New Source of the Geothermal Water in Handlová

ANTON REMŠÍK[1], RADOVAN ČERNÁK[1], JOZEF KORDÍK[2], JURAJ MICHALKO[1]

State Geological Institute of Dionýz Štúr, [1]Dept. of Hydrogeology and Geothermal Energy;
[2] Dept. of Environmental Geochemistry,
Mlynská dolina 1, 817 04 Bratislava, Slovakia; radovan.cernak[a]geology.sk

Abstract: The outcomes of the hydrogeological and hydrogeochemical research of groundwater in a new hydrogeological well RH-1 in Handlová town are presented in the paper. Drilling and research connected to this well were performed within the project „Basic hydrogeological research of Handlovská kotlina Basin" project no. 15 07 that was solved by the State Geological Institute of Dionýz Štúr in years 2007 – 2012. Some results were obtained from the project "Basic hydrogeological and hydrogeochemical maps of Žiar Mts.".
The hydrogeological well RH-1 in town of Handlová (1,201.3 m deep) proved the geothermal water with temperature 37.5 °C at the surface and usable amount of geothermal water 15.0 l . s^{-1}. Inflows of geothermal water into the well (based on the results of geophysical measurements) were in the horizon from 862.0 to 1,201.3 meters. The geothermal water is classified as calcium-magnesium-sulphate-bicarbonate chemical type with a Total Dissolved Solids (TDS) 1,066 mg . l^{-1} with CO_2, H_2S content and is not susceptible to scaling. Thermal water tapped by the well RH-1 is very convenient for bathing and wellness complex. The geothermal water in Handlová town is a renewable resource which is in contrast to lignite mining in the area and opens the possibilities for recreation and sustainable development of the area.

Key words: Handlová, Hornonitrianska kotlina Basin, geothermal energy, resources, well RH-1

6.1 Introduction

State Geological Institute of Dionýz Štúr (SGIDŠ) in Bratislava carried out hydrogeological research in the Handlovská kotlina Basin in years 2007 – 2012. The geological project no. 15 07 "Basic hydrogeological research of the Handlovská kotlina Basin" (Černák et al., 2012) was financed from the budget of the Ministry of Environment SR and was carried out in accordance with the approved concept of geological research and exploration in Slovakia.

The region of the Handlovská kotlina Basin belongs to the deficit areas of Slovakia where systematic hydrogeological survey with identification and acquisition (recovery) of new groundwater resources has not been carried out so far. The results of this project formed the background for planning the sustainable use of groundwater (water supply and other uses), its protection and assessment of environmental impacts in the region.

The aim of the hydrogeological research was focused on the identification of the hydrogeological conditions in the Handlovská kotlina Basin, including the assessment of the relationship between the groundwater with shallow circulation and mineral (geothermal) water. Part of the project was dedicated to calculation of available groundwater and geothermal water amounts in hydrogeologic region PG 063 along with description of geological supporting information for their protection.

Hydrogeological research mainly consisted of hydrogeological mapping, discharge measurements, drilling of hydrogeological wells (shallow and deep), measuring the flow regime and hydrogeological objects and complex hydrogeological assessment of the area with the calculation of the quantity of groundwater.

The paper is focused on new findings that were obtained from the hydrogeological well RH-1 (Remšík and Černák, 2011) in the Handlová town drilled within this project. The aim of the hydrogeological well RH-1 was to verify the amount of groundwater and its chemical properties, description of geological development in the basin and relationship between shallow and geothermal water in the area. The hydrogeological well RH-1 was 1,201.3 meters deep, and so far is the first deep well in the Handlovská kotlina Basin that brought new geological, hydrogeological and hydrogeochemical results.

Earlier works concerning the geological and hydrogeological research consisted of regional and local studies. Geological structure of the area was assessed in regional geological map of the Vtáčnik Mts. and Hornonitrianska kotlina Basin region at scale 1 : 50,000 (Šimon et al., 1997a, b); region Kremnické vrchy Mts. at scale 1: 50,000 (Lexa et al., 1998a, b). The three-dimensional geological model of the Hornonitrianska kotlina Basin was published by Kotulová et al. (2010).

Hydrogeological conditions are outlined on hydrogeological maps published by Kullman et al., (1978, scale 1 : 200,000, sheet 36 – Banská Bystrica), Franko et al. (1993, scale 1 : 50,000, Hydrogeological map of Upper Nitra Basin), Černák et al. (2004, scale 1 : 50,000, Basic hydrogeological and hydrogeochemical maps of the Žiar Mts.). The hydrogeological conditions were described by Marcin (1997 in Šimon et al., 1997b) within the text explanatory notes to geological map of the Vtáčnik Mts. and Hornonitrianska kotlina Basin and 1 : 50,000.

Hydrogeological research including drilling works is based on findings from wells FGHn-1 (depth of 470 m, Fendek et al., 2004). The evaluated area is marginally covered on the western rim of the Handlovská kotlina Basin (hydrogeological survey of the Prievidzská kotlina Basin, borehole HNP-6, depth of 20 m, Bubeník et al., 1976), on the eastern part with research performed by Auxt et al. (1997, "Neovolcanites of the Kremnické vrchy Mts." with well KV-24 of depth 137 m) and hydrogeological research in the northern adjacent Žiar Mts. (Polák, 1997).

Separate hydrogeochemical survey of regional character in this area was not realized, but part of the territory was covered by hydrogeochemical research within works of Auxt et al. (1997), Kováčik et al. (1993), Bátory et al.

(1973), Franko et al. (1993), Bubeník et al. (1976) and Dovina et al. (1985). Overview research performed till 1974 is described in explanatory notes to Basic hydrogeological and hydrogeochemical maps 1: 200,000 (Kullman et al., 1975; Kullman et al. , 1978). An important contribution to the hydrogeochemistry of the area from a regional perspective is given in Geochemical Atlas of the Slovak Republic – Part Groundwater (Rapant et al., 1996). Geological environmental factors and their impact on quality of life for the pilot area of Hornonitrianska kotlina Basin is described in final report of Bodiš et al. (2006).

6.2 Natural conditions

Geomorphological set up

Handlovská kotlina Basin represents the southeast part of Upper Nitra Basin. It has a semi-open nature of the basin (Fig. 6.1).

Altitude ranges from 300 m a.s.l. in Prievidza, to about 500 m a.s.l. in Handlová and the highest point in the area is the hill Grič (971 m) to the southwest of the Handlová town.

The basin is on the N and NE bordered by the Žiar Mts., on the E and SE by the Kremnické vrchy Mts. and on the S and SW by the Vtáčnik Mts. Length of the basin is approximately 14 km, the average width is about 5 km.

Hydrogeological conditions of the Handlovská kotlina Basin and adjacent area

According to the geological structure of the area hydrogeological units with different hydro-geological characteristics, regimes and groundwater chemistry were defined:

- hydrogeological unit crystalline rocks of the Žiar Mts. with fissure permeability;
- hydrogeological unit of Palaeozoic and Mesozoic rocks with fissure and karst-fissure permeability;
- hydrogeological unit of Inner-Carpathian Palaeogene rocks with fissure permeability; hydrogeological unit of Neogene sediments of the Handlovská kotlina Basin with fissure and intergranular permeability;
- hydrogeological unit of Neovolcanic rocks and sediments with fissure and intergranular permeability;
- hydrogeological unit of Quaternary sediments with intergranular permeability.

Generally in granitoids the circulation of groundwater is shallow and is associated with a near-surface zone of disintegration and faulted zones of the massif. Groundwater is of low mineralization, typically silicate or- silicate sulphide type ($Ca\text{-}HCO_3$, $Ca\text{-}HCO_3\text{-}SO_4$ and $Ca\text{-}SO_4$) with TDS 90 – 160 mg . l^{-1} (Černák et al., 2004).

On the crystalline massive Mesozoic envelope is developed in three tectonic units (nappes).

Tatricum tectonic unit (Ráztočno Succession) is characterized by strong tectonic reduction. Middle Triassic carbonates and Jurassic limestones, clays, shales, sandstones and conglomerates of the Tatricum are overlain by carbonates of Fatricum tectonic unit. On the south side of the Žiar Mts. Hronicum tectonic unit (Sklené Mesozoic) is developed. Palaeogene clay sediments create barrier for groundwater circulation on the contact with Mesozoic sequences. Based on a detailed hydrogeological mapping of springs and streams it is clear that there is significant deficit in groundwater discharge (at surface) in relation to the infiltration of precipitation (Černák et al., 2012). The highest values of transmissivity are typically assigned to limestones and dolomites which are the main and most important aquifers in the area. The calculated coefficient of transmissivity in the area $T = 2.48 . 10^{-5} m^2 . s^1$ was obtained from well KV-21 (Auxt, et al., 1997). Groundwater of Mesozoic carbonate is of $Ca\text{-}Mg\text{-}HCO_3$ to $Ca\text{-}HCO_3$ chemical type with TDS typically in range 250 – 450 mg . l^{-1}.

On the surface Inner-Carpathian Palaeogene rocks are present in large extent. They are represented

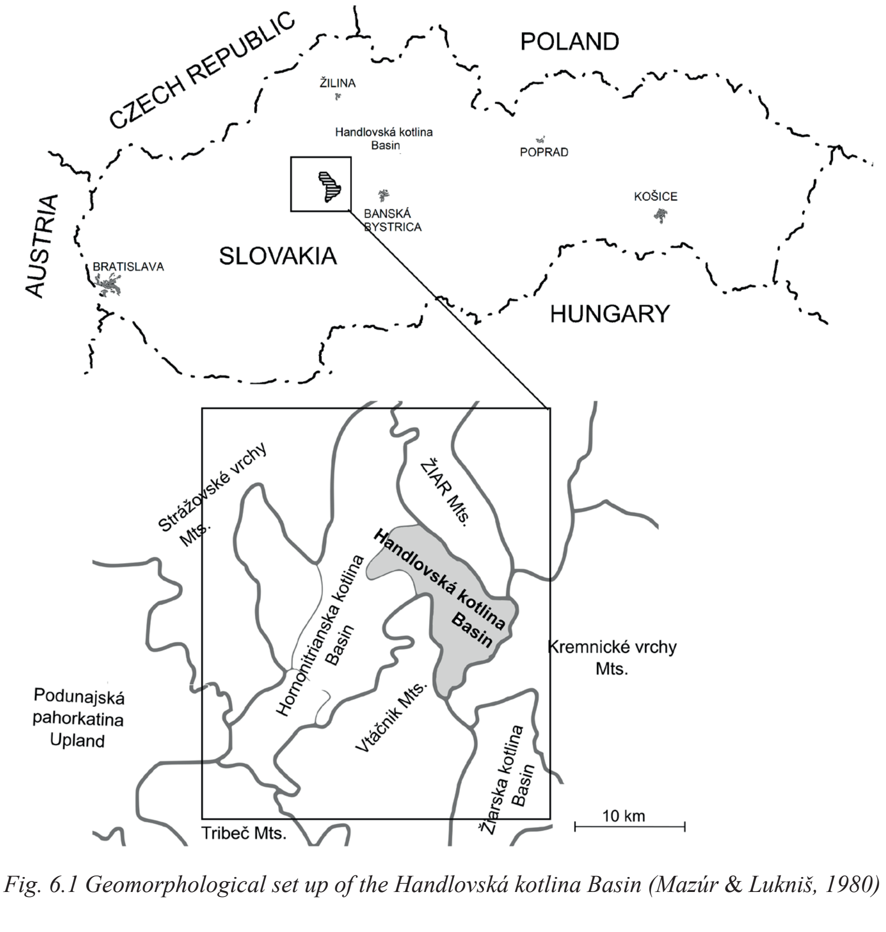


Fig. 6.1 Geomorphological set up of the Handlovská kotlina Basin (Mazúr & Lukniš, 1980)

by Borové Formation (breccia, conglomerates, limestones), marginal (Terchová) formation (clays, positions of conglomerates), Huty and Zuberec formations (clays, flysch) and sandstone of Biely potok Formation (mainly sandstones of Chrenovec Mb.). Groundwater is bound to breccias, conglomerates and sandstones (mainly Borové Fm. and Biely potok Fm.) with fissure permeability. TDS of groundwater with origin in the Borové Fm. in the Handlovská kotlina Basin was in range 176 – 422 mg . l^{-1} with Ca-Mg-HCO_3 chemical type. Palaeogene rocks are in superposition to Palaeozoic-Mesozoic rocks.

