Slovak Geol. Mag., 16, 2 (2016), 125 – 147

Mineral Waters of the Dudince Spa

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Abstract: Dudince Spa town is located on the southwestern edge of the district Krupina. Dudince and Santovka area is built of Neogene sediments – Baďany and Sebechleby formations of the Štiavnica Stratovolcano (outer proximal and distal zones). The basement of the Štiavnica Stratovolcano (Mesozoic and Palaeozoic) crops out to the surface only in the area west of Slatina and Santovka. According to the Ministry of Health Decree no. 100/2006 Coll. natural healing water from the source S-3 in Dudince is highly mineralized, carbonic, sulphane, bicarbonate-chloride, sodium-calcium water with increased content of fluoride, lithium, bicarbonate ions, slightly acidic, very low thermal. Mineral waters of "Levice Spring Line" (NW-SE direction – through the line Levice Santovka, Dudince, Slatina to Veľké Turovce) are of very complex origin. In this paper we present an overall view on the chemical composition of mineral waters occurring in this area – evaluation and graphical interpreting of data obtained through the whole period of mineral water sources use is provided (from 60's of the last Century to the present). The set of data contains the results of more than 740 laboratory analyses of samples of mineral water resources in the study area. Macrochemical assessment of the composition of mineral water of the "Levice Spring Line" gives the opportunity to understand regional hydrogeochemical regularities of their formation. It points to the similarities and differences between the mineral waters of the discharge areas of Dudince and Santovka. The mineral waters of Dudince, Santovka and Slatina have mixed chemical composition – formed by multiple processes. Silicatogenic, hydrosilicatogenic and marinogenic mineralizations are in prevail. However, there occur also carbonatogenic and sulphatogenic mineralizations.

Key words: Natural healing water, Dudince Spa, Levice Spring Line, mineral water, macrochemical composition, geophysical work

8.1 Introduction

Dudince Spa (the status of the spa town Dudince was granted in 1983, currently in Government Resolution no. 456/1999, the Ministry of Health Bulletin, item 13) is located on the eastern edge of the Danube Basin, on the southern foot of the Štiavnické Vrchy Mts. and at the western edge of Krupinská vrchovina Upland.

The first written mention of Dudince (Dyud) is already from the year 1284, the first mention of mineral water dates back to 1551. Since 1904, mineral water has been bottled, the first bath (Gutmann) was opened in 1909. The healing waters from the springs have been acknowledged since the Middle Ages (treatment of rheumatism, inflammation of the eyes, skin diseases and digestive problems). The first bath house in Dudince was opened in 1951. The opening ceremony of the Spa House Hont (later renamed Ruby) was held in 1966. The newest is the Spa House Diamant, which was opened in 1986.

Dudince and Santovka area is built of Neogene sediments – Baďany and Sebechleby formations of the Štiavnica Stratovolcano (outer proximal and distal zone, Fig. 8.1). Mesozoic and Palaeozoic fundament of the Štiavnica Stratovolcano crops out only in the area west of Slatina and Santovka.

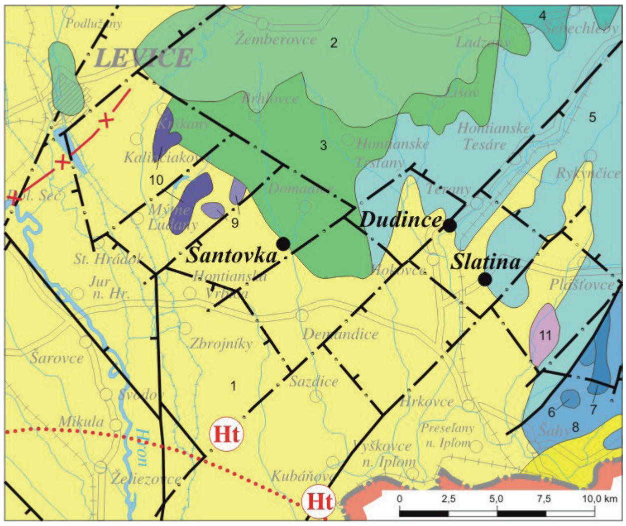


Fig. 8.1 Tectonic conditions in the area of Dudince and Santovka. 1 – Post-rift basinal fill, Neovolcanites: Sarmatian 2 – outer proximal zone, 3 – distal zone; Badenian 4 outer proximal zone, 5 – distal zone, 6 extrusive domes, 7 – breccias, 8 – conglomerates and sandstones; Palaeo-tectonic units: Hronicum 9 – Biely Váh facies, 10 – Čierny Váh facies, 11 – Veporicum – Foederata Series (detail of Tectonic map SR, Bezák et al., 2004, modified)

In this paper we present an overall view on the chemical composition of mineral waters present in this area – evaluation and graphical interpreting of data obtained through the whole period of mineral water sources use is provided (from 60's of the last Century to the present).

8.2 Brief overview of the major work carried out till to date

Hydrogeological surveys and explorations of the mineral waters of the “Levice Spring Line” was addressed by many experts; the most important findings brought works by Hynie (1956; 1957a, b; 1963), Orvan et al. (1965), Holéczyová et al. (1971, 1973, 1975, 1976), Bondarenková & Babíková (1981), Bondarenková (1983), Bondarenková et al. (1984), Melioris & Vass (1982), Melioris et al. (1986), Fendeková & Melioris (1996), Tkáčová (1978, 1980), Vandrová (1988, 1990), Vandrová et al. (1988, 1990, 2008, 2012), Vandrová & Matejčeková (1990), Vandrová & Štefanka (2007). The knowledge gained by these works (especially those last ones) led to calculation of the usable amount of mineral waters from sources in Dudince, Santovka and Slatina and to development of measures for the effective protection of resources (Ministry Decree no. 19/2000 Coll.).

At present, the only used source of natural healing water Dudince Spa – borehole S-3 (60.6 m depth, opened hole section from 52.5 to 60.0 m; Fig. 8.2) was excavated in the 50s of the 20th Century within hydrogeological research carried out by Hynie (1956, 1957a, 1963). During this period, natural springs of mineral water in Dudince had ceased (Hynie stated that there had been 10 of them). Of the nine wells drilled Hynie ordered to equip the boreholes S-3, S-4, S-5, S-6 and V-1. He stated that the initial yield of the object S-3 during the drilling work was 80 l . s^{-1}. It gradually declined and in the nineties it reached merely 10 l . s^{-1} (Rebro, 1996). Later, borehole S-5/A was drilled in the discharge area (Vandrová, 1988) and on the grounds of current swimming pool the hydrogeological drilling HVD-1 (Vandrová & Matejčeková, 1990) and HVD-2 (Vandrová et al., 1990).

Also in Santovka – Malinovec Hynie supervised the first drilling. In 1957, there were excavated three wells (B-1 to B-3), with the result that in the area disappeared many natural mineral water springs. The borehole B-6 – currently used source of natural mineral water in Santovka – was developed in 1964 (Orvan et al., 1965). In 1998 at the grounds of the swimming pool in Santovka a new source of thermal mineral water was drilled – borehole B-3A (Vandrová & Sňahničanová, 1998), which replaced the previously used drill hole B-3. In Slatina operated in the mid-20th Century baths with source Kúpeľný, Viera, Ján and Čulý. Mineral waters had unstable quantitative and qualitative characteristics. The issues of mineral water were also dealt with Hynie in the 60s of the last Century. In this period sources Studňa (*Well*) I, Studňa (*Well*) II and Borehole S-7 were excavated. Until the decommissioning of bottling plant in 2013 there were used in Slatina natural mineral water sources – wells BB-1 and BB-2 (drilled in a detailed hydrogeological . survey in the seventies of the last Century – Holéczyová et al., 1973).

Since 2014 the State Geological Institute of Dionýz Štúr has addressed a project “Search survey of the hydrogeological structure of mineral waters Dudince – Santovka” in the scope of which, inter alia, archival and newly acquired data have been assessed on the chemical composition of mineral water of Dudince, Santovka, Slatina and their vicinity with a goal of the detailed study of their formation processes, likely rock environment of their circulation, accumulation and dissipation.

8.3 Methodology

Natural healing water from the source S-3 in the Dudince Spa has the chemical type Na-Ca-HCO_3-Cl, mineralization 5,682 mg . l^{-1}. Such chemical composition is formed by mixing water from different geological environments as a result of various mineralization processes. Therefore, in summary processing and interpretation of the results of analyses of water samples taken from the sources during the hydrogeological survey made in Dudince it was necessary to get an overview of the chemical composition of groundwater and mineral waters occurring in the wider area. Respecting the specificities of the assembled set of hydrogeochemical data on mineral waters in the territory of interest, the paper introduces hereinafter the classifications and methods of processing.

Fig. 8.2 Natural healing source S-3 Dudince (Photo Bačová, 11. 9. 2013)

The assessment of the total dissolved solids in groundwater and mineral waters within the investigated territory (with mineralization range of 286 – 8,676 mg . l^{-1}) is consistent with the classification applicable to natural healing waters (Ministry Decree no. 100/2006 Coll.).

When describing the mineralization processes share on the resulting chemical composition of mineral waters we use genetic classification of the chemical composition of the groundwater of the Western

Carpathians (Gazda, 1974), adapted in terms of Geological Dictionary, part Hydrogeology Hanzel et al., (1998), Fľaková et al. (2010).

Chemical water types are described in accordance with the classification based on the principle of the prevailing ions – the title includes ions with more than 20 meq . l^{-1} % share. The sample data documenting the chemical composition of mineral water contains the results of more than 740 laboratory analyses of water samples taken from the resources in the study area. Data on the chemical composition of mineral water in the "Levice Spring Line" have been previously evaluated and interpreted as a rule only in relation to the solutions of specific hydrogeological tasks at certain times/areas.

Macrochemical composition of mineral waters is shown in two ways:

- Diagram Langelier-Ludwig (Langelier, Ludwig, 1942), substantially identical to the graph Tolstichin (Tolstichin, 1937). Construction of such a graph requires input data (mass concentrations of the individual macro-compounds – $Na^+ + K^+$, $Ca^{2+} + Mg^{2+}$, $HCO_3^- + CO_3^-$, $Cl^- + SO_4^{2-}$) recalculated to the content in·%, which is then displayed along the axis of the square plot.
- Diagram with a logarithmic scale on both axes, using data from analyses of water samples directly expressed in mass concentrations (Bačová, 2011), while on the axes of the graph coefficients $(Na^+ + K^+)/HCO_3^-$ and $(Ca^{2+} + Mg^{2+})/HCO_3^-$ are plotted.

Such graphic representation and evaluation of the macrocompounds content in mineral waters (supplemented by data on the chemical composition of ordinary groundwaters) gives an overall picture of the chemical composition of mineral waters in the examined area. It enables to assess the likely participation of different mineralization processes in the resulting chemical composition of mineral waters at specific sites; it points to a different portion of a particular process. It contributes significantly to the evaluation of the relationship among the contents of selected macro-compounds of waters.

In the case it would not be possible to define clearly infiltration and transport-accumulation area of mineral water from the results of previous geological research and exploration work, it is very important to process and interpret all the original hydrogeochemical data in detail. Such work could bring us to a knowledge that could substantially contribute to the effective protection of mineral waters, their quantitative and qualitative characteristics.

