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GUIDE

Post-Conference Excursion to the Western Bohemia (Czech Republic)

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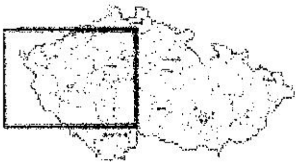
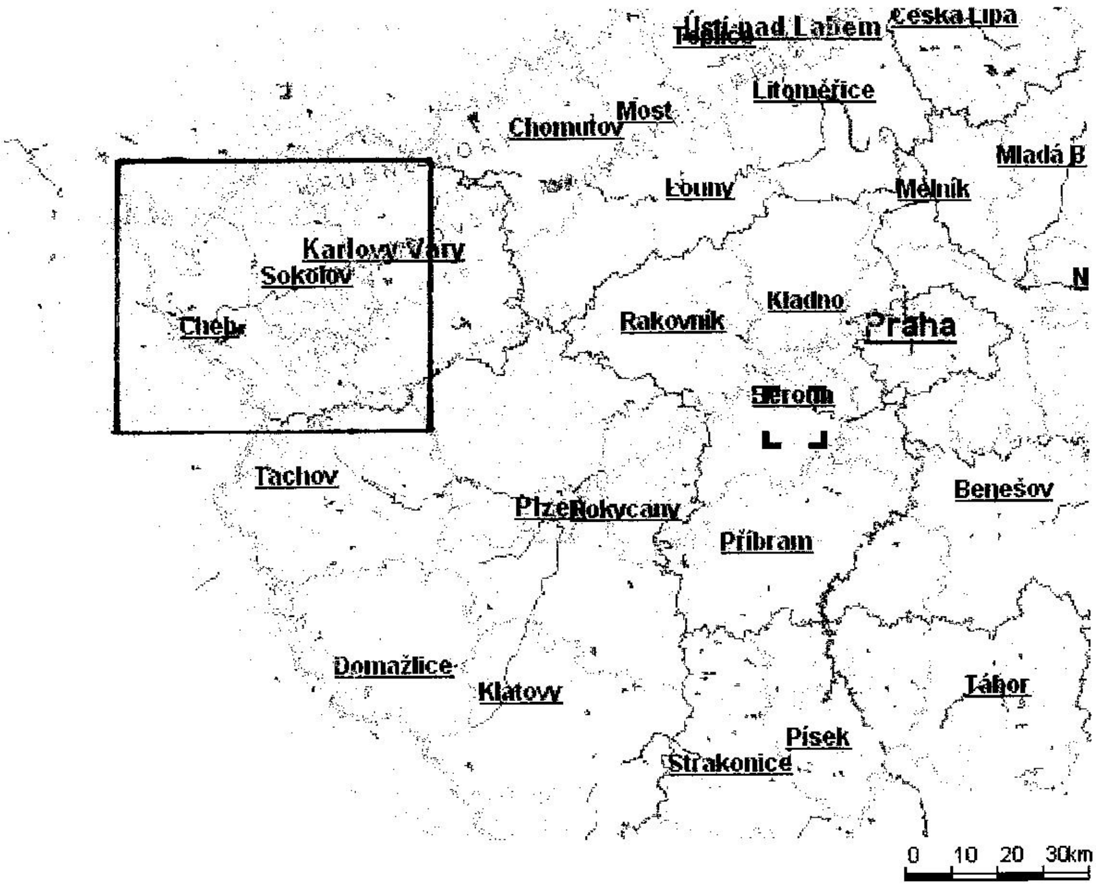
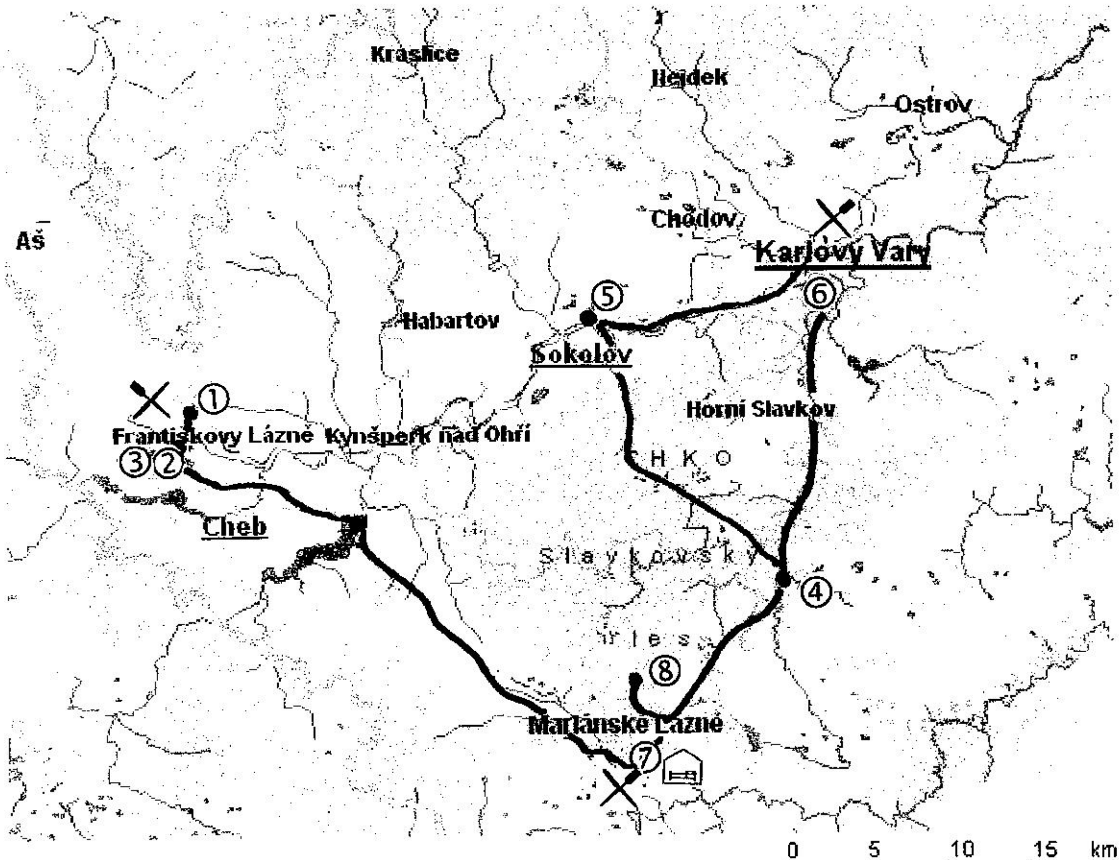



Ústí nad Labem
Teplice
Česká Lípa
Litoměřice
Chomutov
Most
Mladá B
Louny
Mělník
Karlovy Vary
Sokolov
Cheb
Kladno
Rakovník
Praha
N
Beroun
Tachov
Benešov
Plzeň
Rokycany
Příbram
Domažlice
Klatovy
Tábor
Písek
Strakonice
0 10 20 30km


Kraslice
Nejdek
Ostrov
Chodov
Karlovy Vary
Aš
Habartov
Sokolov
①
⑤
⑥
Františkovy Lázně
Kynšperk nad Ohří
③②
Cheb
Horní Slavkov
Slavkovský les
④
⑧
Mariánské Lázně
⑦
0 5 10 15 km

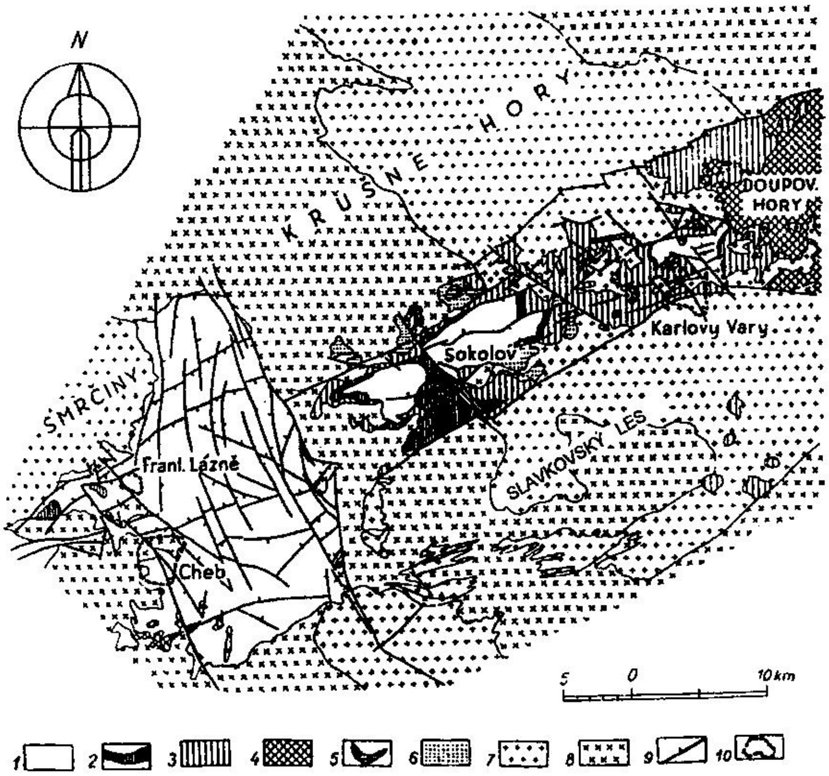
Introduction

GEOLOGIC SETTING

The excursion is focused on the West-Bohemian mineral waters mainly occurring in the piedmont zone of the Krušné hory and Smrčiny Mts. and its environs. In this area crystalline rocks crop out partly covered by Tertiary and Quaternary deposits that are concentrated in so-called Krušné hory piedmont basins (Fig. 1).

The crystalline complexes of highly complicated mutual relations are represented by Proterozoic and Paleozoic formations consisting of varied, primarily sedimentary rocks and igneous rocks, mostly metamorphosed to different degree. These intricate conditions had been affected by later geologic processes, mainly by penetrating Variscan granites and by the Saxon tectonics. The latter was caused by intense Alpine Mesozoic and Cenozoic tectogenesis in the mobile Alpine-Carpathian folding zone to the south of the Bohemian Massif. As a consequence, the system of Neogene basins and extensive volcanic areas originated in the Bohemian Massif. Along the Krušné hory Mts. in their southern piedmont zone three Neogene basins and two montaneous areas of intensive neovolcanic activity occur. From the west to the east they are as follows: the Cheb Basin, the Sokolov Basin, the Doupovské hory Mts. (see Fig. 1) and more to the east the North-Bohemian Basin and the volcanic České středohoří Mts. Stratigraphic correlation of these geologic units is represented in Table 1.

A composite anticlinorial zone of the **Krušné hory and the Smrčiny Mountains** forms the northern part of the area. It is built up of gneisses, mica-schists and phyllites, partly with carbonate and quartzite layers. The Variscan **Karlovy Vary granite massif** of general NNW-SSE strike penetrates the Krušné hory metamorphic complex. This massif extends far to the south into the Slavkovský les Mts. (Fig. 1). The core of the Smrčiny Mts. is also penetrated by a Variscan granite massif, trending transversely to that one of the Karlovy Vary.



1-5: Miocene;
1: Cypris claystone (in the Cheb Basin incl. Pliocene);
2: Main Seam formation;
3: Volcanogenic series (prevalence of subaqueous pyroclasts ± lacustrine deposits);
4: Volcanogenic series (prevalence of terrestrial pyroclasts and lava flows of the Doupovské hory Mts.);
5: Josef-seam formation;
6: Oligocene: Staré Sedlo basal clastics;
7: granitoids of the Karlovy Vary and the Smrčiny massifs;
8: crystalline (mostly metamorphic) rocks of the Krušné hory and the Slavkovský les Mts.;
9: main faults;
10: outlines of principal towns

Fig. 1 Schematic geologic map of the Cheb and the Sokolov Basins

Table 1

Stratigraphy of Tertiary continental deposits and volcanogenic series in the West Bohemia

Stratigraphy of the Tertiary fresh-water sediments								
				Cheb Basin	Sokolov Basin	Doupovské hory Mts.	North-Bohemian Basin	České středohoří Mts.
TERTIARY	Neogene	Pliocene ? (? Early Pleistocene)		1) Vildštejn Formation 1)			terrace A (?) (after Engelmann) 1)	hiatus
		Miocene	...Lower Tortonian	Cypris claystone	Cypris claystone? 1)		Overlying clays and sands 1)	
				Main-seam Formation 1)	Main-seam Formation		Coal-seam Formation Underlying clays and sands (+ basal seam)	
			Aquianitan....	Lower clays and sands 1)	Lower part of Volcanogenic series	Volcanogenic series	Volcano-genic series	Volcano-genic series
					Joseph-seam Formation			hiatus
	Palaeogene	Oligocene (or earlier)		(?) relics of Staré Sedlo basal clastics	Staré Sedlo basal clastics	basal complex, Podbořany kaolinitic sands and clays; quartzites	isolated relics of the basal complex (?)	isolated relics of the basal complex (Žitenice)

1) Approximate stratigraphical arrangement of volcanic activity (apart from the Ist [Lower Miocene] volcanic phase).