Hydrogeological unit of Neogene sediments in the Handlovská kotlina Basin include schliers, clays, tuffites, coal deposits, conglomerates, gravels and sands. Groundwater is bound (linked) to conglomerates, gravels, sands (Kľačany, Lehota and Lelovce Fms.) with fissure and intergranular aquifers. Thus, major hydrogeological aquifers are located mainly in the upper part of the Neogene basin fill. Formation of schliers, clays and clay-tuffite layers (Čausa, Handlová, Nováky, Koš Fms.) represent aquicludes and aquitards. Groundwater from Neogene sediments represent Ca-Mg (K)-(Na)-HCO_3 chemical type with TDS 487 mg . l^{-1} or 658 mg . l^{-1} (based on 2 samples in the Handlovská kotlina Basin).

Hydrogeological unit of Neovolcanic rocks consists of various volcanic rock formations (different types of andesite, volcanic clastic rocks, rhyolites). Fissure permeability prevails especially in andesite, volcanic breccias, conglomerates, volcanic sandstones, siltstones and tuffaceous claystone. Intergranular permeability is prevalent in tuffs and some volcanic breccias. Andesite lava sheets have a drainage function to overlaying volcaniclastic strata with springs yielding up to 10 l . s^{-1}. Groundwater with origin in Neovolcanic effusive rocks is of relatively low TDS of 190 mg . l^{-1} (median 174 mg . l^{-1}). Groundwater from Neovolcanic volcaniclastic has a higher TDS of 335 mg . l^{-1} (median 271 mg . l^{-1}) mainly due to the presence of carbonate components in groundwater. Groundwater is characterized by volcaniclastic Ca (Mg)-HCO_3 type of chemical composition.

Hydrogeological unit of Quaternary sediments includes fluvial, proluvial and deluvial sediments. Fluvial sediments represent the bottom sandy gravel accumulation, gravel and clay in flood plains. The alluvium of the Handlovka River consists of clayey gravel characterized by value of transmissivity coefficient 2.2 . 10^{-4} m^2 . s^{-1}. Fluvial sediments are directly fed from river and aquifer is thus dependent on the river regime. Groundwater in deluvial sediments is dependent on precipitation regime. Groundwater with circulation in fluvial sediments of flood plains have variable chemical composition with Ca (Na)-(Mg)-HCO_3 chemical type and TDS around 500 to 900 mg . l^{-1}.

Geothermal water in the Handlovská kotlina Basin has deeper circulation that is bound to hydrogeothermal structures of pre-Tertiary basement that is located between the Tribeč and Žiar mountains. This morphostructure defined by Fusán et al. (1987) as "Handlovský chrbát" Ridge is built by Mesozoic and Palaeozoic rocks of Fatricum and Hronicum tectonic units. Aquifers of geothermal water are made of mainly Triassic limestones and dolomites. Fig. 6.2 shows geological setup of the Handlovská kotlina Basin.

Within the project "Basic hydrogeological research of the Handlovská kotlina Basin" basic hydrogeological map in scale 1 : 50 000 was compiled showing the lithological content and its hydraulic parameters (as defined in Directive of MoE SR as of 26.10.2004 No. 8/2004-7 on compilation of basic hydrogeological maps at scale of 1 : 50 000).

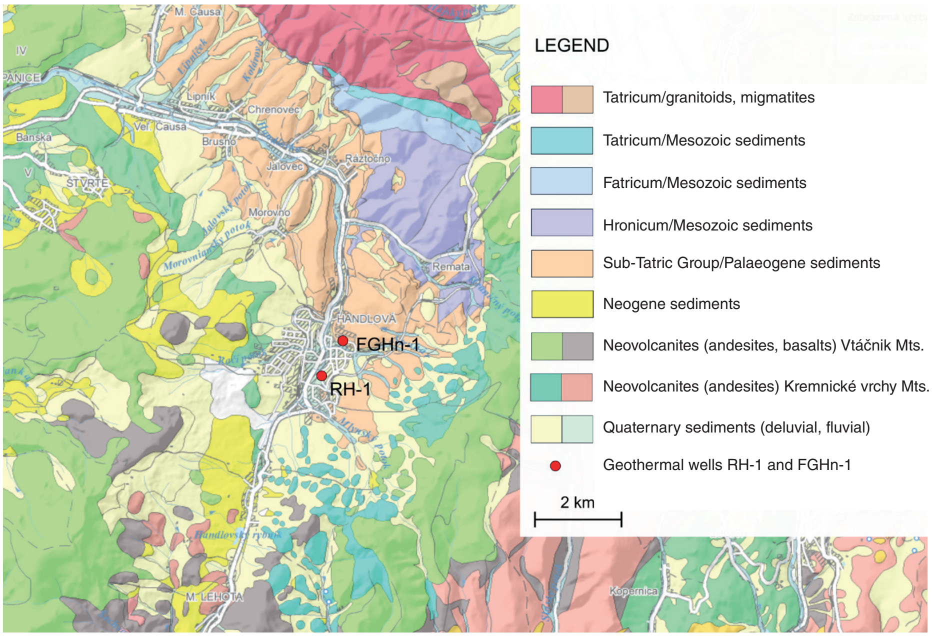


Fig. 6.2 Geological setup of the Handlovská kotlina Basin (http://mapserver.geology.sk)

Mineral and geothermal water in the Handlovská kotlina Basin

Generally, geothermal waters in the Handlovská kotlina are linked to the tectonic units in pre-Tertiary basement, namely Fatricum (Mesozoic limestones) and Hronicum tectonic unit (Triassic carbonates).

There were two reported sources of low temperature geothermal water in the Handlovská kotlina Basin (Krahulec et al., 1978) before the drilling of the well RH-1. They were reported as inflows into the lignite mine in Handlová at a depth of 470 m. The inflow reg. No. PR-12 (l.c.) with yield 10.8 l . s^{-1} and water temperature 32 °C documented in year 1942 was of Ca-Mg-SO_4-HCO_3 chemical type with TDS 2.15 g . l^{-1}. The second inflow (reg. No. PR-11, l.c.) was documented in the year 1945 with yield 2 l . s^{-1}. The temperature and the chemical composition of the water were similar to the previous case though less mineralized (2.05 g . l^{-1}). It was probably the same geothermal water that was reported by Fendek et al. (2004) based on oral information from Ferianc in 2001 (inflow of geothermal water with temperature of 32.5 °C; yield of 5.5 l . s^{-1}; Ca-Mg-SO_4 chemical type and TDS to 2.01 g . l^{-1}). Geothermal water bound to strongly tectonically affected dolomites of Hronicum tectonic unit has been identified on the basis of the Palaeogene rocks in geothermal well FGHn-1 (in Handlová town), 470 m deep (Fendek et al. 2004). Water from well had 19.4 ° C and pumped rate was 2.17 l . s^{-1} with the drawdown of 110.15 meters from the well-head. Chemical type of water was Na-Mg-HCO_3 with TDS 0.39 g . l^{-1}.

Mine water in the Handlovská kotlina Basin

In SW part of investigated area Handlová lignite mine is still in operation. The coal deposit is divided by fault of NNE-SSW direction into eastern high block with mining field Handlová and western block with mining field Cigeľ (Fig. 6.3). Overlaying aquifer system is represented by Lehota Fm. (gravel, sand, clay, sandstone, tuffites, breccias) with intergranular permeability and overlaying Neovolcanites with fissure permeability. The drainage affected mainly overlaying and partly underlying collectors. Pumped amount of mine water from the Handlová mine was rising gradually from 50 l . s^{-1} (in 1960) to 300 l . s^{-1} (in 1980), followed by irregular decline; the average annual yield of water pumped in the dewatering of the mine in 2008 was 117 l . s^{-1} (Beck et al., 2009).

Groundwater with shallow circulation has TDS up to 200 mg . l^{-1}. Groundwater with deeper circulation has higher temperature and total mineralization.

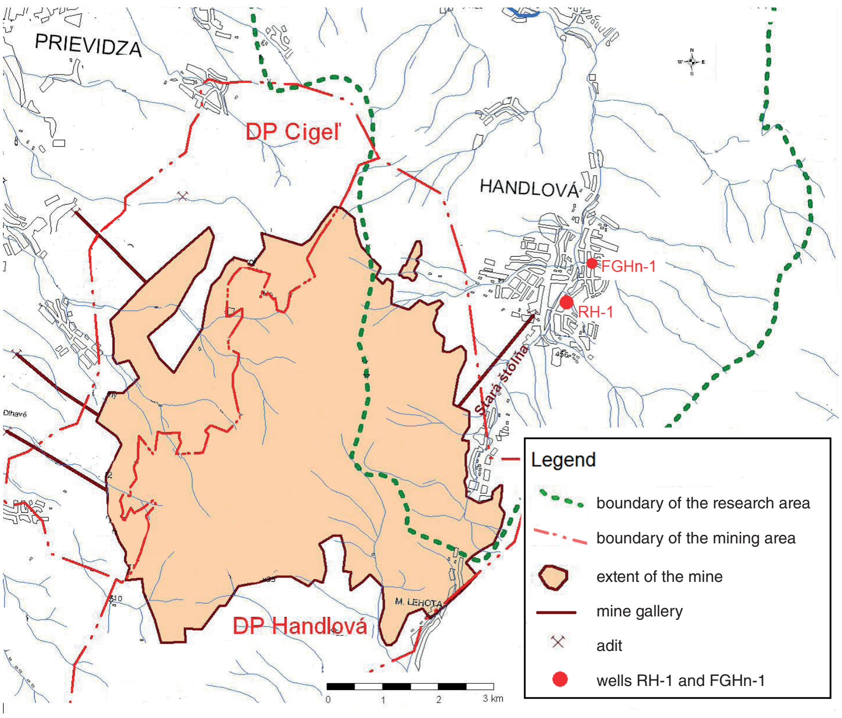


Fig. 6.3 Handlová mine situation in relation to the studied area

6.3 Construction of the hydrogeological well RH-1

Drilling of the hydrogeological well RH-1 in Handlová town

Prior to the drilling, geophysical works (gravimetric and geoelectric measurements) were carried out in 2008 in the larger area of designed well RH-1 (reinterpretation of the measured data performed in 2010). Measured geophysical data provided information for designation of the drilling place.