8.4 Results

8.4.1 The chemical composition of mineral waters in Dudince and its vicinity

Natural healing water from a borehole S-3 Dudince has the chemical type Na-Ca-HCO_3-Cl. In accordance with the Ministry of Health Decree no. 100/2006 Coll. as amended (with effect from July 1, 2013) it is:

By the amount of total dissolved solids *highly mineralized natural healing water*;

According to the content and type of dissolved gaseous substances, *carbonic sulphane*;

According to the content of the prevailing ions *bicarbonate-chloride sodium-calcium*;

According to the content of pharmacologically important ions and compounds of elements of *natural healing water with increased content of fluoride ion, lithium, bicarbonate ion;*

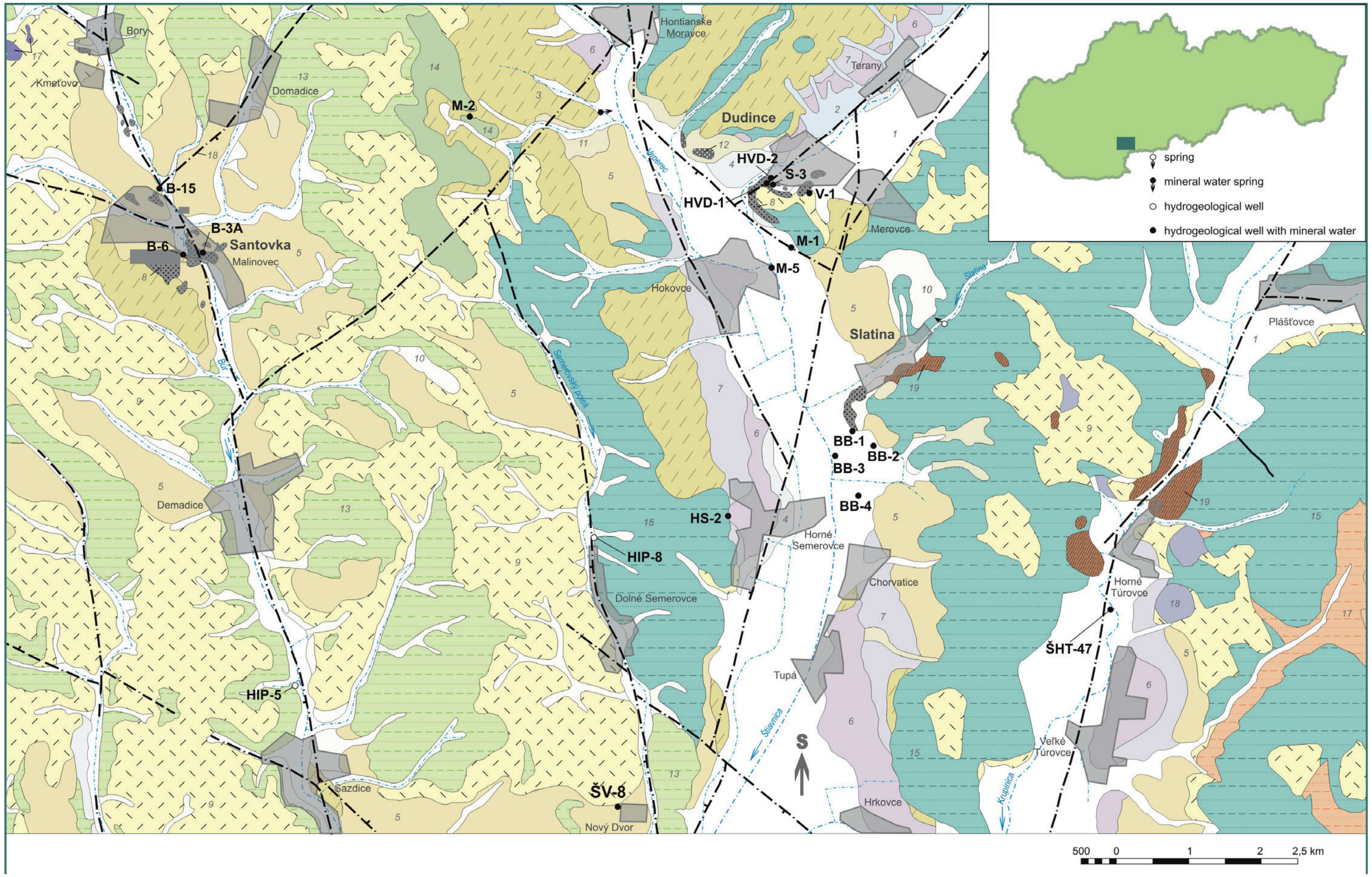
According to pH *slightly acidic*;

According to natural temperature at surge *very low thermal*.

In the section of geological map at scale of 1: 50,000 (compiled from documents Konečný et al., 1998; Nagy et al., 1998) there are displayed the most important hydrogeological objects with mineral water in the area from Santovka to Veľké Turovce (Fig. 8.3). In Tab. 8.1 we present hydrological data on selected wells with mineral water (Dudince, Santovka, Slatina, Hokovce, Mačkáš, Horné and Dolné Semerovce, Veľké Turovce (in the past Stredné and Dolné Turovce) and with ordinary groundwater (wells labelled HIP-1 to HIP-13 – Ipeľská pahorkatina Upland, Fecek, 1981).

Selected qualitative characteristics of mineral waters in Dudince, Santovka, Slatina and vicinity are presented in Tab. 8.2.

Fig. 8.3 Schematic geological map of the area (Konečný et al., 1998; Nagy et al., 1998, modified)



1 – fluvial sediments – prevailingly loamy or loamy-gravelly (Holocene undivided)
2 – proluvial sediments – loams (Pleistocene – Holocene)
3 – deluvial, deluvial-fluvial, eluvial-deluvial and aeolian-deluvial sediments – loams, sandy loams (Pleistocene – Holocene)
4 – fluvial sediments – sandy gravels of bottom accumulation and gravels of low terrace with loess sheet (Late Pleistocene)
5 – aeolian sediments – loess (Late Pleistocene)
6 – fluvial sandy gravels 3rd middle terrace (Middle Pleistocene)
7 – fluvial sandy gravels and gravels 2nd main middle terrace (Middle Pleistocene)
8 – travertines, travertine sinters and foamstones (Quaternary undivided)
9 – eluvial-deluvial loams and deluvial colluvial loams (Quaternary undivided)
10 – deluvial-fluvial loams (Quaternary undivided)
11 – colluvium, landslides (Quaternary)
12 – travertines – solid fresh-water limestones (Neogene: Pontian – Pliocene)
13 – Baďany Fm. – sands, sandstones, tuffaceous clays, tuffites and tuffs, pumice tuffs, conglomerates (Early to Middle Sarmatian)
14 – Ladzany Fm. – epiclastic volcanic sandstones and siltstones with pumice fragments (Early Sarmatian)
15 – Sebechleby Fm. – tuffaceous clays and siltstones (Plášťovce Mb.), tuffaceous sandstones, sandy tuffites (Early to Middle Badenian)
16 – Vinica Fm. – volcaniclastic rocks – breccias, conglomerates, tuffaceous siltstones and claystones (Early Badenian)
17 – Partnach Fm. – clayey shales, clayey limestones (Hronicum – Triassic)
18 – Foederata Group – quartzose sandstones, quartzites, schists – metamorphosed (Veporicum envelope – Triassic)
19 – Foederata Group – Rimava Fm. – sandstones, phyllite schists, conglomerates (Southern Veporicum – Permian)
20 – faults (dash line – assumed, dot-and-dash line – covered by Quaternary)

Tab. 8.1 Selected data on the most important objects with mineral water in the examined area

Site/water source		Well implemented in	Well depth [m]	Open section [m]	Geological data	Yield [l . s^{-1}]	TDS [mg .·l^{-1}]	Chemical type [compounds > 20 meq . l^{-1} %]	Date of analysis	Data source, note
Santovka	B-3	1957	68.7		0.0 − 16.0 Quaternary 16.0 − 68.7 Neogene − Badenian	10 − overflow (exploitable determined – 60s of the last Century)	6,171	**Na-Ca-HCO$_3$-Cl**	*	Hynie, 1963 (50 overflow originally reported)
	B-3A	1998	73.4	45.3 − 49.3 58.2 − 64.3	0.0 − 16.0 Quaternary 16.0 − 73.4 Neogene − Badenian	Exploitable amount cat. B – 15.5 – overflow (Decision ME SR no. 7601/2008-9.1)	5,941	**Na-Ca-HCO$_3$-Cl**	*	Vandrová & Štefanka, 2007
	B-4	1963	30	18 − 28	0.0 − 9.0 Quaternary 9.0 − 30.0 Tortonian − Sarmatian	0.03 (s = 3.98)	3,115	**Ca-Na-HCO$_3$**	*	Orvan et al., 1965
	B-5	1963	29	18 − 26	0.0 − 1.7 Quaternary 1.7 − 29.0 Tortonian − Sarmatian	0.43 (s = 2.75 m)	3,634	**Na-Ca-HCO$_3$**	*	Orvan et al., 1965
	B-6	1963	42	27.0 − 42.0	0.0 − 7.0 Quaternary 7.0 − 42.0 Tortonian − Sarmatian	Permitted exploitable amount 0.5 – pumping (Decision ME SR no. 01184-46/2013/SSC)	3,698	**Ca-Na-HCO$_3$**	*	Orvan et al., 1965
	B-7	1964	40		0.0 − 4.0 Quaternary 4.0 − 40.0 Tortonian − Sarmatian		3,553	**Ca-HCO$_3$-SO$_4$** **Na-Ca-HCO$_3$-Cl**	*	Orvan et al., 1965
	B-8	1964	31.8		0.0 − 2.0 Quaternary 2.0 − 31.8 Tortonian − Sarmatian		6,019	**Na-Ca-HCO$_3$-Cl**	*	Orvan et al., 1965
	Santovka II, B-9	1964	18.2	8.0 − 17.2	0.0 − 8.0 Quaternary 8.0 − 18.2 Tortonian − Sarmatian	0.2 (s = 3.00 m)	3,977	**Na-Ca-HCO$_3$**	*	Orvan et al., 1965
	B-10	1971 − 1972	57		0.0 − 2.0 Quaternary 2.0 − 57.0 Neogene	0.8 (s = 9.52 m)	5,226	**Na-Ca-HCO$_3$-Cl**	*	Holéczyová et al., 1975
	Santovka III, B-11	1975	45	10.5 − 19.6	0.0 − 7.5 Quaternary 7.5 − 45.0 Neogene	0.5 (s = 3.68 m)	2,983 6,106	**Ca-Na-HCO$_3$** **Na-Ca-HCO$_3$-Cl**	*	Holéczyová et al., 1975
	B-12	1972	30		0.0 − 3.9 Quaternary 3.9 − 30.0 Neogene	0.08 (s = 4.35 m)	4,445	**Na-Ca-HCO$_3$-SO$_4$**	7.7.1972	Holéczyová et al., 1975
	B-13	1972	26**	24.0 − 26.0	0.0 − 5.5 Quaternary 5.5 − 26.0 Neogene (tectonic failure line)	1.25 (s = 7.77 m)	6,688	**Na-Ca-HCO$_3$-Cl-SO$_4$**	*	Holéczyová et al., 1975; **60 m – Vandrová et al., 1980
	B-14	1973	45	22.0 − 33.0	0.0 − 8.0 Quaternary 8.0 − 45.0 Neogene	0.1 − overflow	5,344	**Na-Ca-HCO$_3$-Cl**	*	Holéczyová et al., 1975
	B-15	1974 – – 1975	15.7	11.2 − 15.7	0.0 − 5.7 Quaternary 5.7 − 15.7 Neogene	2.0 (s – 6.55 m)	3,428	**Na-Ca-HCO$_3$**	*	Holéczyová et al., 1975; Vandrová et al., 2008
	Santovka IV, HG-4	1972	19	15.0 − 19.0	0.0 − 9.5 Quaternary 9.5 − 19.0 Neogene	0.4 (s = 12.00 m)	3,257	**Na-Ca-HCO$_3$**	*	Holéczyová et al., 1975

