68.10$^{-5}$ | 35 | 0.8 | 0.4 | Ca-Mg-$HCO_3$ |
| Sklené Teplice | ST-4 | 1981 | 1,820 | 1,453-1,695 | Triassic | carbonates | 16 | 2.51.10$^{-4}$ | 57 | 3 | 2.6 | Ca-$SO_4$-$HCO_3$ |
| Sklené Teplice | ST-5 | 1987 | 1,001 | 800-1,001 | Triassic | dolomites | 4.4 $^{+}$ | 2.15.10$^{-4}$ | 46 | 0.57 | 2.7 | Ca-Mg-$SO_4$-$HCO_3$ |
| Sielnica | KMV-1 | 2004 | 417 | 353-407 | Mesozoic | limestones | 3 | 7.74.10$^{-3}$ | 33 | 0.23 | 2.2 | Ca-$SO_4$ |
| Topoľčianky | KD-1 | 1984 | 500 | 404-500 | Triassic | dolomites | 3.5 | | 27 | 0.17 | 4.5 | Ca-Mg-$SO_4$-$HCO_3$ |
| Žiar nad Hronom | RGŽ-2 | 2000 | 2,500 | - | - | - | - | | - | - | - | - |
| Central Slovakian Neogene volcanics SE part | | | | | | | | | | | | |
| Kalinčiakovo | HBV-1 | 1968 | 80 | 15-70 | Triassic | limestones | 25 $^{+}$ | | 25 | 1.05 | 1 | Ca-Mg-$HCO_3$-$SO_4$ |
| Kalinčiakovo | HBV-2a | 1968 | 65 | 11 to 49 | Triassic | limestones | 11.1 $^{+}$ | | 25 | 0.46 | 1 | Ca-Mg-$HCO_3$-$SO_4$ |
| Santovka | B-3A | 1998 | 73 | 45-64 | Badenian | sandstones, lithothamnium limestones | 15.5 | | 26 | 0.71 | 5.7 | Ca-Mg-$HCO_3$ |
| Banská Štiavnica | HR-1 | 2005 | 910 | 748-829 | Neogene | andesites, altered veins filling | 12.5 $^{+}$ | 5.13.10$^{-4}$ | 46 | 1.62 | 2.4 | Na-Ca-$SO_4$-$HCO_3$ |
| Horné Strháre − Trenč Graben | | | | | | | | | | | | |
| Dolná Strehová | M-4 | 1956 | 520 | 520 | Neogene | sand | 2.5 | | 35.4 | 0.21 | 0.4 | Na-$HCO_3$ |
| Dolná Strehová | HGDŠ-1 | 1985 | 625 | 593-615 | Neogene | sand | 0.15/4.0 $^{+}$ | 8.85.10$^{-4}$ | 35.2 | 0.09/0.34 | 0.4 | Na-$HCO_3$ |
| Slovenské Kľačany | TSK-1 | 1991 | 600 | 500-560; 581-587 | Neogene | sand | 2 | 1.70.10$^{-3}$ | 38 | 0.2 | 0.7 | Na-$HCO_3$ |
| Vinica | HG-18 | | 320 | | Neogene | sand | 10 | | 21 | 0.25 | 3.1 | Na-$HCO_3$ |
| Lučenec Basin – Rapovce structure | | | | | | | | | | | | |
| Rapovce | GTL-2 | 2007 | 1,501 | 957-1,439 | Triassic | carbonates | 11.2 | 5.24.10$^{-4}$ | 38 | 1.04 | 12.6 | Na-$HCO_3$ |
| Rimava Basin | | | | | | | | | | | | |
| Bátka | RKZ-1 | 1989 | 658 | 435-658 | Triassic | carbonates | - | | - | - | - | - |
| Tornaľa | HM-5 | 1973 | 158 | 155-157.5 | Triassic | limestones | 45 | 5.86.10$^{-2}$ | 18 | 0.56 | 1.8 | Ca-$HCO_3$ |
| Cakov | BČ-3 | 1984 | 876 | 489-874 | Triassic | carbonates | 3.3 | 1.74.10$^{-4}$ | 29 | 0.19 | 5.9 | Ca-Mg-$HCO_3$ |
| Rimavské Janovce | GRS-1 | 2003 | 2,020 | 767-1,008 | Triassic | carbonates | 10.5 $^{+}$ | 2.41.10$^{-4}$ | 33 | 1.01 | 1.7 | Ca-Mg-$HCO_3$ |
| Ivanice | FGRk-1 | 2007 | 1,050 | 618-1,050 | - | - | - | | - | - | - | - |
| Lučenec Basin – Rapovce structure | | | | | | | | | | | | |
| Rapovce | GTL-2 | 2007 | 1,501 | 957-1,439 | Triassic | carbonates | 11.2 | 5.24.10$^{-4}$ | 38 | 1.04 | 12.6 | Na-$HCO_3$ |