The well was designed as a hydrogeological well and was drilled and tested in the period between 23. 7. 2008 and 9. 4. 2010. The drilling was performed as the traditional rotary technology with rotation of the whole drill string, from the surface to the bottom with bentonite mix as a drilling fluid.

Prior to the drilling, foundations for the drilling rig were constructed. As a part of that introductory casing (520 mm) in length of 4 m was mounted. Technical works started with drilling diameter Ø 444.5 mm to a depth of 130 m. After external casing cementation was applied with casing diameter 355 mm. The next day (12. 8. 2008) effluence of methane (between casings 520 mm and 355 mm) was recorded with concentration 6%. Measured concentration of methane (in period from 12. 8. to 2. 9. 2008) ranged from 1.5 – 10.0 % with a gradual decrease until it disappeared (24. 9. 2008). Further drilling continued with diameter 311 mm until the depth of 575.2 m and external casing cementation was applied.

After cementing of casing column effluence of methane (from between casings 355 mm and 245 mm) was recorded again. After that sealing with rubber sleeve was applied and methane was driven by pipeline outside the workplace. It should be noted that during drilling to a depth of 575.2 meters there were no signs of gas. Gas leak from the casing annulus (between casings 355 mm and 245 mm) did not cease to the end of drilling. The amount of leaking gas measured (27. 10. 2009) was 0.572 m^3 . hr^{-1}. Based on analysis of the gas sampled at 21. 8. 2009 the me-thane concentration was 96.85 % and nitrogen concentration was 2.61 %.

The drilling continued to a depth of 1,064.40 m with diameter 216 mm without major complications. At a depth of 1,064.40 meters there was complete loss of fluid. Additional drilling was interrupted due to production of drilling fluid. At a depth of about 1,178 m further complete loss of fluid was recorded. Since that time restoration of drilling fluid circulation was unsuccessfull till the final drill depth (1,201.3 m). While drilling at a depth of 1,179 m drilling bit was jammed due to instability of the borehole wall (poor circulation, poor fluid quality due to the losses). Borehole was supported by casing of diameter 178 mm to that depth. After the well logging to a depth of 1,179 m (30. 12. 2009) well screen intervals were selected and well-casing of diameter 178 mm was applied in depth interval from 540.4 to 1,179.0 m. Further drilling was performed by drill bit with diameter 140 mm at a depth between 1,179.0 m and 1,195.0 m. Drilling was interrupted due to loss of drilling fluid. Drilling core (Jurassic limestone) was sampled in the depth interval from 1,195.0 to 1,201.3 m and after this drilling of the well was completed on 10. 1. 2010. Logging at the depth interval 1,179.0 to 1,201.3 m was performed at the same day and sections for well screens were selected. Well casing with a diameter of 114 mm was mounted in depth interval from 1,172.5 to 1,201.30 meters.

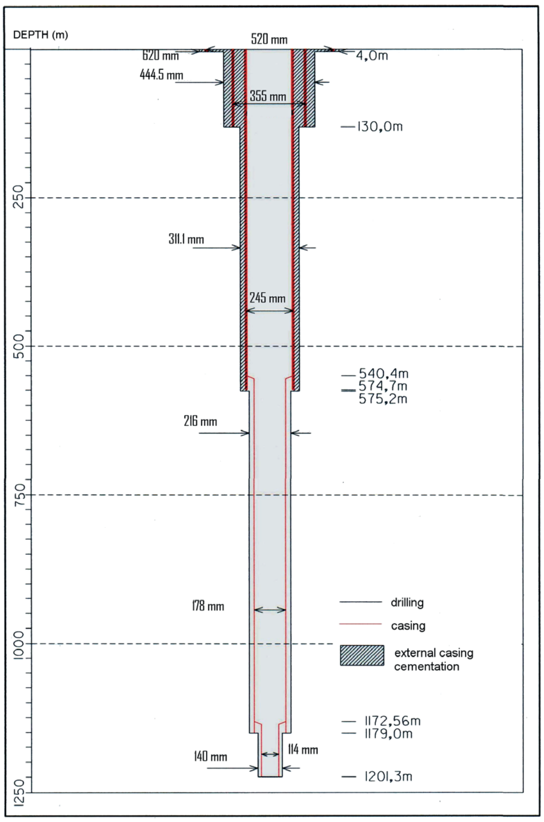
During the drilling drill recoverywas sampled every 5 meters of the borehole depth. Besides that 5 cores were sampled in intervals 0.0 – 8.0 m; 119.0 – 124.5 m; 371.0 – 375.6 m; 567.8 – 574.3 m; 1,195.0 – 1,201.3 m.

The construction of well is outlined in Fig. 6.4a. Perforated casing sections of the column were determined based on the results of geophysical logging measurements and are shown in Fig. 6.4b.

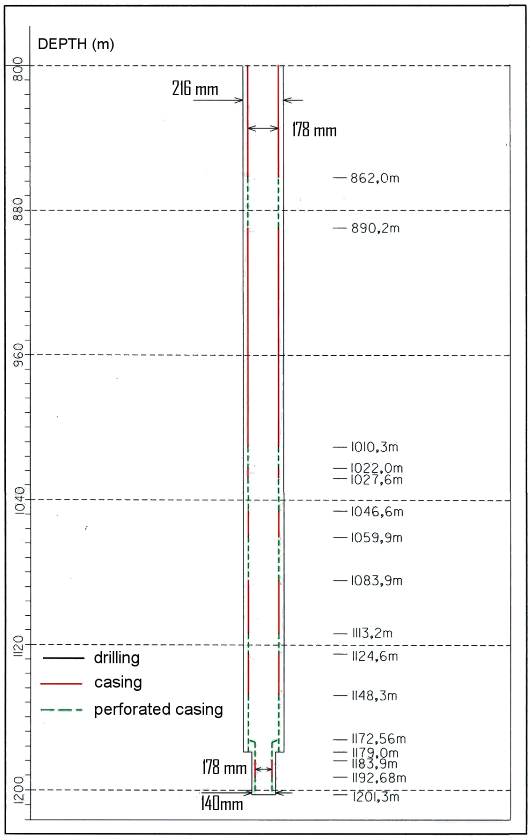
meters, 575.0 to 694.0 meters, 739.5 to 805.5 meters, 868.5 – 968.5 meters. Section from 968.5 to 1,082.7 meters is affected mainly in intervals: from 1,015.0 to 1,018.0 m, from 1,025.0 to 1,041.7 m, from 1,054.6 to 1,055.8 m, from 1,064.3 to 1,082. At the bottom part of the well, from depth of 1,082.7 meters nature of fracturing is changing toward less cavernous, though with more local fractures. Such fractures were documented in depths of 1,116.0 meters, 1,118.5 m, 1,158.5 m, 1,166.5 m, 1,177.5 m, 1,181.8 m and 1,196.9 m.

Water inflow into the wellbore

Inflow of water into the well was documented on the basis of temperature and resistance of the water in the well. Due to high level of cavernosity, drilling was performed using dense clayey drilling fluid that influenced the inflow of water into the well. Fluid resistance across the measuring section was constant and changes in water resistance that would refer to water inflow were not clearly confirmed. However, sections have been reported with changes in temperature gradient, which may be caused by the water inflow into the borehole. Those sections were around 889.8 meters and in intervals 1,032.8 to 1,042.1 m, 1,150.7 to 1,160.1 m, 1,174.0 to 1,179.0 m and 1,194.5 to 1,199.5 m.



a)



b)

Fig. 6.4 a) - The construction of well RH-1; b) - Perforated casing sections of the column

Fracturing of the rock in the well

The whole complex of overlying rock to 968.5 meters is greatly disturbed. Based on drill logging most affected intervals were: 174.1 to 201.9 meters, 434.0 to 507.9

Hydrodynamic tests in the well RH-1

After installation of the casing the recovery of the well was performed on 14. 1. 2010. It consisted of drilling fluid substitution by clean water with focus on washing the screening interval (perforated sections). Afterwards pumping at the rate of 4.16 l . s^{-1} was performed by submersible pump for three days, during which the water temperature reached 31 °C and water level during pumping was at a depth of 43.89 meters below ground. Acid treatment of the well was performed on 28. 1. 2010. After that well was washed again with clean water and pumped by submersible pump for one day. On 2. 2. 2010 – 21. 2. 2010 drilling rig was removed.

Other part of the work was focused on performance of hydrodynamic tests in the well. Hydrodynamic tests were carried out on 23. 2. 2010 – 9. 4. 2010 by company VIKUV (Hungary) (Gyűrüsi, 2010 in Černák et al., 2012).

Step-drawdown test was performed in three steps, each of a duration 1 day with yield Q_1 = 3.0 l . s^{-1}, Q_2 = 6.9 l . s^{-1}, Q_3 = 11.0 l . s^{-1}, which was continuously followed by yield Q = 15 l . s^{-1} for 22.7 days. Afterwards recovery test lasting 15 days was performed.

During hydrodynamic tests hydraulic parameters were investigated. Steady water level in the well before pumping test was on the level 47.94 meters (from the well-head). Level in the well during the hydrodynamic tests (at the pumping rate 15 l . s^{-1}) was at level 47.20 meters (from the well-head) with the temperature of water (at the surface) 37.5 °C.

Temperature measured at the bottom of the well (measuring device was able to reach only to the depth 1,186 m) was 38.5 °C (23. 2. 2010), or 39.9 °C (7. 4. 2010). Based on a set of data temperature from 23. 2. 2010 it can be indicated that in steady state conditions interlayer flow in open interval between 1,070 – 1,186 m is observed (with expected downward direction in the column). Long-term pumping caused heating up of the rock environment around the well. From this data the reciprocal value of temperature gradient G_g amounted 39.67 m/°C.

Vertical profile of the temperature at the end of the pumping phase (22. 3. 2010) and at end of the recovery phase (7. 4. 2010) is shown at the Fig. 6.5. Maximum yield of geothermal water pumped by submersible pump from well RH-1 was 16.7 l . s^{-1}.