Continuation of Tab. 8.1

	Site/water source	Well implemented in	Well depth [m]	Open section [m]	Geological data	Yield [l . s^{-1}]	TDS [mg .·l^{-1}]	Chemical type [compounds > 20 meq . l^{-1} %]	Date of analysis	Data source, note
Dudince	Kúpeľný well S-3	1954 1994 – 1995	60.65	52.5 – 60.0	0.0 – 7.5 Quaternary 7.5 – 60.65 Neogene – Badenian	exploitable amount cat. B 6.2 – overflow (Decision ME SR of 25. 9. 2012)	5,682	**Na-Ca-HCO$_3$-Cl**	*	Hynie, 1963 (70 – 80 overflow in 60s, 9,8 in 90s)
	Gejzír well S-4	1955	70.33	Wooden caisson	0.00 – 7.05 Quaternary 7.05 – 55.2 Neogene – Badenian 55.20 – 70.23 Mesozoic – Early Triassic	2.6	6,191	**Na-Ca-HCO$_3$-Cl**	*	Hynie, 1963
	Rímsky well V-1	1953	107,5		0.00 – 15.30 Quaternary 15.30 – 103.00 Neogene – Badenian 103.00 – 107.50 Mesozoic – Early Triassic		2,365	**Na-HCO$_3$-Cl**	*	Hynie, 1963
	well S-5/A	1987	70	39.0 – 65.0	0.0 – 10.2 Quaternary 10.2 – 58.4 Neogene – Badenian 58.4 – 70.0 Mesozoic – Early Triassic (quartzite)	1.2 (s = 9.90 m)	4,839	**Na-Ca-HCO$_3$**	*	Vandrová, 1988
	well S-6	1956	12		0.0 – 5.0 Quaternary 5.0 – 12.0 Neogene – Badenian		2,440	**Ca-HCO$_3$ (S-6/A)**	*	Hynie, 1963, Vandrová et al., 1990
	well HVD-1	1989	85	45.0 – 57.0 57.0 – 67.0	0.0 – 9.0 Quaternary 9.0 – 81.0 Neogene – Badenian 81.0 – 85.0 Mesozoic – Early Triassic	exploitable amount cat. B 1.2 – overflow (Decision ME SR of 25. 9. 2012)	5,540	**Na-Ca-HCO$_3$-Cl**	*	Vandrová & Matejčeková, 1990
	well HVD-2	1990	80	53.0 – 57.0 62.0 – 72.0	0.0 – 10.0 Quaternary 10.0 – 71.0 Neogene – Badenian 71.0 – 80.0 Mesozoic – Early Triassic	0.1 – overflow (0,3 m above surface)	6,425	**Na-Ca-HCO$_3$-Cl**	*	Vandrová et al., 1990
	Kmeťovce, HIP-3	10.1974	80	54.0 – 76.0	24.0 – Quaternary 80.0 – Late Miocene (from 67 m andesite)	3.0 (s = 17.7 m) 3.4 (s = 31.8 m)	423 – 427	**Ca-Mg-HCO$_3$**	3. – 4.1975	Fecek, 1981
	Drženice, HIP-4	12.1975	111	29.0 – 107.0 5 sections	3.4 – Quaternary 111.0 – Pannonian	0.1 (s = 45.0 m)	600	**Na-Ca-Mg-HCO$_3$**	26.3.1975	Fecek, 1981
	Sazdice, HIP-5	12.1972	141	20.0 – 95.0 4 sections	5.0 – Quaternary 141.0 – Badenian, Sarmatian	4.0 (s = 2.1 m)	755 – 791	**Ca-Mg-HCO$_3$**	4.1973	Fecek, 1981
	Trhyňa (Sikenica) HIP-6	1.1973	165	16.0 – 155.0 5 sections	11.0 – Quaternary 165.0 – Badenian, Sarmatian	< 0.01 (s = 5.2 m)	1,211 – 1,259	**Na-Ca-HCO$_3$**	1. – 2.1973	Fecek, 1981
	Trhyňa (Lontov) HIP-7	10.1972	250	26.4 – 154.0 7 sections	1.3 – Quaternary 250.0 – Badenian, Sarmatian	4.0 (s = 2.5 m)	749 – 751	**Ca-Na-HCO$_3$**	6. – 7.1973	Fecek, 1981
	Dolné Semerovce HIP-8	3.1973	203	30.5 – 145.6 3 sections	6.0 – Quaternary 203.0 – Badenian	4.1 (s = 20.2 m)	693 – 698	**Ca-Mg-HCO$_3$**	5.1973	Fecek, 1981
	Kubáňovo HIP-9	10.1973	202	54.3 – 185.0 5 sections	2.4 – Quaternary 202.0 – Badenian, Sarmatian	2.25 (s = 19.6 m)	955 – 1,123	**Na-Ca-HCO$_3$**	12.1973	Fecek, 1981
	Hontianske Trsťany HIP-13	1. – 2.1975	205	58.0 – 168.0 4 sections	6.0 – Quaternary 205.0 – Badenian, Sarmatian	5.7 (s = 6.5 m) 5.71 (s = 6.83 m)	558 – 586	**Ca-Mg-HCO$_3$**	6. – 7.1977	Fecek, 1981
	Mačkáš M-2	1983	490	438 – 469	0.0 – 6.0 Quaternary 6.0 – 300.0 Neogene 300.0 – 490.0 Mesozoic		5,626	**Na-Ca-HCO$_3$-Cl**	*	Melioris et al., 1986

Continuation of Tab. 8.1

<table>
<tr><th colspan="2">Site/water source</th><th>Well implemented in</th><th>Well depth [m]</th><th>Open section [m]</th><th>Geological data</th><th>Yield [l . s⁻¹]</th><th>TDS [mg .·l⁻¹]</th><th>Chemical type [compounds > 20 meq . l⁻¹ %]</th><th>Date of analysis</th><th>Data source, note</th></tr>
<tr><td rowspan="2">Hokovce</td><td>M-1</td><td>1980</td><td>321</td><td>150 − 220</td><td>0.0 − 3.9 Quaternary
3.9 − 12.0 Neogene
12.0 − 220.0 Palaeozoic (Veporicum envelope)</td><td></td><td>5,936</td><td>Na-Ca-HCO₃-Cl</td><td>*</td><td>Melioris et al., 1986</td></tr>
<tr><td>M-5</td><td>1983</td><td>220</td><td>150 − 220</td><td>0.0 − 5.0 Quaternary
5.0 − 30.0 Neogene
30.0 − 220.0 Palaeozoic (Veporicum envelope)</td><td>0.0012 – overflow
(0.9 m above surface)</td><td>6,442</td><td>Na-Ca-HCO₃-Cl</td><td>*</td><td>Melioris et al., 1986</td></tr>
<tr><td rowspan="7">Slatina</td><td>well S-7</td><td>1957</td><td>14.8</td><td>9.0 − 12.6</td><td>7.5 − 8.3 Early Triassic (quartzites)</td><td>1.5</td><td>2,758</td><td>Na-Ca-HCO₃-Cl</td><td>26.7.1964</td><td>Hynie, 1963</td></tr>
<tr><td>well S-II
(pôv. studňa)</td><td>1957</td><td>17</td><td>12.0 − 15.0</td><td></td><td>0.8 − 1.4</td><td>3,176</td><td>Na-Ca-HCO₃-Cl</td><td>28.3.1964</td><td>Hynie, 1963</td></tr>
<tr><td>well BB-1</td><td>1972</td><td>34.3</td><td>30.0 − 34.3</td><td>33.8 − Early Triassic (quartzites)</td><td>1.5
(recommended)</td><td>4,370</td><td>Na-Ca-HCO₃-Cl</td><td>26.8.1979</td><td>Holéczyová et al., 1973;
Bondarenková & Bab&ková, 1981</td></tr>
<tr><td>well BB-2</td><td>1972</td><td>33.3</td><td>31.5 − 33.3</td><td>8.0 − Quaternary
33.3 − Neogene</td><td>Permitted exploitable amount
1.5 – pumping
(Decision no. 00767-026/2011/SSC)</td><td>1,840</td><td>Na-HCO₃-Cl</td><td>30.9.1979</td><td>Holéczyová et al., 1973;
Bondarenková & Babíková, 1981</td></tr>
<tr><td>well BB-3</td><td>1983</td><td>150</td><td>102 − 130
3 sections</td><td>102 − 130 Neogene − Badenian
133 − 150 – Early Triassic (quartzites)</td><td>1.5 (s = 4.38 m)</td><td>4,735</td><td>Na-Ca-HCO₃-Cl</td><td>3.7.1987</td><td>Bondarenková et al., 1984</td></tr>
<tr><td>well BB-4</td><td>1984</td><td>233</td><td>144 − 178</td><td>144 − 178 – Early Triassic (quartzites)
178 − 233 – Permian</td><td>1.0 (s = 2.93 m)</td><td>5,571</td><td>Na-Ca-HCO₃-Cl</td><td>2.7.1987</td><td>Bondarenková et al., 1984</td></tr>
<tr><td>well BB-5</td><td>1987</td><td>60</td><td></td><td>0.0 − 1.8 Quaternary
1.8 − 8.5 Neogene
8.5 − 60.0 Mesozoic − Early Triassic</td><td>0.3 (s = 11.53 m)</td><td>1,279</td><td>Na-HCO₃-SO₄</td><td>4.11.1987</td><td>Vandrová et al., 1988</td></tr>
<tr><td rowspan="3">Semerovce</td><td rowspan="2">Dol. Semerovce, ŠV-8</td><td rowspan="2">6.1964 –
– 9.1966</td><td rowspan="2">1,204</td><td>550 − 570</td><td rowspan="2">0.0 − 17.0 Quaternary
17.0 − 21.0 Sarmatian
21.0 − 542.0 Badenian
542.0 − 688.0 Early Triassic
688.0 − 932.6 Permian
932.6 − 1,203.6 Older Palaeozoic (phyllites)</td><td>0.33 (s = 88 m)</td><td>7,028</td><td>Na-Mg-HCO₃-Cl</td><td>23.3.1967</td><td rowspan="2">Biela, A., 1978;
Vass, D. et al., 1981</td></tr>
<tr><td>853 − 932</td><td>0.33 (s = 89 m)</td><td>6,926</td><td>Na-Ca-HCO₃-Cl</td><td>22.4.1967</td></tr>
<tr><td>Hor. Semerovce, HS-2</td><td>1991</td><td>150</td><td>80 − 145</td><td>18.0 − Quaternary
150.0 − Neogene</td><td>6.0 (s = 11.83 m)</td><td>3,067</td><td>Na-Ca-HCO₃</td><td>1991</td><td>Lauko et al., 1991</td></tr>
</table>

Continuation of Tab. 8.1

Site/water source		Well implemented in	Well depth [m]	Open section [m]	Geological data	Yield [l . s^{-1}]	TDS [mg .·l^{-1}]	Chemical type [compounds > 20 meq . l^{-1} %]	Date of analysis	Data source, note
Horné Turovce	well ŠHT-47	1975	150	85 − 145	5.8 – 6.1 – Neogene 6.1 – 150.0 – Early Triassic. Permian (phyllites, quartzy sandstones and conglomerates)	0.5 (s = 2.15 m)	3,874	**Na-Ca-HCO_3-Cl**	2.8.1977	Rebro et al., 1978
	well ŠHT-48	1975	160	45 − 50.9 104 – 150	5.4 – 5.9 – Neogene 5.9 – 160.0 – Early Triassic, Permian	0.518 (s = 2.96 m)	5,491	**Na-Ca-HCO_3-Cl**	2.8.1977	Rebro et al., 1978
	well ŠHT-49	1975	150	25 − 95	9.0 – 16.9 – Neogene 16.9 – 150.0 – Early Triassic, Permian	1.45 (s = 6.26 m)	4,932	**Na-Ca-HCO_3-Cl**	2.8.1977	Rebro et al., 1978
Bohunice, HIP-1		10.1974 – – 12.1974	43	27.0 − 43.0	7.0 − Quaternary 43.0 − Late Miocene	0.8 (s = 17.4 m)	304 − 386	**Ca-Mg-HCO_3**	3.1975	Fecek, 1981
Bátovce, HIP-2		12.1974	205	29.0 − 200.0 3 sections	18.0 − Quaternary 205.25 − Miocene (from 195 m andesite)	2.7 (s = 20.0 m)	504	**Ca-Mg-HCO_3**	18.2.1975	Fecek, 1981

Tab. 8.2 Selected data on the macrochemical composition of mineral waters Dudince and the surrounding area