The Krušné hory - Smrčiny crystalline complex extends northwards to the German territory where it gradually plunges beneath the younger non-metamorphosed sedimentary units. To the south, the Krušné hory - Smrčiny anticlinorium is bounded by the topographically most striking Krušné hory fault zone of SE-NW strike, representing the northern limit of the piedmont tectonic graben filled in by deposits of the Neogene Sokolov Basin (Fig. 1). The position and extension of another basin, the Neogene Cheb Basin, is considerably influenced by the Mariánské Lázně fault system and the accompanying Planá graben, perpendicular to the Krušné hory fault zone (Fig. 1).

The Cheb Basin is situated in the extreme western part of the Czech Republic, between the towns Cheb, Františkovy Lázně and Kyšperk nad Ohří, occupying an area of about 300 km^2. Its flat surface, gently undulating only along the streams, lies at 400 m level and is fringed by about 200 m higher elevations of the Smrčiny Mts., Krušné hory Mts. and Slavkovský les Mts. built up of crystalline rocks. The eastern limit of the basin represented by the Mariánské Lázně fault (strike NNW-SSE, so called Český les trend ranging h 9-12 – see Fig. 1) is topographically clearly marked. The basin is deepest (up to 300 m) along this fault and shows a step-like westward shallowing (Fig. 2). In the central part of the less regular western boundary of the basin the Františkovy Lázně corridor of the Krušné hory trend (h 3-6) originated, in which Tertiary deposits extend to the German territory. The characteristic form of the Cheb Basin results from the crossing of the two above-mentioned tectonic grabens generated by multi-phase Saxon tectonics (Fig. 1). The Ohře river and its tributaries drain the basin.

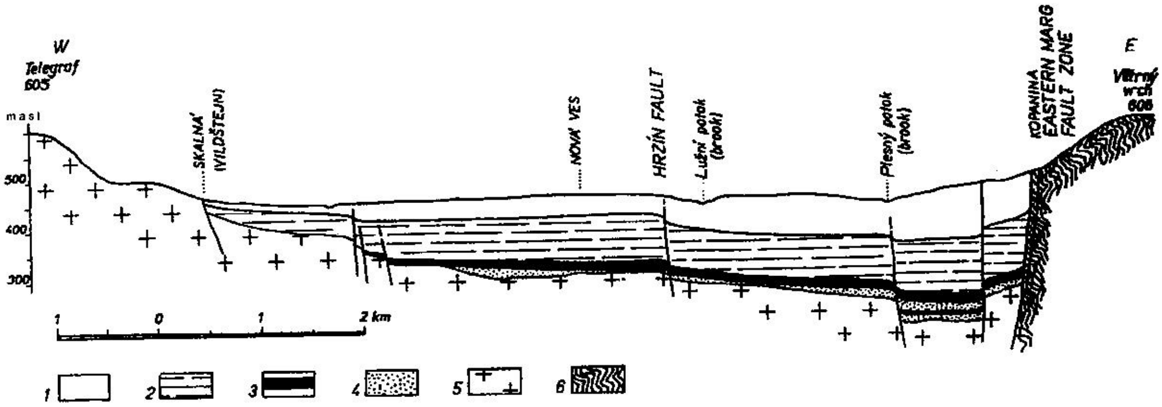


Fig. 2 Geologic section across the Cheb Basin (W-E) from the Smrčiny granite massif to the crystalline ridge between the Cheb and the Sokolov Basins

1: Vildštejn formation (Pliocene);
2-4: Miocene:
2: Cypris claystone;
3: Main seam formation;
4: Lower clays and sands;
5: Smrčiny granite;
6: crystalline schists

A minor part of the basement in the NW of the basin is composed of the Smrčiny granite massif, a larger part of crystalline schists, i.e., phyllites and mica-schists. During the Mesozoic and particularly the Paleogene the bedrock suffered strong kaolinic weathering to depths of 50-70 m and even more.

The oldest sediments termed as the **Staré Sedlo basal clastics** of probably Paleogene age are preserved only in relics. The Miocene sedimentation started with the **lower clays and sands**, subordinately containing also gravels, of thickness usually up to 40 metres.

Neovolcanic rocks that are abundant in the adjacent Sokolov Basin occur only sporadically in the Cheb Basin, being represented by effusive and pyroclastic rocks.

The **Coal-seam formation** occupies about two thirds of the basin. The productive facies is confined to three tectonically affected depressions. This complex attains the maximum thickness at the eastern margin of the Cheb Basin where the coal seam proper is up to 32 m thick.

Cypris claystones consist mainly of yellow-green to greyish-brown claystones with intercalated clays carrying a fine micaceous-sandy admixture. They are the thickest complex of the basin attaining up to 170 m at the eastern margin of the basin.

The youngest **Vildštejn formation (upper clays and sands)** is sandy or clayey (kaolinitic), showing numerous transitions and cross bedding. As compared with the Cypris claystone, it occupies a larger area, especially in the north of the basin.

The <u>**Sokolov Basin**</u> covers an area of more than 200 km^2 with an altitude ranging between 370 to 500 m a.s.l. It is separated from the Cheb Basin in the west by an elevation built of crystalline schists and from the North Bohemian Basin in the east by volcanic rocks of the Doupovské hory Mts. Unlike other Krušné hory piedmont basins the Sokolov Basin is tectonically divided into blocks of distinct vertical position thus forming many separate depressions and elevations even with outcrops of the basement. As a whole, however, the Sokolov Basin is elongated in the SW-NE direction reflecting the Krušné hory fault zone trend (Fig. 1). The topographically marked tectonic boundaries of the basin are built of crystalline rocks of the Krušné hory Mts. in the NW and the Slavkovský les Mts. in the SE.

The basement of the basin is built of granite of the Karlovy Vary massif in the east and mostly of mica-schists in its western part where the filling reaches its maximum thickness of almost 400 m.

The basal lithologically most varied **Staré Sedlo clastic complex** is probably of Paleogene age. It consists of poorly sorted kaolinite sands and clays, fine to coarse-grained sandstones and in places gravel-sands and conglomerates. This clastic complex is mostly only several metres thick but its maximum thickness reaches up to 40 m.

The **Joseph coal seam formation** of total thickness up to 20 m is separated from the basal clastics by a marked hiatus but its upper part passes without break into the **Volcanogenic series**. Sands, clays, thin mostly unproductive coal seams or layers of coal clays, tuffites or tuffite agglomerates build this series. Fluvial and lacustrine detrital sediments substitute volcanogenic deposits and vice versa. The thickness of the series increases from a few metres in the west up to 350 m in the east, in the area of the Doupovské hory Mts. The lower part of the Volcanogenic series separates the coal sedimentation of the Joseph-seam formation from the Main-seam formation, and its upper part extends into the latter and probably also to the base of the Cypris claystone.

The **Main coal seam formation** includes the Anežka and Antonín seams. In the western part of the Sokolov Basin the two seams are separated by sandy, clayey and tuffite deposits, which wedge out in the central part of the basin. Where joined the Anežka and the Antonín seams have an aggregate thickness up to 62 m (greatest thickness of a coal seam in the Czech Republic).

The sedimentation of the Main-seam formation was brought to an end by the sudden rise of the water level and by the origin of a vast lake. The **Cypris formation** of the present thickness up to 180 m was deposited there. It consists prevalently of kaolinite and coal-bearing clays, in places gypsum bearing.

The Sokolov Basin furnishes some raw materials of economic importance: brown coal (lignite) mined up to now in the vicinity of the town of Sokolov, kaolin of Karlovy Vary (the world-known „Sedlec standard kaolin“) and ceramic ball clays.

The products of **young volcanism** are distributed over the entire northern half of Bohemia and in the northern part of Moravia. Their occurrences are mainly centred to the volcanic areas of the Doupovské hory Mts. at the eastern boundary of the area of our excursion and more to the east in the České středohoří Mts. In other regions volcanic activity was manifested by a large number of minor eruptions. According to their chemical composition and tectonic position, the Tertiary (and partly Quaternary) alkaline volcanism is ranged to the igneous rocks of platform type. They belong to the volcanic belt occurring to the north of the Alpine mountain system and extending across Europe from the Massif Central in France through Eifel Mts. in west Germany to the Central European volcanic province that ends in Polish Silesia. According to the character of feldspars Tertiary volcanic rocks are divided into three groups:

- trachytic rocks mainly with alkaline feldspars
- andesitic rocks mainly with acid plagioclases
- basaltic rocks with prevalent basic plagioclases or without feldspars (foidites, melilitites)

The **Doupovské hory Mts**. represent a big stratovolcano whose main feeding conduit, at present filled with essexite, is located in its centre. The lava effusions form about 20 per cent of the mass of the Doupov stratovolcano, the remainder is pyroclastic material. The simple structure and magmatic differentiation in the Doupovské hory region contrasts with the intricate structure and variety of petrographical types of the České středohoří Mts. The latter involves a number of volcanic centres and minor eruptions, built up of rocks showing a great petrographical variety.

To the south of the Krušné hory piedmont graben the crystalline rocks once more crop out in the **Slavkovský les Mts.** They consist of metamorphic rocks as phyllites, mica-schists, gneisses and metabasites, penetrated by the southern part of the Variscan Karlovy Vary massif.

OCCURRENCES AND ORIGIN OF MINERAL AND THERMAL WATERS

West Bohemia is very rich in **mineral and thermal waters**. This area acquired a world-wide reputation thanks to the spas among which Karlovy Vary, Mariánské Lázně and Františkovy Lázně are the most famous forming the so-called "West-Bohemian Spa triangle" (Fig. 3). Great amount of mineral water occurrences is dispersed in their wide environs and in the neighbouring German territory as well (both in Bavaria and Saxonia). Chemical type of these mineral waters, characteristic of prevailing and usually high content of sodium, sulphates, chlorides and bicarbonates and usually containing carbon dioxide, is known as the so-called **„Karlovy Vary (Carlsbad) type of mineral waters"** (Tables 2 – 5).

Mineral waters of the Karlovy Vary Spa, the Mariánské Lázně Spa and the Františkovy Lázně Spa are the main representatives of the "Carlsbad type". In addition to its specific chemical composition there are some other features that make this type and the whole region extraordinary even on the world-wide scale:

- Entirely distinct hydrogeologic environment of their origin and flow: "host" rock of the thermal water of the Karlovy Vary Spa is granite, cold mineral waters of the Mariánské Lázně Spa occur in different types of crystalline rocks (granites, amphibolites, gneisses) and those of the Františkovy Lázně Spa in Neogene deposits of the Cheb Basin.

- Not taking into account the newly discovered brines, the Carlsbad type is characteristic of a broad variety of chemical types with TDS ranging from hundreds mg/l to 24 g/l (Glauber IV spring in the Františkovy Lázně Spa). Also the CO_2 content is different.

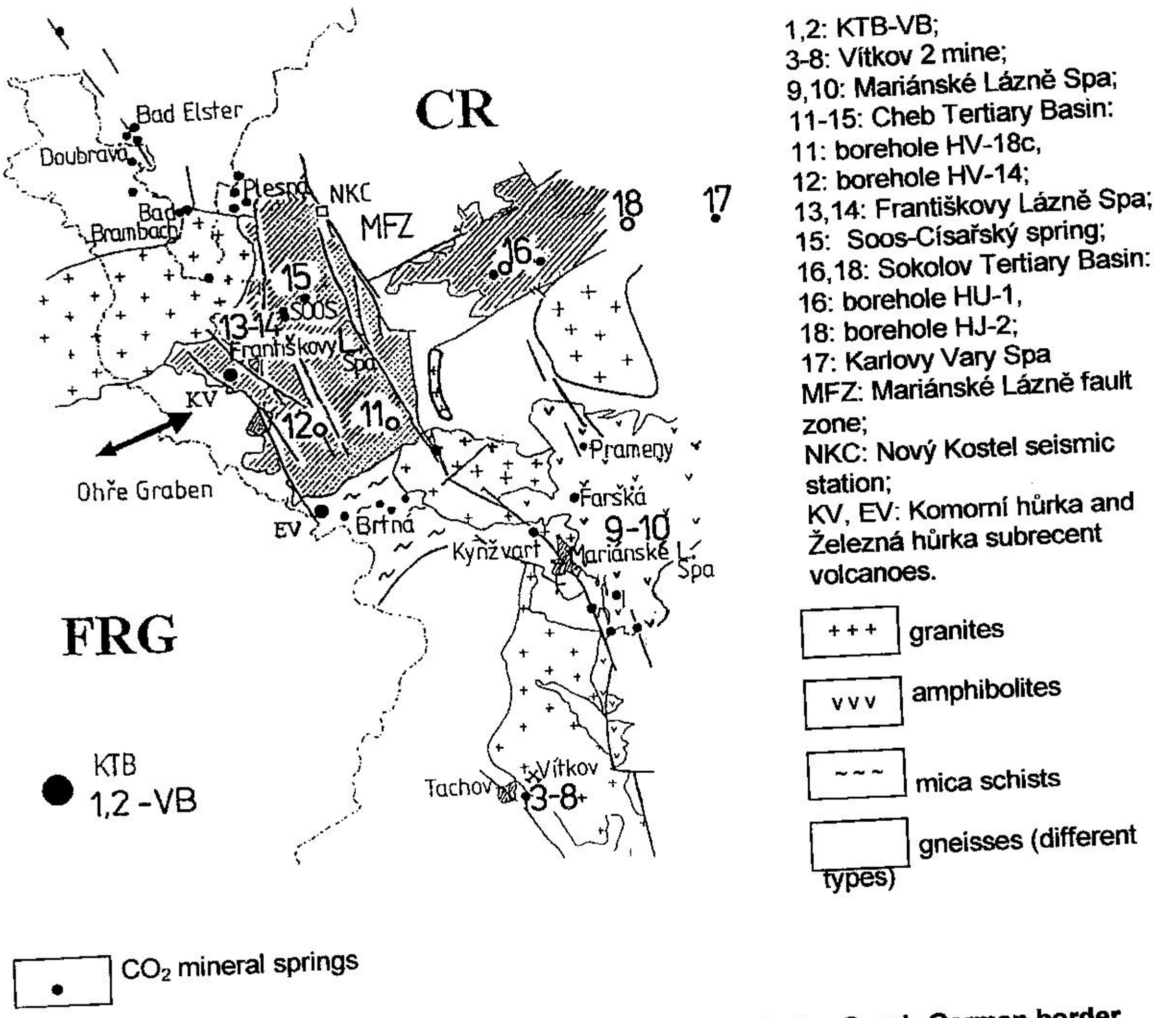
- Temperature ranges within broad interval from cold to thermal waters up to 72^0 C in the Karlovy Vary Spa.