*Note: $^{*}$ – re-injection borehole, ** – geothermal observation borehole, $^{***}$ – oblique well (perforated section corresponds to the length, not the depth), $^{****}$ borehole developed from adit. $^{*****}$ – structural-geological borehole, adapted in 2006 – 2008 as geothermal borehole, now 3,400 m deep, $^{+}$ – yield at pumping, $^{X}$ – collapsed borehole.*

of the coefficient of transmissivity contained greater share of sandy component, which deposited on the slope of the subsiding basin and finer particles of the pelitic component were deposited to larger distance from the basin edge. In evaluating the aquifers of each prospective geothermal area of Slovakia based on the T value (condition over 3 wells in the area) the Košická kotlina Basin seems to be the most favourable, followed by the Central Depression of the Danube Basin (Tab. 1.7). The drillings carried out in the Košická kotlina Basin were mainly located in the area of predominance of sand deposits transported by the then Hornád palaeoflow. The drillings in the Central Depression of the Danube Basin are distributed across the whole area with different proportion of sandy component. The depth of the wells in the Košická kotlina Basin ranges from 160 m to 190 m, while in the Central Depression the borehole depths are ranging from 290 m to 3,303 m and Md of the wells depth is 1,800 m.

The lowest value of the transmissivity coefficient T for Neogene sediments in the wells has been documented in the Central Depression of the Danube Basin – W and SE edge (Chorvátsky Grob – FGB-1) Strháre-Trenč Graben (Slovenské Kľačany – TSK-1) and Humenné Ridge (Sobrance – TNS-1).

The Neogene sediments (sands, sandstones, conglomerates) of the Western Carpathians have got an important position in the process of the mineral waters formation and their accumulation. First, they are aquifers of significant thicknesses in the basins and depressions, and secondly they were often deposited directly upon the Mesozoic basement of the Central and Inner Carpathians. This way, the basal clastics of Neogene together contribute to the genesis of the mineral waters of the Vienna Basin and Levice block. This fact is the best documented by sources of mineral water along the Levice-Turovce thermal Springs Line that stretches with the length of about 20 km. On this line surge out the mineral waters of varied chemical composition with very different content of $CO_2$, at many places this phenomenon is accompanied by deposition of travertine. The function of horst in all its length changes due to its gradual subsidence, but also due to a change in the nature of Mesozoic sediments. The Neogene sediments that overlay the western part of the Horst, are Sarmatian in age (tuffaceous siltstones and claystones) and in the

Tab. 1.6 The transmissivity coefficient for Mesozoic aquifers in Slovakia verified by deep boreholes

| **Age of aquifer** | **Lithology of aquifer** | | **Yield [l . s$^{-1}$]** | **T [m$^2$ . s$^{-1}$]** | **Temperature at well head [°C]** | **Heat power [MWt]** | **TDS [g . l$^{-1}$]** |
|---|---|---|---|---|---|---|---|
| Mesozoic | carbonates | n | 77 | 56 | 77 | 76 | 76 |
| | | Min | 1.6 | 6.70 . 10$^{-6}$ | 18.0 | 0.1 | 0.4 |
| | | Max | 100.0 | 9.25 . 10$^{-2}$ | 129.0 | 29.0 | 90.0 |
| | | Md | 12.4 | 8.26 . 10$^{-4}$ | 39.0 | 0.9 | 1.8 |
| | | Mn | 19.4 | 5.87 . 10$^{-3}$ | 44.7 | 3.3 | 5.5 |
| | | G | 12.3 | 9.08 . 10$^{-4}$ | 40.1 | 1.2 | 2.2 |
| | | σ / σ log T | 19.0 | 0.90 | 23.1 | 5.7 | 11.9 |

*Note: **t** – transmissivity coefficient, **n** – count of boreholes, **Min** – minimum value, **Max** – maximum value, **Md** – median, **Mn** – arithmetic mean, **G** – geometrical mean,* σ *– standard deviation,* σ log T *– standard deviation of the transmissivity coefficient logarithm values, **TDS** – total dissolved solids*