Site	Source	Water t [°C]	pH	TDS	Li^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Sr^{2+}	F^-	Cl^-	SO_4^{2-}	HCO_3^-	H_2SiO_3	CO_2	H_2S	Chemical type	Source
				[mg.l^{-1}]															
Dudince	ZV-70 S-3	24.0	6.7	5,898	3.24	885	120	502	133	10.2	2.8	553	549	3,087	21.1	1,428	17.00	Na-Ca-HCO_3-Cl	Vandrová et al., 2007
		26.8	6.7	5,548	2.99	776	133	477	123	9.2	2.0	562	563	2,824	21.1	704	6.89	Na-Ca-HCO_3-Cl	Bačová 6.9.2016
	ZV-71 S-4 Gejzír	27.5	5.9	5,341		823	170	380	133			562	532	2,654	52.1	1,312	6.77	Na-Ca-HCO_3-Cl	Krahulec et al., 1977
		16.2	6.8	1,440	0.5	142	34	194	26	2.5	0.8	81	307	635	8.0	381		Na-Ca-HCO_3-Cl	Melioris et al., 1986
	ZV-72 S-5	14.0	7.8	3,091	1.9	746	116	21	27	0.2		346	12	1,776	19.0	40		Na-HCO_3-Cl	Melioris et al., 1986
	ZV-84 S-5/A	16.3	6.5	4,767	2.77	691	110	405	110	7.5	2.8	425	520	2,429	34.2	2,134	2.58	Na-Ca-HCO_3	Vandrová et al., 1990
			5.5	5,400	2.29	705	118	434	126	7.7	2.6	462	482	2,633		905	1.76	Na-Ca-HCO_3	Melioris & Drexler, 2002
	S-6	12.0	6.0	2,350	0.53	76	33	420	47	3.5		24	95	1,599	37.1	1,819	1.50	Ca-HCO_3	Melioris et al., 1986
	S-6/A	11.9	6.5	2,505	0.54	85	38	420	53	4.3	1.9	26	120	1,647	75.8	1,692	0.90	Ca-HCO_3	Vandrová et al., 1990
			6.1	2,388	0.72	86	54	395	45	4.8	2.5	25	122	1,586	47.2	898	0.12	Ca-HCO_3	Bačová 10.11.2015
	ZV-69 V-1 Rímsky	14.7	7.9	2,825	1	630	101	44	73	0.8	0.1	549	8	1,386	5.5	48		Na-HCO_3-Cl	Krahulec et al., 1977
		24.8	7.5	2,363	1.59	455	83	65	61	3.4	1.0	377	6	1,208	18.4	155	0.97	Na-HCO_3-Cl	Vandrová et al., 1990
		14.3		2,897		620	115	48	73			545	15	1,393		44		Na-HCO_3-Cl	Melioris et al., 1986
	ZV-85 HVD-1	30.0	7.4	5,942	3	895	131	502	131		3.2	590	573	3,051	28.7	1,539	6.53	Na-Ca-HCO_3-Cl	Vandrová et al., 1990
	ZV-86 HVD-2	23.5	6.5	6,433	4	998	156	516	142	10.0	2.2	803	479	3,252	26.1	1,379	2.31	Na-Ca-HCO_3-Cl	Vandrová et al., 1990
	ZV-68 well	11.0	6.5	4,864		791		425	107			434	488	2,557	33.8	1,450		Na-Ca-HCO_3	Krahulec et al., 1977
		10.7	6.6	5,086	2.87	792	135	358	137	6.9	1.7	525	504	2,575	18.3	954		Na-Ca-HCO_3-Cl	Melioris et al., 1986
Santovka	LE-15 B-3	26.0	6.5	6,195		939	136	508	162			634	604	3,210	23.4	1,440	5.29	Na-Ca-HCO_3-Cl	Orvan et al., 1965
		26.0	6.4	6,031	18	836	152	501	167			650	578	3,124	27.3	1,325	5.92	Na-Ca-HCO_3-Cl	Holeczyová et al., 1975
	B-3A	25.8	6.6	6,187	3.49	910	133	513	161	9.7	2.6	631	541	3,216		1,306	5.10	Na-Ca-HCO_3-Cl	Vandrová & Sňahničanová, 1998
			6.7	6,067	3.18	851	135	480	146	9.1	1.0	673	612	3,068	22.2	594	3.93	Na-Ca-HCO_3-Cl	Bačová 13.7.2016
	LE-34 B-6	13.6	6.1	4,340		532	100	469	108			372	408	2,343	58.4	2,310	0.46	Ca-Na-HCO_3	Orvan et al., 1965
		14.3	6.3	2,980	0.85	239	40	449	59	3.7		158	331	1,654		1,999		Ca-Na-HCO_3	Vandrová a Sňahničanová, 1998
		11.2	6.2	3,828	1.58	430	70	440	84	5.7	2.4	277	375	2,081		2,426		Na-Ca-HCO_3	Vandrová. 1998
			6.3	3,438	1.36	326	63	428	60	5.1	1.9	234	378	1,779	28.1	691		Ca-Na-HCO_3	Bačová 6.9.2016

Continuation of Tab. 8.2

Site	Source	Water t [°C]	pH	TDS	Li^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Sr^{2+}	F^-	Cl^-	SO_4^{2-}	HCO_3^-	H_2SiO_3	CO_2	H_2S	Chemical type	Source
				[mg.l^{-1}]															
Slatina	LE-31 B-1	14.0	5.6	3,128	2.18	384	100	276	92	3.5	1.2	259	374	1,629		2,083		Na-Ca-HCO_3	Franko et al., 1975
	LE-39 BB-1	14.8	6.4	4,810	2.62	777	128	360	119	7.3	2.1	652	517	2,203	10.6	2,336		Na-Ca-HCO_3-Cl	Melioris et al., 1986
	LE-40 BB-2	14.5	6.9	3,217	1.96	476	130	241	80	5.3		389	356	1,507	10.8	1,426		Na-Ca-HCO_3-Cl	Bondarenková & Babíková, 1981
			6.5	1,293	0.72	156	42	129	27	2.0	0.3	101	160	635		568		Na-Ca-HCO_3-SO_4	Vandrová et al., 1987
	LE-46 BB-3	19.3	6.7	6,997	3.59	1,147	173	523	174	7.9	2.6	978	757	3,173		1,502		Na-Ca-HCO_3-Cl	Bondarenková et al., 1984
		20.0	6.9	7,037	3.63	1,181	173	518	165	8.3	2.5	993	753	3,185		827		Na-Ca-HCO_3-Cl	Bondarenková et al., 1984
		14.8	6.2	1,351	0.86	181	48	115	35	1.9		113	158	677	12.7	807		Na-Ca-HCO_3	Melioris et al., 1986
			6.4	4,735	2.96	676	125	375	115	6.5		502	327	2,490		1,056		Na-Ca-HCO_3-Cl	Vandrová et al., 1988
	LE-47 BB-4	22.0	6.5	6,739	4.33	1,058	176	516	170	8.2	1.8	865	726	3,142		1,724		Na-Ca-HCO_3-Cl	Bondarenková et al., 1984
		12.1	6.4	5,571	3.6	919	159	361	145	7.9		766	544	2,557		1,899		Na-Ca-HCO_3-Cl	Vandrová et al., 1988
	BB-5	14.0	7.9	1,279	0.94	210	62	61	37	2.4		106	316	452		78		Na-HCO_3-SO_4	Vandrová et al., 1988
	LE-25 S-7		6.9	2,726		420	83	232	63			327	301	1,299				Na-Ca-HCO_3-Cl	VÚFBK. Mariánské Lázně
		10.5	5.9	2,171	2.1	313	64	181	52		2.0	241	248	1,014	33.7	330		Na-Ca-HCO_3-Cl	Krahulec et al., 1977
		12.0	6.5	3,971	2.17	549	118	356	114	5.7	2.0	451	790	1,538	7.0	416		Na-Ca-HCO_3-SO_4-Cl	Melioris et al., 1986
	LE-26 ST-2	9.0	5.9	2,781		416	79	240	73			312	308	1,324	5.2	2,200		Na-Ca-HCO_3-Cl	Krahulec et al., 1977
	borehole on the grounds of service station		7.2	1,538	0.02	21	12	306	39	1.1	0.4	300	235	537	48.1	79		Na-Ca-HCO_3-Cl	Bačová 6.9.2016
Mačkáš	M-2	32.0		5,625		798	120	478	140			493	485	3,033		1,715	8.02	Na-Ca-HCO_3	Melioris et al., 1986
		33.1		5,578		802	113	478	139			525	496	2,965		1,277	11.20	Na-Ca-HCO_3-Cl	Melioris et al., 1986

Continuation of Tab. 8.2

Site	Source	Water t [°C]	pH	TDS	Li^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Sr^{2+}	F^-	Cl^-	SO_4^{2-}	HCO_3^-	H_2SiO_3	CO_2	H_2S	Chemical type	Source
				[mg.l^{-1}]															
Hokovce	LE-44 M-1	11.4	6.4	6,109		888	160	445	170			644	584	3,124	11.7	1,056		Na-Ca-HCO_3-Cl	Melioris et al., 1986
		16.4	6.6	6,881		1,104	165	481	122			770	637	3,466	12.0	924		Na-Ca-HCO_3-Cl	Melioris et al., 1986
		7.3	6.2	6,358	5.4	701	153	428	162	6.5		627	288	3,624	10.2	2,161		Na-Ca-HCO_3-Cl	Melioris et al., 1986
		13.0	6.0	931	0.22	37	17	121	26	1.5	0.9	39	120	480	63.3	510	0.03	Ca-HCO_3-SO_4	Bačová 28.7.2015
	LE-45 M-5	11.6	6.6	3,704	1.85	567	92	297	93	5.4	1.3	462	375	1,776	14.1	986		Na-Ca-HCO_3-Cl	Melioris et al., 1986
		12.9	6.5	5,350	2.63	865	156	409	123	6.1	1.4	723	560	2,477	5.2	594		Na-Ca-HCO_3-Cl	Melioris et al., 1986
		14.2	6.3	6,832	4.7	1,003	179	537	187	7.6		899	649	3,295	10.4	1,385		Na-Ca-HCO_3-Cl	Melioris et al., 1986
		14.2	6.3	5,054	3.69	702	120	410	119	8.1	1.2	620	633	2,318	56.4	1,220		Na-Ca-HCO_3-Cl	Bačová 28.7.2015
	LE-32 spring at the road	12.9	6.7	1,327	0.61	46	34	160	50	3.2	0.6	25	92	848	33.7	216		Ca-Mg-HCO_3	Bačová 28.7.2015
Hontianske Moravce	ZV-67 spring Kyslá	18.7	6.6	1,625	0.55	156	27	206	36			88	112	1,040	65.8	176	0.01	Ca-Na-HCO_3	Bačová 23.7.2014
Dolné Semerovce	ŠV-8	29.6	6.9	6,934		1,267	82	441	195			1,134	808	2,952		277		Na-Ca-HCO_3-Cl	Franko & Gazda, 1968
		47.3	6.9	6,925		1,231	82	441	207			1,099	791	3,010		295		Na-Ca-HCO_3-Cl	Franko & Gazda, 1968
		19.7	7.0	6,866		1,272	120	341	231			1,134	799	2,913		570		Na-Mg-HCO_3-Cl	Franko & Gazda, 1968
		39.2	7.1	7,027		1,302	120	341	243			1,170	822	2,971		583		Na-Mg-HCO_3-Cl	Franko & Gazda, 1968
Horné Semerovce	HS-2		6.1	3,067	2.04	363	91	284	88	3.4		174	264	1,794				Na-Ca-HCO_3	Lauko et al., 1991
Veľké Turovce	LE-41 ŠHT-47	15.0	6.2	3,874	1.9	575	111	257	130	4.1	1.7	448	240	2,081	5.1	2,128		Na-Ca-Mg-HCO_3-Cl	Rebro et al., 1978
		13.8	6.2	4,040	3.33	627	121	206	109	4.7	2.1	505	267	2,166	15.3	898	0.03	Na-Ca-HCO_3-Cl	Bačová 9.6.2015
	LE-42 ŠHT-48	13.0	6.4	5,491	2.98	932	169	346	136	6.6	2.2	703	523	2,624	8.5	2,638	0.12	Na-Ca-HCO_3-Cl	Rebro et al., 1978
	LE-43 ŠHT-49	14.6	6.3	4,833	2.79	869	147	284	125	6.0	2.1	649	464	2,349	9.3	2,250	0.49	Na-Ca-HCO_3-Cl	Rebro et al., 1978

The chemical composition of the mineral waters of the most important objects in Dudince, Hokovce and Slatina is presented in Fig. 8.4 – map of thickness of Tertiary deposits was compiled on the basis of the results of geophysical works (Tkáčová, 1978). Macrocompounds content is displayed in meq . l^{-1} % using the radar chart.