- In addition to the mentioned mineral waters other different mineral waters occur in the region (e.g., the Jáchymov Spa, Bad Brambach).

- Recently, new occurrences of brines have been found in deep wells and mines. Among them the most important are as follows: Uranium mine Vítkov 2, deep boreholes tapping the bedrock beneath the Tertiary filling of the Cheb and Sokolov Basins, KTB borehole (Continental Deep Borehole Program of the Federal German Republic) at Windischeschenbach (Fig. 3).

The Carlsbad type, due to its uncommon chemical composition and enormous variety of mineral waters in the whole region, has attracted attention of many scientists. They have tried to define conditions of its origin. Some of the studies were based on results of detailed hydrogeological and hydrochemical studies of the authors, other were of speculative or synthetic nature. Recently, Dvořák (1990) formulated a synthetic theory of origin of the Carlsbad type, based on his long-term studies in the area. He presumes the origin of main components of the Carlsbad type from saline waters of a closed lake having occurred in the region during the Neogene period. After Dvořák (1990, 1998) the basic content of the Carlsbad mineral waters is formed by leaching of the relict salt content originally precipitated in Tertiary salt lakes and afterwards penetrated into different rock complexes. The resulting chemical composition is formed by mixing of recent or relatively younger recharged waters with relict Tertiary brines of original salt content in hundreds g/l. The original prevailing sodium sulphate and chloride mineralization is recently supplemented by bicarbonates originating through interaction of water highly saturated by CO_2 with different types of rocks in the pathways of mineral waters. Complex and specific geologic and hydrogeologic conditions and different degree of leaching (from original brine content to the present state of washed-out environment) result in a great variety of types of mineral and thermal waters in the area. Therefore, other types have been derived depending on their local hydrogeologic position and different influences acting both in space and in time from a "basic" Carlsbad type. On the other hand, new sources of mineral water of the Carlsbad type of different salt content and its composition, temperature and CO_2 content can be revealed in accordance with the respective hydrogeologic conditions.

The idea of Dvořák was extended and complemented by Hanzlík & Krásný (1998). The authors presume that the origin of decisive components of mineral waters of the Carlsbad type and saline content of deep brines in the region is connected with the two periods of the downward leakage of surface saline waters that have originated under arid conditions. This opinion is based mainly on the analysis of paleohydrogeologic development, taking also into account the recently revealed brines in deep zones of crystalline rocks in the region.



1,2: KTB-VB;
3-8: Vítkov 2 mine;
9,10: Mariánské Lázně Spa;
11-15: Cheb Tertiary Basin:
11: borehole HV-18c,
12: borehole HV-14;
13,14: Františkovy Lázně Spa;
15: Soos-Císařský spring;
16,18: Sokolov Tertiary Basin:
16: borehole HU-1,
18: borehole HJ-2;
17: Karlovy Vary Spa
MFZ: Mariánské Lázně fault zone;
NKC: Nový Kostel seismic station;
KV, EV: Komorní hůrka and Železná hůrka subrecent volcanoes.