Tab. 1.7 Values of geometric means of coefficient of transmissivity and standard deviation of the transmissivity coefficient logarithm values, calculated for different aquifer types of perspective geothermal areas in Slovakia

| **Perspective geothermal area** | **Type of aquifer** | **n** | **G(T)** | **σ log T** |
|---|---|---|---|---|
| Komárno marginal block | C | 3 | 1.53 . 10$^{-4}$ | 0.04 |
| Liptovská kotlina Basin | C | 4 | 2.88 . 10$^{-4}$ | 0.82 |
| Central Depression of the Danube Basin | N | 43 | 5.27 . 10$^{-4}$ | 0.57 |
| Topoľčany embayment and Bánovská kotlina Basin | C | 7 | 5.32 . 10$^{-4}$ | 1.16 |
| Košická kotlina Basin – carbonates | C | 3 | 3.77 . 10$^{-4}$ | 0.62 |
| Košická kotlina Basin – Neogene sediments | N | 3 | 1.28 . 10$^{-3}$ | 0.26 |
| Central Slovakian Neogene volcanics NW part | C | 7 | 9.37 . 10$^{-4}$ | 1.08 |
| Levočská kotlina Basin W and S part | C | 7 | 1.11 . 10$^{-3}$ | 0.44 |
| Rimavská kotlina Basin | C | 3 | 1.35 . 10$^{-3}$ | 1.42 |
| Komárno high block | C | 6 | 2.42 . 10$^{-3}$ | 0.9 |
| Upper Nitra Basin | C | 3 | 3.73 . 10$^{-3}$ | 1.33 |

*Note: **C** – Mesozoic carbonates with karst-fissure permeability, **N** – Neogene sediments with intergranular permeability, **n** – count of boreholes, **G(T)** – geometrical mean of the transmissivity coefficient **T** [m$^2$ . s$^{-1}$]; **σ log T**– standard deviation of the transmissivity coefficient logarithm values;*

Tab. 1.8 Values of standard specific capacities and geometric means of derived values of transmissivity and hydraulic conductivity coefficients, calculated for aquifers of the Inner Carpathian Palaeogene & Buda Palaeogene sediments in Slovakia (Malík et al., 2007)

| No. | Description | Origin and classification | Group | n | M[1q] | Md[1q] | G[T] | σ log T | G[K] |
|---|---|---|---|---|---|---|---|---|---|
| **58** | Calcareous siltstones and claystones, occasionally with coal intercalations | Shallow sea sediments of the Buda Palaeogene | PG | 116 | 0.054 | 0.068 | $1.15 . 10^{-4}$ | 0.92 | $4.66 . 10^{-6}$ |
| **59** | Sands, marly and calcareous sands, decomposed sandstones and siltstones | Shallow sea sediments of the Buda Palaeogene | PG | 16 | 0.126 | 0.141 | $3.44 . 10^{-4}$ | 0.56 | $1.29 . 10^{-5}$ |
| **60** | Gravels, decomposed conglomerates | Shallow sea sediments of the Buda Palaeogene | PG | 3 | 0.151 | 0.120 | $1.40 . 10^{-4}$ | 0.25 | $1.34 . 10^{-5}$ |
| **61** | Claystones, calcareous claystones and marls and layers with overwhelming claystones/ marlstones over sandstones, including menilite layers | Marine sediments of Inner Carpathian Palaeogene | PG | 127 | 0.107 | 0.117 | $1.73 . 10^{-4}$ | 0.81 | $1.39 . 10^{-5}$ |
| **62** | Claystone flysch – flysch with prevailing claystones or marlstones | Flysch sediments of Inner Carpathian Palaeogene and Late Cretaceous | PG | 7 | 0.010 | 0.012 | $9.60 . 10^{-6}$ | 0.57 | $4.70 . 10^{-7}$ |
| **63** | Normal flysch – claystones/marls, siltstones | Flysch sediments of Inner Carpathian Palaeogene and Late Cretaceous | PG | 220 | 0.102 | 0.102 | $1.49 . 10^{-4}$ | 0.77 | $1.11 . 10^{-5}$ |
| **64** | Sandstone flysch – flysch with prevailing sandstones | Flysch sediments of Inner Carpathian Palaeogene and Late Cretaceous | PG | 13 | 0.120 | 0.100 | $1.21 . 10^{-4}$ | 0.65 | $5.51 . 10^{-6}$ |
| **65** | Conglomerate flysch – flysch with prevailing conglomerates | Flysch sediments of Inner Carpathian Palaeogene and Late Cretaceous | PG | 4 | 0.158 | 0.178 | $3.94 . 10^{-4}$ | 0.62 | $2.06 . 10^{-5}$ |
| **66** | Sandstones with thin intercalations of claystones | Flysch sediments of Inner Carpathian Palaeogene and Late Cretaceous | PG | 120 | 0.123 | 0.145 | $2.02 . 10^{-4}$ | 0.74 | $7.92 . 10^{-6}$ |
| **67** | Multicomponent conglomerates and breccias, variably with beds of sandstones | Sea sediments and subaqueous slides of Inner Carpathian Palaeogene | PG | 17 | 0.068 | 0.078 | $7.70 . 10^{-5}$ | 0.80 | $3.68 . 10^{-6}$ |
| **68** | Calcareous breccias and conglomerates, sandy limestones, and limestones, variably with beds of sandstones, occasionally also marlstones | Sea sediments of Inner Carpathian Palaeogene and Late Cretaceous | PG | 60 | 0.251 | 0.209 | $3.58 . 10^{-4}$ | 0.99 | $1.58 . 10^{-5}$ |