By recent hydrogeological survey works in the years 1983 – 1990 there were obtained new findings, which show that in the past distinguished types of mineral water – Dudince, Santovka and Slatina – cannot be clearly separated accounting for the latest data on the content of determining ions. This is confirmed by Figure 8.4, where in addition to the concentrations of individual macrocompounds data on water mineralization are presented. To show the macrocompounds content in mineral waters from large amounts of archive data there were selected for each

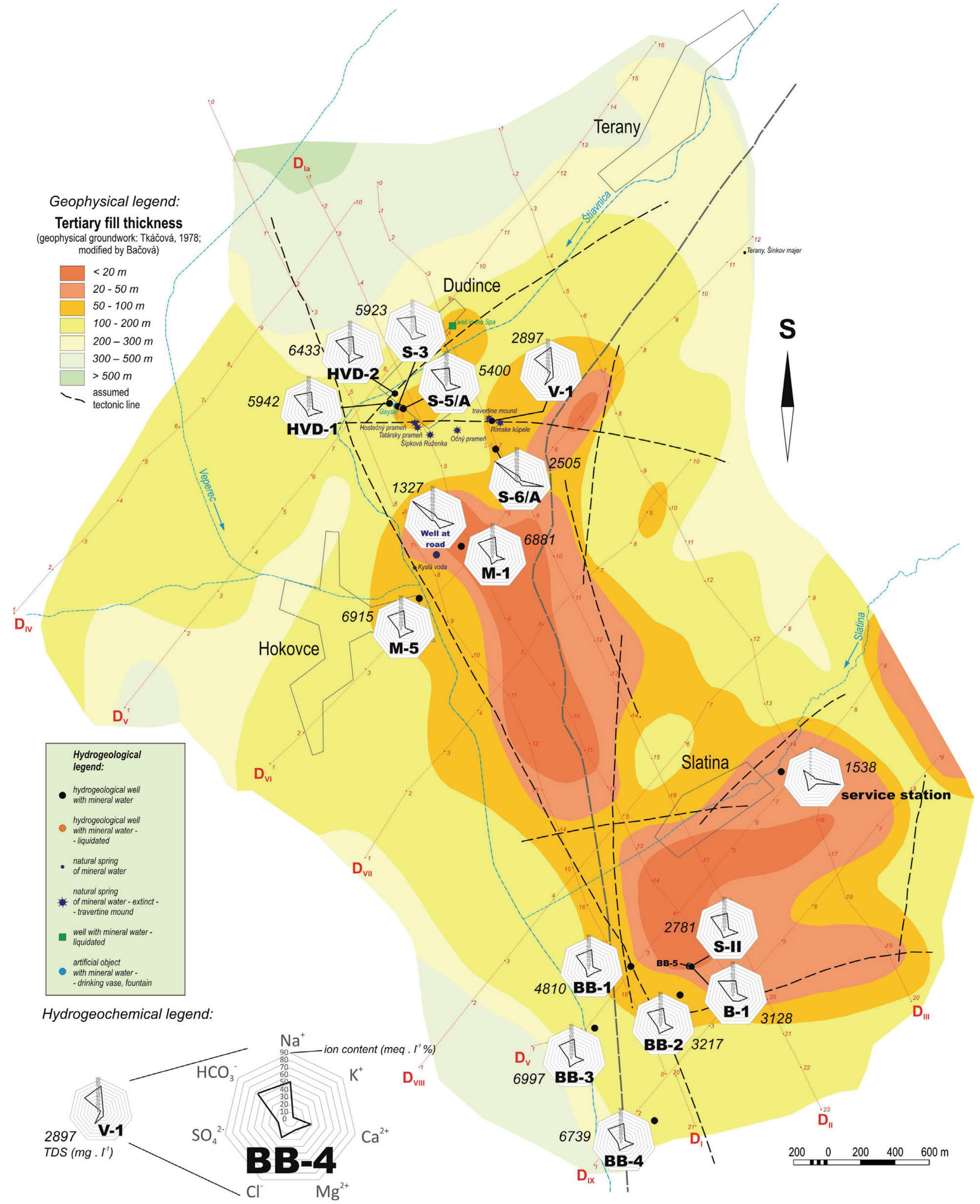


Fig. 8.4 Chemical composition of mineral waters on a base map of the Tertiary sediments thickness in the area of interest

object the analysis of the sample, in which it was detected the highest content of dissolved solids

Up-to-now known data on the thickness of Tertiary filling (represented in the area mostly by tuffs and tuffaceous sediments of Neogene volcanics) the results of drilling works in the area are displayed also on the map of field geophysical measurements – map of the thickness of Tertiary filling (Fig. 8.5., Tkáčová, 1978).

The high accuracy and reliability of geophysical interpretations was confirmed, since the wells drilled in the period after implementation and evaluation of geophysical measurements have determined thickness of Tertiary sediments corresponding to the results provided by geophysics. Tertiary bedrock in the area (determined by the wells HVD-1 and HVD-2 in Dudince and boreholes BB-3, BB-4 and BB-5 in Slatina, Fig. 8.5) are made of southern Ve-

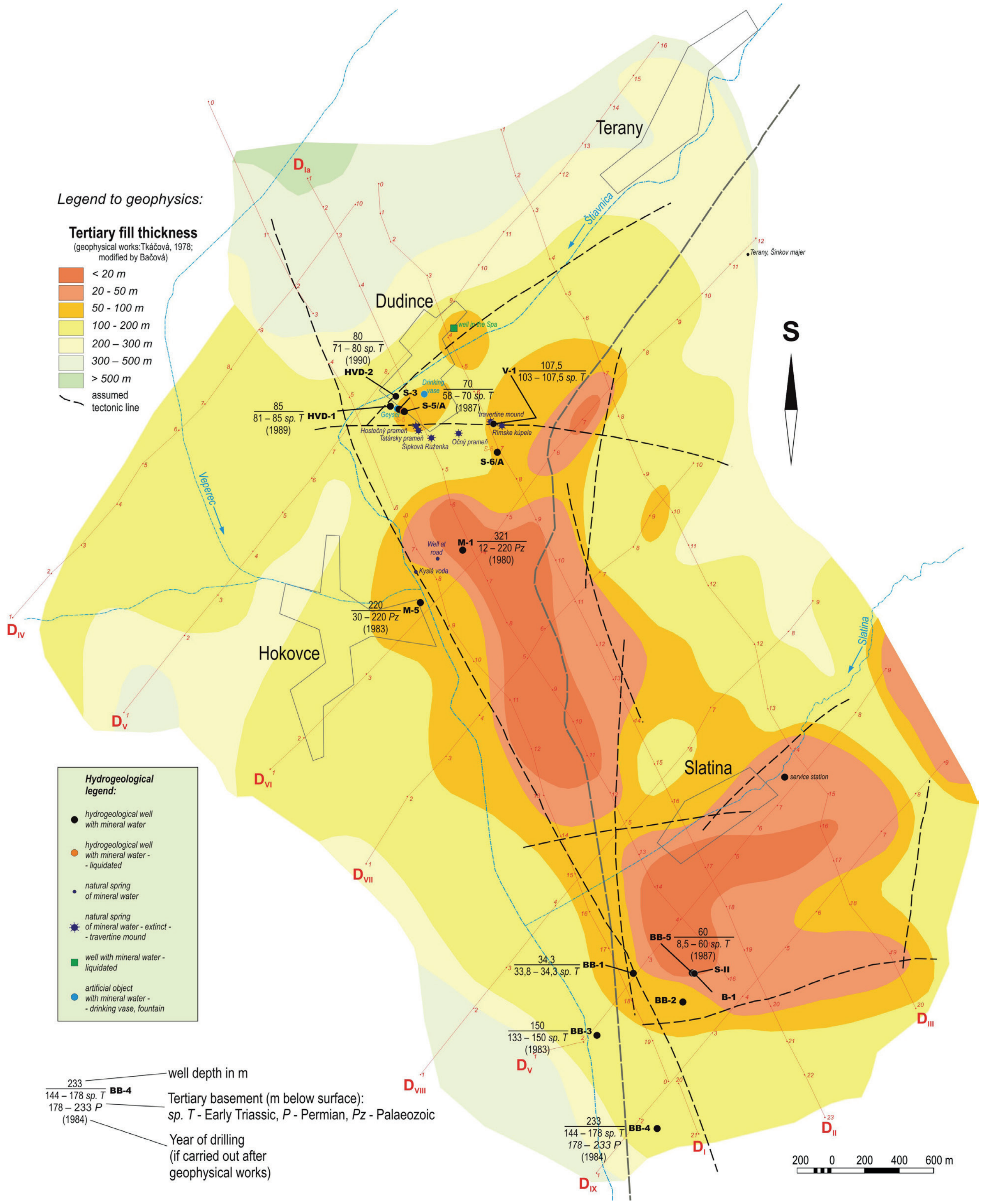


Fig. 8.5 The thickness of Tertiary filling derived from the results of geophysical measurements (Tkáčová, 1978) and the documentation of boreholes

poricum rocks – mostly quartzites and quartzose shale of the Early Triassic with underlying quartz conglomerates, phyllite schists of Permian and phyllites, quartzites and metadiabases of Early Palaeozoic (Veporicum crystalline).

8.4.2 Macrochemical composition of mineral waters

Based on the chemical composition the mineral water from Santovka, Dudince and Slatina were assigned to three types (Melioris et al., 1986; Melioris & Trnovec, 1986):

Dudince – characterized by elevated temperature, stable chemical composition, the presence of CO_2 and H_2S (mineral water from a source S-3 in Dudince, B-3A in Santovka and M-2 in Mačkáš – water type Na-Ca-HCO_3-Cl);

Slatina – characterized by lower (with the depth increasing) temperature, higher content of CO_2 and H_2S present only sporadically, wide range of mineralization of water (mineral water from sources in Slatina, M-1 and M-5 in Hokovce – water type Na-Ca-HCO_3-Cl and S-6 Dudince – water type Ca-HCO_3);

Santovka – characterized by wide range of water mineralization, a higher content of CO_2 – like the Slatina type (mineral waters of sources in Santovka: B-6 – chemical type Ca-Na-HCO_3, HG-4 –chemical type Na-Ca-HCO_3 and B-13 – chemical type Na-Ca-HCO_3-Cl-SO_4).

Total dissolved solids in these waters ranges from below 1,000 to 7,670 mg . l^{-1}. CO_2 content varies from several dozens to 3,100 mg . l^{-1}, in some sources high in carbon dioxide (S-3 Dudince, Santovka 3A-B) and at the same time a high content of hydrogen sulphide (found so far in the range of a few milligrams to 20 mg . l^{-1}). In 2014 and 2015 in the waters of the wells S-3 and B3A maximum hydrogen sulphide content was found 5,93 mg . l^{-1}.

Macrochemical composition of mineral water of the “Levice Spring Line” (shown at the Langelier-Ludwig graph in Fig. 8.6) is quite diverse. From typical water with carbonatogenic mineralization (boreholes HBV-1, HBV-2 and HBV-3 in Levice) cez through water of mixed chemical composition (water of deeper circulation, e.g. from sources S-3, HVD-1, HVD-2 in Dudince, B-13, B-3 and B-3A in Santovka, M-2 in Mačkáš, from the wells BB-1, BB-2, BB-3 and BB-4 in Slatina) to the waters with a hydrosilicatogenic mineralization (well HIP-9 in Kubáňovo).