+++ granites
vvv amphibolites
~~~ mica schists
gneisses (different types)
● CO$_2$ mineral springs

Fig. 3 Location of main mineral water (brine) occurrences in the Czech-German border region

- The first period started with the Variscan orogeny. Arid conditions had lasted for a long Permian (and Triassic) periods, evidently for ten millions of years. Therefore, the process of salinization might be very intense. Extensive occurrences of brines of this origin can be found in many areas of the Bohemian Massif. Even though the prevailing anion is chloride, somewhere also higher content of sulphates occur, depending on chemical composition of catchment of drainless basins. In the Czech-German border region brines from KTB and Vítkov are probably of this origin.

- The second period was limited both in time and in space. Surface saline water bodies had occurred only in the area of the Cheb and Sokolov Basins and their environs during the time of "Cypris shale" sedimentation (in Miocene). Brines of the Carlsbad type as a product of this period "flow" over the older (and in general "hydrogeologically" deeper) brines of Permian age. The main evidence that brines of the Carlsbad type are of this origin is supported by the fact that no brines of this type have been found in the North Bohemian Basin. The latter had not been a closed basin in Neogene, even though geologic conditions are comparable with those of the Cheb and Sokolov Basins: due to deep fracturation of rocks, also CO$_2$ waters and thermal waters occur there - but no brines.

These theories can considerably change the existing approaches to mineral water protection in the West-Bohemian region. As the reserve of original salts of the Carlsbad type of mineral waters has to be considered static and quantitatively restricted these mineral waters should be protected as non-renewable natural resource. Decrease in salt content observed in different mineral-water springs of the area supported the above-mentioned opinion.
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1. Františkovy Lázně Spa

The Františkovy Lázně springs of cold carbon dioxide mineral waters rise in the western spur of the Tertiary Cheb Basin noted by its significant deposits of mineral resources and abundance of mineral waters.

The existence of mineral water springs in the vicinity of Cheb has been known since ancient times. The first records on "Cheb" water date from the 10th century. In 1793 a spa was established at the "Cheb" springs, which in 1803 was named Františkovy Lázně. Today, Františkovy Lázně is a world-renowned spa with a long-lasting balneological tradition (treatment of gynaecological, cardiovascular and rheumatic diseases).

North- and westwards of the Františkovy Lázně Spa, the Smrčiny massif extends. It is built of a porphyritic medium- and fine-grained biotite-muscovite granite. Its outcrops represent an important recharge area of ground waters flowing towards the low-lying Cheb Basin in general. During this movement part of the recharged water is mixed with deep-seated relict brines and obtains its CO_2 ascending from the crystalline basement. The contact of the Smrčiny granite with phyllite under the deposits of the Cheb Basin and a NW-SE striking fault zone are considered the main paths of CO_2 supply. The accumulations of CO_2 mineral waters typically occur along the northwestern boundary of the Cheb Basin with outcrops of the Smrčiny massif where the basal Tertiary deposits up to 75 m thick are developed as coarse-grained sands and gravels, only partly covered by coal-seams and Cypris formations. Most of mineral waters is discharged in the area of the Františkovy Lázně Spa due to the occurrence of an elevation built by the less permeable "Cheb" phyllites to the south of the Spa. In this discharge zone along the Slatinný potok brook a thick layer of first-quality sulphurous-ferric peat-bog is developed, which has been almost completely exploited.

More than 25 springs have occurred at Františkovy Lázně, forming a narrow WNW-ESE trending zone (Fig. 4). Some of them are natural springs captured at shallow depths, others are borings that tapped mineral water at depths between 29 and 85 m. Part of springs was liquidated.

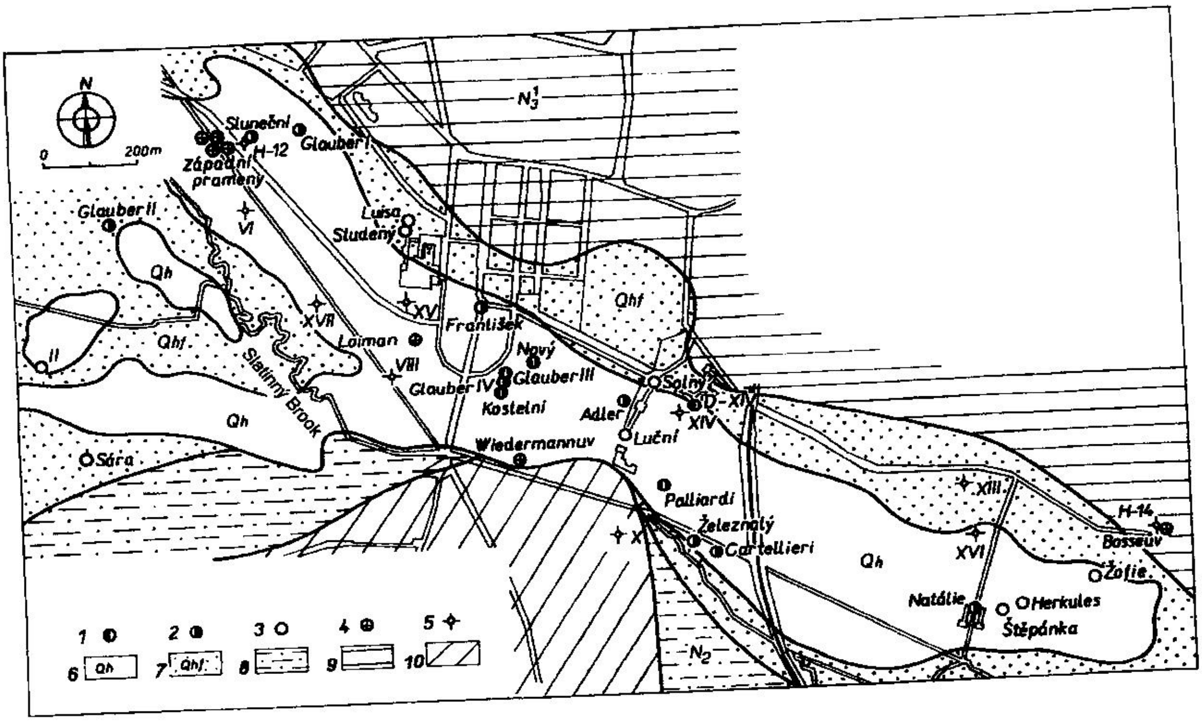

Fig. 4 Location of springs in the Františkovy Lázně Spa (after Kolářová & Myslil 1979)

1-5 – springs of mineral water:
1 – used for bathing treatment,
2 – used for drinking cures,
3 – out of use,
4 – liquidated,
5 – test drillings;
6 – peat-bog,
7 – Quaternary sandy and clayey deposits,
8 – upper clays and sands,
9 – Cypris claystones,
10 – biotitic phyllite mica-schist with quartzite

The mineral springs at the Františkovy Lázně Spa are distinguished by different amount of dissolved solids, varied ratio of content of particular elements, different gas-content and mineral water hydraulic head. The Františkovy Lázně carbon dioxide waters are mostly of sodium-sulphate-bicarbonate-chloride and sodium-sulphate-chloride-bicarbonate types with TDS up to 22 g/l (Table 2). The comparatively rare type of cold carbon dioxide water with high content of TDS, esp. of Na^+ and SO_4^{2-} ions, is represented by the "Spring" Glauber IV.

The water temperature fluctuates between 8 - 9 °C in natural springs and reaches up to 12 - 13 °C in wells. It is estimated that the total yield of springs have increased from a total yield of 5-7 l/s under natural conditions to at least 25 l/s caused by recent anthropogenic impacts. The yield of the shallow springs varies considerably after the precipitation changes.

Part of mineral water flows eastwards from the Františkovy Lázně Spa to the regional discharge zone of the whole Cheb Basin occurring at the confluence of the Ohře and Odrava rivers. Natural ground (mineral) water discharge has been considerably increased by groundwater abstraction from Quaternary aquifers in the Nebanice well field. The withdrawn water contains high contents of carbon dioxide (more than 1 g/l) in some water wells there.

Table 2
Chemical analyses of springs in the Františkovy Lázně Spa

Kostelní spring
Abstraction well 29.5 m deep
Location in Fig. 4
Yield 2.4 l/s
Analysed by the Laboratories of the Ústřední ústav geologický Praha
Sampling in February 1975
Temperature: 11.6 °C
pH: 4.9
TDS: 4.00 g/l
Free CO_2: 2.14 g/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	1.61	0.23	0.52	Cl^-	374.00	10.55	24.06
Na^+	922.0	40.13	91.70	Br^-			
K^+	19.0	0.48	1.09	J^-			
NH_4^+	0.31	0.017		F^-	0.91		
Mg^{2+}	9.12	0.75	1.71	NO_3^-	5.6	0.09	
Ca^{2+}	38.00	1.90	4.36	SO_4^{2-}	1121.00	23.3	53.15
Mn^{2+}	0.38	0.013		HPO_4^{2-}	2.64	0.05	
Fe^{2+}	6.80	0.24	0.54	HCO_3^-	598.00	9.80	22.35
Σ	997.22	43.76	99.92	Σ	2101.15	43.79	99.56

Be	9.3	μg.l^{-1}	Rb		μg.l^{-1}	Zn	< 10	μg.l^{-1}	Al		μg.l^{-1}
Ba	0.005	μg.l^{-1}	Co	< 1	μg.l^{-1}	Pb	1.0	μg.l^{-1}	As	451.9	μg.l^{-1}
Sr		μg.l^{-1}	Ni	1.0	μg.l^{-1}	Cu	19.8	μg.l^{-1}	U	1.0	μg.l^{-1}
V		μg.l^{-1}	Mo		μg.l^{-1}	Ag		μg.l^{-1}	Ra		μg.l^{-1}

date of sampling	CO_2	H_2S	O_2	N_2	He	H_2	Ar	CH_4	total amount [ml.l^{-1}]
	vol. %								
22.4. 1975	98.2	0.0	0.20	1.60	0.0018	0.0005	0.03	< 0.01	

Spring Glauber IV
Abstraction well 92.6 m deep
Location in Fig. 4
Yield 0.02 l/s
Analysed by the Laboratories of the Ústřední ústav geologický Praha
Sampling in February 1975
Temperature: 13.5 °C
pH: 6.1
TDS: 23.44 g/l
Free CO_2: 1.27 g/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	13.0	1.87	0.50	Cl^-	2705.0	76.30	23.01
Na^+	6820.0	296.50	88.22	Br^-			
K^+	112.0	2.86	0.85	J^-			
NH_4^+	1.8	0.10		F^-	0.62		
Mg^{2+}	166.6	13.70	3.80	NO_3^-	82.00	1.32	
Ca^{2+}	416.8	20.80	5.40	SO_4^{2-}	9805.00	203.90	60.72
Mn^{2+}	0.19	0.01		HPO_4^{2-}	2.28	0.05	
Fe^{2+}	7.0	0.25	0.07	HCO_3^-	3307.00	54.20	16.00
Σ	7537.39	336.09	98.84	Σ	15902.90	335.77	99.73

Be	1.1	µg.l^{-1}	Rb	390	µg.l^{-1}	Zn	16	µg.l^{-1}	Al		µg.l^{-1}
Ba	0.005	µg.l^{-1}	Co	2.0	µg.l^{-1}	Pb	1.0	µg.l^{-1}	As	70.0	µg.l^{-1}
Sr	3200	µg.l^{-1}	Ni	5.0	µg.l^{-1}	Cu	139.0	µg.l^{-1}	U	2.6	µg.l^{-1}
V		µg.l^{-1}	Mo		µg.l^{-1}	Ag		µg.l^{-1}	Ra		µg.l^{-1}

2. Komorní hůrka Hill

The hill is situated approximately 3 km SSW of the centre of the Františkovy Lázně Spa. It is an evidence of the youngest Pleistocene phase of volcanic activity in western Bohemia, one of the two occurrences of this age there (the second one is the Železná hůrka Hill – see Fig. 3).

At the eastern slope of the hill volcanic ash and other pyroclastic material were mined in an open pit. Years ago the mining has ceased and the hill was declared a Natural reserve. In the quarry face multicoloured volcanic material of almost horizontal bedding can be observed containing also pieces of underlying rocks (phyllites, Tertiary deposits) carried out during the eruption.

Into the southern slope of the hill an exploratory gallery was driven in the 19th century to arbitrate a geological dispute between the so-called „neptunists“ and „plutonists“. At the entrance to the gallery on the wall of a basalt dyke a memorial tablet with the graven image of Johann Wolfgang von Goethe was placed to remind his part at the gallery realisation.

3. Soos

The Soos (Hájek) sub-basin lies in the Cheb Basin SE of the Františkovy Lázně Spa, not far from the basin boundary with the Smrčiny granite massif. In terms of geology and hydrogeology, its regional position is similar to that one of the Františkovy Lázně Spa. The Soos basin is situated between the Vonšovský potok and the Hájecký potok brooks. It is a 2200 m long and 1400 m wide depression formed of two parallel small basins separated from each other by a sand accumulation.

