ALVAN JOURNAL OF SOCIAL SCIENCES (AJSS)
FACULTY OF SOCIAL AND MANAGEMENT SCIENCES
ALVAN IKOKU FEDERAL UNIVERSITY OF EDUCATION, OWERRI
https://www-ajsspub-org.b12sites,com https://www.ajsspub2.org
E- ISSN: 3043 – 5463 ISSN: 1595 – 5842 VOULUME 2, ISSUE 2, 2025

RESEARCH ARTICLE

FROM ROCK TO ROOT: TRACKING THE DYNAMICS OF SOIL NUTRIENTS IN GRANITIC HIGHLAND ECOSYSTEMS

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ABSTRACT

This study examined the weathering processes of several cations, their mobility, and utilization by trees at a highland forest ecosystem. Samples were collected from a drill-core and a soil-pit, with depths reaching up to 2345 cm and 150 cm, respectively. These samples were processed following lab procedures. Statistical analyses were used to determine the relationships between the soil elemental concentrations and distribution with respect to the profile depth. The results showed extremely low concentrations of Ca and Mg along the entire depth, ranging from 500 to 3000 ppm. At $P<0.05$, there was a significant positive regression coefficient (R^2) of 0.5288 (Ca) and 0.0469 (Mg). On the other hand, Al concentration throughout the entire profile was consistently high at about 60500 ppm. Surprisingly, the concentration of all the cations showed positive correlations in relation to soil depth. Forest management practices, such as liming, forest floor litter preservation, and mixed tree planting, should therefore be used to increase base cation concentrations. Further study on the role of other environmental factors (precipitation, temperature, and relief) on weathering rates should also be conducted to come up with more successful soil management.

Key words: Acidification, atmospheric deposition, weathering process, granite, vegetation-ecosystem.

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Received: 10/6/2025; **Revised:** 25/7/2025; **Accepted:** 29/7/2025; **Published:** 30/7/2025

1.0. INTRODUCTION

Weathering is a term that describes the general process by which rocks are broken down at the Earth’s surface into such things as soils, sediments, clays, and substances that are dissolved in water. Meanwhile, weathering processes are important determinants of basic soil nutrients, their quantity, and cycling potential. The mobility of the basic soil elements (Ca, Mg, K, Al, Na, Fe) is significant to the ecology, geography, biology, geology, and chemistry of grassland vegetation (Pavlů et al., 2013) and forest ecosystems (Krám et al. 1997). The most essential soil nutrients for plant growth and development include Calcium(Ca), Magnesium (Mg), Phosphorus (P), Nitrogen (N), and Potassium (K). The deficiencies in the supply of these elements, in most cases, limit the productivity of the plant's ecosystem (Likens & Bormann 1995). The major sources of soluble soil elements in the forest ecosystems are atmospheric deposition and mineral weathering. Moreover, the forest ecosystems' regulatory functions regarding the acid-base composition of the soils and soil solutions crucially depend on the atmospheric deposition and mineral weathering inputs (van Breemen et al. 1984).

Furthermore, external processes such as leaching, drainage outflow, and biomass removals (especially in non-natural ecosystems) are the primary causes of basic soil mineral depletion in forest ecosystems. On the other hand, the internal factors such as vegetation uptake and release, mineralization of soil organic matter, secondary mineral formation, and basic elemental exchange are also paramount. These, to a larger extent, affect not only the soil biological activities and availability but also the distribution of basic soil nutrients in the forest ecosystem (Krám et al. 1997). Aluminum and hydrogen ions became forms of substitute to the soil acid deposition-depleted soil components (including Ca, Mg, K, etc) (Cronan and Grigal 1995*)*. The granitic geology was more affected by the atmospheric depositions compared to its adjoining catchment regions. Studies revealed that basic soils of this granite origin are more vulnerable to depletion (Chadwick et al. 1991). Consequently, the soils of Lysina catchment of the Slavkov Forest became of higher interest since it is predominated by granite features (Nwaogu et al. 2014).

Naturally base-poor forests are particularly sensitive to environmental perturbations, including phenomena such as anthropogenic input of acid compounds, contamination of forest soils by toxic metals, and/or excessive timber harvesting. These human-induced processes accelerate the export of base-cations from the ecosystem, causing acidification and degradation of soils, which in turn have a negative influence on the overall health and productivity of the affected forest. Temperate coniferous forests developed on naturally base-poor substrates (i.e. bedrocks depleted in Ca, Mg, K, etc.), located in the industrialized parts of the Czech Republic, are particularly prone to the above phenomena and their negative effects. Hence, a better understanding of elemental fluxes and geochemical cycling of the major base-cations and toxic metals, in naturally base-poor forests, is of primary importance for sustainable forest management strategies.