The graph in Fig. 8.6 shows the results of previously conducted analyses of samples of mineral water in the examined area. The data from the work were used: Bondarenková, 1979; Bondarenková & Babíková, 1981; Bondarenková, 1983; Bondarenková et al., 1984; Bondarenková et al., 1988; Čermák & Gaža, 1973; Demian et al., 1991; Dobiš, 1987; Fecek, 1981; Fendek et al., 1989; Franko et al., 1975; Franko & Michalíček, 1975; Franko et al., 1982; Hensel et al., 1955; Holeczyová et al., 1971; Holeczyová et al., 1973; Holeczyová et al., 1975; Holeczyová & Motlíková, 1976; Jalč & Frličková, 1982; Klago et al., 1979;

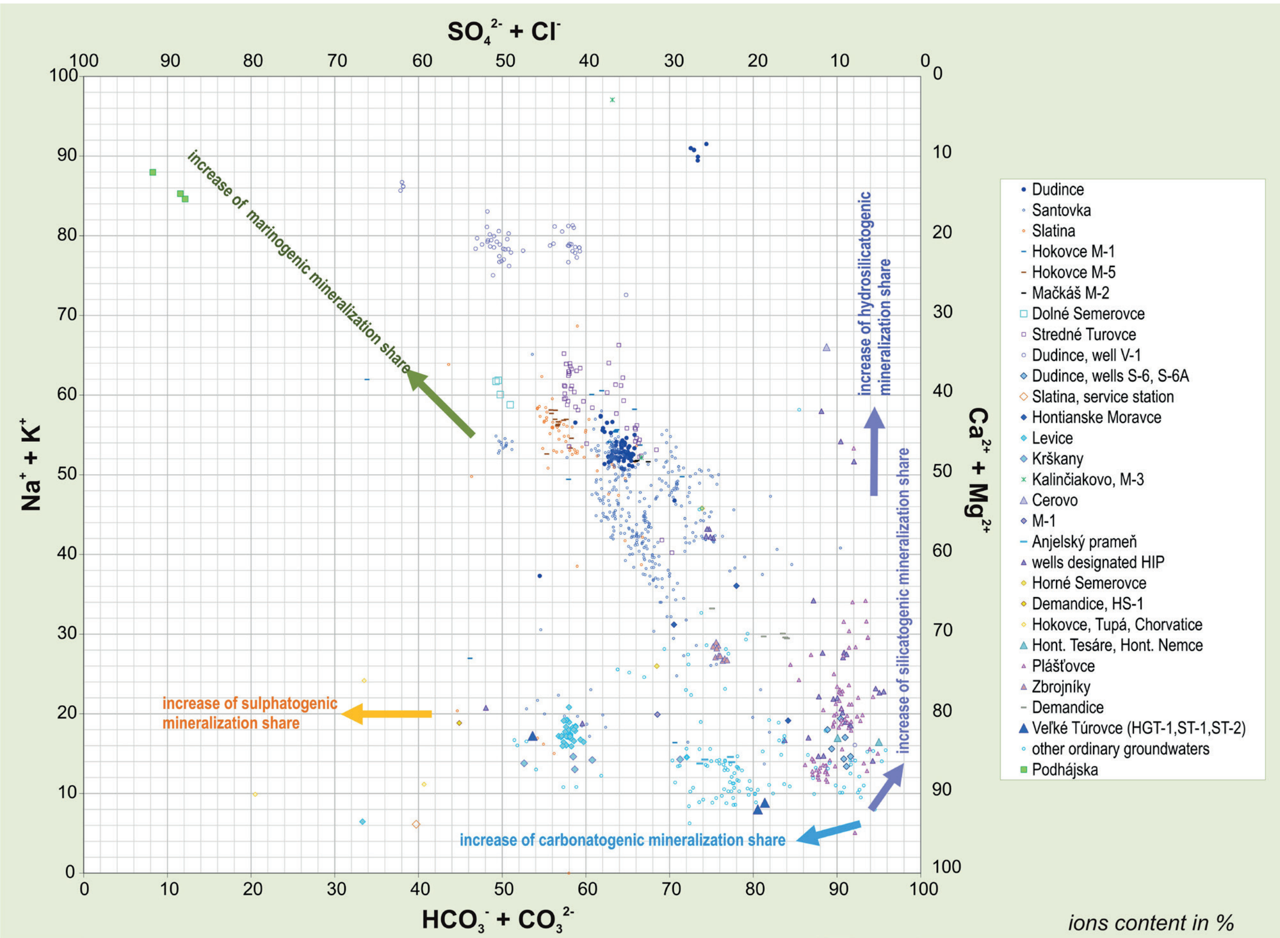


Fig. 8.6 Macrochemical composition of mineral water – Langelier-Ludwig diagram

Krahulec et al., 1977; Lauko et al., 1991; Melioris et al., 1986; Melioris, 1995; Melioris & Drexler, 1997; Melioris & Drexler, 2002; Orvan et al., 1965; Orvan & Hornung, 1968; Ostrolúcky, 1979; Rebro, et al., 1979; Vandrová et al., 1987; Vandrová, 1988; Vandrová 1988a; Vandrová & Potyš, 1988; Vandrová et al., 1988; Vandrová, 1990; Vandrová & Matejčeková, 1990; Vandrová et al., 1990; Vandrová & Sňahničanová, 1998; Vandrová & Štefanka, 2007; Vandrová et al., 2008; Vandrová et al., 2009; Vandrová et al., 2012. In Figs. 8.6 and 8.7 there are maintained the same types of colours and brands for different water sites (or sources).

The chart is supplemented by data on macrocompounds content in common groundwater in the area of the "Levice Spring Line" and its surroundings, obtained from the following works: Čubrík et al., 1985 (Dolné Semerovce); Danielová, 1991 (Veľké Turovce); Demian et al., 1991 (Hontianska Vrbica, Demandice, Tupá, Šahy); Ďuriančík, 1968 (Santovka); Ďuriančík, 1993 (Hokovce); Fecek, 1980; Fecek et al., 1980a, 1980b (vicinity of Plášťovce); Hlavatý & Modlitbová, 1969 (Santovka); Hlavatý et al., 1974 (vicinity of Plášťovce, Medovarce); Izso & Potyš, 1967 (Santovka); Jalč et al., 1981 (Zbrojníky); Jalč, 1982 (Demandice); Jalč & Frličková, 1982 (Dolné Semerovce), 1983 (Hokovce); Jalč, 1983 (Horné Semerovce); Koša et al., 1968 (Rykynčice); Lauko, 1981a, 1981b (Demandice); Lauko et al., 1991 (Horné Semerovce); Laurenčík, 1987a, 1987b (Demandice, Horné Semerovce); Lipovská et al., 1982a, 1982b (Bory, Domadice); Lipovská et al., 1983 (Santovka); Némethyová et al., 1990 (Demandice); Neupauer, 1981 (Hontianske Nemce); Ostrolucký, 1979 (Horné Semerovce); Šimovičová, 1976 (Hontianske Tesáre); Vandrová, 1995 (Santovka).

In Fig. 8.7 the macrochemical composition of the mineral waters of Dudince, Santovka and Slatina is displayed on the chart with a logarithmic scale, where coefficients are plotted calculated from the mass concentrations. To construct such a graph it was necessary to know only the weight concentrations of sodium, potassium, calcium, magnesium, bicarbonates (unlike of the previous graph, where all the data on the content of all the determining ions in waters had to be processed, and calculate the content in meq . l^{-1} %).

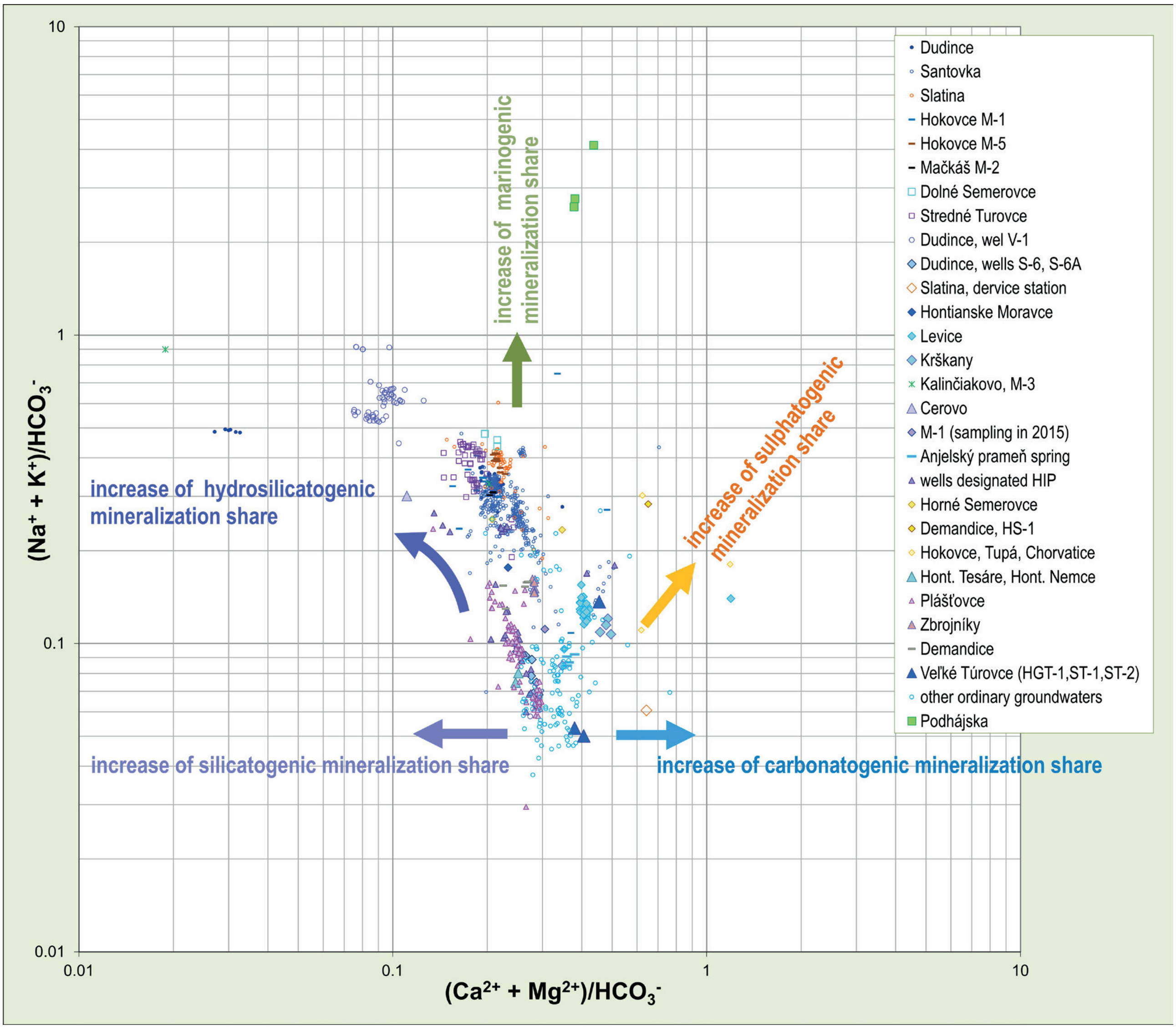


Fig. 8.7 Macrochemical composition of mineral waters – graph by Bačová (2011)

Waters with different macrocompounds content in the chart are defined by their position, which refers to the dominant processes shaping their chemical composition. The lowest points represent water with silicatogenic and carbonatogenic mineralization (with the lowest total dissolved solids content). Upwards and to the left the points are placed showing water with an increasing share of hydrosilicatogenic mineralization, up and to the right with a growing share of sulphatogenic mineralization and straight up rising share of marinogenic mineralization. Around the value of the coefficient $(Na^+ + K^+)/HCO_3^-$ equalling 1 the marinogenic mineralization is prevalent in the waters.

Mineral waters of Dudince, Santovka and Slatina have mixed chemical composition – formed by multiple processes. Silicatogenic, hydrosilicatogenic and marinogenic mineralizations are in prevail. However, carbonatogenic and sulphatogenic mineralizations are also manifested.

