



# **Monitoring of Atmospheric Precipitation at NPBS**

## **Annual Report 2010**

**Geologický ústav AV ČR, v.v.i.  
Rozvojová 269, 165 00 Praha 6**

**Monitoring of Atmospheric  
Precipitation at NPBS  
Annual Report 2010**

*Prague  
02 2011*

**Institute of Geology AS CR, v.v.i.**  
Rozvojová 269, 165 00 Praha-Lysolaje

# **Monitoring of Atmospheric Precipitation at NPBS Annual Report 2010**

Project No. GLÚ AV ČR: 7214

.....  
RNDr. Václav Cílek, CSc.  
Director GLÚ AV ČR

.....  
RNDr. Tomáš Navrátil, PhD.  
Responsible investigator

.....  
RNDr. Tomáš Navrátil, PhD.

Tomáš Navrátil. Osvědčení o odborné způsobilosti č. 2082/2008 projektovat, provádět a vyhodnocovat geologické práce v oborech geochemie a zkoumání geologické stavby podle zákona č. 62/1988 Sb. ve znění pozdějších předpisů a vyhlášky MŽP č. 206/2001 Sb.

Institute of Geology AV ČR, v.v.i.  
Rozvojová 269  
165 00 Praha 6-Lysolaje

## Monitoring of Atmospheric Precipitation at NPBS. Annual Report 2010

### Report prepared by:

*Navrátil T.*

### Contributions:

*Dobešová I.  
Rohovec J.  
Nováková T.*

**Customer:** ČR – Správa národního parku České Švýcarsko  
**Company:** ČR – Bohemian Switzerland National Park Administration  
**Address:** Pražská 52  
**Zip code and city:** 407 46, Krásná Lípa

### Abstract:

Primry data gathered through duration of this project since May 2008 until December 2010 cover period of 31 months. Thirty samples from each site has been sampled, processed and analyzed. The final database on deposition and mass fluxes contains 3120 items related to the area of the National Park Bohemian Switzerland (NPBS).

Deposition of  $\text{SO}_4^{2-}$  through bulk precipitation ranged from 12.6 to 16.7  $\text{kg}\cdot\text{ha}^{-1}$  at the monitored stations in the area of NPBS. In the forested parts of NPBS the deposition of  $\text{SO}_4^{2-}$  has been over two-fold on 44.7 44,7  $\text{kg}\cdot\text{ha}^{-1}$ . The deposition of nitrogen compounds  $\text{NO}_3^-$  a  $\text{NH}_4^+$  through bulk precipitation ranged from 16.0 to 20.7  $\text{kg}\cdot\text{ha}^{-1}$  and from 4.3 do 7.0  $\text{kg}\cdot\text{ha}^{-1}$ , respectively.

## Contents

1. Introduction .....	6
2. Sampling sites .....	6
3. Sampling methods, treatment and analysis .....	7
4. Results .....	9
4.1 Precipitation budget.....	9
4.2 Chemical composition of precipitation and deposition fluxes .....	11
4.2 Seasonal changes in concentrations of solutes in bulk precipitation.....	13
4.3 Statistical analysis .....	14
4.4 Experimental .....	16
5 Summary .....	17
6 References .....	18
7 Annexes and Tables .....	19

### List of Tables

Table 1 Detection limits of used analytical procedures .....	7
Table 2 Comparison of annual solute fluxes on monitored sites in area of NPBS in period from 2002 to 2010 .....	12
Table 3 Correlation coefficients for the concentrations of analytes in bulk precipitation at sites SS, DM and KV in period from 2002 to 2010. ....	15

### List of Figures

Figure 1 Position of monitored sites in area of NP Bohemian Switzerland.....	6
Figure 2 Annual precipitation amounts at sites SS, DM, KV and KV-thsf .....	10
Figure 3 Average monthly precipitation amounts in period from 2002 to 2010 on sites SS, DM a KV .....	10
Figure 4 Percentual proportion of main solutes as equivalents per liter in bulk precipitation, data are an average from all three monitored sites SS, DM a KV on the area of NPBS..	11
Figure 5 Changes of precipitation volume (mm dk), pH values and concentration of analytes Na, Cl, $\text{NH}_4^+$ , $\text{SO}_4^{2-}$ , Ca and Al for individual months of a year. ....	13
Figure 6 Image of precipitate of seepage solution from site Březák.....	16

### List of Annexes and Tables

Tables of analyte concentrations in precipitation and monthly fluxes	
Tables of annual mass fluxes for the period from 2002 to 2010	

## 1. Introduction

New stage of systematical monitoring of the atmospheric deposition of selected major and minor elements in the area of National Park Bohemian Switzerland has begun in May 2008 and it lasted until December 2010. This report includes data gathered during the whole duration of project. Monitoring of atmospheric precipitation aims to assess the current state and changes in chemical composition of precipitation over area of NPBS.