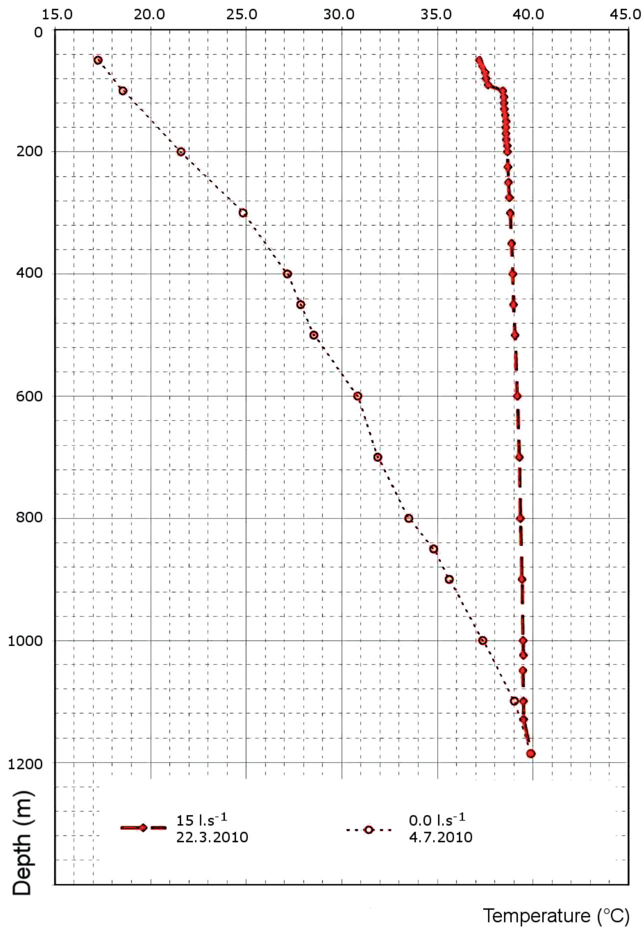


Fig. 6.5 Vertical profile of the temperature at the end of the pumping phase (22. 3. 2010) and at the end of the recovery phase (7. 4. 2010) measured in RH-1 well

Major inflow into the wellbore detected by well logging prior to casing and has a source in sandstones, conglomerates, limestones and dolomites from interval 862.0 to 1,201.3 meters. Measuring of the flow in the well after casing was performed at 22. 3. 2010 (at the end of the pumping phase) with borehole rheometer VIKUV REO-40. Inflow and outflow of water in the well is con-

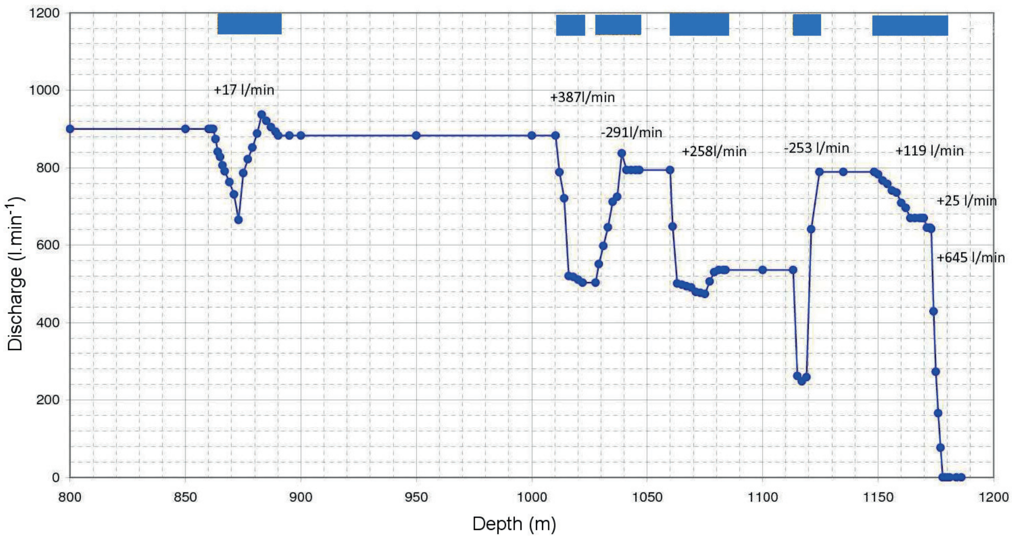


Fig. 6.6 Distribution of inflow and outflow of water in the well RH-1 at pumping rate 15 l . s^{-1} measured on 22.3.2010

nected only to the sections where perforated casing is present. The measured values from measurement in the well are in Fig. 6.6.

Hydraulic parameters of the rock environment were calculated based on pumping and recovery test from data in period February – April 2010 are shown in Tab 6.1.

Tab. 6.1 Calculated hydraulic parameters of aquifer based on measurements from pumping test performed on hydrogeological well RH-1

Tp	$1.423 \, . \, 10^{-11}$	m^3	Coefficient of intrinsic (absolute) transmissivity
K_p	$3.557 \, . \, 10^{-13}$	m^2	Permeability coefficient
k_f	$5.047 \, . \, 10^{-6}$	$m \, . \, s^{-1}$	Hydraulic conductivity
T	$2.018 \, . \, 10^{-4}$	$m^2 \, . \, s^{-1}$	Coefficient of transmissivity

Monitoring of the gases in water from well RH-1 was performed during the constant yield pumping at rate $15 \, l \, . \, s^{-1}$. Total amount of the gas was $9.48 \, l \, . \, m^{-3}$ with methane concentration $0.32 \, l \, . \, m^{-3}$.

By the obtained measurements we assume that groundwater from well RH-1 has origin in fissure environment, aquifer is confined and likely to have a large extent.

6.4 Main results brought by hydrogeological well RH-1

Geological interpretation of the RH-1 well

Known geological profile of the well RH-1 allowed re-interpretation (in 2010) of the measured geophysical data (gravimetric and geoelectric measurements carried out in 2008) and draw attention to geological significance of earlier detected tectonic zone NW-SE, that crosses Handlová fault (NNE-SSW). Based on geophysical results, the NW-SE fault zone most probably separates two different facies of the Tertiary fill – direction NE of the fault without the Neogene sediments and SW with the Neogene sediments. In addition, fault zone of direction NW-SE is likely to separate the two types of pre-Tertiary basement (with interpretations of carbonates to the NE and with different types of bedrock to the SW).

Hydrogeological well RH-1 provided new data into the clarification of the complicated geological structure in the area. Its geological content and lithostratigraphical interpretation are outlined in Tab. 6.2

Chemical composition of geothermal groundwater in the well RH-1 Handlová

Sampling of the groundwater from the well RH-1 for chemical analysis was performed during the pumping test on 5. 3. 2010, 12. 3. 2010 and 17. 3. 2010. The results of chemical analysis of groundwater borehole are summarized in Fig. 6.7.

The temperature of sampled groundwater ranged between 36.6 and 36.9 °C, neutral pH water reaction was in interval 6.9 to 7.04 and total dissolved solids ranged in $1{,}066 – 1{,}073 \, mg \, . \, l^{-1}$ indicate chemical composition. Chemical type of water was classified as Ca-Mg-HCO_3-SO_4. Dominant cations and anions were Ca^{2+} ($165 \, mg \, . \, l^{-1}$), HCO_3^- ($378 – 398 \, mg \, . \, l^{-1}$) and SO_4^{2-} ($368 – 386 \, mg \, . \, l^{-1}$). The contents of the other basic components were sig-

Tab .6.2 Lithological profile of the well RH-1 in Handlová (based on Buček et al. 2011 in Černák et al., 2012).

Age			Tectonic unit	Lithostratigraphy	Depth (m) FROM	TO	Lithology
QUATERNARY					0.0	4.1	clayey loams, sandy gravel
TERTIARY	PALAEOGENE - NEOGENE	OLIGOCENE - EGGERIAN	SUBTATRIC GROUP	Chrenovec Mb.	4.1	122.7	grey and dark grey micaceous clays and claystones
					122.7	180.0	grey coarse-grained siliceous and micaceous sandstones
		PRIABONIAN - OLIGOCENE		Zuberec Fm.	180.0	310.0	dark grey sandstones and claystones
				Huty Fm.	310.0	371.0	dark grey claystones
		PRIABONIAN		Borové Fm.	371.0	460.0	grey and light grey carbonate conglomerates
PALAEOZOIC	PERMIAN		HRONICUM	Malužiná Fm.	460.0	1,020.0	red shales, siliceous sandstones and conglomerates, arkoses dark shales
	CARBONIFEROUS			Nižná Boca Fm.	1,020.0	1,040.0	light grey shales, sandstones
MESOZOIC	TRIASSIC Late (Rhaetian)			Norovice Fm.	1,040.0	1,070.0	light grey organodetritic limestones, crinoidal limestones, dolomites, shales
	CRETACEOUS Early		FATRICUM	Mráznica Fm.	1,070.0	1,085.0	grey limestones with shale and marly shale layers
				Osnica Fm.	1,085.0	1,090.0	grey and light grey marly limestones with marly shale layers (calpionela limestones, Biancone, maiolica)
	JURASSIC	MALM		Jasenina Fm.	1,090.0	1,097.5	grey, greenish, red, purple limestones with marly shale layers
		DOGGER		Ždiar Fm.	1,097.5	1,105.0	grey and greenish radiolarian limestones
				crinoidal limestones	1,105.0	1,170.0	grey and light grey crinoidal limestones
				?"siliceous fleckenmergel"	1,170.0	1,178.5	dark grey siliceous limestones and crinoidal limestones
		LIAS		?"Allgäu Fm."	1,178.5	1,183.5	grey marly limestones and marly shales (fleckenmergel)
				Hierlatz Limestone	1,183.5	1,201.3	crinoidal limestones of pink and red colours

Slovak Geol. Mag., 16, 2 (2016), 91 – 104

nificantly lower: Na^+ 20.0 to 30.7 mg . l^{-1}, Mg^{2+} 46.6 to 49.3 mg . l^{-1}, Cl^- 11.0 to 24.1 mg . l^{-1}.

Groundwater chemistry is genetically related to the Middle Triassic carbonates (Hronicum and Fatricum) and Lower Triassic gypsum (Werfenian Mb., as confirmed by isotope research). The rate rMg/rCa (average 0.48) indicates the circulation in the mixed limestone-dolomite environment (however this coefficient can also be affected by the mobilization of calcium in the dissolution of evaporites).

Slightly higher chloride content (11.0 to 24.1 mg . l^{-1}) probably indicates insignificant mixing of water with groundwater from overlying Tertiary sediments containing salt of marine origin.

The increased iron (2.45 to 12.1 mg . l^{-1}) and manganese contents (0.054 to 0.137 mg . l^{-1}) indicate the groundwater movement under reduced conditions. The concentrations of the analysed trace elements are mostly low, below the detection limit of the relevant analytical method. Measured data confirmed the high stability of the chemical composition of the groundwater from the well RH-1 (Kordík in Černák et al., 2012).