Based on current knowledge about mineral waters of the "Levice Spring Line" and also according to graphic display of macrocompounds content the earmarking of the Dudince, Santovka and Slatina types does not seem justified. This is documented by both methods of displaying the chemical composition of mineral waters (Fig. 8.6 and 8.7), and by depiction of the selected data on the qualitative characteristics of these waters in Figs. 8.8, 8.9 and 8.10. In the Dudince and Santovka hydrogeological objects (at different depths) mineral waters were identified satisfying the criteria under which they were earmarked the Dudince and Santovka types, but also the Slatina type. Varied chemical composition and significant differences in mineralization of waters of the objects of the discharge areas (Dudince, Santovka, Slatina) reflect complex geological and tectonic conditions depending upon a variety of factors – such as the position and depth (i.e. the depth of the open section) of each mineral water source, often also a change in the exploited amount of water, CO_2 content. Mineral waters from Slatina are distinctly different from the mineral waters of Dudince and Santovka by a higher share of marinogenic component of the resulting chemical composition.

Content of chlorides and sulphates in mineral waters

Available data on concentrations of chlorides and sulphates in mineral waters of the "Levice Spring Line" are plotted in Fig. 8.8. Investigation of the relationship between these characteristics of the chemical composition of water allows us to distinguish between water with share of carbonatogenic and sulphatogenic mineralizations from the waters in which such mineralization does not exist or its participation in a total dissolved solids content is minimal. From the line along which most points are allocated representing the waters from the investigated territory (with the direction towards the points, showing the content of chloride and sulphate in sea water), towards the upper left corner of the chart the water with increasing presence carbonatogenic and sulphatogenic mineralization are displayed (thermal water from Levice, Krškany). On the other side, there are points representing water with a significant proportion of hydrosilicatogenic and marinogenic mineralizations.

Mineral water from boreholes B-3 and B-3A in Santovka has noticeably higher content of both macrocompounds as natural healing water from a borehole S-3 in Dudince. Slightly lower levels of sulphate and chloride have been found in the water from the well of M-2 in Mačkáš (Fig. 8.8 – bottom graph).

Content of chlorides and bicarbonates in mineral waters

Information on concentration of bicarbonate and chloride in the investigated waters is provided in Fig. 8.9. Mineral waters of different sites (and even specific sources) are distinguished by the same numerals as in the previous figure. In the direction from the lower left corner to the upper right content of each macrocompound rises, reflecting mainly the deep circulation of mineral water (i.e. the depth of the tapping). Upwards right points are placed representing mineral water from the deepest sources (with the greatest depths of open sections in boreholes).

In addition to the above described dependence, the graph manifests another significant linear relationship – the line joining points representing water from wells M-1 Hokovce, M-5 Hokovce, BB-3 and BB-4 Slatina, SV-8 Dolné Semerovce (Fig. 8.9 – the lower graph). This points out to the fact, that the higher is the concentration of bicarbonate in the mineral water; the lower is the concentration of the chloride and the chloride content in the mineral water increases, and content of bicarbonates decreases in the direction from the north to the south.

By comparing the thermal water from a borehole B-3A (Santovka) with natural healing water from a borehole S-3 (Dudince), again we see a difference – the first one has clearly higher content of chlorides and bicarbonates. By comparing with the mineral waters from Slatina and Veľké Turovce these waters have a relatively higher content of bicarbonates, and less chlorides.

The content of sodium and calcium in mineral water

The relationship between sodium and calcium in the mineral waters (Fig. 8.10), similar to the relationship between the content of chloride and sulphate in mineral waters, served to distinguish water having carbonatogenic and sulphatogenic mineralization from the waters without such a mineralization (determining are the hydrosilicatogenic and marinogenic mineralizations). Among the objects in the studied area the highest share marinogenic mineralization have the waters from wells in Slatina, in Stredné Turovce (drillings ŠHT47, SHT-48 and SHT-49) and in Dolné Semerovce (well SV-8). This is confirmed by Fig. 8.10.

8.5 Discussion

From the lessons learned so far by hydrogeological exploration and research work in the area it has been shown that the mineral waters of the "Levice Spring Line" are of a very complex origin. They are formed by the mixing of waters from different geological environments in varying proportions, resulting in a very diverse chemical composition of waters from the existing and destroyed