## 2. Sampling sites

Geochemical monitoring of the composition of cumulative bulk precipitation samples and throughfall has been carried out on four individual sites similar to those in year 2008:

**Site SS** – bulk precipitation on meadow below Stříbrné stěny (SS).

**Site DM** – bulk precipitation on meadow by the peat deposit at Dolský mlýn (DM).

**Site KV** – bulk precipitation on meadow below Kuní vrch (KV).

**Site KV-thsf** – spruce throughfall at site Kuní Vrch (KV) inside the forested area.

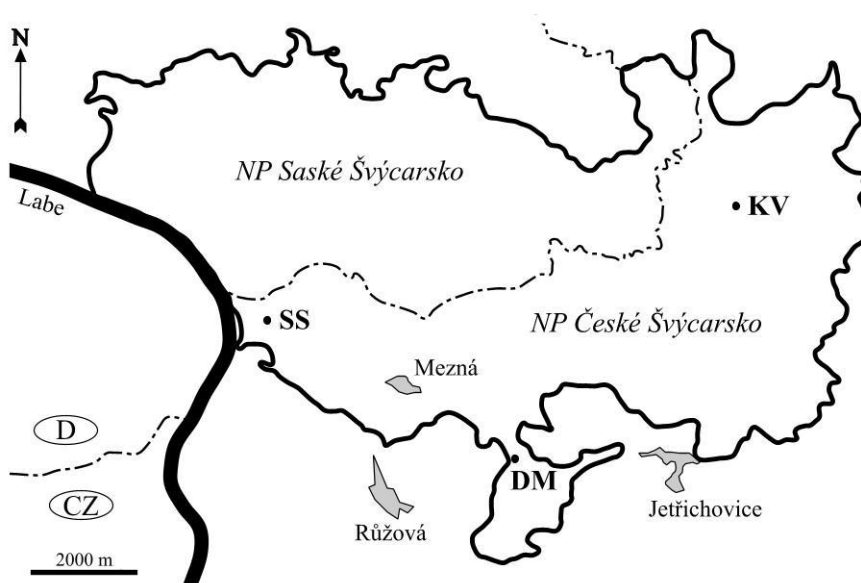


Figure 1 Position of monitored sites in area of NP Bohemian Switzerland

### 3. Sampling methods, treatment and analysis

Cumulative samples were taken with monthly step at four individual sites. The samplers were classical VOSS samplers (used in monitoring networks of the Czech Republic). For the analysis of the trace elements the samplers were modified and equipped with glass funnels to prevent from adsorption of analytes onto plastic walls of sampler (Skřivan et al. 2000). The sample has been cumulated into 1L polyethylene containers held in 1.5m height above ground.

In laboratory containers were weighted for evaluation of the sample volume (necessary for calculation of fluxes). Then conductivity and pH has been evaluated and samples were filtered through membrane filters (pore size 0.45  $\mu\text{m}$ ).

Concentrations of Ca, K, Mg, Na, Al, Fe, Cu, Sr and Mn were evaluated with optical emission spectrometer with inductively coupled plasma (ICP-OES) made by company Thermo Elemental (Iris Intrepid Duo), with the concentric nebulizer and axial plasma setting.

**Table 1 Detection limits of used analytical procedures**

Analyte	Det. limit [ $\mu\text{g/L}$ ]	Analyte	Det. limit [ $\mu\text{g/L}$ ]
Al	0.6	Zn	10
Fe	0.6	As	0.5
Mn	0.5	$\text{NH}_4^+$	0.02
Cu	0.5	Si	20
Ca	0.05	P	2.0
K	10.0		
Mg	0.1	Analyt	Det. limit [ $\text{mg/L}$ ]
Na	1.0	$\text{NO}_3^-$	0.3
Cd	0.04	$\text{SO}_4^{2-}$	0.5
Pb	0.5	$\text{Cl}^-$	0.15
Rb	0.5	$\text{F}^-$	0.02
Sr	0.5	$\text{HCO}_3^-$	0.6

Concentrations of Cd, Pb and Rb were evaluated by the atomic absorption spectrometry (AAS) on VARIAN SpectrAA 300 by electro-thermic atomization (ETA) on the graphite cell. Concentrations of As were analyzed by hydride generation on the similar atomic absorption spectrometer. Since year 2010 As has been analyzed by means of ICP-MS using the Thermo Element2 analyzer. The ICP-MS is more sensitive than the former method at least by order of a magnitude.

Concentrations of  $\text{NH}_4^+$  and  $\text{F}^-$  were determined with ion selective electrode CRYTUR. The concentrations of main anions ( $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ) were determined by chromatographic method HPLC on KNAUER analyzer at the laboratories of Institute of Geology AS CR, v.v.i.