The Soos Basin is filled with Holocene organodetrital sediments. They consist of a sedge bog with an admixture of reed. Diatomaceous soil originated from freshwater and salt-water diatoms in the southern part of the depression. The remaining part of the Soos Basin is filled with a peat-bog complex. A specific sign of the bog and diatomaceous soil of the Soos Basin are their high dissolved solids characterized by a considerable content of pyrite and its oxidation products.

More than 20 mineral water springs and CO_2 exhalations were registered in the area of the Soos Basin. Almost all of them occur in the southern small basin scattered in an irregular belt on the diatomaceous layer. The chemical composition and type of carbon dioxide waters are close to those of the Františkovy Lázně Spa. TDS varies between 1 and 6.5 g/l, the type is sodium-sulphate with higher content of chlorides. The temperature of carbon dioxide water ranges from 10 to 15 °C. An exception is the Císařský pramen spring with a constant temperature of 17.5 °C (see Table 3). The total yield of ground-water springs is about 9 l/s. In the northern part of the Soos Basin, only water of the sodium-bicarbonate type with 0.3 g/l TDS and several springs of ferric carbon dioxide water issue.

The Soos Basin lies in the area of the NW-SE trending fault zone that is of regional hydrogeologic importance. Along it carbon dioxide water is discharged from the Miocene sediments representing a basal artesian aquifer. The dry CO_2 exhalations (mofettes) in the southern part of the Soos Basin are linked up with this fault zone. The borings proved that in the southern depression only a thin layer of Tertiary sands and Cypris claystones occur, which lie directly upon the elevation of crystalline rocks. The absence of thick coal seams and basal clayey-sandy formations restricts the horizontal migration of carbon dioxide water there. Therefore, it percolates through the overlying fissured Cypris claystone into the morphological depression of the Soos Basin.

The Soos Basin is a protected National Reserve.

Table 3

Císařský spring

Shallow well

Location in Fig. 3

Temperature: 17.5 °C
TDS: 5.6 g/l
Free CO_2: 2.5 g/l
SiO_2: 100 mg/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	3.05	0.44	0.57	Cl^-	594.6	16.77	21.52
Na^+	1575	68.48	89.04	Br^-			
K^+	37.1	0.95	1.24	J^-			
NH_4^+	0.01			F^-			
Mg^{2+}	24.3	2.00	2.60	NO_3^-	7.0	0.11	0.14
Ca^{2+}	71.1	3.55	4.62	SO_4^{2-}	1769	36.79	47.21
Mn^{2+}	1.88	0.06	0.08	HPO_4^{2-}	8.92	0.18	0.23
Fe^{2+}	40.1	1.43	1.86	HCO_3^-	1469.3	24.08	30.90
Σ	1752	76.91	100.01	Σ	3848.82	77.93	100.00

Be	67	µg.l^{-1}	Rb	0.34	µg.l^{-1}	Zn	10	µg.l^{-1}	Al		µg.l^{-1}
Ba	340	µg.l^{-1}	Co	1.0	µg.l^{-1}	Pb	1	µg.l^{-1}	As	407	µg.l^{-1}
Sr	110	µg.l^{-1}	Ni	1.0	µg.l^{-1}	Cu	2	µg.l^{-1}	U		µg.l^{-1}
V		µg.l^{-1}	Mo		µg.l^{-1}	Ag		µg.l^{-1}	Ra		µg.l^{-1}

4. Bečov nad Teplou

The castle Bečov nad Teplou was founded by the Lords of Osek in the 13th century as a sentry castle on the crossroads of various trading routes. The biggest vigour of the castle as an important defensive stronghold was in the late 15th century. The owner of the castle at that time was the family Pluh of Rabštejn, one of the most powerful families in the country, who was engaged in gold, silver and particularly tin mining. The Pluh family carried out extensive reconstruction of the castle in the Late-Gothic style, connected two older parts and later built a new representative and residential palace in the Renaissance style. The main features have been preserved in this form until now. Kaspar Pluh stood up in the head of the failed Estates uprising against the Emperor Ferdinand I. He was sentenced to death and his castle was confiscated. The Thirty Years War made an end of tin prosperity and in 1648 the Swedish army damaged the castle and occupied it.

In the 18th century, on the bases of the former fortifications above the castle moat a Baroque chateau with octagonal tower was built. Belgian duke Fréderic Auguste de Beaufort-Spontin purchased the Bečov estate in 1813. The castle was connected with the chateau into one complex. The project of reconstruction of the complex in the Romantic style by architect Josef Zítek was realised only partly, mainly in the interiors. The family of Beaufort-Spontin lived at Bečov till 1945. After World War II all its possessions were confiscated by the Czechoslovak state and the family was expelled from the country. A school was established in the chateau. During the last years the chateau went through complete reconstruction.

The reliquary of Saint Maur, the second most valuable treasure in the Czech Republic after the crown jewels, is worth seeing in the Bečov castle.

The reliquary was made in the first third of the 13th century by goldsmiths from a workshop on the German-French border on the request of a Benedictine abbey, whose dignitaries wanted to place the remains of St. Maur, and was deposited in the St. John the Baptist cathedral in Florennes (today in Belgium). It served as a revered liturgical object until the 18th century. In 1798, however, the monastery was dissolved as a result of the French revolution and its property was to a large extent destroyed.

The reliquary of St. Maur was luckily saved in one of the sacristies of a local church. Duke Alfred de Beaufort discovered it there, in a ruined state, and in 1838 he bought it from the church and had it repaired. After the Brussels exhibition in 1888 the Beauforts let the reliquary be brought to their Bohemian estate in Bečov nad Teplou where they exhibited it in the chateau chapel. After the formation of an independent Czechoslovakia in 1918, the family tried to ensure that nobody found out about the reliquary. The last written mention of it appeared in 1932. Before leaving Czechoslovakia in 1945, Beauforts buried the casket beneath the floor in the castle chapel of the Visitation of the Virgin Mary.

The reliquary was hidden there for 40 years. In 1984 an American businessman made the Czechoslovak embassy in Vienna an unusual offer. He said he would pay a quarter of a million dollars for the legal exhumation and removal of an object, which nobody here was missing anyway. While the Foreign Ministry was negotiating with him, the criminologists were trying to find this unknown object. On November 1985 the reliquary was found, surrounded by bottles of wine and cognac. Sixty Czech as well as foreign specialists participated in its restoration. Since May 2002 the reliquary has been exposed in a special safe deposit room in the chateau Bečov.

The chest itself is nearly 140 cm long, 42 cm wide and almost 65 cm high. Its wooden core is richly decorated with gilded silver and gilded copper making up figural, relief and filigree elements. The filigrees are set with roughly 300 precious stones.

5. Královské Poříčí – the open cast mine Jiří

The Sokolov Basin is an old mining district where the first reference to granting mining license to a coal mine near Loket goes back to the year 1642. Nevertheless, the major expansion of mining for minerals in the Sokolov Basin began at the very beginning of the 18th century. Pyrite was extracted from the Josef coal seam in the environs of Lipnice around the year 1800. The mineral was used for production of blue stone, sulphur and sulphuric acid.

Underground mining for lignite was concentrated mostly in the area between the villages of Lomnice and Královské Poříčí. The first references to mining in this area go back to the year 1818. Several water breakouts occurred in mines extracting the Josef coal seam on the turn of the 19th and 20th century. The discharge of the most severe water breakout fluctuated around 170 l/s at an elevation of 236 m a.s.l. Three months after the water breakout, the yield of Karlovy Vary hot springs was reduced. However, a straight relationship between water breakout in the Maria Mine and lower yield of hot springs in Karlovy Vary failed to be proved. Nevertheless, the extraction of lignite from the Josef seam was prohibited following some fears among hydrogeologists that mining operations may affect the Karlovy Vary springs.

The first open cast mining of the Josef coal seam began in 1918. Substantial part of the major coal-bearing formation (Antonín and Anežka seams) in western and central parts of the Sokolov Basin was mined out during the 20th century. More than 16 villages must have been abandoned and destroyed because of face advance. Some railroad tracks and roads and highways must have also been relocated. The open cast mine Jednota was first developed near the village of Vintířov, which was then in 1960 redeveloped in large open cast mine Jiři, which is still in operation. The villages of Alberov and Jehličná, which were located within mining area, were demolished. The open cast mine Družba was situated in the mining area of Nové Sedlo.