The primary goal of this project is to generate continuous weathering profiles for elements of vital interest based on the analysis of elemental concentrations in the samples of rocks/soils that were recently recovered by two drill cores at the geologically contrasting sites (i.e., the granitic Lysina, and serpentinite-dominated Pluhův Bor). The study also focused on not only identifying the key soil elements (Ca, Mg, K, Na, Fe and Al) but also determining their weathering fluxes, mobility, and distribution in a granitic acid soil of a mountainous spruce forest. Furthermore, the effects of the deficiencies of selected soil nutrients on the plants were also highlighted. The drill cores reached a depth up to about 24 meters below the surface, and thus the recovered sample materials cover a significant portion of the local ‘weathering profiles’, with potentially well-defined concentration gradients of Ca, Mg, and other elements controlled by the weathering intensity and biological activity at my site.

The profiles of elemental concentrations, as a function of depth, which is generated by this project in turn allowed the quantification of the rate of release (or accumulation) of the specific element along the weathering profile. This knowledge helps in the identification of the zone(s) of maximum leaching and/or accumulation of the element of interest during the weathering and/or biological uptake by forest biomass, which has implications for possible sources and bioavailability of these elements for the growth of the local forest.

2.0. DESCRIPTION OF THE STUDY AREA

2.1 Study Site/Area: Lysina, Slavkov Forest

The study area is located in the mineralogically diverse Slavkov Forest (Slavkovsky´ les), western Bohemia, Czech Republic, about 120 km west of Prague (**Fig. 1**). The region is preserved as a Protected Landscape Area (CHKO Slavkovsky´ les). The region was not glaciated and is overlain by residual soil. Streams in the Slavkov Forest experienced marked declines of SO_4^2, NO_3^-, Ca and Mg concentrations in the 1990s (Majer et al., 2005) mainly due to decreases in emissions of SO_2 from fossil fuel burning (Shanley et al., 2004) and associated decreases in acidic atmospheric deposition (Hruška and Kram, 2003). Lysina is in the Czech GEOMON network of catchments and in the International Long-Term Ecological Research network.

Furthermore, Lysina is in the International Cooperative Programme – Integrated Monitoring ICP IM and the ICP Waters. Lysina became one of the four main Critical Zone Observatories of the Soil Transformation for European Commission (SoilTrEC) project. The task in this project involved studies of base cation nutrients, i.e., the concentration analysis of Ca, Mg, and others in a drill core (a total depth of approximately 24 meters) recovered from the naturally base-poor watershed Lysina, in the Slavkov Forest (**Fig. 1**), located at 50° 03'N and 12° 40'E. The Lysina site is a monolithologic catchment underlain by leucogranite (i.e. acidic igneous rock depleted in Ca and Mg), which is a naturally base-poor bedrock, and therefore the coniferous forest developed at this site is particularly vulnerable to effects of the anthropogenic acid deposition and the ongoing export of base cations from the catchment (Krám et al., 2012).

The Lysina watershed has elevation which ranges from 829 to 949 meters above sea level, and the site is characterized by mean annual precipitation of about 985 mm. Local vegetation cover consists predominantly (ca. 99-100%) of Norway spruce (*Picea abies*) plantations. In the past centuries, the predominant and original forest species in Lysina were Norway spruce (*Picea abies*), European beech (*Fagus sylvatica*), and silver fir (*Abies alba*). However, to support tin mining and smelting in the central European region, the 15th -18th centuries recorded intensive forest cutting in the Lysina site together with other catchments of the Slavkov Forest.

Consequently, early 19th century marked the afforestation of the first generation of Norway spruce monoculture at Lysina. Norway spruce (*Picea abies)* economic and ecological significant in the Czech Republic can never be over-emphasized. Humanly supervised and managed stands of this sine-qua-non tree species cover 55% of the forested landscapes in the Czech Republic. It is of records that as at the last 20-30 decades, more than 473 km^2 of dead or dying Norway spruce stands were excavated in the Czech Republic.

In Lysina catchment, the integration of several industrial forces such as the high SO_2 concentrations, acidic deposition, and poor nutritional status in highly acidic soil (especially low Ca and Mg) contributed to the death of Norway spruce (Krám et al. 1997)