Until April 2010 the anions and  $\text{NH}_4^+$  were determined in laboratories of Czech Geological Survey, Prague.

## 4. Results

Primary data gathered during the whole duration of project are contained in tables (Chapter Annexes and Tables) together with appropriate precipitation amounts, pH values and conductivity. These basic data were used for calculation of deposition fluxes for given period of time usually about one month (Chapter Annexes and Tables).

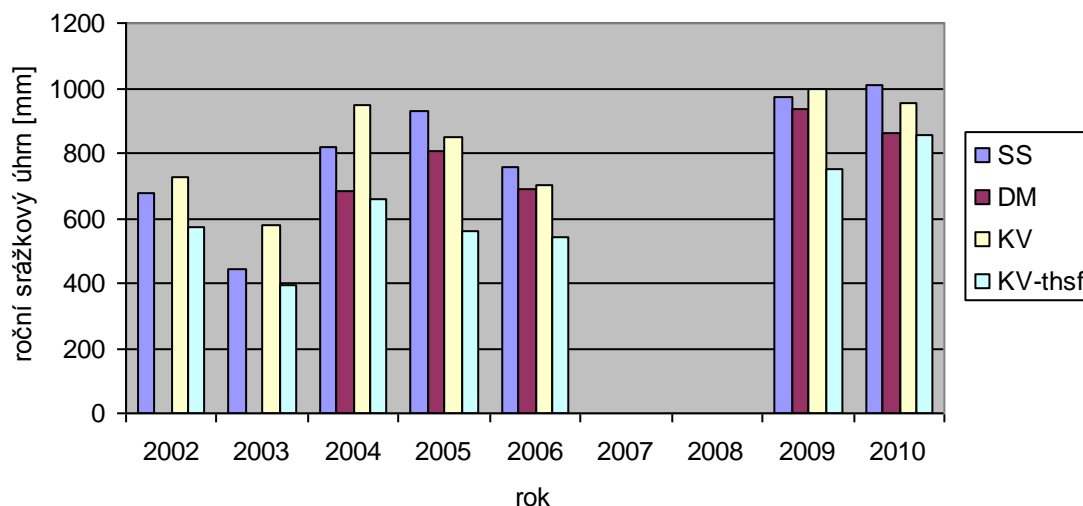
The monitoring in framework of this project covered 980 days, sampled, processed and analyzed was 30 samples from each site so that the total number of samples has reached 120. Each sample has been subject to 26 physico-chemical analyses so that the final database includes 3120 items.

### ***4.1 Precipitation budget***

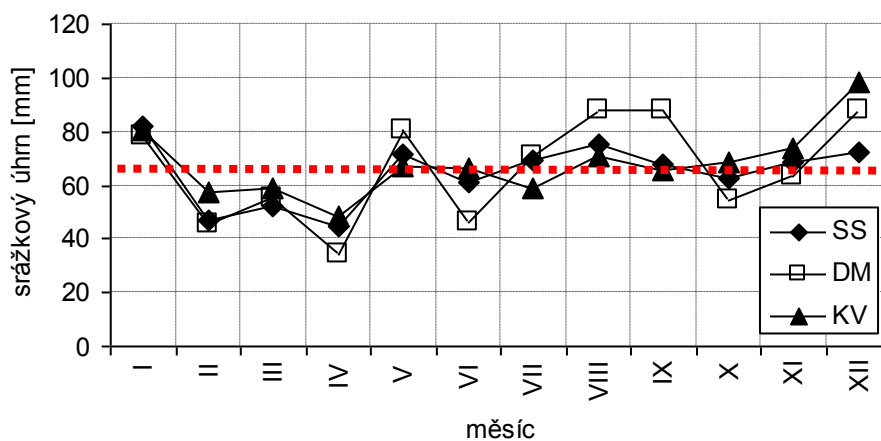
The annual precipitation amount was quantified for calendar years 2009 and 2010, because these years had the complete record needed. The average annual precipitation amounts at stations SS, DM, KV and KV-thsf reached 799, 794, 821 and 620 mm (Fig. 2) in period from 2002 to 2010 (amounts in 2007 and 2008 are missing). The mean amounts at all sites correspond with the long-term average (800mm) of annual precipitation for the area of NPBS (Hartel 2005). Although the precipitation amount in years 2009 and 2010 was greater the average value (Fig. 2).

The site with spruce plantation KV-thsf was typical with precipitation amount reaching 75% of that at bulk precipitation on the closest site KV in period from 2002 to 2010. The precipitation amount at site KV-thsf was high, although there could be an error due to impossible monthly step in sampling during the period from 12/2009 to 02/2010. Bottles with sample were blocked in sampler holders and it was also impossible to reach the sites due to great thickness of snowpack. The missing data were extrapolated using the data from the nearest station Tokáň.