The present day mining for lignite is under way only in central part of the Sokolov Basin. The area extent of mining has been established by governmental resolution specifying strict boundaries for coal mining, outer dumps and also demarcating mining reservations (protective zones) around villages. Two open cast mines are in operation (Družba and Jiří), which are owned and operated by Sokolovská uhelná a.s. Company. Both mines lie in protective zones of the 2nd degree of natural curative springs of the Karlovy Vary spa. Only the Antonín seam is being mined presently. The extraction of the Josef coal seam below the elevation 360 m a.s.l. is prohibited because of nearby mineral springs of Karlovy Vary. As follows from intentions of the Sokolovská a.s. Company, the open cast mine will be remedied by flooding. The mining operations in the area are expected to be terminated in 2035.

The areas affected by mining will be remedied as soon as the mining operations are finished. An area of ca 2444 hectares has already been remedied in the Sokolov coal district since the late fifties of the last century, particularly in areas of former underground mines and outer dumps. Out of the above-mentioned total area some 937 hectares were converted into farmland, 1449 ha into forest, 29 ha were flooded and the remaining 29 ha turned into land for other purposes. Remedial works are expected to go on for a few decades after termination of mining operations. Because of lack of dump material, the open cast mines Jiří, Družba and others will be flooded so that large lakes will emerge in the area of the Sokolov Basin.

The area under consideration has been fairly explored by drilling. Exploratory drilling in search for minerals and engineering geology drilling prevail. Only very few boreholes were drilled to resolve exclusively some hydrogeological problems, but some engineering geology and mineral exploration drilling also provided some hydrogeological data.

The major hydrogeological problem, which the majority of works in the Sokolov Basin intend to resolve is the establishment whether there exists a relationship between thermal waters occurring in the basin and thermal springs in Karlovy Vary spa, which is essential for demarcation of protective zones of thermal waters.

Hydrogeological conditions in the area have considerably changed due to extensive mining of the major coal-bearing formation. Quaternary aquifers are in many places disturbed by open cast mining or buried under thick layer of impermeable dumps. Cypris Formation as overburden of the Antonín coal seam was completely removed, which led to the extinction of the original aquifer. The major coal-bearing formation (Anežka and Antonín seams) is nowadays mostly restricted to eastern part of the basin. The aquifer in central and western parts of the basin has been mostly mined out or affected by controlled draining during concurrent mining operations.

Hydrogeological conditions of the aquifer confined to the Josef coal seam were substantially affected by underground mining in particular. After several years the extraction of the Josef seam was terminated for economic reasons, and the Antonín coal seam began to be mined. Open cast mining of the Josef seam started in the eighties of the 19th century and lasted until 1992 when the mining ceased because of high contents of sulphur and arsenic. The permeability of sediments increased and infiltration of atmospheric water into the coal seam accelerated in areas affected by underground mining. Along with acceleration of groundwater circulation the content of oxygen increased leading to oxidation of sulphides and subsequently to the increase of sulphates in local groundwaters.

The present day water regime in the Josef coal seam including the basal aquifer is affected mostly by draining of mineralised and gas-containing waters from the basal aquifer in the bottom of the Jiří open cast mine. The basal aquifer shows distinct artesian character of which piezometric height of groundwater exceeds the level of the extracted Antonín coal seam. Under such conditions, there was a danger of breaking the bottom of open cast mines and subsequent uncontrollable escape of gas-containing groundwaters. This, besides making further mining impossible and change in hydrogelogical conditions in the Sokolov Basin, the possibility of immediate threat to the Karlovy Vary curative springs could have not been excluded. Therefore, a governmental resolution was adopted to implement protective measures, which have to be observed and which make the mining operations dependent on these measures. Areas with indispensable control of the bottom by nivelation and areas where the pressure on the bottom of open cast mines must be reduced by decrease of confined groundwater level of the basal aquifer are demarcated.

The Jiří open cast mine is located in the area where the groundwater level has to be maintained at an elevation of 330 m a.s.l. The reduction of pressure in the Jiří open cast mine bottom is being done by discharge of gas-bearing thermal waters from the basal aquifer. Currently some 1-2 m^3/min. are discharged and a limit of 2.2 m^3/min must not be exceeded. The discharge is currently secured by 3 - 4 boreholes situated in the open cast mine bottom. The extent and magnitude of the depression are monitored by a grid of observation wells on the bottom of the open cast mine, in its forefield and at other even more remote places. The aquifer level of the Josef coal seam and that of the basal aquifer are measured in observation wells. Currently 7 observation boreholes drilled in the Josef seam aquifer and 18 boreholes in the basal aquifer are being monitored. A large breakdown happened in 1995 in one of the drainage wells when uncontrollable escape of groundwater containing gases occurred. Average total volume of escaping water was 46.8 l/s, which was by more than 10 l/s exceeding the amount of water permitted by the imposed protective measures. This breakdown was recorded in all observation wells but not in natural curative springs in Karlovy Vary. The most remote observation well, which was affected by the above-mentioned breakdown, is located in the eastern border of central part of the basin.

6. Karlovy Vary Spa

The thermal springs at the Karlovy Vary Spa yield the warmest water in the Czech Republic. They ascend in the southern part of the Karlovy Vary granite massif in the deeply incised valley of the Teplá river ("Teplá" is for warm), to the south of its confluence with the Ohře river. This Variscan granite massif intrudes the Krušné hory crystalline complex of NNW-SSE strike from Eibenstock in Germany (Saxony) as far as the Slavkovský les Mts. south of Karlovy Vary. The granite complex is not homogeneous. It consists of several intrusions. The earlier intrusion of Normal granite (Gebirgsgranit) encompasses the N-S trending body of the later Autometamorphic granite (Erzgebirgsgranit). The later Variscan intrusions suffered from autometamorphic processes giving rise to rich ore aureole and manifestations of hydrothermal mineralization.

The tectonic setting of the Karlovy Vary granite massif is very intricate. The centre of the ascent of the Karlovy Vary thermal gas-charged water is located in the valley of the river Teplá, where the submeridional trench crosses the longitudinal southern marginal Ohře fault zone and the transversal SE-NW trending "thermal zone".

The former natural springs formed travertine accumulations, the largest of which are the mound under the present Vřídlo spring and the mound under St. Magdalene´s church. Today, the springs in Karlovy Vary are divided into two groups: The first group ("large springs") is represented by the most important spring called "Vřídlo" (Sprudel), the second group of "small (or colonnade) springs" comprises a number of springs that originally rose within a 1600 metres long and approximately 150 metres wide thermal zone between the northernmost Sadový spring and the southernmost Štěpánka spring (Fig. 5). In addition to the eleven numbered springs (and to the Vřídlo spring as the Karlovy Vary spring number one), designated by traditional names and used for drinking cures at colonnade outflows, an inventory made by the end of 1998 listed altogether 219 historical and present-day concentrated thermomineral issues within the thermal zone.

The large springs were previously captured by ten shallow borings (of the maximum depth of 8 m) in the travertine mound of the Vřídlo spring. In the eighties of the 20th century, after a long-term complex investigation consisting of geological, geophysical and hydrogeological studies and extensive test drilling, the Vřídlo spring was tapped by four permanent inclined wells BJ-35, BJ-36, BJ-37, BJ-70 of depths between 48.1 and 88.6 metres (Fig. 6). The boreholes identified quite precisely the open fissure that conveys thermal water from the depth to the surface (Fig. 7). In the vicinity of the Vřídlo spring, shallow regulative wells were drilled to reduce the pressure caused by free carbon dioxide beneath the travertine mound. Such an excessive pressure had repeatedly caused a break-through of the travertine cover as in the case of a small "earthquake" in 1809.

The total yield of the Vřídlo spring is approximately 2000 l/min., maximum temperature 73.4 °C. Carbon dioxide exhalations are 2000 l/min.

The "small springs" were originally captured directly from the fissures in granite. Like the Vřídlo spring, they were tapped by wells of maximum depth of 70 metres in the eighties of the last century. The total yield of small springs is about 44-48 l/min, i.e. approximately only 2.5 % of the yield of the Vřídlo spring. Temperature of small springs ranges from 64 °C (Kníže Václav I. spring) to 39 °C (Sadový spring). The Tržní and Sadový springs have the largest gas content. The altitude of the springs is 378 m a.s.l., the Horní Zámecký spring is 14 m higher.