On a sample analysed at the end of 16. 3. 2010 the determination of organic and microbiological parameters was made in accordance with Slovak Government Regulation No. 496/2010 (amending and supplementing Slovak Government Regulation No. 354/2006 Coll.) stating requirements on water intended for human consumption and quality control of water intended for human consumption. The water from the well RH-1 was characterized by a slight microbial activity and does not contain any specific organic substances.

In accordance with the Decree of the Ministry of Health of the Slovak Republic no. 100/2006 mineral water from the well RH-1 is described as low temperature, neutral (based on pH), moderately mineralized with prevailing Ca-HCO_3-SO_4 chemical composition, with increased content iron (of 1 mg . l^{-1}) and sulphate (above 200 mg . l^{-1}).

Chemical composition of geothermal groundwater in adjacent area

Hydrogeothermal structure of Hronicum tectonic unit is characterized by geothermal water of Ca-Mg-HCO_3 and Ca-Mg-HCO_3-SO_4 type and TDS around 0.7 – 1.0 g . l^{-1} (Bojnice – well BR-1, Vyhne – well H-1 and well HGV-3, Koš – well Š1-NBII).

Hydrogeothermal structure of Fatricum tectonic unit is characterized by geothermal water of Ca-Mg-HCO_3-SO_4 and Ca-Mg-SO_4 type and TDS around 1.1 to 2.7 g . l^{-1} (inflows in Handlová mine – "Biely prameň", Kremnica – well KŠ-1, Sklené Teplice – wells ST-1 and ST-4, Chalmová – well CH-3, Turčianske Teplice – wells HM-2, TJ-20, TTK-1, TTŠ-1).

It is assumed that the source of geothermal water is rainwater, as indicated by high values of the characterization factor rHCO_3/rCl (20 – 144) suggesting an open hydrogeothermal structure. A characterization factor rMg/rCa (0.36 – 0.49) indicates the circulation of water in the mixed – limestone-dolomitic complex. A considerable proportion of the sulphate component is documented in Sklené Teplice by the high values (above 0.4) of a characterization factor rSO_4/TDS (wells ST-1 and ST-2 with circulation of water in gypsum). Genesis and chemical composition of water from geothermal well FGHn-1 in Handlová is different. Groundwater is of Na-Mg-HCO_3 type of chemical composition with TDS of about 400 mg . l^{-1} (Tab. 6.3).

Specific features of the chemical composition of above described thermal water sources are evident from Piper diagram in Fig. 6.8.

Significantly different in cationic part is only water borehole FGHn-1.

Other sources of geothermal water are placed in a relatively small cluster with dominant presence of calcium cation. There is an evident increase in the proportion of the sulphate component in the thermal waters of the Fatricum tectonic unit, which is reflected in most cases in the higher levels of total dissolved solids (bottom graph) compared to geothermal waters of the Hronicum tectonic unit. The proportion of the sulphate component in both cases is significantly variable.

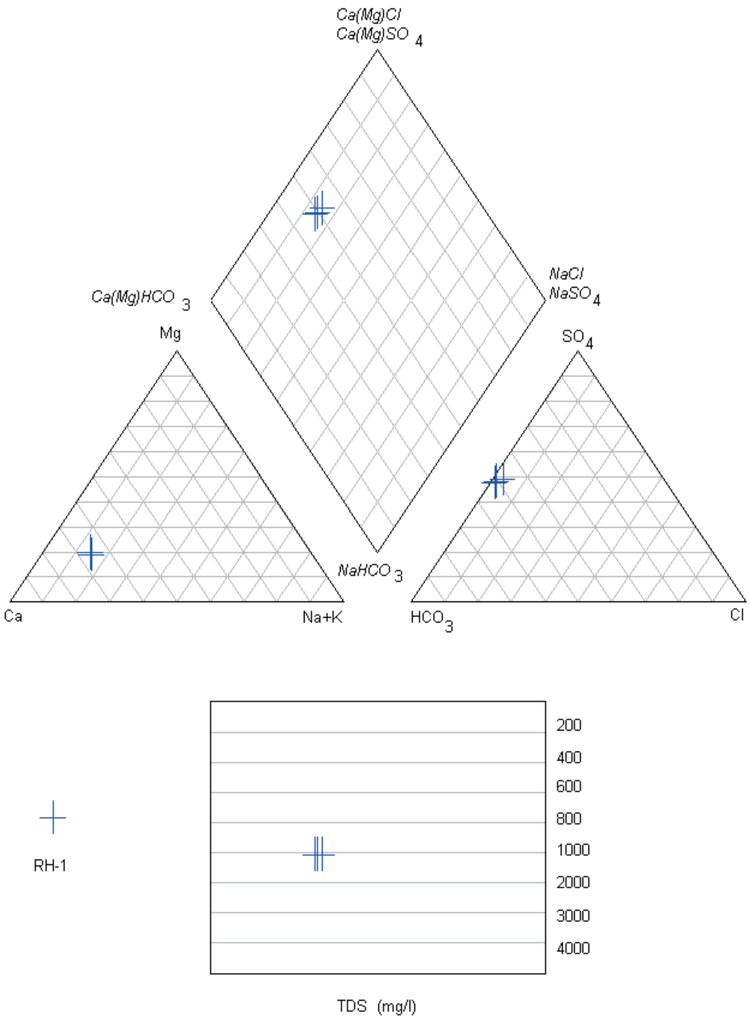


Fig. 6.7 Adapted Piper diagram of the groundwater in the well RH-1

Geothermal water from Hronicum unit in comparison with Fatricum unit water is significantly undersaturated to gypsum and anhydrite. The most significant undersaturation to the anhydrite and gypsum is evident for water from well FGHn-1. In most cases, water from Hronicum and Fatricum units are comparatively supersaturated with aragonite to calcite and dolomite. Significant oversaturation to aragonite, calcite and dolomite was also found in the water supply FGHn-1.

As indicated above, proportion of the sulphate component has significant dispersion in the chemical composition. From this perspective, the share of a characterization factor rSO_4/M with increasing temperature shows notable increase trend (with the exception of Bojnice therma (BR-1) and the source Š1 NBII). This correlation could be related to the length and depth of geothermal waters circulation, where the water with a higher temperature is characterized by a longer residence time in the environment and increase the proportion of sulphates and total dissolved solids in these waters.

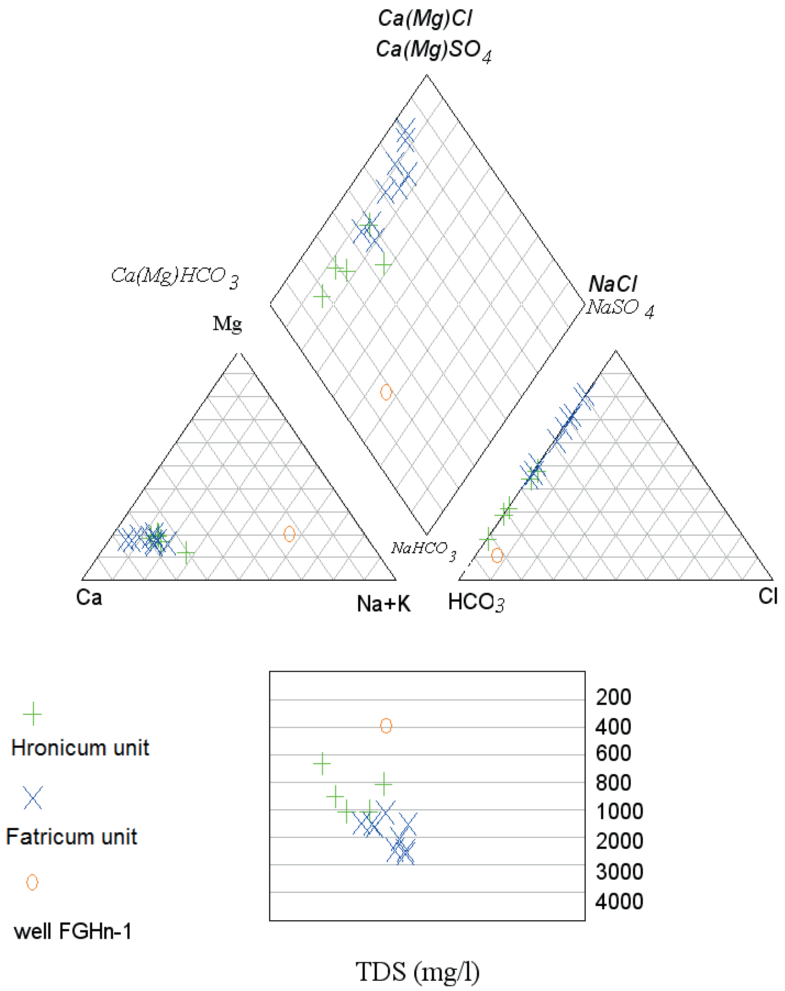


Fig. 6.8 Adapted Piper diagram of geothermal water resources from the Handlovská kotlina Basin and adjacent area (incorporated sources in diagram are from Tab.6.2)

Isotopic composition of geothermal groundwater in well RH-1 and adjacent area

The isotopic composition of oxygen and hydrogen was monitored in precipitation (Prievidza airport) from November 2008 to October 2009. The main factor governing the presence of isotopes in precipitation is the temperature, which is in general function of latitude, altitude, season of the year and age (cold and warm geological period).

The isotopic composition of oxygen and hydrogen in groundwater was monitored in selected resources during the period from December 2008 to February 2010 five times. All monitored groundwater sources, including well RH-1 and a source in Handlová mine (Bajtoš et al., 2011), are of clearly meteoric origin, which is documented by their relationship to the global meteoric line (Fig. 6.9).