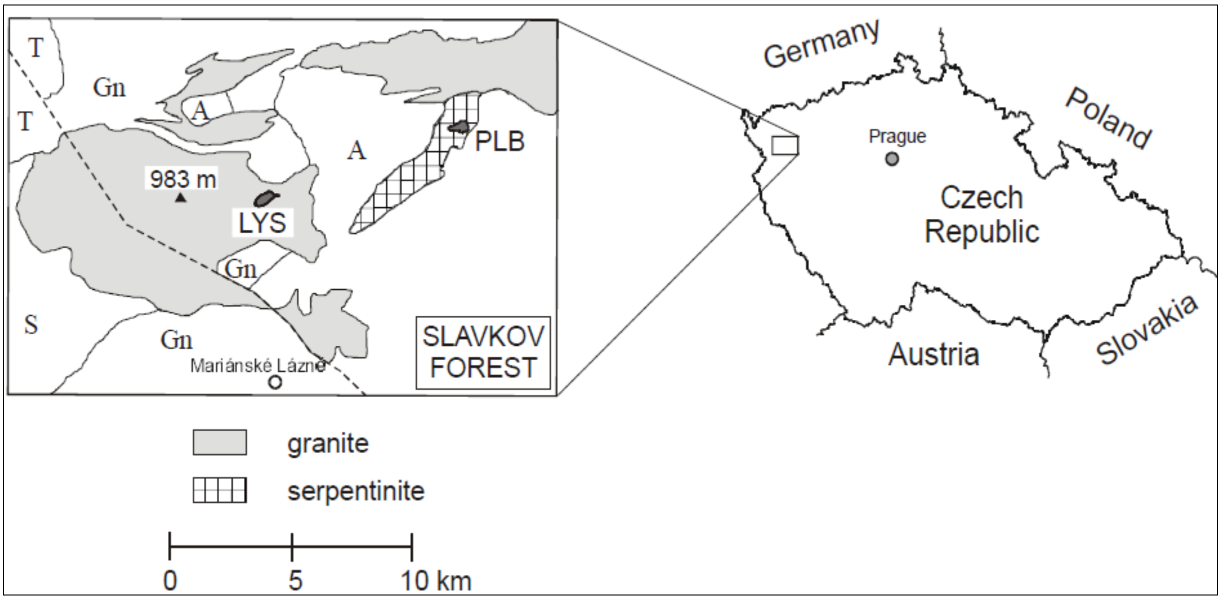


Figure 1: Czech Republic showing the study site. Left panel: map of the Slavkov Forest with the locations of catchments Lysina (LYS) and major geologic formations (granite, serpentinnite, A-amphibolite, Gn-gneiss, S-mica schist, T-tertiary sediments, dashed line-fault)

3.0. MATERIALS AND METHODS

3.1. Data collection and analysis

Primary sources of data collection were basically employed in this research project. A total of sixty (60) geological (rock/soil) samples were collect for this project and the procedures and methods are described as follows: Drill cores were created using mechanical devices. Samples of rocks were collected from these cores. The drill core ca. 2400 cm deep was complemented by a pot-hole/ditch of 150cm deep which was also dug and soil samples were collected from every 15 cm interval. Therefore, the soil samples were being collected from ten differentiated zones along the 150 cm depth pit. At the Czech Geological Survey (CGS), the samples from the core and pit-hole were cut, polished, cleaned, arranged, labeled for easy identifications and collected for homogenization (grinding into powdered form).

The results of the laboratory analysis were excellently generated and collected for further computations. The statistical analysis was based on weathering rates for base nutrient cations/ soil properties and the soil profile depth. Correlation, regression, one-way ANOVA and Principal Component Analysis (PCA) statistical techniques for analyses were used. The multi-correlation, regression and ANOVA were used to measure the relationships existing among the soil elements, their concentrations as well as their distribution throughout the entire profile depth. The PCA was used to show the variations in the horizontal or vertical (Shallow, Middle and Deepest horizons) concentrations of the soil elements.

4.0. PRESENTATION OF RESULTS AND DISCUSSION

4.1. Presentation of Results

4.2. Atmospheric Depositions, Weathering, Concentration and Distribution of Elements

Table 1: Multi-correlation coefficient (R) matrix of the soil elements

	Ca	Mg	K	Na	Fe	Al
Ca	1					
Mg	-0.12451	1				
K	0.080711	-0.10228	1			
Na	-0.04898	-0.36672	-0.05021	1		
Fe	-0.27114	0.337603	-0.06839	-0.1548	1	
Al	0.147013	0.198397	0.807803	0.01459	0.148618	1

Half of the elemental concentrations correlated indicated positive relationships among themselves (Table 1 and Figure 2). Top on this category of soil elements with positive correlations were Al/K (r = 0.808) which was remarkably significant compared to others in this group. Al had 100% positive correlation with all the elements investigated. Ca and Mg showed 40% positive correction each with other elements studied. Ca is negatively correlated with Mg (r = -0.1245), Na (r = -0.0489), and Fe (r = -0.2711) whereas, Mg had a positive relationship with Al (r = 0.1984) and Fe (r = 0.3376). Similarly, Fe and Na produced a strong negative value of – 0.1548. This explained that increase in Fe resulted in a decline in Na, vice vera (Table 2, Figure 3 and Figure 4).