Mean monthly precipitation amounts at sites SS, DM and KV were quite similar such as in previous years and reached 19, 81 and 76 mm for year 2009.



**Figure 2 Annual precipitation amounts at sites SS, DM, KV and KV-thsf**

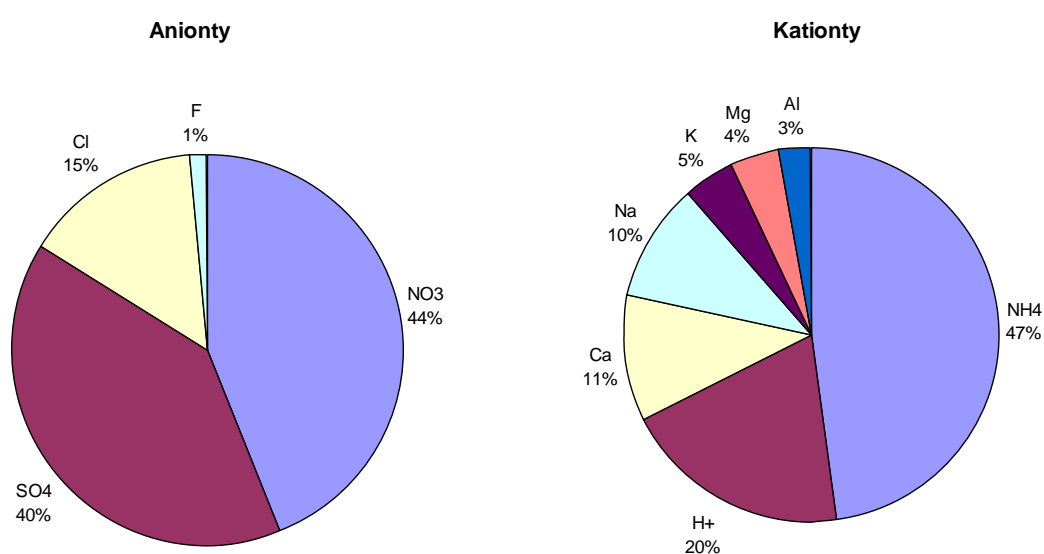


**Figure 3 Average monthly precipitation amounts in period from 2002 to 2010 on sites SS, DM a KV**

The average monthly precipitation amounts at sites SS, DM and KV are similar and reached 68, 67 a 71 mm in period from 2002 to 2010. Months with precipitation amounts greater than the average were January, May, August and December (Fig. 3). On site DM the precipitation amount was greater than the average also in September.

## 4.2 Chemical composition of precipitation and deposition fluxes

Presence of main anions in the precipitation on the sites SS, DM and KV can be characterized by following order  $\text{NO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{F}^-$ , while the characteristic order for the cations would be  $\text{NH}_4^+ > \text{H}^+ > \text{Ca}^{2+} > \text{Na}^+$  (Fig. 4). Until recently the literature reported sulfate  $\text{SO}_4^{2-}$  as the main anion in the precipitation at the area of former Black Triangle (Zimmermann et al. 2006), but according to the results the concentration of nitrate ( $\text{NO}_3^-$ ) has become at least similarly important or greater than sulfate in some samples.



**Figure 4** Percentual proportion of main solutes as equivalents per liter in bulk precipitation, data are an average from all three monitored sites SS, DM and KV on the area of NPBS

We used a theoretical calculation of marine derived  $\text{SO}_4^{2-}$  in the bulk precipitation. We are aware that this calculation has its limits since it is based on the fact that all Na in precipitation is of marine origin but it is commonly used (Zimmermann et al. 2006). The results indicate that 2 to 7% from the total bulk deposition of  $\text{SO}_4^{2-}$  is of marine origin. Proportion of 93 to 98% from the total bulk deposition of  $\text{SO}_4^{2-}$  originates from the anthropogenic sources.

**Table 2 Comparison of annual solute fluxes on monitored sites in area of NPBS in period from 2002 to 2010**

Unit	Analyte	SS	DM	KV	KV-thsf
mm	Precip.	799	794	821	632
kg.ha <sup>-1</sup>	NO <sub>3</sub> <sup>-</sup>	20.71	15.98	20.09	47.99
"	SO <sub>4</sub> <sup>2-</sup>	16.71	12.57	16.50	44.66
"	NH <sub>4</sub> <sup>+</sup>	7.04	4.29	5.33	11.74
"	Cl <sup>-</sup>	4.13	3.21	4.18	10.17
"	Na	2.11	1.55	2.02	4.06
"	Ca	1.94	1.29	1.70	8.72
"	K	1.58	1.18	1.33	18.54
"	Fe	1.29	0.23	1.87	4.52
"	Mg	0.52	0.37	0.44	1.74
"	H <sup>+</sup>	0.25	0.23	0.27	0.38
"	Al	0.19	0.12	0.18	0.37
"	F <sup>-</sup>	0.17	0.17	0.17	0.54
"	Mn	0.15	0.07	0.07	0.87
g.ha <sup>-1</sup>	Zn	69.8	44.0	52.8	95.6
"	Cu	25.2	7.7	4.7	15.8
"	Sr	14.1	12.2	9.8	27.2
"	Pb	10.0	5.9	9.1	5.9
"	Rb	7.0	6.6	10.7	60.8
"	As	4.2	2.9	5.1	4.1
"	Cd	0.6	0.4	0.5	0.7