*Explanation of abbreviations:* ***n*** *– number of interpreted hydraulic tests on hydrogeological boreholes and wells;* ***M(¹q)*** *– arithmetic mean of the standard specific capacity* ***¹q*** *[l . s⁻¹ . m⁻¹];* ***Md(¹q)*** *– median value of the standard specific capacity* ***¹q****;* ***G(T)*** *– geometrical mean of the transmissivity coefficient* ***T*** *[m² . s⁻¹]; σ log* **T** *– standard deviation of the transmissivity coefficient logarithm values;* ***G(K)*** *– geometrical mean of the hydraulic conductivity coefficient* ***K*** *[m . s⁻¹];* ***PG*** *– group of Palaeogene sediments.*

Tab. 1.9 Characteristics of the Neogene sedimentary aquifers verified through deep boreholes

| Age of aquifer | Lithology of aquifer | | Yield [l . s⁻¹] | T [m² . s⁻¹] | Temperature at well head [°C] | Heat power [MWt] | TDS [g . l⁻¹] |
|---|---|---|---|---|---|---|---|
| Neogene | sediments | n | 58 | 49 | 58 | 57 | 58 |
| | | Min | 0.3 | $4.17 . 10^{-5}$ | 18.0 | 0.01 | 0.4 |
| | | Max | 25.0 | $6.93 . 10^{-3}$ | 91.0 | 6.8 | 30.0 |
| | | Md | 10.0 | $5.14 . 10^{-4}$ | 52.0 | 1.6 | 2.6 |
| | | Mn | 10.5 | $1.02 . 10^{-3}$ | 52.1 | 1.9 | 4.2 |
| | | G | 7.7 | **$5.35 . 10^{-4}$** | 47.4 | 1.0 | 2.6 |
| | | σ / σ log T | 6.9 | 0.51 | 20.3 | 1.8 | 5.3 |

*Note:* ***n*** *– count of boreholes,* ***Min*** *– minimum value,* ***Max*** *– maximum value,* ***Md*** *– median,* ***Mn*** *– arithmetic mean,* ***G*** *– geometrical mean, σ – standard deviation, σ log T – standard deviation of the transmissivity coefficient logarithm values* eastern part Badenian in age (epiclastic sandstones). The complexity of geological and tectonic structure of the area is a reflection of orogenic processes, where one part of the territory subsided (Danube Basin), other on was lifted up (*Štiavnica* Stratovolcano). The presence of multiple aquifers with varied nature of the water in terms of the chemical and isotopic composition portrays well the complexity of forming of different chemical types of the mineral waters of the Western Carpathians.

### 1.4.5 Aquifers of mineral waters in neovolcanites

The complex is characterized by neovolcanite rocks of fissure-intergranular permeability. The regional tectonic lines are essential elements in the accumulation and distribution of mineral waters either due to complex neovolcanic rocks as well as the basement, which is built of Mesozoic sediments and rocks of Crystalline. Therefore sources of mineral waters are often present in the rock environment of neovolcanites which have their origin in the bedrock formed by Mesozoic rocks as in the case of sources Kremnica – KŠ-1, Vyhne – H-1, Vyhne – HGV-3, Lukavica – LKC-4, Sklené Teplice – ST-4 and Sklené Teplice – ST-5.