The distribution of soil minerals with respect to depth were examined (Table 3). The concentrations of all elements were either constant or slowly increasing within the top-soil horizon. Subsequently, the concentration trend was fluctuated around the profile depth of 500 – 1000 cm. A relatively steady distribution pattern was found immediately after 1000cm depth until around 1,800cm depth where significant drop was recorded in all the elements (Figure 4). A general decline scenario was also observed around the soil profile depth of 700cm. This remarkably created a visible form of ‘V- shaped’ slope-like structure in almost all the elements. Al decreased from about 70,000 – 50,000 ppm, Ca (2,500-1,500 ppm), Mg (1,000- 500 ppm), K (25,000 – 19,000 ppm), Na (18, 000 – 13,000ppm) and Fe (8, 000 – 6,000ppm) (Figure 4).

The highest elemental concentrations for all the soil minerals were recorded towards the end of the soil regolith/profile. This became significant between 2,000cm – 2,200 cm depth. At the deepest depth Na and Fe concentrations were not significant (Table 2, Figure 3 and 4). Although Al/K, Ca/K, and Al/Mg recorded positive relationships in their concentrations (Figure 2), yet their distributions within the weathering soil profile were not uniform. For instance, Al concentration clustered majorly between 45,000-85,000ppm, while Ca and K between 2,000 – 7,000 ppm and 23,000 – 30,000 ppm respectively. Fe like Al had a high concentration values which ranges between 6,000 – 16,000ppm with bulk distribution around 7,000 ppm (Figure 4). On the other hand, the correlation of some other elements yielded negative relationships (K/Mg, Ca/Mg, Na/Mg, K/Na, Na/Ca) (Figure 3).

The multiple regression and ANOVA were also conducted for the elemental concentrations against the soil profile depth. All the soil cations showed positive regression coefficient (R^2) with the weathering profile/depth (Figure 5). Ca had a significant positive regression coefficient ($R^2 = 0.5288$) with the profile depth. Fe concentration as distributed throughout the whole profile depth was also significant at $R^2 = 0.1807$. Others were Mg ($R^2 = 0.0469$), K ($R^2 = 0.0343$), Na ($R^2 = 0.0035$) and Al ($R^2 = 0.0307$) (**Figure 6**). The adjusted R-square value of 0.5688 revealed that all the soil elements was significantly related with the soil profile depth (Table 2). The test of ANOVA was employed to support the regression analyses in validating the results on the weathering rates, concentrations and distributions in Lysina catchment. At $p < 0.05$, Ca ($p = 2.079 \times 10^{-7}$) and Fe ($p = 0.0129$) revealed and confirmed that Ca and Fe had significant correlation with depth. On the other hand, Mg, K, Na, and Al showed no significant at P-Values of 0.2165, 0.6729, 0.2719, and 0.225 (Table 2). The pattern is in contrary to Umo et al 2021 whose F value yields 40,035.113 and statistically significance at (0.05)8/24 confidence level.

The ordination PCA was used to further measure, understand and explain the behavior and vertical distribution trend of the elements. The profile depth (0-2400 cm) was classified into three (30 horizons. Depth of 0 – 500cm represented the ‘Shallow Horizon (SH)’, depth 501 – 1,500 cm represented the ‘Middle Horizon (MI)’ while, 1500 – 2400 cm for the ‘Deepest Horizon (DE)’ (Table 3). In the shallow horizon Ca and Na concentrations showed rapid decline trend unlike Fe and Mg which had increased concentrations. K and Al concentrations were relatively high and constant.

In the Middle Horizon, Ca together with Mg and Fe concentrations depicted a decreased trend while, Na showed an increased concentration pattern. The Deepest Horizon was characterized by continuous fluctuations in the concentration of almost all the elements. However, the highest concentrations of 95 percent of the elements were recorded in the Deepest Horizon (DE) as depicted in Table 3 and Figure 4. The PCA (Figure 7) was used to make a clearer representation and analyses of the vertical profile-depth distribution of the soil elements. Ca concentrated mainly in the Deepest Horizons while, Mg and Fe dominated the shallow horizon.