The mutual comparison of annual deposition fluxes on sites SS, DM and KV in period from 2002 to 2010 indicates that sites SS and KV were subject to increased but similar level of acid deposition (Tab. 2). On station DM the deposition was slightly smaller but this could be caused due to smaller dataset starting from year 2004 at site DM. The greatest level of NH<sub>4</sub><sup>+</sup> deposition occurred at site SS which could be caused by local effects like the vicinity of Hřensko village and road No.62 in the valley of river Labe or in position towards the more distant sources of pollution such as city of Děčín. Other elements with increased level of deposition at site SS were Mn, Zn, Pb and Cd. The origin of this combination of metals could be the combustion processes or small industrial activities etc.

Deposition of acidificants S and N in the forested parts reached more than double the level on open sites (Tab. 2). Dry deposition of S and N is thus still playing an important role. Great differences between fluxes of K and Mn (and into a lesser extent of Ca and Rb) originate in metabolic processes of forest vegetation.

## 4.2 Seasonal changes in concentrations of solutes in bulk precipitation

Changes of Na and Cl for individual months of a year indicate that concentrations of these analytes are increased before all in the cool period of year from November to March (Fig.5).

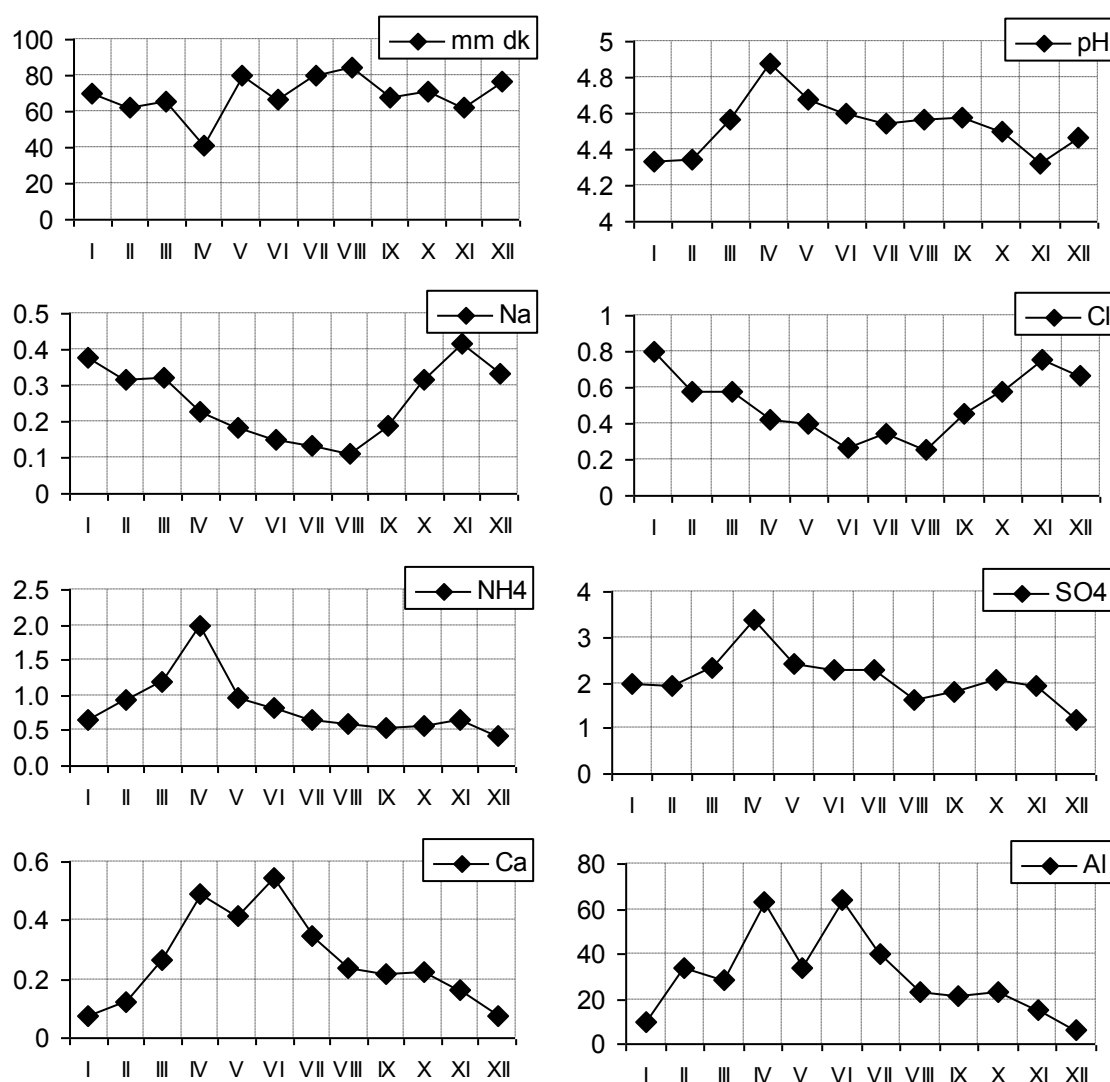


Figure 5 Changes of precipitation volume (mm dk), pH values and concentration of analytes Na, Cl,  $\text{NH}_4^+$ ,  $\text{SO}_4^{2-}$ , Ca and Al for individual months of a year. Values are arithmetic average of monthly concentrations from period 2002 – 2010. Concentrations are in  $\text{mg.l}^{-1}$  only for Al in  $\text{ug.l}^{-1}$ .

We assume that the source of Na and Cl in precipitation is the dust generation connected with usage of deicing salts. Although another less probable explanation would be more precipitation events coming from the north direction where is located the nearest sea - North Sea. The highest concentrations of  $\text{SO}_4^{2-}$  and  $\text{NH}_4^+$  were