The greatest potential for accumulation of mineral water in rock complexes of the Central Slovakian neovolcanites, which contributed to the formation of mineral waters in Santovka – Dudince area, have Badenian volcanic epiclastics. These sediments fill the depression at the contact of neovolcanites with their basement. Tuffaceous sandstones were documented by 80 m deep borehole Dvorníky – HG-3 northeast of Dudince. Pumping tests lasting 16 days documented yield Q = 10.5 l . $s^{-1}$ /s = 7.5 m. The value of the coefficient of hydraulic conductivity for these aquifers was k = $8.10^{-5}$ m . $s^{-1}$ and of the transmissivity coefficient T = 3.24 . $10^{-3}$ $m^2$ $s^{-1}$. The water was of chemical type Ca-$HCO_3$ and TDS amounted to 0.32 g . $l^{-1}$ (Hlavatý & Fecek, 1973). The wells HT-1 and HIP-13 in Hontianske Trsťany were 150 m and 173 m deep; they documented the tuffaceous sand to sandstone of thicknesses of 40 m and 120 m. For the well-HT 1 it was documented yield Q = 12 l . $s^{-1}$/s = 1.43 m by hydrodynamic test lasting 36 days. The water was of chemical type Ca-Na-$HCO_3$ with TDS 0.54 g . $l^{-1}$. The evaluation of the pumping test gave the value of coefficient of hydraulic conductivity k = 6.25 . $10^{-5}$ m . $s^{-1}$ and transmissivity coefficient T = 2.07 . $10^{-2}$ $m^2$ . $s^{-1}$ (Lauko & Novomestská, 1989). 30 days-long hydrodynamic test in the borehole HIP-13 documented yield Q = 5.7 l . $s^{-1}$/s = 6.5 m (s = drawdown). The water was of chemical type Ca-$HCO_3$ with TDS 0.56 g . $l^{-1}$ and temperature 17 °C. Hydraulic parameters determined from the evaluation of the pumping tests gave coefficient of hydraulic conductivity k = 3.33 . $10^{-5}$ m . $s^{-1}$ and transmissivity coefficient T = $2.47.10^{-3}$ $m^2$ . $s^{-1}$ (Fecek et al., 1981).

The aquifers of mineral waters in neovolcanites (Badenian andesites) documented by deep borehole Rusovce – HGB-1 in the Danube Basin reached a value of the transmissivity coefficient T = 1.14 . $10^{-5}$ $m^2$ . $s^{-1}$ (Bondarenková et al., 1977). Tectonic affected neovolcanites rock complexes in Banská Štiavnica were explored by borehole HR-1. Hydrodynamic tests documented favourable conditions for the accumulation of mineral water in altered andesite vein filling and the coefficient of transmissivity T = 5.13 . $10^{-4}$ $m^2$ . $s^{-1}$ (Remšík et al., 2007).

## 1.5 Conclusions

The richness of any country in the incidence of sources of mineral waters is either a manifestation of specific natural conditions or technical maturity. In the Slovak conditions the number of natural sources clearly outweighs the artificial ones; however, the physical state of some of them is not very good. By the inventory of the sources of mineral water in 1997-2000, 1,687 sources were documented in Slovakia; 111 were not found, 297 expired and 30 have been destroyed. Among the 111 not found sources 80 accounted for springs and 27 for wells; 4 of them were dug wells. In some places there occurs a destruction of natural sources due to various factors, but still there is a need to implement new sources to ensure supplies for the purposes of filling the mineral waters into the consumer packaging, for medical care, recreation and use of their thermal-energy potential.

The largest representation of mineral waters in Slovakia is recognized in the zones of the Central Western Carpathians (43 %), of which account for most of the sources Inner Carpathian Palaeogene (24.1 %) and Mesozoic sediments (15.2 %). The smallest number of sources accounted for metamorphic rocks (3.2 %) and magmatic rocks (1.5 %). The second most numerous sources of mineral water fall within Neogene sediments (31.7 %). This structural-geological facies manifests the largest representation of the mineral water sources that have been acquired through technical works (the number of wells far outweighs the number of springs). The third and fourth most numerous sources of mineral water fall within the Flysch Zone (13.3 %) and Neovolcanites (6.8 %). The lowest representation of mineral water is within the Klippen Belt (4.2 %).