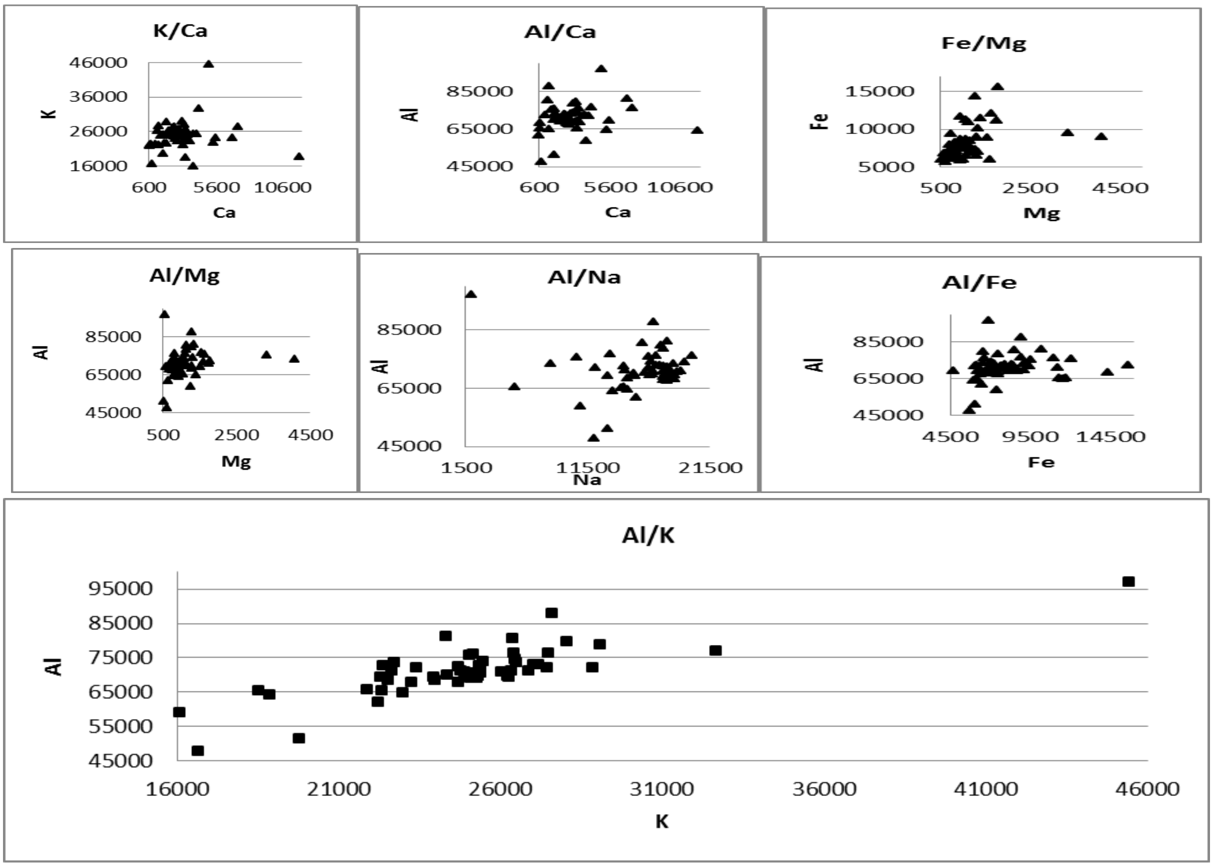
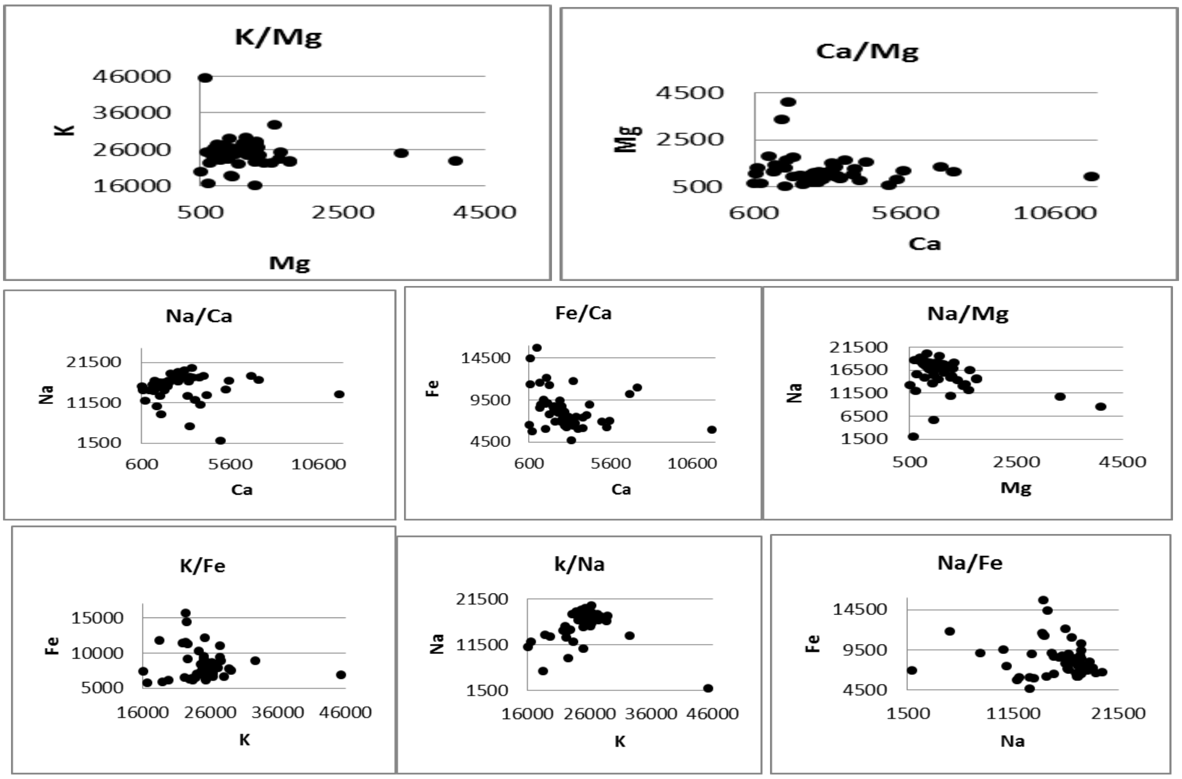