detected in April (Fig. 5) but the cause of this is probably the lowest precipitation amount in April. The atmosphere in April is washed-out by smaller amounts of rain therefore the concentrations of abundant  $\text{SO}_4^{2-}$  and  $\text{NH}_4^+$  are thus greater. The increased concentrations of Ca and Al were typical for the period from April to June, which is a period with very variable precipitation amounts (Fig. 5). These increased concentrations cannot thus be explained solely by changing precipitation amounts but there must be another factor such as agricultural activities or increased touristic activities and connected local generation of dusts.

### **4.3 Statistical analysis**

Correlation analysis has been performed on concentrations of individual analytes gathered by the workers of NPBS in years 2002 – 2006. The relationships between individual analytes can help during investigation on their origin or common sources. The total count of records for the correlation analysis was 102, and on probability level of  $p < 0.001$  the lowest correlation coefficient indicating valid relationship equals to  $\pm 0.32$ . This analysis did not include elimination of effect of values below than detection limit, so the coefficients for the trace metals should be regarded with caution.

Detected negative correlation between concentrations of  $\text{H}^+$  and K, Ca,  $\text{NH}_4^+$  means that increased amounts of these elements in precipitation are typical for samples with decreased concentrations of  $\text{H}^+$  and thus increased pH value. These increased concentrations can in fair number of samples originate from contamination of bulk precipitation sample by organic debris. Very strong statistical relationship has been found between concentrations of Na and Cl (Tab. 3). Common source of Na and Cl concentrations could be the marine aerosol (Vach et al. 2004) or the dusts originating from road salts during dry periods in winter. Significant correlation between concentrations of Ca and Al has been rather interesting. Relationship of  $\text{NO}_3^-$  and  $\text{NH}_4^+$  concentrations could be primary due to similar emission source but could be also a result of bacterial transformation processes especially in the summer period. Relatively high correlation of  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  concentrations indicates their mutual source – thermal power plant emissions.

**Table 3 Correlation coefficients for the concentrations of analytes in bulk precipitation at sites SS, DM and KV in period from 2002 to 2010. The greatest level of correlation  $r > \pm 0,75$  – bold values, high level of correlation  $r > \pm 0,50$  – values in bold italics, correlating values  $r \geq \pm 0,32$  – values in italics.**