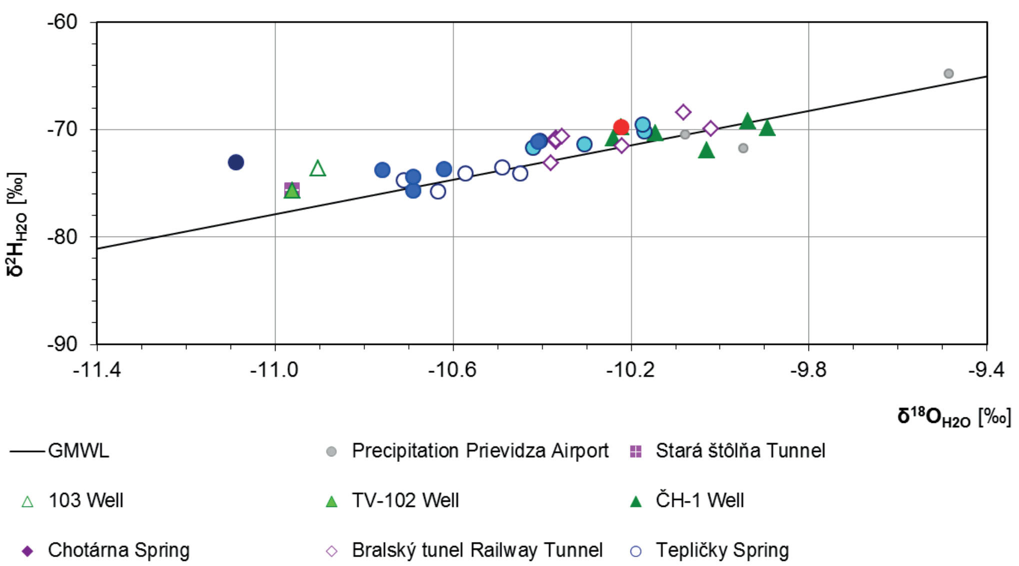


Fig. 6.9 The isotopic composition of oxygen and hydrogen in monitored groundwater resources in the Handlovská kotlina Basin

Tab. 6.3 The chemical composition of selected indicators of geothermal waters of the Hornonitrianska kotlina Basin and adjacent area with anticipated origin in distinguished tectonic units based on chemical composition of the geothermal water

	Source	Site	T water	pH	TDS	SiO_2	free CO_2	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3	$rHCO_3/rCl$	rNa+rK/rMg+rCa	rMg/rCa	rSO_4/M	rSO_4/rCl
Hronicum tectonic unit	RH-1	Handlová	36.9	7.04	1,066	18.4	70.4	28.0	7.7	164.0	49.1	11.0	368.0	398	21.02	0.12	0.49	0.27	24.69
	Š1-NBII	Nováky - Koš	62.0	6.77	816	37.1	88.9	51.2	11.6	140.0	27.4	5.7	288.0	360	36.82	0.27	0.32	0.25	37.43
	BR-1 Jesenius II	Bojnice	46.5	7.35	670	26.8	59.4	19.9	3.0	101.0	29.7	2.4	86.9	394	93.82	0.13	0.48	0.11	26.29
	H-1	Vyhne	35.3	6.50	1,084	31.2	122.3	23.2	22.4	178.0	45.2	2.8	245.3	531	110.16	0.13	0.42	0.18	64.65
	HGV-3	Vyhne	29.1	7.09	909	29.8	70.4	16.6	12.0	152.0	40.1	2.1	187.0	469	127.94	0.09	0.44	0.17	64.80
Fatricum tectonic unit	Baňa Handlová - Biely prameň (inflow in Handlová mine)	Handlová	35.0	6.73	2,074	18.6		67.2	20.4	373.0	93.8	10.1	975.0	498	28.65	0.13	0.41	0.35	71.25
	CH-3	Chalmová	39.5	7.00	1,118	30.5	33.0	26.1	9.8	200.0	53.5	9.1	494.1	317	20.26	0.10	0.44	0.33	40.08
	KŠ-1	Kremnica	44.0		1,542			46.0	19.4	290.6	63.8	7.6	802.0	311	23.94	0.13	0.36	0.38	78.41
	HM-2	Turč. Teplice	42.8	6.85	1,613	49.6	162.8	67.8	10.9	262.9	64.2	6.4	540.4	610	55.57	0.18	0.40	0.26	62.52
	TJ-20	Turč. Teplice	44.7	6.85	1,518	40.4	491.0	45.3	9.9	259.7	62.3	2.5	549.3	549	128.66	0.12	0.40	0.28	163.50
	TTK-1	Turč. Teplice	31.5	7.05	1,505	47.9	436.7	39.6	9.1	245.3	71.0	3.6	485.2	598	97.87	0.11	0.48	0.25	100.87
	TTŠ-1	Turč. Teplice	52.0	7.60	2,477	43.5	70.4	35.0	23.2	462.5	119.2	2.1	1,251.2	531	144.81	0.06	0.42	0.37	433.58
	ST-1	Sklené Teplice	52.1	7.35	2,490	27.0	125.6	21.3	12.1	498.6	113.8	3.2	1,460.7	342	62.04	0.04	0.38	0.42	336.91
	ST-4	Sklené Teplice	46.5	6.75	2,620	22.3	164.0	29.3	21.6	524.3	120.4	3.7	1,494.0	403	63.24	0.05	0.38	0.41	298.03
	FGHn-1	Handlová	20.0	8.76	393	18.0	0.0	51.0	8.3	25.2	20.8	19.1	28.2	217	6.61	0.82	1.36	0.06	1.09

Note: water temperature in °C; TDS, SiO_2, free CO_2, anion, cation content in mg . l^{-1}; information sources: Kordík in Černák et al. (2012): RH-1, Biely prameň, Fendek et al. (2004): FGHn-1, CH-3, Vandrová et al. (1999): HM-2, TJ-20, TTK-1, TTŠ-1, Pirman & Potyš (1990): KŠ-1, Orvan et al. (1967): H-1, Žitňan (2008): HGV-3, Ďurovič (1999 in Černák et al., 2012): ST-4, Struňák et al. (1965): ST-1

Sulphur present in groundwater as sulphate may originate from multiple sources which have characteristic isotopic composition. Gypsum and anhydrite of sedimentary origin from marine water essentially retain the original isotopic composition of marine sulphate. In our conditions the highest representation of the light isotope $\delta^{34}S$ was in water of Permian ocean. For the corresponding evaporites of age (Permian, Lowermost Triassic) $\delta^{34}S$ is around 10 ‰ (4 ‰ – 13 ‰). On the other hand, the highest rate of heavy sulphur isotopes is characteristic for Lower Triassic (Werfenian) sediments, with values $\delta^{34}S$ about 25 ‰ (20 ‰ – 29 ‰). Gypsum and anhydrite are well soluble and the highest concentrations of sulphate have most likely origin in these sediments.

Another source (depleted sulphur) has origin in scattered sulphides in sediments, in the studied area present mainly in coal deposits. Additional source of sulphur can be considered sulphur which is genetically linked to neovolcanites; in case of a deep source $\delta^{34}S$ with value near zero.

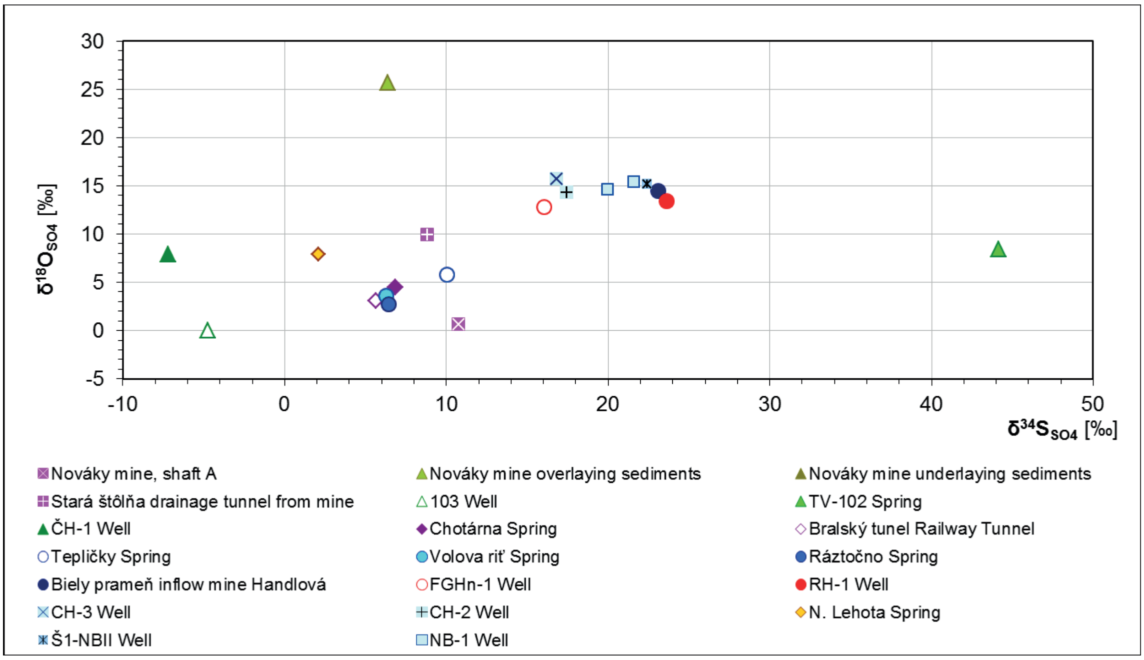


Fig. 6.10 Oxygen isotopic composition of sulphate, depending on the sulphur isotopic composition of sulphate anion in monitored water sources

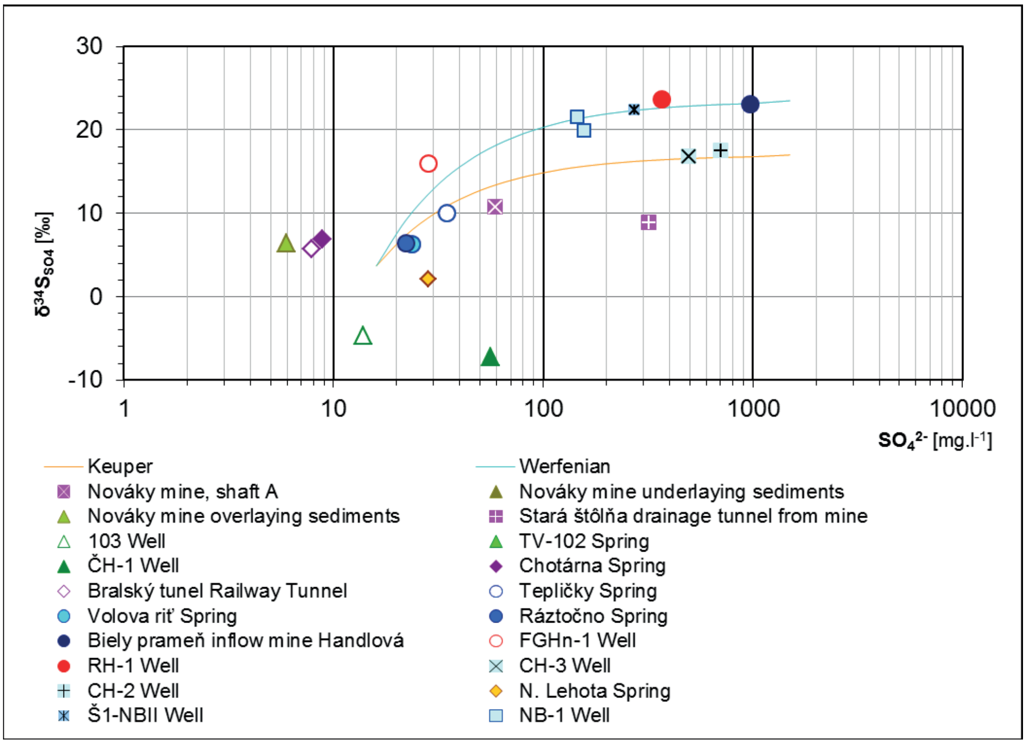


Fig. 6.11 The isotopic composition of the sulphur according to the concentration of the sulphate anion in water

Slovak Geol. Mag., 16, 2 (2016), 91 – 104

Low sulphate concentrations (~ 10 – 30 mg . l^{-1}) in groundwater with relative light sulphur ($\delta^{34}S$ ~ 2 ‰ - 8 ‰) have probably origin in precipitation. As documented by Malík et al. (2000), the isotopic composition of sulphur in the snow from Handlová – Nová Lehota represents value $\delta^{34}S$ = 6.2 ‰ at a concentration of sulphates 4.3 mg . l^{-1}.