The mineral water sources in Slovakia are characterized by quite a varied representation of chemical water types with a wide range of TDS, temperature and yield. Colourful presence of chemical types of mineral water depends on the nature of the aquifers of mineral water, the tectonic disturbances and storage conditions at depth.

Individual structural-tectonic zones of the Western Carpathians in Slovakia are characterized by representation of mineral waters of different chemical types. In the Flysch Zone in the near-surface zone chemical type Ca-$HCO_3$ is dominant, while with the increasing depth the share of the component $A_1$ increases according Palmer-Gazda classification of groundwater. Some sources with shallow water circulation exhibit $H_2S$ presence. On major fault lines emerge waters of chemical type Na-$HCO_3$ and Na-$HCO_3$-Cl, eventually Na-Cl-$HCO_3$. An interesting feature is the presence of mineral water of chemical type Mg-$SO_4$-$HCO_3$ (Zbudský Rokytov) or the presence of thermal water of chemical type Na-Cl in the well FPJ-1 in Oravská Polhora with TDS up to 50 g . $l^{-1}$ and a water temperature of 31.3 °C, which was documented in the sediment of the Obidowa-Słopnice-Zboj unit.

Mineral waters of the Klippen Belt with shallow ground water circulation are of dominant chemical types Ca-Mg-$HCO_3$ and Ca-Na-$HCO_3$. Waters with deeper circulation, surging along the tectonic lines are of chemical-type Na-$HCO_3$ (Nimnica) and Ca-Mg-$HCO_3$-$SO_4$ (Mojtín). Water from Belušské Slatiny descends into greater depth and at the surface it reaches a temperature of 21.5 °C.

In the zone of the Central Western Carpathians thanks to its variegated rock representation there are present the most chemical types of mineral waters. The mineral waters of Crystalline with shallow circulation are of chemical types Ca-Mg-$HCO_3$ and Na-$HCO_3$. At greater depth, and within the tectonic zones the water of chemical type Na-$HCO_3$ is present with water temperature up to 25 °C. In the Vlachovo and Čučma a province of nitrogen acratotherms has been earmarked. The Mesozoic sediments of the Krížna Nappe are characterized by mineral waters of chemical type Ca-Mg-$HCO_3$-$SO_4$, which in the case of deep circulation reach a temperature of 33 – 53 °C. Carbonated mineral waters of this nappe are of the same chemical type, but achieve a lower temperature of 20 – 45 °C. In the Plavnica – Lipany area, near the Klippen Belt the Mesozoic sediments Krížna Nappe were verified by wells of depth of 3,500 m to 4,000 m in the bedrock of the Inner Carpathian Palaeogene sediments. These Mesozoic sediments are water-saturated and the water is of chemical types Na-$HCO_3$-Cl-$SO_4$ and Na-Cl. Mesozoic sediments of the Choč Nappe are characterized by the presence of acratotherms of chemical type Ca-Mg-$HCO_3$. At some places (e.g. Kalinčiakovo, Vyhne) from the Mesozoic sediments of the Choč Nappe surge mineral waters of chemical type Ca-Mg-$HCO_3$-$SO_4$. Carbonic and weakly mineralized mineral waters of the Mesozoic sediments of the Choč Nappe are of chemical types Ca-Mg-$HCO_3$, Ca-Mg-$HCO_3$ and Ca-Mg-$HCO_3$-$SO_4$. The carbonates of the Hungarian Central Highlands in the area of Patince – Komárno bind thermal waters (20 – 40 °C).

Mineral waters Inner Carpathian Palaeogene are characterized by the presence of mineral water of chemical types Ca-Mg-$HCO_3$ and Na-$HCO_3$; sometimes even with the presence of $H_2S$. Cold carbonated waters are of che- mical types Ca-Mg-$HCO_3$, Ca-Mg-Na-$HCO_3$ and in contact with the Hornádska kotlina Basin and Branisko Mts. surge mineral waters of chemical type Ca-Mg-Na-$HCO_3$-Cl (Slatvina, Vojkovce). Neogene sediments have a wide representation of chemical types of mineral water with a wide range of TDS. Mineral waters with shallow circulation are the chemical type Ca-Mg-$HCO_3$ and with increasing depth they are enriched in component $A_1$ according to Palmer-Gazda classification of groundwater. In the Záhorská nížina Lowland the mineral waters from greater depths are of chemical types Ca-$SO_4$, Na-$SO_4$. At great depths of the Neogene basin we encounter the highly mineralized waters of chemical type Na-Cl. While in the case of the Central Depression of the Danube Basin and Záhorská nížina Lowland the waters are with thalassogenic mineralization, in the case of the Eastern Slovakia Basin dominate the water with halitogenic mineralization.