Figure 2: Relationships between elemental concentrations/distribution (in ppm)

▪ represents High/Significant Positive relationship; ▲ represents weak Positive relationship



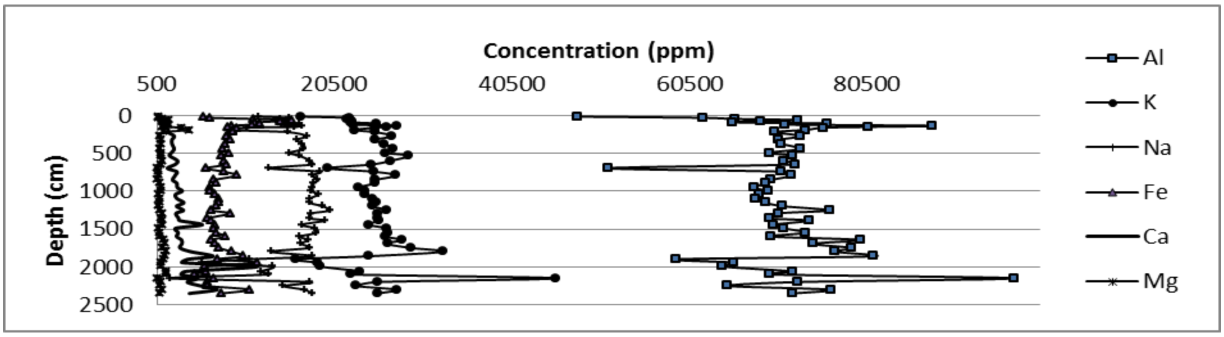


Figure 3: Soil elements that showed negative Correlation/ Relationships between in their elemental concentrations/distribution (in ppm)

- = Negative relationship

Figure 4: Vertical distribution of Essential Soil Elemental Concentrations along the weathering (regolith) profile

These long-term improvements in stream water carbonate chemistry at the Slavkov Forest were, however, associated with a continuous decline in the concentrations of major soil elements such as Ca and Mg, in local runoff (Fig. 5).

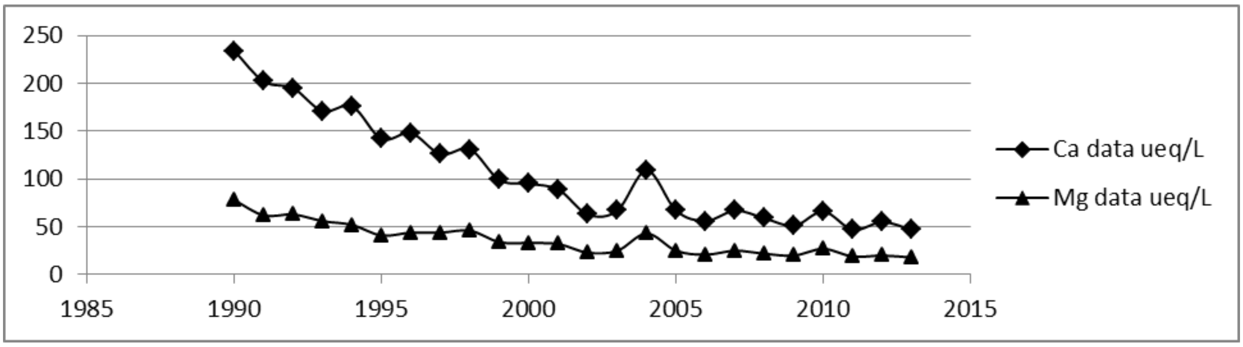


Figure 5: showing the steady decline of soil most essential elements (Ca and Mg) for the study site (Lysina) – Stream water (Annual discharge weight means): Krám,et al.; Unpublished data.