The main processes that affect the quality and quantity of sulphate present in the groundwater can be considered dissolution (and precipitation), redox processes and mixing. We do not consider progressive (bacterial) reduction of sulphate based on the findings on the absence of hydrogen sulphide in the water.

In selected groundwater resources isotopic composition of sulphur and oxygen respectively in the water was measured.

Water from Mesozoic bedrock in Handlová mine seepage (source in "Východná šachta" (Eastern shaft) 200 m a.s.l., seepage in mine galleries of $VIII^{th}$ horizon) has isotopically heavy sulphur with $\delta^{34}S$ = 23.1 ‰, which is usually characteristic of sediments of Werfenian Mb. or ocean sediments of Miocene age. The fact that this is the dissolution of the gypsum is demonstrated by high concentration (975 mg . l^{-1}) of the sulphate anion in water. This idea does not contradict either the oxygen isotopic composition of sulphate (Fig. 6.10).

Sulphate present in water in high concentrations detected within three sampled sources – seepage Mesozoic bedrock in Handlová mine seepage (Eastern shaft), geothermal borehole Š1-NBII Laskár and geothermal well RH-1 in Handlová, is from isotopic point of view (sulphur and oxygen) practically identical (Fig. 6.10 and Fig. 6.11). Sulphate probably originates from the same source, wherein the isotopically lighter sulphur suggests the mixing of water with background sulphur (the position of the mixing curve in Fig. 6.11). Thus isotopically enriched sulphur ($\delta^{34}S$ = 23.1 ‰, 22.4 ‰ and 23.6 ‰) is usually characteristic for evaporites (anhydrite) of Werfenian facies (Early Triassic).

6.5 Discussion

The Handlovská kotlina Basin is a part of delineated geothermal groundwater body Hornonitrianska kotlina Basin ("Upper Nitra Basin" respecting definition and delineation by Franko, Remšík and Fendek, eds., 1995). The Handlovská kotlina Basin is in direct contact with geothermal areas "Central Slovak Neovolcanites – NW part". In both defined geothermal groundwater bodies geothermal waters are bound to Triassic carbonates of the Hronicum and Fatricum units, as well as to the basal Palaeogene breccias and conglomerates that are overlying the Triassic carbonates (creating one aquifer).

In the deeper parts tectonic units of Hronicum, Fatricum and Tatricum are present in the Handlovský chrbát Ridge (as defined by Fusán et al., 1987) and its surrounding structures. All three units crop out in Tribeč, Žiar and Veľká Fatra mountain rangess and are possible recharge areas for geothermal waters in the Handlovská kotlina Basin.

At the area of Handlová town, geothermal aquifer linked to Triassic carbonates of Tatricum tectonic unit is less probable due to its considerably reduced form.

Geothermal aquifers in Fatricum and Hronicum tectonic units are segmented by faults into several, more or less partial structures that can be relatively independent in hydraulic and hydrogeochemical regime and temperature.

More extended structures and aquifers are built by carbonate rocks of Fatricum tectonic unit creating transition and accumulation reservoirs of geothermal water. These are situated below the Hronicum tectonic unit represented by carbonate (Triassic dolomites and limestones) or non-carbonate bedrock (Ipoltica Group) (Remšík in Černák et al., 2012). Aquifers of these tectonic units can be interconnected in tectonic zones by geothermal water communication. Triassic carbonates, particularly in the Hronicum unit, can form more or less separate floes in their extension, as well as thickness, due to erosion and tectonic evolution.

Thus Triassic carbonates of Fatricum, Hronicum and the basal Palaeogene clastics can create conditions for the existence of two geothermal aquifers in superposition one above the other, or side by side. The extension of transit-storage and accumulation areas of these structures thus can spread to the mountains of Vtáčnik, Handlovská kotlina Basin, Kremnické vrchy Mts. It can be assumed that geothermal aquifers in given area (geothermal water in the well RH-1) are connected to Handlovský chrbát Ridge built by tectonic Fatricum and Hronicum units and they are "isolated" from neighbouring hydrogeothermal structures of Kremnica depression and Žiarska kotlina Basin. However, hydrogeothermal structure spatial definition (surface, thickness, boundary) currently faces a lack of direct data and information.

Geothermal water from Triassic carbonates of Fatricum tectonic unit in the Handlovský chrbát Ridge can be found in two inflows into the mine Handlová at a depth of 470 m (200 m above the see level) in the eastern shaft. Yields were 10.8 l . s^{-1} and 2.0 l . s^{-1} respectively, with water temperature 32 °C. Water is of Ca-Mg-SO_4-HCO_3 type with TDS 2.05 – 2.15 g . l^{-1}, the CO_2 content of 127.6 mg . l^{-1} and H_2S 0.14 mg . l^{-1} (Krahulec et al. , 1978). The same chemical type of water was confirmed by the analysis of water in 2010 (Černák et al., 2012). Similar geothermal water was detected in underground borehole KŠ-1 in Kremnica.

Geothermal water from hydrogeothermal structure of the Hronicum tectonic unit near Handlová is characterized by Ca-Mg-HCO_3 type and TDS around 0.7 – 1.0 g . l^{-1}. The hydrogeological well RH-1 in Handlová (depth 1,201.3 m), tapped geothermal water mainly from Mesozoic limestone and dolomite and from Permian clastic rocks and shales of Hronicum and Fatricum tectonic units in the depth interval of 862 – 1,201 m (441 – 780 m below the see level). The main inflow to the well (87.7 % yield) was from the Jurassic limestones of Fatricum tectonic unit. Yield of the water from well RH-1 was 15.0 l . s^{-1}, water temperature 37.5 °C, chemical type Ca-Mg-HCO_3-SO_4 with TDS 1.07 g . l^{-1}, CO_2 70.4 mg . l^{-1} and H_2S 0.25 mg . l^{-1}. Sulphur had almost the same isotopic composition ($\delta^{34}S_{SO4}$) as the seepage of geothermal water in the mine Handlová (Michalko in Černák et al., 2012). By chemical composition this water shows affinity to aquifer in Fatricum tectonic unit, but with unusually low TDS for this structure. The cause of this can be low CO_2 content, a relatively short circulation time, or can be the result of mixing higher mineralized water form Fatricum tectonic unit with less mineralized water form Hronicum tectonic unit.

In case the geothermal water from the well RH-1 is a result of water mixing with origin in Hronicum and Fatricum units, we cannot attribute recharge to a single area. This idea supports different isotopic composition of oxygen and hydrogen of water in the well RH-1 and seepage of geothermal water in Handlová mine (Michalko in Černák et al., 2012).

Possible mixing of the water can occur at the contact of Hronicum and Fatricum units (in the area of the well RH-1) where at the depth interval 1,040 – 1,201 m (thickness of only 161 m) reduced strata of Jurassic-Cretaceous limestones (Fatricum unit) are overlain by Upper Triassic carbonates (Hronicum unit). Suitable conditions for mixing of the water from different tectonic units are given as well by position of the well at the fault zone of N-S direction (the valley of Handlovka River). Geothermal water remaining in the structure is characterized by its age, which has the value of 9,230 ± 110 years (Šivo & Richtáriková, 2010 in Černák et al., 2012).

6.6 Conclusion

In period 2009 – 2010 the hydrogeological well RH-1 was drilled as a part of regional geological research. Prior to the drilling geophysical measurements were performed and detected tectonic zone of NW-SE direction as a key element in tectonic scheme.

Geothermal water from hydrogeological well RH-1 in Handlová (1,201.3 m deep) is linked to the Mesozoic limestones and dolomites (geothermal aquifer). Inflow of geothermal water into the well (based on the results of geophysical measurements) was in the interval from 862.0 to 1,201.3 meters. Water table in the well before pumping test was at the level of 47.94 meters (from the well-head). Usable amount of geothermal water 15.0 $l \cdot s^{-1}$ was calculated and approved by Ministry of Environment based on 22.7 day pumping test. The water level in the well during the pumping test reached 47.20 meters (from the well-head) and water temperature at the surface was 37.5 °C. Hydraulic parameters of aquifers were calculated. Coefficient of absolute transmissivity valued by $1.423 \cdot 10^{-11}$ m^3, permeability coefficient $3.557 \cdot 10^{-13}$ m^2, hydraulic conductivity $5.047 \cdot 10^{-6}$ $m \cdot s^{-1}$ and coefficient of transmissivity $2.018 \cdot 10^{-4}$ $m^2 \cdot s^{-1}$. Calculated usable amount of geothermal energy represents 1.41 MW.

Geothermal water is calcium-magnesium-bicarbonate-sulphate chemical type ($Ca\text{-}Mg\text{-}HCO_3\text{-}SO_4$ type) with a TDS of about 1,066 $mg \cdot l^{-1}$ with higher CO_2, H_2S and CH_4 content and is not susceptible to scaling.

The hydrogeological well RH-1 tapped geothermal water linked to Hronicum and Fatricum tectonic with main inflow (87.7 % yield) from the Jurassic limestones of Fatricum tectonic unit as proven by sulphur isotopic composition ($\delta^{34}S_{SO4}$) and chemical composition. Reason for unusually low TDS (for this structure) can be low CO_2 content, a relatively short circulation time, or can be the result of mixing higher mineralized water form Fatricum tectonic unit with less mineralized water form Hronicum tectonic unit. It can be assumed that the geothermal water from the borehole RH-1 has circulation in aquifer with recharge and transit-accumulation zones but has no natural spring area. In this case it is a result of water mixing with origin in Hronicum and Fatricum units and thus we cannot attribute recharge to a single area. Though we assume, that precipitation is main recharge source which means that the source of geothermal water and geothermal energy is renewable. Geothermal water age is estimated to 9,230 ± 110 years based on carbon dating.

Thermal conditions in the Handlová area (well RH-1) were documented at the depth of 500 meters (below surface) with temperature 25 °C, at a depth of 1,000 m with temperature 35 °C and a depth of 1,200 m with the temperature of about 40 °C. The mean value of geothermal gradient for the well RH-1depth section 100 – 1,200 m reached 21.0 $°C \cdot km^{-1}$.