	n=243, p<0.001, r=0.32																			
	H+	Na	K	Ca	Mg	NH <sub>4</sub> <sup>+</sup>	F	Cl	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Al	As	Cd	Cu	Fe	Mn	Pb	Rb	Sr	Zn
H+	<b>1.00</b>																			
Na	0.09	<b>1.00</b>																		
K	-0.34	-0.02	<b>1.00</b>																	
Ca	-0.37	-0.03	<i>0.43</i>	<b>1.00</b>																
Mg	-0.26	<i>0.30</i>	<b><i>0.56</i></b>	<b><i>0.55</i></b>	<b>1.00</b>															
NH <sub>4</sub> <sup>+</sup>	-0.37	0.09	<i>0.41</i>	<i>0.40</i>	<b><i>0.51</i></b>	<b>1.00</b>														
F	0.03	-0.11	0.04	0.07	-0.03	-0.03	<b>1.00</b>													
Cl	0.17	<b>0.85</b>	-0.01	-0.09	0.26	0.01	-0.02	<b>1.00</b>												
NO <sub>3</sub> <sup>-</sup>	0.15	0.26	0.19	0.32	0.27	<b><i>0.50</i></b>	0.03	<i>0.34</i>	<b>1.00</b>											
SO <sub>4</sub> <sup>2-</sup>	-0.07	0.10	0.36	<b><i>0.56</i></b>	<i>0.44</i>	<b><i>0.53</i></b>	0.07	0.18	<b><i>0.72</i></b>	<b>1.00</b>										
Al	-0.24	0.06	0.28	<b>0.82</b>	<i>0.45</i>	<i>0.37</i>	0.03	-0.01	<i>0.34</i>	<i>0.46</i>	<b>1.00</b>									
As	-0.16	0.05	0.12	0.38	0.14	0.36	-0.12	-0.04	0.13	0.20	0.25	<b>1.00</b>								
Cd	0.01	0.05	0.06	0.13	0.03	0.26	-0.10	0.01	<i>0.31</i>	0.27	<i>0.34</i>	<i>0.42</i>	<b>1.00</b>							
Cu	-0.21	-0.07	0.16	0.24	0.11	0.13	-0.06	-0.02	0.02	0.22	0.11	0.23	-0.01	<b>1.00</b>						
Fe	-0.09	-0.09	-0.01	0.00	-0.07	-0.03	-0.08	-0.13	-0.05	-0.01	0.03	-0.02	-0.02	-0.06	<b>1.00</b>					
Mn	-0.02	0.11	0.32	0.23	0.29	0.32	-0.01	0.09	0.27	<i>0.34</i>	<i>0.40</i>	<i>0.42</i>	<b><i>0.57</i></b>	0.11	0.01	<b>1.00</b>				
Pb	0.14	0.07	0.14	0.48	0.25	0.22	0.00	0.04	<i>0.46</i>	<b><i>0.53</i></b>	<i>0.49</i>	0.04	0.23	0.18	-0.01	0.15	<b>1.00</b>			
Rb	-0.15	0.04	<b><i>0.57</i></b>	0.21	0.39	0.37	-0.07	0.04	0.21	0.28	0.27	0.00	0.22	0.10	0.16	<i>0.48</i>	0.02	<b>1.00</b>		
Sr	-0.15	-0.18	0.17	0.06	0.05	0.08	0.05	-0.12	-0.17	-0.01	0.01	0.02	0.07	0.33	-0.09	0.11	-0.11	0.07	<b>1.00</b>	
Zn	-0.07	0.14	0.16	0.28	0.16	<i>0.43</i>	-0.11	0.10	<i>0.39</i>	<i>0.44</i>	<i>0.31</i>	<b><i>0.67</i></b>	<i>0.42</i>	<b><i>0.56</i></b>	0.02	<b><i>0.60</i></b>	<i>0.30</i>	<i>0.32</i>	0.04	<b>1.00</b>

#### 4.4 Experimental

A well known phenomenon in the area of NPBS is the salt efflorescence on the sandstone rocks and the connected unwanted erosion and collapsing of the rock formations (Přikryl et al. 2007). The most important minerals forming the salt crusts were found to be sulfates - gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and K- alum ( $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ ). The source of sulfur has been detected as atmospheric sulfur originating from fossil fuel burning by means of isotopic analysis (Schweigstillova et al. 2009), but the source of elements such as Ca, K and Al was not allocated so far.

For the publication of Vařilová et al. (2011) it was necessary to perform experiments with precipitation and seepage waters. These experiments enabled to verify atmospheric deposition of Ca as a possible source for salt efflorescence. On the other hand absence of K-alum in precipitate from the rainwater indicates origin of Al (possibly of K) the sandstone. Figure 6 depicts the salt efflorescence in an electron microscope image of the precipitate from the seepage solution at site Březák. due. The hedgehog like body are the crystals of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and the area around flat crystals of K-alum ( $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ ).