Nature of water from neovolcanites is greatly influenced by their deep position. Mineral waters of shallow circulation are of chemical types Ca-Mg-$HCO_3$, Ca-Mg-Na-$HCO_3$ Na-Ca-Mg-$HCO_3$. The mineral waters of deeper circulation reach higher temperatures and are of chemical type Na-Ca-$SO_4$-$HCO_3$. Provided the neovolcanites complex is a part of the sedimentary basin fills then the waters are of chemical type Na-Cl or with thalassogenic or halitogenic mineralization.

The most important aquifers from the genetic viewpoint of mineral waters in Slovakia are the Mesozoic sediments of the Central Western Carpathian and the Neogene sediments of the basins filling.

For the Crystalline aquifers (metasomatic limestone in phyllites of the Gelnica Series), the borehole GVL-1 in Vlachovo gave the transmissivity coefficient $T = 1.15 \,.\, 10^{-3}\ m^2 \,.\, s^{-1}$. Favourable characteristics for accumulation of mineral water were also found from at the contact of greisens with the phyllites of the Gelnica Series (RS-1 borehole Čučma).

The Mesozoic aquifers (limestones and dolomites) of the mineral waters have been verified by 79 hydrogeological boreholes (56 pumping tests) and the value of the geometric mean of the transmissivity coefficient $G(T) = 9.08 \,.\, 10^{-4}\ m^2 \,.\, s^{-1}$. Drillings carried out in the environment of Mesozoic carbonates are also reported to have relatively large yields (Md Q = 12.4 l . $s^{-1}$/Mn Q = 19.4 l . $s^{-1}$), whereas the most productive is the borehole OZ-2 in *Oravice* (Q = 100 l . $s^{-1}$).

For the Inner Carpathian Palaeogene aquifers (sandstones, conglomerates, breccias), the transmissivity coefficient T value was obtained for the elevation part of the bedrock within the discharge area of Malé and Veľké Bielice. The value of this indicator ranges from $2.81 \,.\, 10^{-3}\ m^2 \,.\, s^{-1}$ to $3.11 \,.\, 10^{-3}\ m^2 \,.\, s^{-1}$. Specified range of values for faulted breccia exceeds the value of $G(T) = 3.58 \,.\, 10^{-4}\ m^2 \,.\, s^{-1}$ obtained for a set of wells to which data were available from 60 pumping tests across Slovakia.

The Neogene sedimentary aquifers (sands, sandstones, conglomerates) of the mineral waters have been verified by 58 hydrogeological boreholes (49 pumping tests) and the value of the geometric mean of the transmissivity coefficient $G(T) = 5.35 \,.\, 10^{-4}\ m^2 \,.\, s^{-1}$. The drillings carried out in the Neogene sediments environment achieved balanced yield (Md Q = 10.0 l . $s^{-1}$/Mn Q = 10.5 l . $s^{-1}$), whereas the most productive wells FGG-2 and FGG-3 are in Galanta (Q = 25 l . $s^{-1}$).

The neovolcanites aquifers (volcanic epiclastics) of mineral waters, which are involved in the formation of the mineral water in Santovka – Dudince have been verified by 3 hydrogeological boreholes 80-173 meters deep. The values of the transmissivity coefficient $T = 2.47 \,.\, 10^{-2}\ m^2 \,.\, s^{-1}$ to $T = 2.07 \,.\, 10^{-2}\ m^2 \,.\, s^{-1}$. These aquifers (Badenian andesites) were encountered by deep borehole HGB-1 in Rusovce in the Danube Basin; the value of the transmi- ssivity coefficient $T = 1.14.10^{-5}\ m^2 \,.\, s^{-1}$. In the area of Banská Štiavnica in the tectonically affected neovolcanite rock complexes the transmissivity coefficient $T = 5.13 \,.\, 10^{-4}\ m^2 \,.\, s^{-1}$.

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