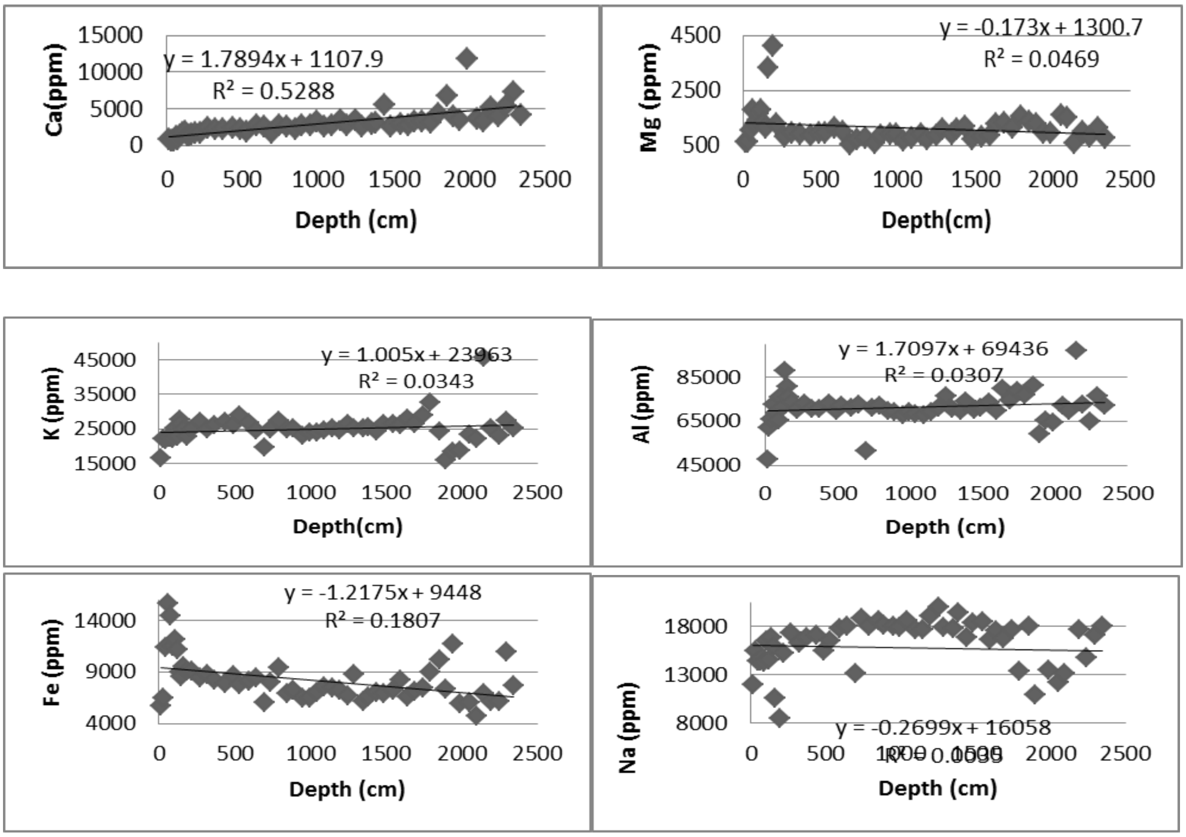


Figure 6: Regression coefficient (R^2) between the basic soil elements and depth

Table 2: Multiple Regression and ANOVA for essential soil elemental concentrations versus soil profile depth

Table 2A: Summary of Regression Model

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.785311	0.616713	0.568803	491.0885	55

Table 2B: Summary of ANOVA Model

Model	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	6	18626041	3104340	12.872112	1.313E-08
Residual	48	11576059	241167.9		
Total	54	30202100			

Table 2C: Correlation Model

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	497.7812	772.8981	0.644045	0.5226120	-1056.23	2051.797	-1056.23	2051.797
Ca	0.245366	0.040534	6.05329	2.079E-07	0.163866	0.326865	0.163866	0.326865
Mg	-0.1866	0.149016	-1.25225	0.2165477	-0.48622	0.113012	-0.48622	0.113012
K	-0.01488	0.035038	-0.42468	0.6729693	-0.08533	0.055568	-0.08533	0.055568
Al	0.0225	0.020243	1.111448	0.2719116	-0.0182	0.063202	-0.0182	0.063202
Fe	-0.09388	0.036347	-2.58277	0.0129049	-0.16695	-0.0208	-0.16695	-0.0208
Na	-0.02805	0.022802	-1.23034	0.2245665	-0.0739	0.017793	-0.0739	0.017793

*[P<0.05]

4.2. DISCUSSION OF FINDINGS

4.3. Cations Weathering Rates, Processes, Concentrations and Distributions

As earlier stated, this study focused on the basic nutrient cations (Ca, Mg, K and Na) which are soil essentials for plants' uptake. Some trace elements, such as Fe and Al were also studied. This stemmed to their significant roles, especially Al in influencing most of the BC, as also revealed by previous scientists (Krám et al 2009).