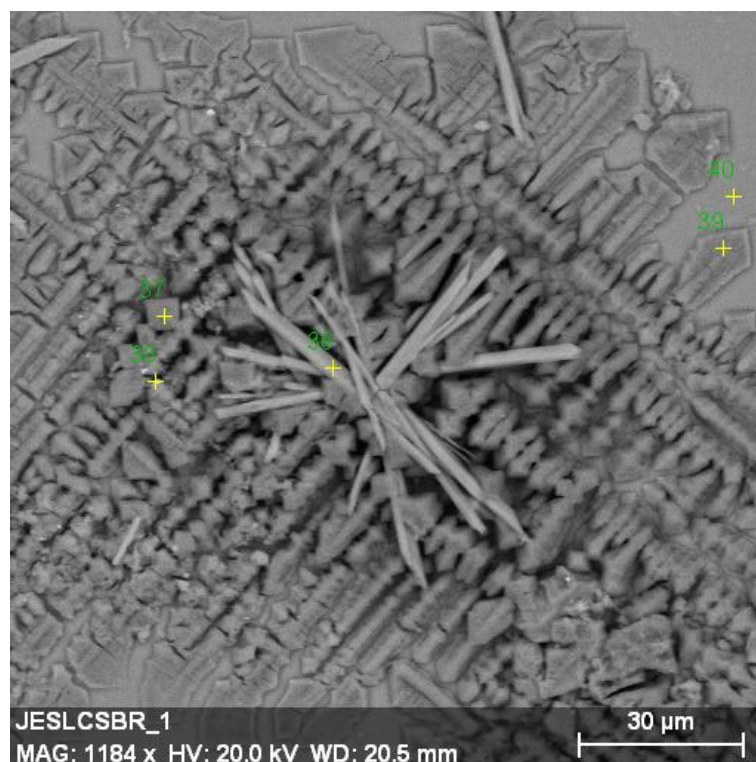


Figure 6 Image of precipitate of seepage solution from site Březák

## 5 Summary

From the results on deposition at the area of NPBS it was possible to conclude on following:

- Annual precipitation amounts reached on average 799, 794 and 821 mm on sites SS, DM and KV, where the precipitation was sampled on an open area
- On site KV-thsf with spruce vegetation the annual precipitation reached 620 mm due to evapotranspiration
- Main anion in precipitation on the area of NPBS were nitrates ( $\text{NO}_3^-$ ), followed by sulfates ( $\text{SO}_4^{2-}$ )
- Main cation in precipitation on the area of NPBS were ammonium ion ( $\text{NH}_4^+$ ), followed by protons ( $\text{H}^+$ )
- Theoretical calculation indicates that 93-98% from deposited sulfates ( $\text{SO}_4^{2-}$ ) originates from anthropogenic sources
- Bulk deposition of  $\text{SO}_4^{2-}$  on monitored sites ranged from 12.6 to 16.7  $\text{kg}\cdot\text{ha}^{-1}$ , while at forested areas it reached 44.7  $\text{kg}\cdot\text{ha}^{-1}$
- Bulk deposition of nitrogen compounds  $\text{NO}_3^-$  and  $\text{NH}_4^+$  on monitored sites within NPBS ranged from 16.0 to 20.7  $\text{kg}\cdot\text{ha}^{-1}$  and from 4.3 to 7.0  $\text{kg}\cdot\text{ha}^{-1}$ , respectively
- The smallest precipitation amounts were typical for April, and as a consequence the concentrations of  $\text{SO}_4^{2-}$  and  $\text{NH}_4^+$  in precipitation are the highest
- The highest concentrations of Na and Cl in bulk precipitation were typical from November to March
- Correlation analysis of the data indicated strong relationships for these pairs of elements Na-Cl, Ca-Al and  $\text{NO}_3^-$ - $\text{SO}_4^{2-}$
- Experimental evaporation enabled to suggest possible sources of Ca, Al and K for the salt efflorescence

## 6 References

- Hartel H. (2005) Podnebí. [http://www.labskepiskovce.cz/public/npcs\\_lp/cz/\\_podnebi.html](http://www.labskepiskovce.cz/public/npcs_lp/cz/_podnebi.html)
- Schweigstillova J, Novotna M, Prikryl R (2009) Chemical and isotopic composition of salt efflorescence from the sandstone castellated rocks of the Bohemian Cretaceous Basin (Czech Republic) Environ Geol, Online First
- Skřivan P., Minařík L., Burian M., Martínek J., Žigová A., Dobešová I., Kvídová O., Bendl J., Navrátil T., Fottová D. (2000): Biogeochemistry of beryllium in an experimental forested landscape of the “Lesní potok “ catchment in Central Bohemia, Czech Republic. GeoLines 12, 41 – 62
- Vach, M., Fišák, J., Navrátil, T., Fottová, D., Špičková, J., Skřivan, P. (2004). The precipitation chemistry over central Bohemia, sources and pathways. Stud. Geophys. Geodaet., 48, 791-809
- Vařilová, Z., Navrátil, T., Dobešová, I. (2011). Recent Atmospheric Deposition and its Effects on Sandstone Cliffs in Bohemian Switzerland National Park, Czech Republic. Water Air Soil Poll., (Online First).
- Zimmermann, F., Matschullat, J., Bruggemann, E., Plessow, K., Wienhaus, O. (2006). Temporal and elevation-related variability in precipitation chemistry from 1993 to 2002, Eastern Erzgebirge, Germany. Water Air Soil Poll., 170, 123–141.

## **7 Annexes and Tables**