The Karlovy Vary thermal water has the time-constant total dissolved solids of 6.5 g/l that is the same in both large and small springs. The chemical type is sodium-bicarbonate-sulphate-chloride. Results of selected mineral water analyses are in Table 4.

The thermal mineral water from the springs is used for bathing and in the salt works for the production of the renowned Karlovy Vary salt. The water of the small springs is destined for drinking cures and the water of the Mlýnský spring is bottled.

At Karlovy Vary mainly affections of the stomach, liver, intestines and metabolic disorders are treated.

The protection of the thermal mineral waters of the Karlovy Vary Spa has had a long tradition since 1761 when a decree prohibiting coal mining in the environs of Karlovy Vary was promulgated. In 1859 the first protection zones were demarcated, for the first time in the Austrian Empire. The last protection zones were declared by the Czechoslovak government in 1966 based on results of regional hydrogeologic studies carried out in the early sixties. Yet opencast coal mining in the Sokolov Tertiary Basin, where up to 60 l/s of thermal water are estimated to have been pumped during the last years, endangers the Karlovy Vary thermal springs. Investigation done in the last decades considers a hydraulic connection of the Karlovy Vary thermal water with the CO_2-charged thermal water of the basal artesian aquifer in the central part of the Sokolov Basin very probable despite the distance of approximately 12 km between the two sites.

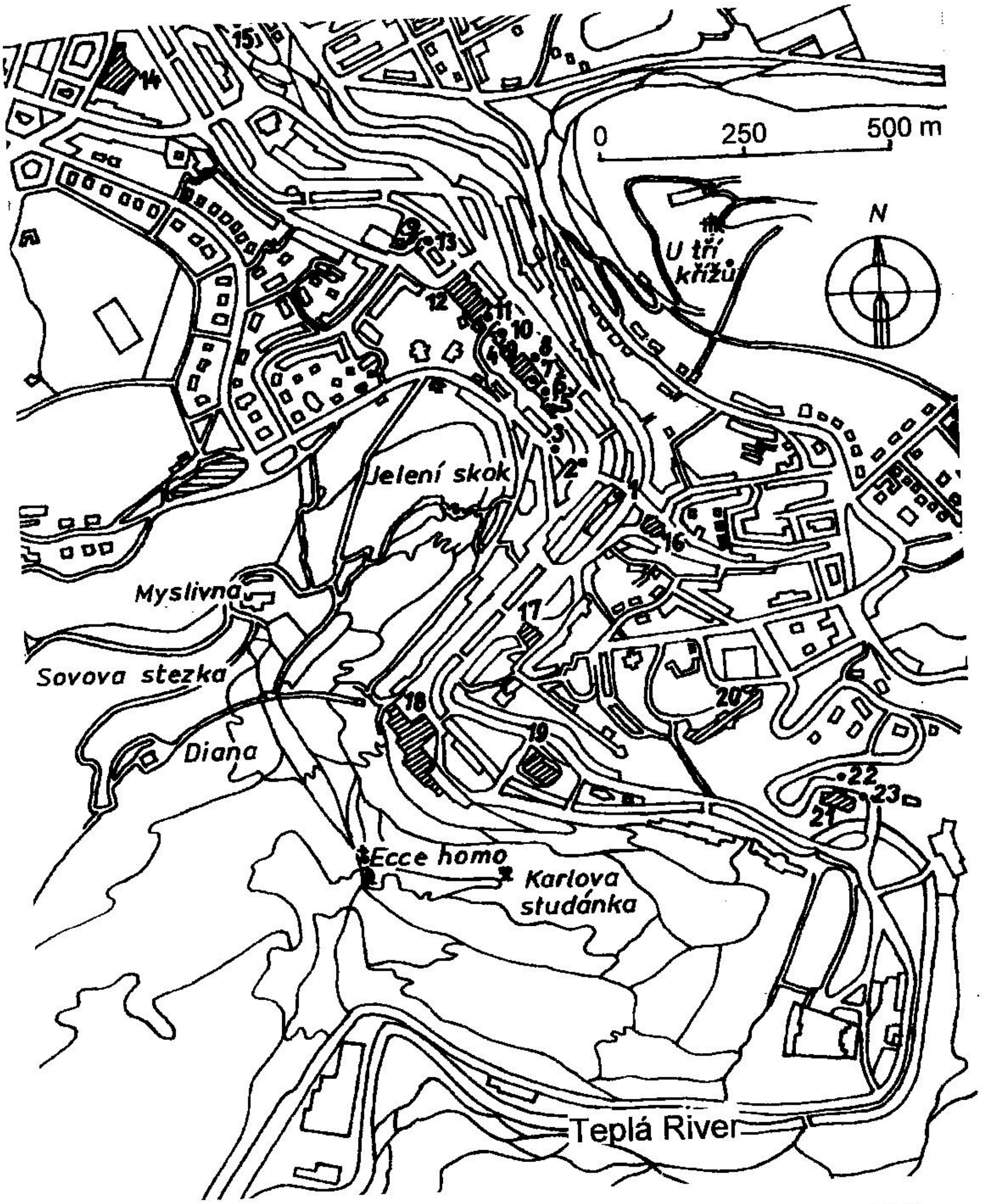

Fig. 5 Location of springs in the Karlovy Vary Spa (after Kolářová & Myslil 1979)

1 – Vřídlo spring,
2 – Tržní spring,
3 – Horní a Dolní zámecký spring,
4 – Mlýnská Colonnade,
5 – Mlýnský spring,
6 – Libuše spring,
7 – Kníže Václav spring,
8 – Kníže Václav II spring,
9 – Rusalka spring,
10 – Skalní spring,
11 – Svoboda spring,
12 – Lázně III (Bathhouse III),
13 – Sadový spring,
14 – Lázně V (Bathhouse V),
15 – Železnatý spring,
16 – St. Magdalene´s church,
17 – Theater,
18 – Grandhotel Pupp,
19 – Lázně I (Bathhouse I),
20 – Sanatorium Imperial,
21 – Lázně VI (Bathhouse VI),
22 – Dorotka spring,
23 – Štěpánka spring

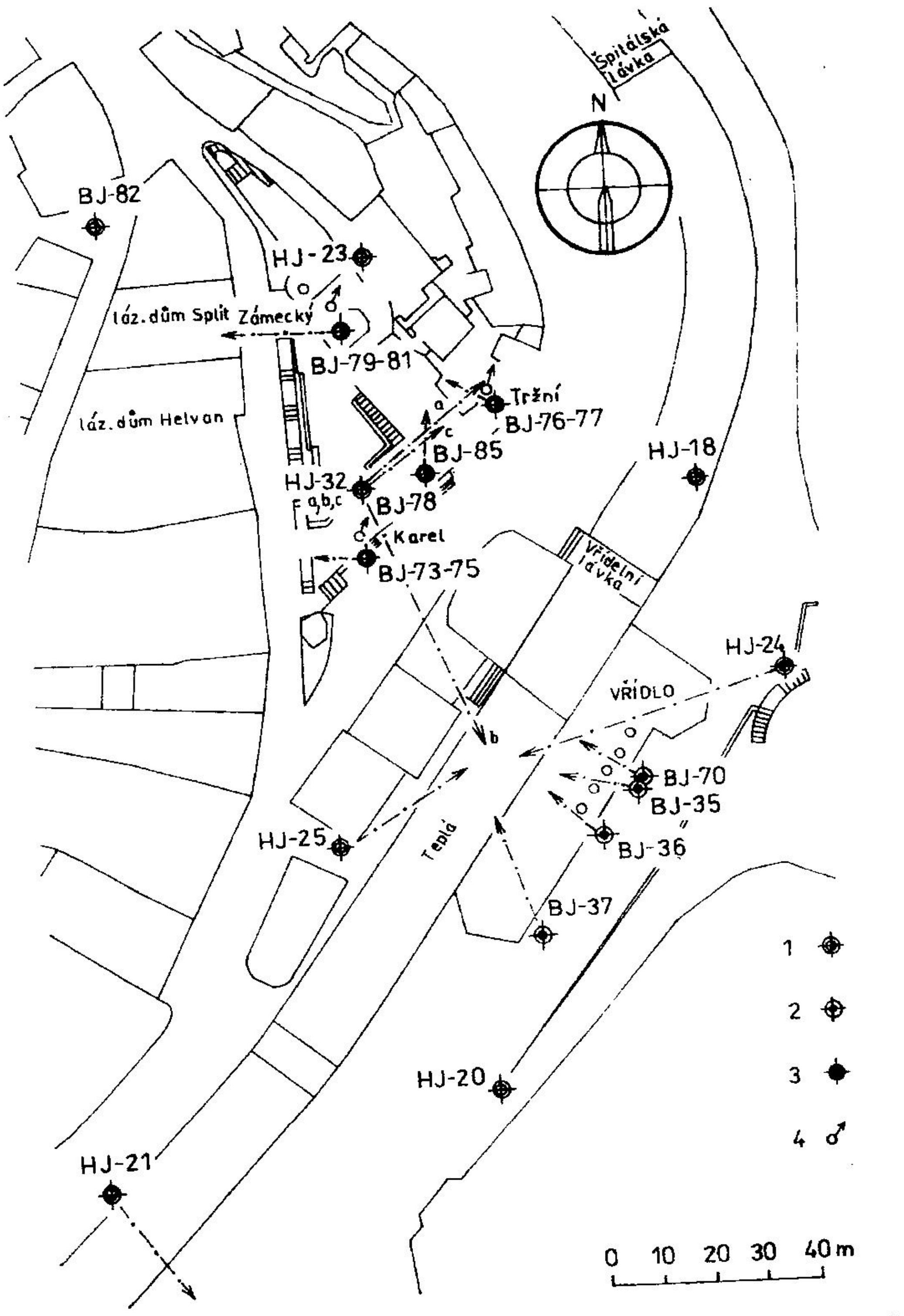

Fig. 6 Location of test holes and permanent wells in the environs of the Vřídlo spring (after Vylita 1991)

1 – test holes,
2 – new abstraction wells of the Vřídlo spring,
3 – test holes and new abstraction wells of "small springs",
4 – sites of original issues of "small springs"

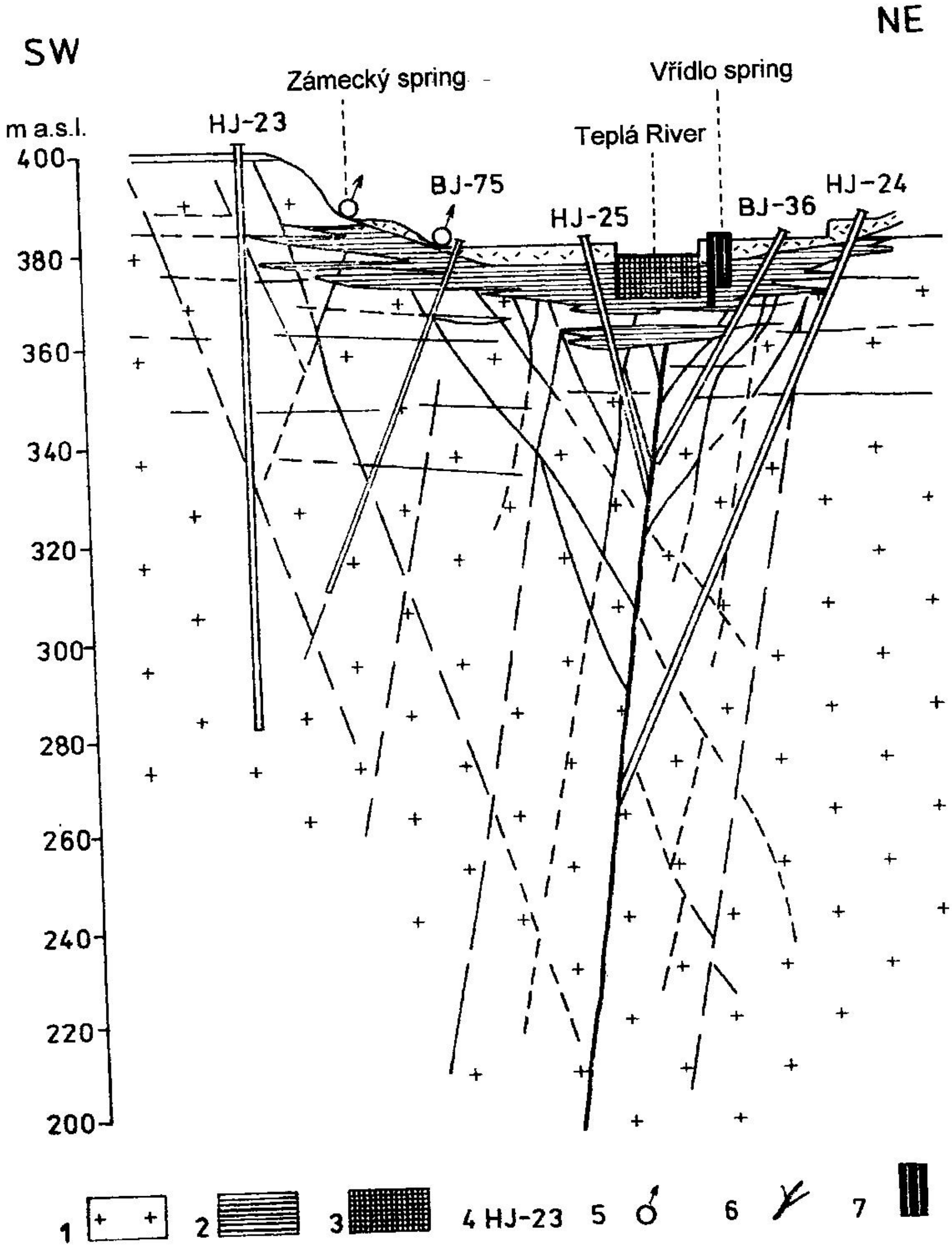

Fig. 7 Schematic geologic section across the Teplá River valley at the Vřídlo spring
(after Vylita 1984, 1991)

1 – granite,
2 – travertine,
3 – old sealing of the Teplá River bed,
4 – test holes and permanent abstraction wells,
5 – "small springs",
6 – ascending pathways of thermal water (fissure zones),
7 – old shallow wells of the Vřídlo spring

Table 4

Chemical analyses of springs in the Karlovy Vary Spa (source Kolářová & Myslil 1979)

Vřídlo II spring

Old abstraction well 8.10 m deep

Location in Fig. 5

Temperature: 72.2 °C
TDS: 5.97 g/l
Free CO_2: 0.38 g/l
HBO_2: 3.6 mg/l
SiO_2: 69.02 mg/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	2.95	0.425	0.52	Cl^-	612.50	17.27	21.24
Na^+	1566.0	68.10	83.95	Br^-			
K^+	99.42	2.54	3.13	J^-			
NH_4^+	0.36	0.02		F^-	2.14	0.11	0.14
Mg^{2+}	44.11	3.63	4.47	NO_3^-			
Ca^{2+}	127.00	6.34	7.82	SO_4^{2-}	1403.0	29.21	36.01
Mn^{2+}	0.27	0.01		HPO_4^{2-}	0.20	0.0	
Fe^{2+}	1.45	0.05		HCO_3^-	2105.00	34.50	42.53
Σ	1841.56	81.125	99.89	Σ	4123.84	81.09	99.42

Sadový spring

Shallow well

Location in Fig. 5

Temperature: 47.4 °C
TDS: 6.32 g/l
Free CO_2: 0.67 g/l
HBO_2: 4.79 mg/l
SiO_2: 74.41 mg/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	2.03	0.29	0.34	Cl^-	597.00	16.84	19.56
Na^+	1685.00	73.27	85.15	Br^-			
K^+	90.12	2.30	2.67	J^-			
NH_4^+	0.43	0.02		F^-	1.63	0.09	
Mg^{2+}	43.60	3.58	4.16	NO_3^-			
Ca^{2+}	130.50	6.51	7.57	SO_4^{2-}	1660.00	34.56	40.14
Mn^{2+}	0.14	0.01		HPO_4^{2-}	0.32	0.00	
Fe^{2+}	1.32	0.05		HCO_3^-	2111.00	34.60	40.19
Σ	1953.14	86.03	99.89	Σ	4370.05	86.09	99.89

Be		µg.l^{-1}	Rb		µg.l^{-1}	Zn		µg.l^{-1}	Al		µg.l^{-1}
Ba		µg.l^{-1}	Co		µg.l^{-1}	Pb		µg.l^{-1}	As		µg.l^{-1}
Sr	263	µg.l^{-1}	Ni		µg.l^{-1}	Cu		µg.l^{-1}	U		µg.l^{-1}
V		µg.l^{-1}	Mo		µg.l^{-1}	Ag		µg.l^{-1}	Ra		µg.l^{-1}

7. Mariánské Lázně Spa

The Mariánské Lázně Spa lies in the southern part of the Slavkovský les Mts. at an elevation of 500 m a.s.l. Different types of crystalline rocks, gneisses and mica schists, basic rocks belonging to the Mariánské Lázně metabasite complex and granites build the area. The southernmost part of the Karlovy Vary granite massif intruded there into the metamorphic rocks during the late phase of Variscan magmatic wedging. The complex geologic position of the Mariánské Lázně Spa can be seen in Fig. 8. The most important tectonic features are the NNW-SSE trending Mariánské Lázně fault with a vertical throw of more than hundreds of meters and the ancient tectonic zone of the „Bohemian Quartz Lode“ generally of the same strike.

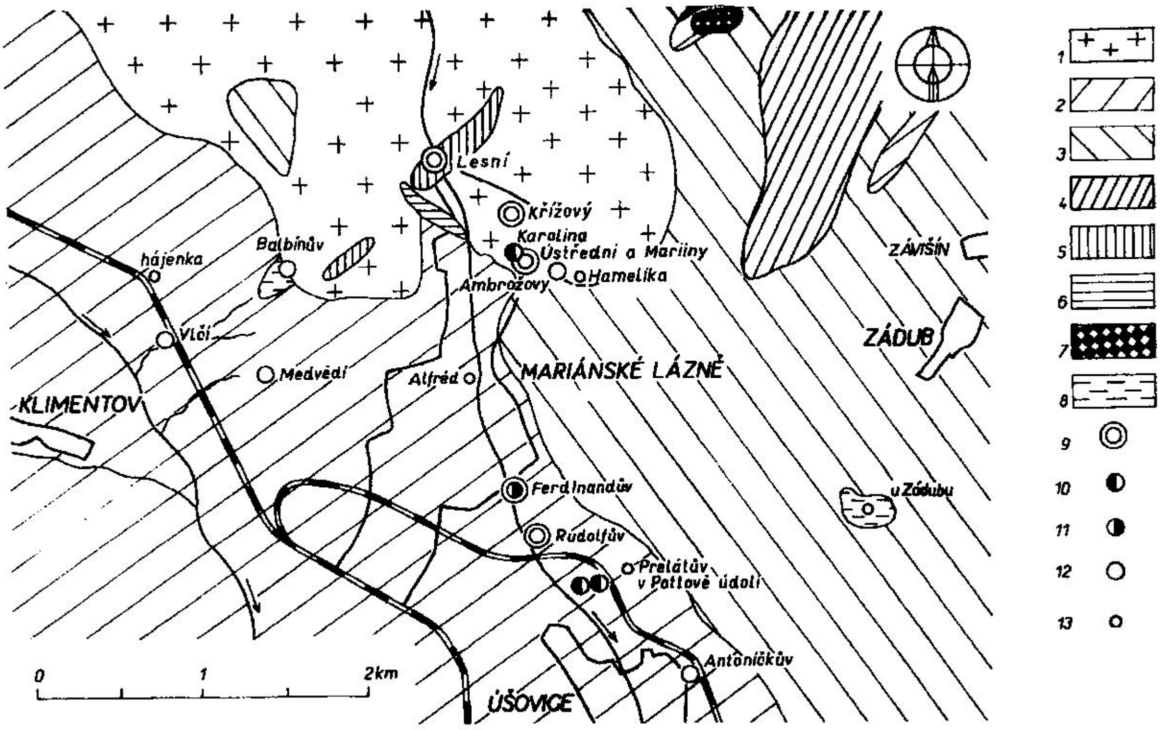

Fig. 8 Location of springs in the Mariánské Lázně Spa (after Kolářová & Myslil 1979)

1 – granite,
2 – gneiss,
3 – amphibolite,
4 – garnet-pyroxene gneiss,
5 – diorite,
6 – vein quartz and siliceous dislocation breccia,
7 – basalt,
8 – peat-bog;
9-13 – springs of mineral water:
9 – used for drinking cures,
10 – used for bathing treatment,
11 – used for bottling,
12 – therapeutic purposes,
13 – disappeared and out-of-use wells

Mineral waters in the Mariánské Lázně area are generally incorporated into a shallow groundwater flow. In deeper boreholes, high contents of sulphates and chlorides and consequently TDS up to 11.5 g/l are due to considerable part of residual waters of Tertiary age. At fissured zones, recharged water is permanently supplied by juvenile carbon dioxide ascending from postvolcanic deep accumulations. Carbon dioxide content increases the leaching and dissolving capacity of ground water.

Mineral water in the area originates at depths of several tens up to a few hundred meters and ascends rapidly to the surface along the most open fissures and faults of several directions and at their intersections in depressions of the relief.

In addition to the Mariánské Lázně Spa area, mineral waters are scattered in its wide environs. These occasionally form large groups of carbon dioxide springs as, e.g., in the vicinity of the Lázně Kynžvart Spa and of localities Prameny, Číhaná and Dolní Kramolín. Their temperature ranges from 7 to 11 °C,

Table 5 Chemical analyses of springs in the Mariánské Lázně Spa

(source Kolářová & Myslil 1979)

Ferdinand VI spring (Excelsior)

Abstraction well 11.0 m deep used for bottling
Location in Fig. 8
Yield 0.4 l/s

Analysed by the Laboratories of the VÚB Mariánské Lázně
Date of sampling: 10.5.1966
Temperature: 9.25 °C
pH: 5.3
TDS: 1.78 g/l
Free CO_2: 3.44 g/l
HBO_2: 3.11 mg/l
SiO_2: 51.49 mg/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	0.77	0.11	0.45	Cl^-	143.70	4.053	16.74
Na^+	424.7	18.47	75.88	Br^-			
K^+	10.08	0.26	1.06	J^-			
NH_4^+	0.11	0.006	0.02	F^-	0.1	0.005	0.02
Mg^{2+}	31.85	2.619	10.76	NO_3^-	0.54	0.008	0.03
Ca^{2+}	54.06	2.698	11.09	SO_4^{2-}	436.32	9.09	37.55
Mn^{2+}	0.49	0.018	0.07	HPO_4^{2-}	0.98	0.024	0.10
Fe^{2+}	3.88	0.139	0.57	HCO_3^-	672.7	11.026	45.55
Σ	526.94	24.320	99.90	Σ	1254.34	24.206	99.99

Be		μg.l^{-1}	Rb		μg.l^{-1}	Zn	20.7	μg.l^{-1}	Al	47	μg.l^{-1}
Ba	126	μg.l^{-1}	Co		μg.l^{-1}	Pb		μg.l^{-1}	As	0.9	μg.l^{-1}
Sr	620	μg.l^{-1}	Ni		μg.l^{-1}	Cu	19.2	μg.l^{-1}	U		μg.l^{-1}
V	0.2	μg.l^{-1}	Mo		μg.l^{-1}	Ag		μg.l^{-1}	Ra		μg.l^{-1}

Křížový III spring

Abstraction well 45 m deep used for drinking cure
Location in Fig. 8
Yield 0.02 l/s

Analysed by the Laboratories of the VÚB Mariánské Lázně
Date of sampling: 10.3.1970
Temperature: 7.00 °C
pH: 6.11
TDS: 9.49 g/l
Free CO_2: 2.90 g/l
HBO_2: 4.2 mg/l
SiO_2: 76.26 mg/l

	mg.l^{-1}	meq.l^{-1}	meq %		mg.l^{-1}	meq.l^{-1}	meq %
Li^+	5.0	0.77	0.6	Cl^-	857.9	24.19	18.5
Na^+	2588.0	112.5	85.8	Br^-			
K^+	46.3	1.18	0.9	J^-			
NH_4^+	0.26	0.02	0.0	F^-	0.30		
Mg^{2+}	92.5	7.61	5.8	NO_3^-	0.0		
Ca^{2+}	148.0	7.39	5.6	SO_4^{2-}	2945.0	61.34	46.9
Mn^{2+}	0.58	0.02	0.0	HPO_4^{2-}	0.74	0.05	0.0
Fe^{2+}	28.4	1.02	0.8	HCO_3^-	2770.0	45.39	34.7
Σ	2914.04	130.51	99.5	Σ	6573.94	130.97	100.1

Be		μg.l^{-1}	Rb		μg.l^{-1}	Zn	12.6	μg.l^{-1}	Al	4310	μg.l^{-1}
Ba	40	μg.l^{-1}	Co		μg.l^{-1}	Pb		μg.l^{-1}	As	470	μg.l^{-1}
Sr	850	μg.l^{-1}	Ni	13.6	μg.l^{-1}	Cu	13.7	μg.l^{-1}	U		μg.l^{-1}
V	1.1	μg.l^{-1}	Mo		μg.l^{-1}	Ag		μg.l^{-1}	Ra		μg.l^{-1}

content of free CO_2 from 1.5 to 3.2 g/l, TDS from 0.15 to 11.6 g/l. In the wider Mariánské Lázně spring area also dry CO_2 exhalations and mofettes occur.

The chemical composition of mineral water in the Mariánské Lázně spring area depends on the degree of leaching of original (residual) brine content and on the local lithology through which the mineral water flows (Fig. 8). Besides plain and ferric carbon dioxide water also sodium-calcium-bicarbonate, magnesium-calcium-bicarbonate, sodium-chloride and sodium-sulphate types occur. Water types marked by high magnesium content originate in the zone of metamorphic utrabasic rocks. Water originating in metamorphic (basic) rocks is characterized, having a low alkali content, by a prevalence of calcium and magnesium. Higher content of alkalis is characteristic of mineral waters issuing from acid igneous rocks. In this case calcium and magnesium contents are more or less equal. Examples of chemical composition of springs are in Table 5.