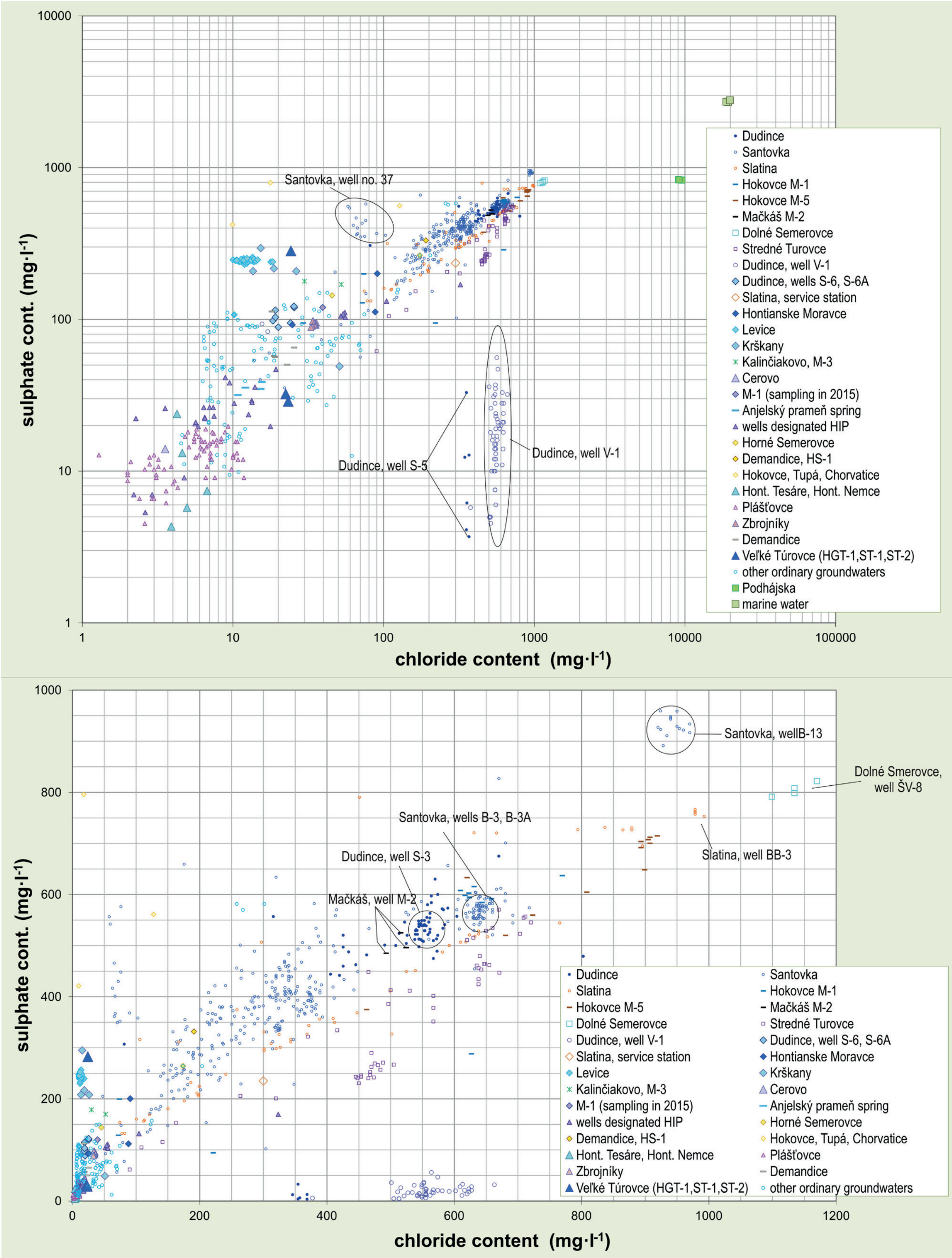


Fig. 8.8 The concentration of chloride and sulphate in mineral waters

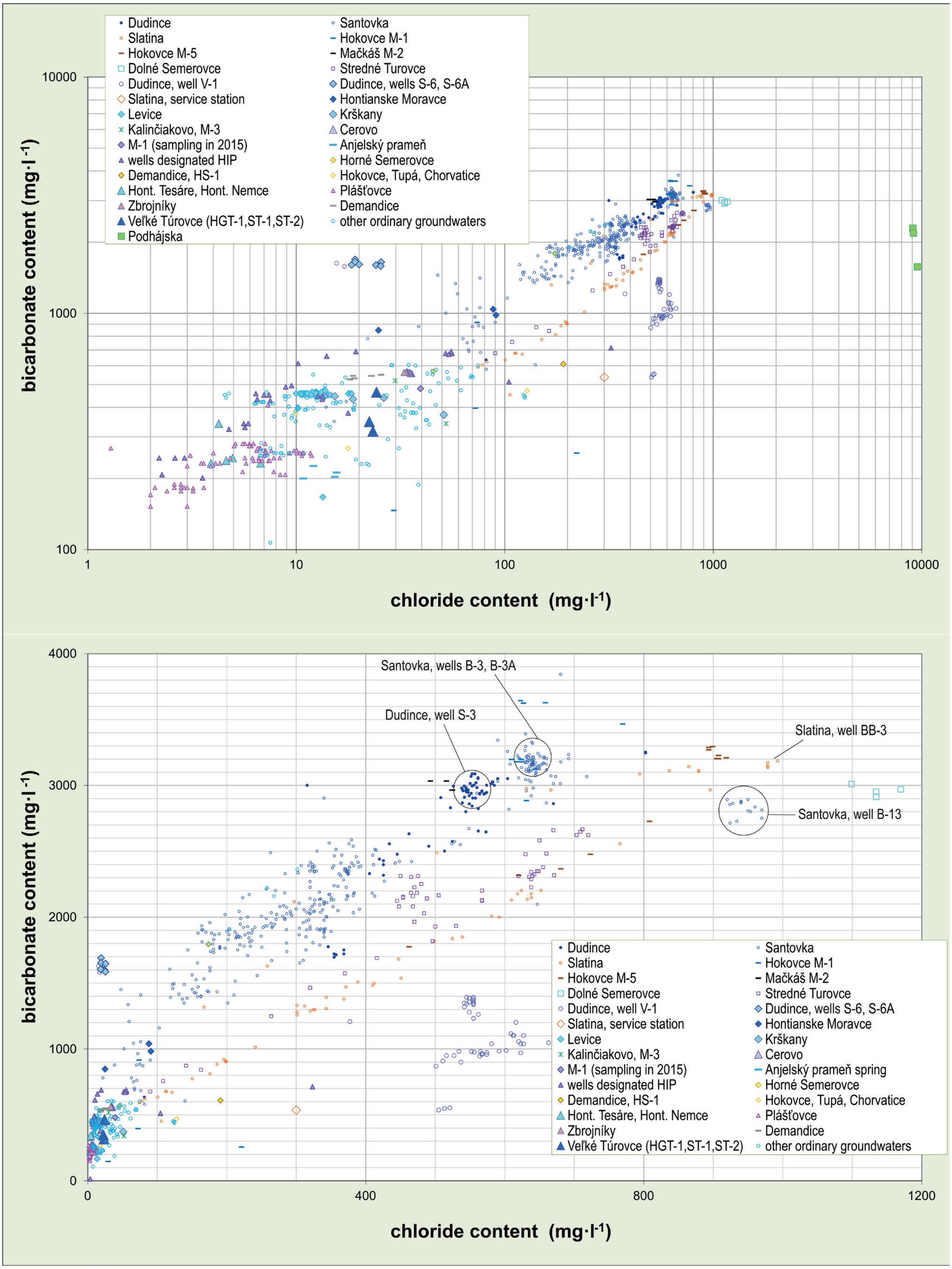


Fig. 8.9 The concentration of bicarbonate and chloride in mineral water

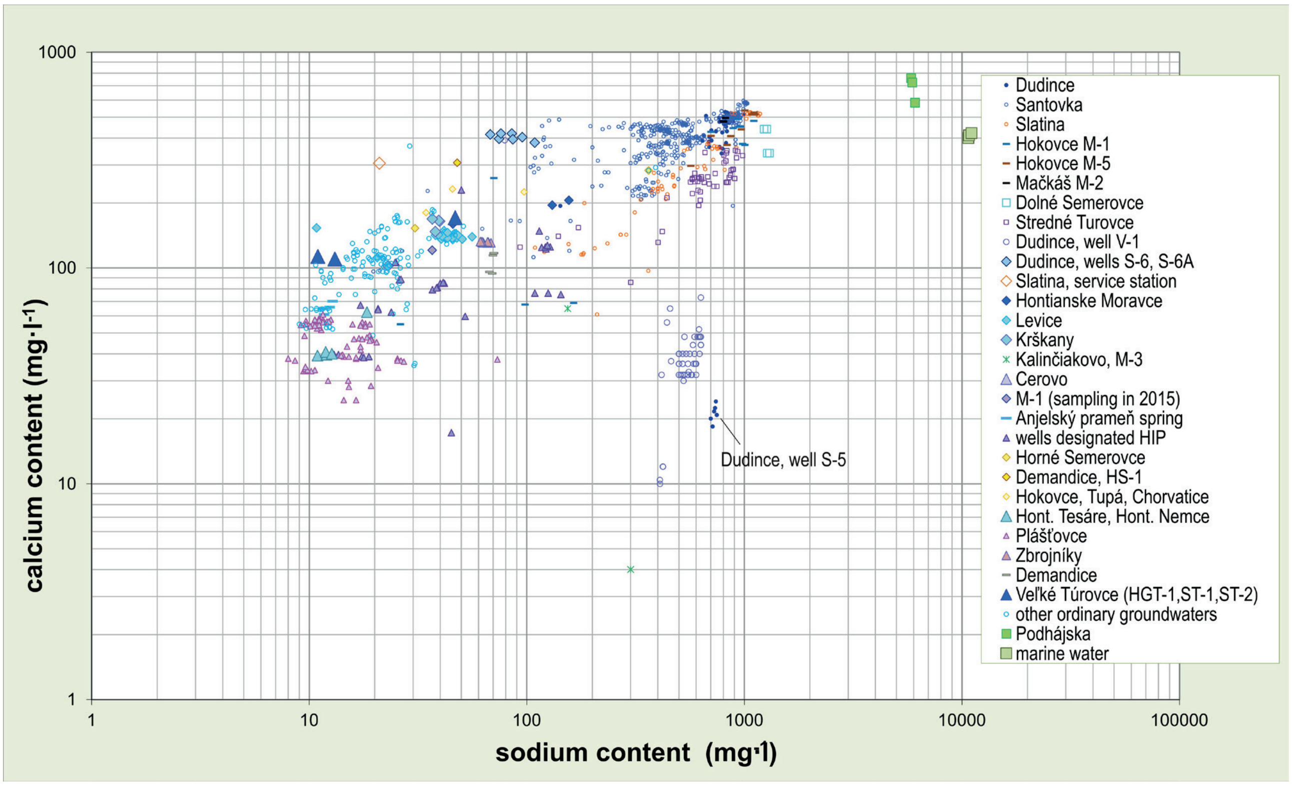


Fig. 8.10 The concentration of sodium and calcium in mineral water

hydrogeological objects. Almost identical chemical composition have the waters from the wells B-3A (Santovka), S-3 (Dudince) and M-2 (Mačkáš). Even here there are some differences – in the water from borehole M-2 has clearly higher share of hydrosilicatogenic mineralization compared to other ones, water from borehole B-3A has the highest share of marinogenic mineralization observed (among all three). The fact that the mineral waters from different sources in the discharge areas Dudince and Santovka are of relatively varied chemical compositions, reflects the complex conditions of their formation (the rock environment intensely tectonically disturbed at the contact volcanic mountain ranges and sedimentary basins with Tertiary bedrock represented by Veporicum rocks, involving deep CO_2).

At the sites Santovka and Dudince natural mineral springs existed in the past. At the time of the first drilling of the wells in the discharge areas at these sites in the 50s and 60s of the last Century all the springs gradually disappeared. At present, at their places only the travertine mounds with conduit remains (channels) in their centres have been preserved (Fig. 8.11). The natural mineral springs occurred in major tectonically disturbed zones (or within the fault crossings).

Drilling works in Dudince and Santovka were carried out in the 70s and 80s of the last Century – primarily with the goal to acquire new sources of mineral waters. In 2015 the last well was excavated (at the site of liquidated borehole S-6) designated as S-6/A. The decline in available mineral waters from existing older objects can be a consequence of their poor technical condition, as well as changing the pressure conditions in the discharge areas. We can conclude on the basis of knowledge of hydrodynamic test results that verified productivity of the most wells gradually declined. As a rule, a verified (or recommended) high yield of wells was stated in the period immediately after the objects construction; later it was often significantly lower. In some cases, the qualitative characteristics of mineral water are directly dependent of the exploited amount – especially in waters of a shallower circulation (borehole B-6 in Santovka, drillings BB-1 and BB-2 in Slatina). These groundwaters quality may also be impacted by climatic factors (such as long-lasting period without rainfall), but also ordinary high groundwater withdrawal near the mineral water source.

Data from long-term observation of the objects of the mineral waters in Dudince and Santovka in the current period are processed and evaluated, but even now we can say that the chemical composition of mineral waters from the source B-3A (and the destroyed borehole B-3) in Santovka and S-3 in Dudince appears to be stable. Our opinion is that given the mixed chemical composition of these waters of the type Na-Ca-HCO_3-Cl (sources B-3A and S-3), in which the waters of different types from different geological environments are involved, we need to consider several catchments, transport routes to the discharge areas and areas of accumulation (this issue was described in detail by Hynie (1957b, 1963), Franko (in Franko et al., 1975), in many works by Melioris (e.g. Melioris et al., 1986; Melioris, 1998 and others – in the references) and byother experts). Currently there are carried out new determinations of stable isotopes of O, H, and S in the mineral water of the objects in this respect until now without any investigation. We assume that the data can significantly contribute to clarifying the existing views.

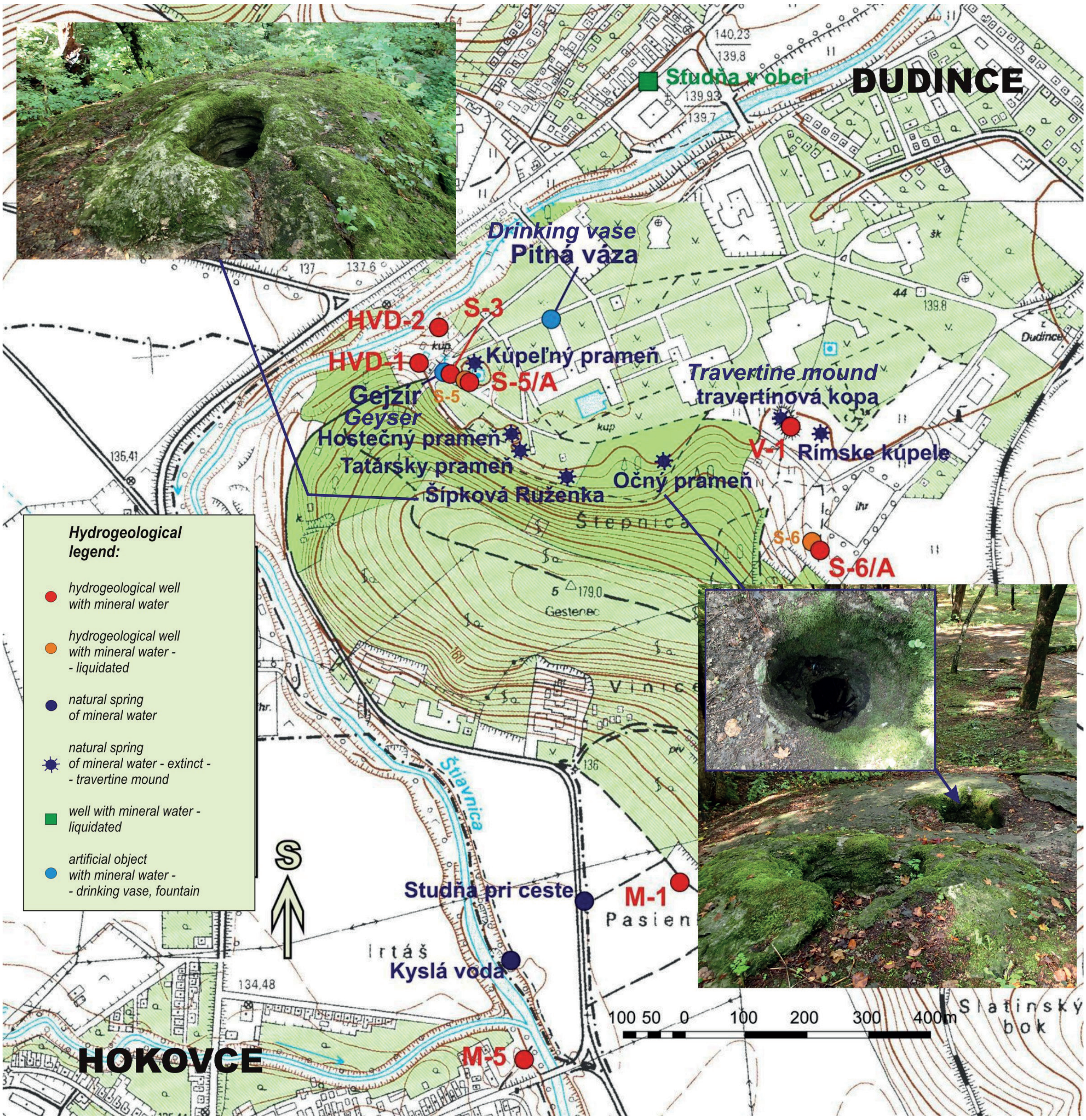


Fig. 8.11 Travertine mounds of extinct springs in Dudince

Hydrogeological structure is defined as a structural geological unit (part of the geological space), which is different from other parts of the geological area by common integrated and continuous circulation of groundwaters from the infiltration area through circulation zone to the drainage area. Its most important characteristic are the geometric shape, size and spatial distribution of hydrogeological collectors (STN 75 0111 Terminology of hydrogeology).

The hydrogeological structure of the mineral waters in the examined area – "Levice Spring Line" (which includes locations Dudince, Santovka, Slatina) – is considered to be complicated, with multiple separate structures and discharge areas. It is classified as the open structure with semi-open and semi-closed discharge areas. Central Slovakian volcanic rocks of the Krupinská vrchovina Mts. or Štiavnické vrchy Mts are considered to be the infiltration areas. It is assumed that the accumulation zone of the natural healing water from the source S-3 in Dudince are volcano-sedimentary rocks between Dudince and Hontianske Tesáre and the special role played the Badenian basal gravel complex in Dudince, which allows for increased accumulation of the mineral water (Melioris et al., 1986, Ministry of Health Decree no. 19/2000 Coll.).

8.6 Conclusion

Macrochemical assessment of the composition of mineral water of the "Levice Spring Line" in this paper makes it possible to realize regional hydrogeochemical regularities in the studied area and its surroundings. It points to the similarities and differences between the mineral waters of the discharge areas of Dudince and Santovka. The silicatogenic and hydrosilicatogenic mineralization contribution can be clearly seen (waters formed in Neogene sediments), marinogenic mineralization (the highest proportion was found in the waters coming from the rock environment Palaeozoic – Permian), and probably also carbonatogenic and sulphatogenic mineralization (water likely originating from Mesozoic carbonate rocks).

In the Dudince Spa the natural healing water is currently used from the source S-3, and it is the natural overflow. Any influence of the pressure conditions (in particular the implementation of new drillings) in the discharge area of Dudince can cause serious operational problems. Equally important is to satisfy the prescribed recoverable amount of the natural mineral water.

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STN 75 0111 Terminology of hydrogeology.