Documented physical and chemical properties of the geothermal water from the well RH-1 have shown that water is very convenient for bathing and wellness complex. The geothermal water in the Handlová town is a renewable resource which opens the opportunities for sustainable use and new activities in the region for example the recreation.

References

Auxt, A., Klúz, M., Šalagová, V., Beracko, I., Galisová, M., Dorčík, G., Szabová, H., Urbaník, J., Berzáková, M., 1997: Neovulkanity Kremnických vrchov – severná časť, vyhľadávací HGP, Žilina, Ingeo, 1997, 133 p.

Bajtoš, P., Cicmanová, S., Baláž, P., Stupák, J., Pramuka, S., Michalko, J., Šesták, P., 2011: Banské vody Slovenska vo vzťahu k horninovému prostrediu a ložiskám nerastných surovín. Final report. Manuscript, Geofond Archive SGIDŠ, Bratislava.

Bátory, V., Takáčová, J., Lopašovský, K., Hauskrecht, J., Palkovičová, M., Makrányiová, Z., 1973: Horná Nitra – HGP, cieľ: overiť zvodnenie štrkopiesčitých terciérnych sedimentov v spomínanej oblasti. Vodné zdroje Bratislava, Manuscript, Geofond Archive SGIDŠ, Bratislava, 30 p.

Beck, J., Šarkan, J., Daubner, P., Sivák, I., Hopková, M., Pipíška, S., Chríbik, J., 2009: Záverečná správa s výpočtom zásob výhradné ložisko Handlová, dobývací priestor Handlová. Surovina: hnedé uhlie. Stav k: 1. 1. 2009. Manuscript, Geofond Archive SGIDŠ, Bratislava, 64 p.

Bodiš, D., Klukanová, A., Švasta, J., Rapant, S., Gajdoš, V., Hók, J., 2006: Vplyv geologických faktorov na kvalitu života, Kvalita života – zdravie, výživa, vzdelávanie, č.2003SP28/OSO 0066/000 00 00, Manuscript, Geofond Archive SGIDŠ, Bratislava.

Bubeník, I., Frličková, M., Beracko, I., Šalaga, I., 1976: Prievidzská kotlina – vyhľadávací hydrogeologický prieskum, HGP, účel: overiť možnosť skrytých priestupov podzemných vôd z okrajových pohorí situovaním vrtov na okraji kotliny, SGÚ Žilina, IGHP, Manuscript, Geofond Archive SGIDŠ, Bratislava, 79 p.

Černák, R., Kordík, J. (eds.), Bottlik, F., Havrila M., Helma J., Kohút M., Šimon L., 2004: Základná hydrogeologická a hydrogeochemická mapa pohoria Žiar v mierke 1: 50 000, Ministerstvo životného prostredia Slovenskej republiky, Štátny geologický ústav Dionýza Štúra, Bratislava, Manuscript, Geofond Archive SGIDŠ, Bratislava.

Černák, R., Remšík, A., Malík, P., Kordík, J., Michalko, J., Bajtoš, P., Baráth, I., Boorová, D., Bottlik, F., Buček, S., Elečko, M., Filo, I., Gregor, M., Jankulár, M., Kohút M., Lenhartová, E., Marcin, D., Olšavský, M., Ondrejka, P., Polák, M., Siráňová, Z., Šimon L., Zlinská, A., Žecová, K., Filo, J., Gretsch, J., Gyürüsi, Cs., Mikuška, J., Olejník, M., Pašteka, R., Šivo, A., 2012: Základný hydrogeologický výskum Handlovskej kotliny, Ministerstvo životného prostredia Slovenskej republiky, Štátny geologický ústav Dionýza Štúra, Bratislava, Manuscript, Geofond Archive SGIDŠ, Bratislava, 181 p.

Directive of the MoE SR as of 26. 10. 2004 No. 8/2004-7 on compilation of basic hydrogeological maps at scale of 1 : 50,000

Dovina, V., Lexa, J., Vrana, K., Konečný, V., Gross, P., Vozár, J., Kullmanová, A., Planderová, E., Sitár, V., 1985: Zhodnotenie hydrogeologických pomerov Vtáčnika, čiastková záverečná správa, 1981 – 1985, Hydrogeologický výskum vybraných oblastí SSR. ŠGÚDŠ Bratislava, Manuscript, Geofond Archive SGIDŠ, Bratislava, 161 p.

Fendek, M., Havrila, M., Šimon, L., Hók, J., Žecová, K., Michalko, J., Bajtoš, P., Obernauer, D., Fendeková, M., Ženišová, Z., Král, M., Grand, T., Džuppa, P., Komoň, J., 2004: Regionálne hydrogeotermálne zhodnotenie Hornonitrianskej kotliny. Manuscript, Geofond Archive SGIDŠ, Bratislava.

Franko, O., Kullman, E., Melioris, L., Vrana, K., 1993: Vysvetlivky ku hydrogeologickej mape 1 : 50 000 regiónu Horná Nitra, Interim final report, Manuscript, Geofond Archive SGIDŠ, Bratislava, 189 p.

Franko, O. (ed.), Remšík, A. (ed.), Fendek, M. (ed.), 1995: Atlas geotermálnej energie Slovenska. Geologický ústav Dionýza Štúra, Bratislava, p. 1 – 267.

Fusán O., Biely A., Ibrmajer J., Plančár J., Rozložník L., 1987: Podložie terciéru vnútorných Západných Karpát. Geol. úst. Dionýza Štúra, Bratislava, p. 7 – 103.

Regulation No. 354/2006 Coll. of 10 May 2006, laying down requirements for water intended for human consumption and quality control of water intended for human consumption.

Kotulová, J., Pauditš, P., Janega, A., Dananaj, I., Halmo, J., Švasta, J., Elečko, M., Šimon, L., Zlocha, M., Šarkan, J., Fazekaš, J., Müller, M., 2010: Hornonitrianska kotlina – trojrozmerné geologické modelovanie exponovaného územia, regionálny geologický výskum, Manuscript, Geofond Archive SGIDŠ.

Kováčik, M., Marsina, K., Vrana, K., Határ, J., Smolárová, H., Čížek, P., Čurlík, J., 1993: Súbor regionálnych máp geofaktorov životného prostredia SR v mierke 1 : 50 000, región Horná Nitra, záverečná správa, projekt: Výskum geologických faktorov životného prostredia, doba riešenia: 1991 – 1993. Manuscript, Geofond Archive SGIDŠ, 30 p.

Krahulec, P., Rebro, A., Uhliarik, J., Zeman, J., 1978: Minerálne vody Slovenska, 2, vydavateľstvo Osveta, Martin, 1978.

Kullman, E., Gazda, S. et al., 1978: Základná hydrogeologická mapa 1 : 200 000 list 36 – Banská Bystrica, čiastková záverečná správa. Názov úlohy: Základný hydrogeologický výskum spojený s edíciou hydrogeologických máp. Manuscript, Geofond Archive SGIDŠ, 472 p.

Kullman, E., Gazda, S., Jetel, J., Škvarka, L., Franko, O., 1975: Základná hydrogeologická mapa 1: 200 000 list Trnava, čiastková záverečná správa za roky: 1974 – 1975. Názov úlohy v perspektívnom pláne: Edícia hydrogeologických máp. Manuscript, Geofond Archive SGIDŠ, 308 p.

Lexa, J. (ed.), Halouzka, R., Havrila, M., 1998a : Geologická mapa Kremnických vrchov, MŽP SR – GSSR Bratislava.

Lexa, J. (ed.), Halouzka, R., Havrila, M., Hanzel, V., Kubeš, P., Liščák, P., Hojstričová, V., 1998b : Vysvetlivky ku geologickej mape Kremnických vrchov 1 : 50 000. Bratislava, GS SR, Vyd. D. Štúra, 308 p.

Malík, P., Michalko, J., Rapant, S., Scherer, S., 2000: Izotopy síry v zimných zrážkach na území Slovenska, Podzemná voda VI./2000 č. 2, p. 174 – 184

Mazúr, E. & Lukniš, M., 1980: Regionálne geomorfologické členenie SSR 1 : 500 000, Geografický ústav SAV Bratislava.

Orvan, l, 1967: Vyhne – hydrogeologický štruktúrny vrt H- l. Final report, Manuscript, Geofond Archive SGIDŠ, Bratislava, 21 p.

Pirman, L & Potyš, Z., 1990: Turčianske Teplice ochranné pásma, Final report, Manuscript, Geofond Archive SGIDŠ, Bratislava.

Polák, R., 1997: Hydrogeologický rajón M 064 – mezozoikum severnej časti pohoria Žiar, vyhľadávací prieskum, Manuscript, Geofond Archive SGIDŠ, 192 p.

Rapant, S., Vrana, K., Bodiš, D., Doboš, V., Hanzel, V., Kordík, J., Repčoková, Z., Slaninka, I., Zvara, I., 1996: Geochemický atlas Slovenskej republiky – časť podzemné vody. GSSR, Bratislava, 127 p.

Regulation No. 496/2010 Coll., which amends Slovak Republic Government Order No. 354/2006 Coll., laying down requirements on water intended for human consumption and quality control of water intended for human consumption.

Remšík, A. & Černák, R., 2011: Hydrogeologický vrt v Handlovej, Preliminary Report, Manuscript, Geofond Archive SGIDŠ, Bratislava, 14 p.

Struňák, V., 1965: Hydrogeologický prieskum minerálnych vôd v Sklených Tepliciach. Final report, Manuscript, Geofond Archive SGIDŠ, Bratislava.

Šimon, L. (ed.) Elečko, M., Lexa, J., Pristaš, J., Halouzka, R., Konečný, V., Gross, P., Kohút, M., Mello, J., Polák, M., Havrila, M., Vozár, J., 1997a: Geologická mapa Vtáčnika a Hornonitrianskej kotliny.MŽP SR – GSSR Bratislava.

Šimon, L. (ed.) Elečko, M., Lexa, J., Pristaš, J., Halouzka, R., Konečný, V., Gross, P., Kohút, M., Mello, J., Polák, M., Havrila, M., Vozárová, A., Vozár, J., Kohlerová, M., Stolár, M., Jánová, V., Marcin, D. & Szalaiová, V., 1997b: Vysvetlivky ku geologickej mape Vtáčnika a Hornonitrianskej kotliny 1 : 50 000. GSSR, Vyd. D. Štúra, Bratislava, 281 p.

Vandrová, G., Potyš, Z., Urbaník, J., Zuberec, M., Hajčík, J., 1999: Budiš – ochranné pásma minerálnych vôd, vyhľadávací HGP. MŽP SR Bratislava, Ingeo Žilina, Manuscript, 119 p.

Žitňan, M., 2008: Vyhne – vrt HGV-3 – využiteľné množstvá podzemných vôd v kategórii B, doplnkový HGP. Manuscript, AQUA-GEO, Bratislava, 43 p.