The Mariánské Lázně Spa belongs to the largest Czech spas. For drinking and bathing cures mineral water from more than 40 springs and borings has been utilised. The minimum annual total yield of mineral water sources is relatively small - around 400 l/min.

8. Kladská and Mnichov - long-term hydrochemical changes in two catchments with contrasting vulnerability to acidification

Introduction

Severe disturbances to ecosystems resulting from air pollution have been documented in central Europe (Prechtel et al. 2001). In the Czech Republic, air pollution and planting of spruce monocultures are two key factors causing the acidification of forested areas. There is an interest in predicting the response of soils and drainage waters to changes in atmospheric deposition and land-use employing through dynamic acidification models.

Emissions of SO_2 peaked in 1982 in the Czech Republic. In the years 1982–1992 the emission decline could be explained by the reduced volume of extracted coal. However, there is a break point in 1993 when the first power plants were desulphurized. This process was completed in 1999. As a result, the emissions declined from 2.4 Tg (i.e. $2.4*10^6$ tons) of SO_2 in 1982 to 1.4 Tg in 1993 and then to 0.26 Tg in 1999. According to the Gothenburg Protocol the target emission in 2010 is 0.283 Tg for the Czech Republic. Thus the emissions measured in 1999 already meet the 2010 target.

Methods and materials

The Lysina (LYS) near Kladská and Pluhův Bor (PLB) near Mnichov catchments are situated in the western part of Bohemia (Tab. 1). The two catchments are just 8 km apart (Fig. 9). The site selection criteria included proximity to each other, similar climate, atmospheric deposition, topography, vegetation cover, size, and chemically differing bedrock. PLB is underlain by serpentinite bedrock, consisting primarily of the Mg-silicate mineral, antigorite (Table 6). The bedrock at LYS is coarse-grained, light-colour leucogranite. The major Mg mineral of granite is biotite, however, the bedrock at LYS contains only trace amount of it. The catchments are drained by streams, which begin 900 m from the outlet at LYS and 800 m at PLB.

The outflow from the catchments has been monitored continuously since 1989 (LYS) and since 1991 (PLB) using a V-notch weir and a water level recorder. Runoff samples were collected weekly. Two bulk precipitation collectors situated in the open area in the middle of the LYS catchment were sampled since 1990 (since 2001 at PLB). Throughfall (precipitation below tree canopies) has been collected monthly from five collectors in each of two plots at LYS (since 1991) and at one plot with five collectors at PLB (since 1991). A second throughfall plot was instrumented at PLB in 2001. All annual mean concentrations are volume-weighted and are based on water years (Nov–Oct). Procedures for chemical analysis are described in Krám et al. (1997).

MAGIC model was designed to reconstruct past and predict future drainage water and soil chemistry (Cosby et al. 1985, Cosby 2001). The MAGIC model uses a lumped representation of physical and chemical properties.

Results and discussion

The mean pH of streamwater (surface water) at LYS (in low-flow conditions) represented 8% quantile of values in surface waters sampled at elevations above 700 m a.s.l in the Czech Republic, the elevation similar to the outflows from our catchments (Fig. 10). In contrast PLB represented the 95% quantile of the regional streamwater pH (Veselý and Majer 1998, Majer, pers. com. 2002). The reason for the contrast between LYS and PLB is different bedrock mineralogy and chemistry (Tab. 6).

Total sulphur deposition (wet plus dry) measured in the beginning of the 1990s was in the range of 30-40 kg ha^{-1} yr^{-1} (Fig. 11). Dry deposition contributed about 60% of total deposition. After a decade of S deposition reduction, only approximately 7-11 kg ha^{-1} yr^{-1} was measured in the beginning of 2000s, and the dry deposition fraction was about 20-30%. Therefore, the total deposition of S declined by approximately 75%. Streamwater SO_4^{2-} declined steadily from 570 µeq l^{-1} in 1990 to 145 µeq l^{-1} in 2002 at LYS (Fig. 12). This decline (74%) is similar to the decline in SO_4^{2-} deposition. Sulphate declined even more dramatically from 1035 µeq l^{-1} in 1992 to 215 µeq l^{-1} in 2002 at PLB. Such dramatic decline in SO_4^{2-} concentrations in streamwater was not documented in any other European catchment (Prechtel et al., 2001).

The sum of base cations in streamwater at LYS declined steadily between 1990 and 2002 (Fig. 12) from 430 µeq l^{-1} to 160 µeq l^{-1}, representing a decline of 63%. Divalent cations (Ca^{2+} and Mg^{2+}) declined much more sharply compared to monovalent K^+ and Na^+. Ca^{2+} declined by 73%, Mg^{2+} by 71%. Streamwater pH was extremely low (Fig. 12) during the observed period. Annual averages increased only slightly (from 3.92 to 4.01, a 18% decrease of H^+ concentration) compared to the

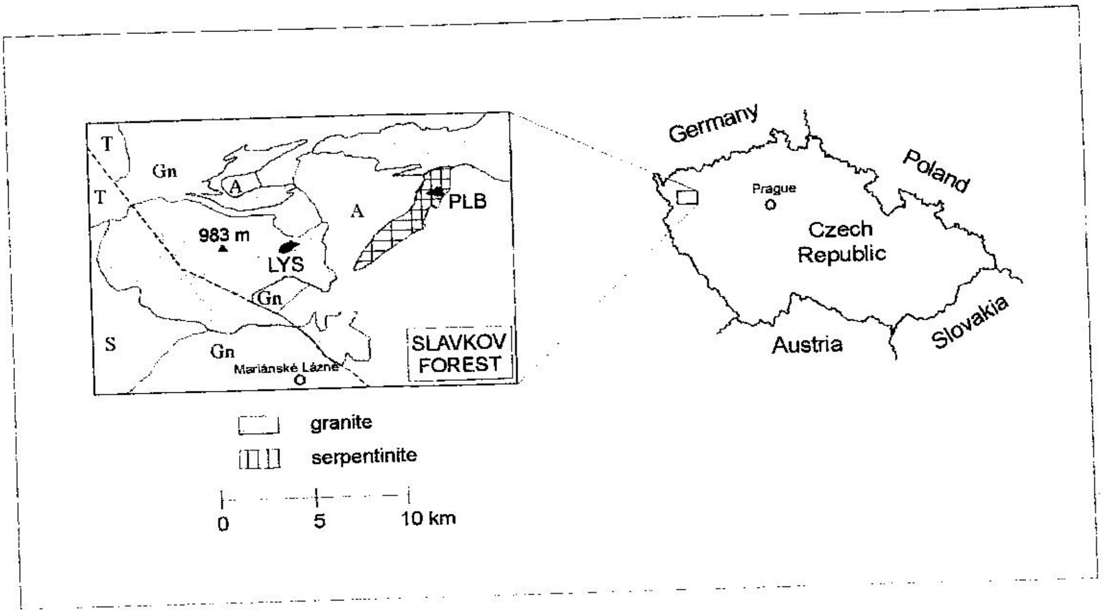

Fig. 9. Map of the Czech Republic, showing studied region. Left panel: map of the Slavkov Forest with the locations of the catchments Lysina (LYS) and Pluhův Bor (PLB), and major lithologies (granite, serpentinite, A – amphibolite, Gn – gneiss, S – mica schist, T – Tertiary sediments, dashed line – fault.

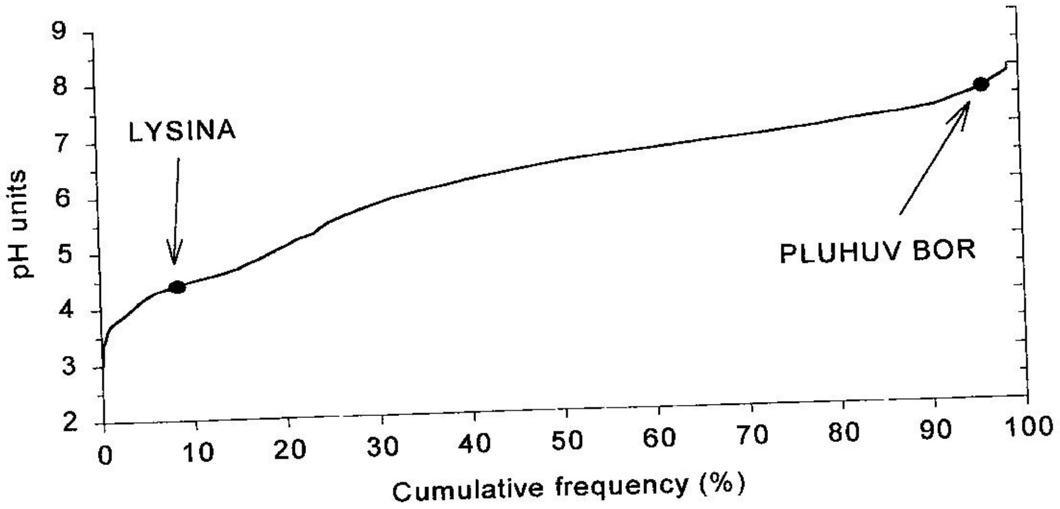

Fig. 10. Frequency distribution of streamwater pH at altitudes >700 m a.s.l. from the regional survey of Czech surface water quality conducted during baseflow conditions (derived from Veselý and Majer 1998, Vladimir Majer pers. commun. 2002). Dots represent the Lysina and Pluhův Bor catchment data from the baseflow conditions as well.

substantial decline of SO_4^{2-} concentrations. LYS is a typical catchment where acidification caused toxic Al mobilisation (Hruška et al. 2002).

The sum of base cations in runoff at PLB declined steadily between 1990 and 2002 (Fig. 12) from 1590 µeq l^{-1} to 1030 µeq l^{-1}, representing a decline of 35%. Divalent cations declined again much more sharply compared to the monovalent ones (Ca^{2+} by 42%, Mg^{2+} by 35%). Annual streamwater pH values were high (Fig. 12) and varied between 6.6 - 7.3 according to the annual water budget. Lower pH values were observed in wetter years.

If atmospheric deposition remains at 2000/2001 level, predicted streamwater SO_4^{2-} concentrations at LYS will decrease to ca. 120 µeq l^{-1} around 2010 and to 110 µeq l^{-1} in 2030 (Fig. 12). This value will be similar to concentrations simulated at the beginning of the 1950's, but only 15% of the highest SO_4^{2-} simulated for 1983. Despite this pronounced decline, SO_4^{2-} will still be the dominant inorganic anion. At PLB deposition reduction resulted in a sharper decline of streamwater SO_4^{2-} compared to LYS. PLB is more completely forested (Table 6) and the decline in dry deposition had probably a more pronounced effect, as well as calibrated lower sulphate adsorption capacity of catchment soils. Streamwater SO_4^{2-} declined from its simulated peak in 1980's (1200 µeq l^{-1}) to ca. 170 µeq l^{-1} in 2030 representing only 14% of the in 1980's peak (Hruška and Krám 2003).

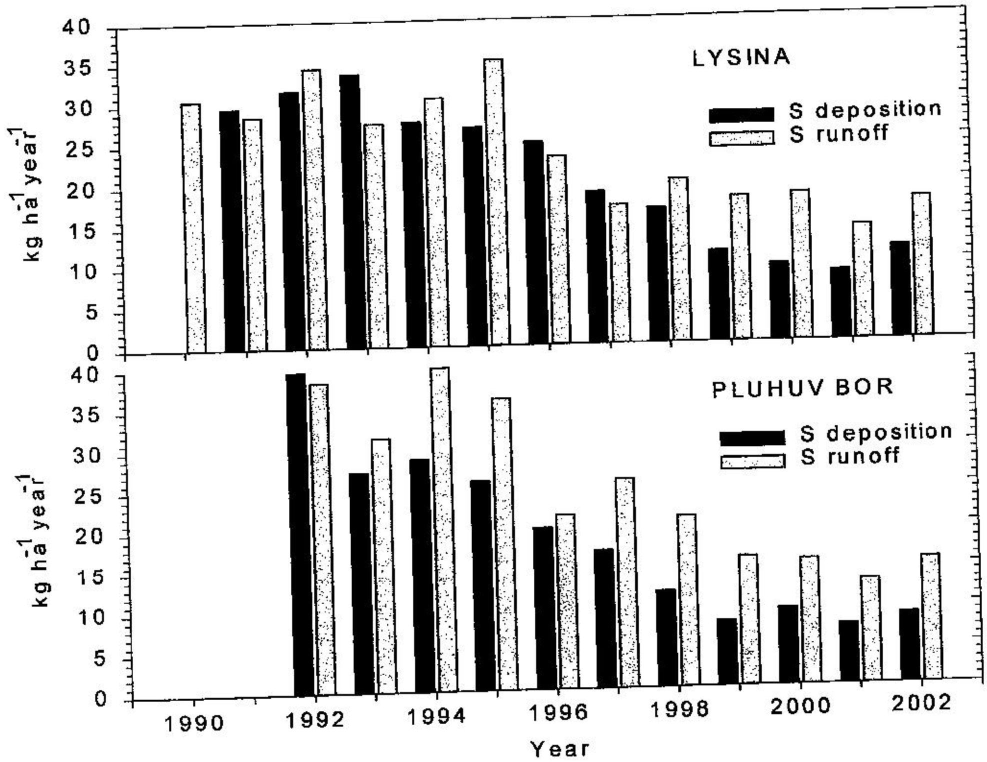

Fig. 11. Sulphur budgets (inputs versus outputs) for the Lysina and Pluhův Bor catchments measured from 1990 to 2002.

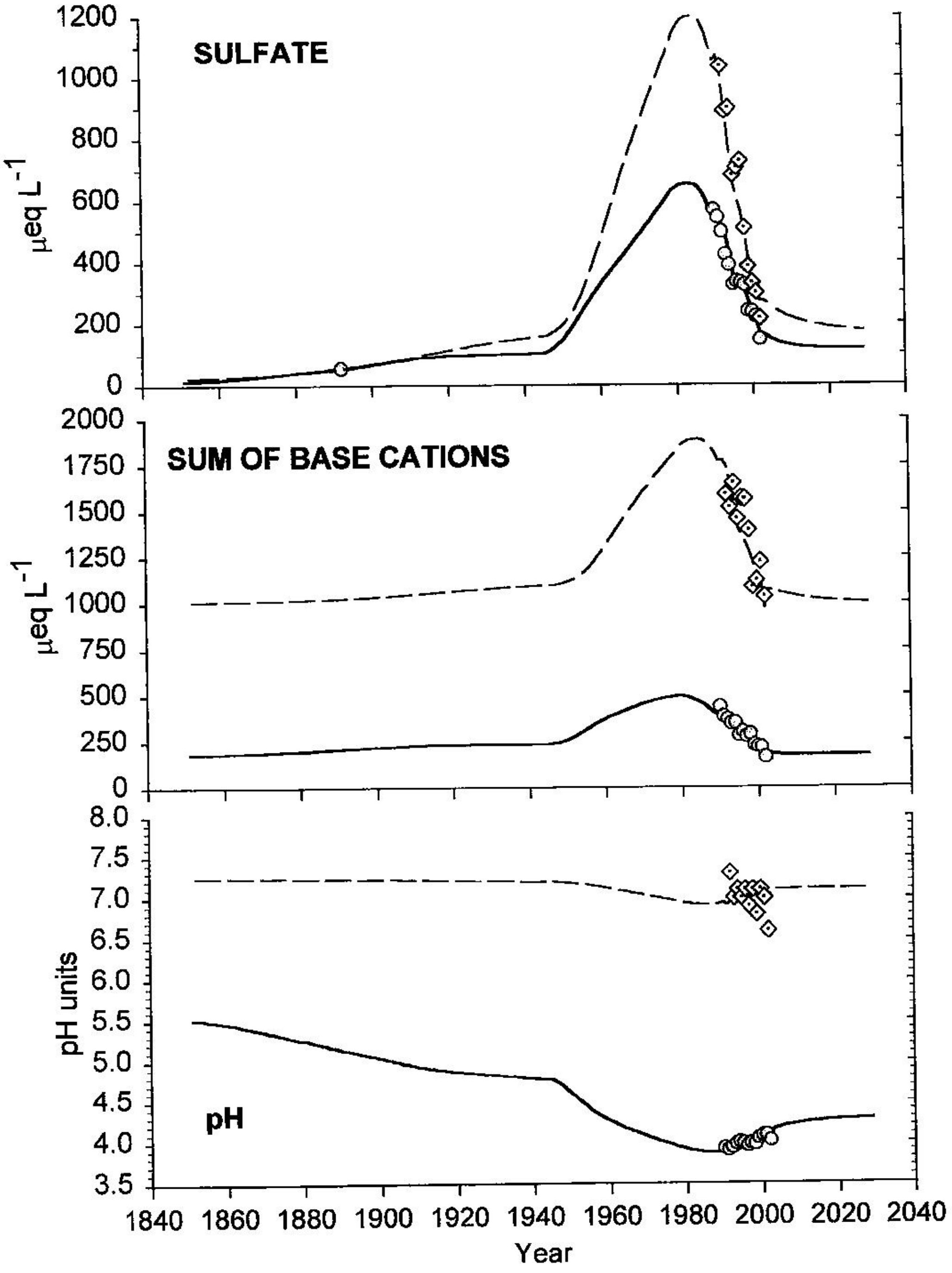

Fig. 12. Measured and simulated changes in streamwater chemistry The sum of base cations includes calcium, magnesium, potassium and sodium. Atmospheric deposition measured in 2000-2001 was used for the forecast in 2003-2030.

grey dots	measured values (1990-2002) at Lysina
diamonds	measured values (1992-2002) at Pluhův Bor
solid line	simulated values (1851-2030) at Lysina
dashed line	simulated values (1851-2030) at Pluhův Bor

Table 6. Characteristics of the Lysina and Pluhův Bor catchments

	LYSINA	PLUHŮV BOR
Altitude (m a.s.l.)	829-949	690-804
Drainage area (km^2)	0.273	0.216
Forest stands structure	Closed-canopy forest (70%)	Closed-canopy forest (93%)
Tree species	Norway spruce *(Picea abies)*	Norway spruce *(Picea abies)* (92%)
Average age of spruce trees (yr)	50	120
Bedrock	Leucogranite	Serpentinite
Major bedrock minerals	Quartz: SiO_2, feldspars: $NaAlSi_3O_8$, $KAlSi_3O_8$, biotite: $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	Antigorite: $Mg_3Si_2O_5(OH)_4$
Bedrock composition for base cations (mass%)	CaO: 0.52 MgO: 0.11 K_2O: 4.4 Na_2O: 2.9	CaO: trace MgO: 36.8 K_2O: 0.29 Na_2O: 1.3
Prevailing soils	Podzolic brown forest earth	Eutrophic brown forest earth
Soil pools (fine fraction <2mm) of exchangeable base cations (eq m^{-2})	Ca: 1.0 Mg: 0.22 K: 0.53 Na: 0.113	Ca: 3.9 Mg: 91.2 K: 0.54 Na: 0.108
Bulk precipitation (mm yr^{-1})	991	783
Throughfall (mm yr^{-1})	715	529
Runoff (mm yr^{-1})	454	273
Streamwater type (eq%)	Ca-Na-SO_4	Mg-SO_4-HCO_3 (until 1997) Mg-HCO_3-SO_4 (since 1998)
Proportion of base cations in streamwater (eq%)	Ca: 48 Mg: 16 K: 7 Na: 29	Ca: 6 Mg: 90 K: 0.3 Na: 4

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