There was a relatively decrease in the soil vertical profile distribution trend of almost all the elements studied. This trend of depletion was also recently reported in the Canadian Shield region of North America (Augustin et al 2015). Thorough examination of all the soil nutrients indicated that Ca and Mg had the highest weathering rates, while Na and K had the lowest weathering estimated in the Lysina catchment profile. By applying the MAGIC calibration procedure, Hruška and Krám (2003), published the annual weathering rates of 65 Meq M^{-2} yr^{-1} for Lysina catchment. This value fell within the documented weathering rates estimated for granitic areas in Northern Europe, which range from 10 – 85 Meq M^{-2} yr^{-1} (Langan et al 2001).

However, the weathering rates value of 65 Meq M^{-2} yr^{-1}) reported for Lysina was relatively low compared to other catchments bordering its location in Czech Republic and the entire Central Europe. For example, Pluhuv Bor had weathering rates estimated at 241 Meq M^{-2} yr^{-1} (Hruška and Krám 2003). Furthermore, the weathering rates of all the BC in Lysina in comparison to other sites were convincing support of low weathering rates in Lysina. It has been on the records that the average weathering rates (Meq M^{-2} yr^{-1}) of Mg^{2+}, Ca^{2+}, K^{+}, Na^{+} and all BC sum were 10, 29, 4, 22 and 65 respectively. (Krám et al., 2012; Hruška and Krám 2003). These Lysina weathering rates values were more than five times below those of Pluvhu Bor and Na Zeleném.

Apart from atmospheric deposition, adequate mineralization due to low weathering rates was an important factor in determining the average elemental ratio, pH of soil solution or streamwater (Krám et al., 2014). Lysina recorded the Ca/Al ratio of 4 and 3.9 µmol/L at the organic and E-horizons respectively. On the contrary, Fe and especially Al concentrations are remarkably high from the shallow horizon to the deepest (Figure 5 and Table 4); thus, the weathering rates of Na, K, Fe and Al have been observed as often exceeding those of Ca and Mg(Augustin et al, 2015). The higher concentration and weathering rates of other elements (in exemption of Ca and Mg) were concluded to have been as a result of higher demand and uptake of Ca and Mg by plants unlike the other BCs and trace elements.

Other regions that had the same cases of acid deposition have relatively contrasting element concentration values with Lysina. For instance, the Solling areas of Germany and the upland Llyn Brianne of Wales had 2.3 and 0.22 for organic horizons, and 0.4 and 0.11 for E-horizons, respectively (Hruška and Krám, 1994). Lysina's average Ca/Mg ratio was 4.4, a value higher than the world average ratio of 4.0 (Drever, 2002) while, Pluvhu Bor and Na Zelenėm which border it had estimated averages of 0.12 and 2.1, respectively. Similarly, Lysina catchment had K/Mg average ratio of 1.3 compared to 0.013 (Pluhu Bor) and 0.24 (Na Zelenėm) (Krám et al., 2012). The influence of low mineralization or weathering rates of soil elements, including pH can never be underestimated in Lysina. It was recorded that Lysina has one of the lowest pH in streamwater and soil solution compared with other surrounding catchments. This supported the past studies which emphasized that Lysina has the most acidic vulnerable part of the Slovkov Forest (Nwaogu et al., 2014).

4.2 Soil Elemental Weathering and Mobility: Contributions from and/or to other Ecosystem Factors and Processes

Atmospheric deposition, weathering and net cation exchange leaching have been assumed as the sources of BCs, whereas runoff and biological-plant uptakes were assumed as the sinks (Egli et al 2006). Similar to many areas in Czech Republic, Lysina catchment is a focus area of acid deposition (SO_2 and NOx). Lysina has approximately 40% quantile deposition for the Czech Republic (Hruška et al 2002). In addition to sulphur and Nitrogen deposition, Leucogranite which is the predominant bedrock at Lysina (Table 4) is a primary reason for the area's acidity. According to Hruška et al (2002), Leucogranite has relatively low concentrations of Ca and Mg which were estimated at 3.7g kg^{-1} and 0.7g kg^{-1} respectively. But Na (22g kg^{-1}) and K (37g kg^{-1}) were moderately concentrated while, Al (74g kg^{-1}) showed high concentrations (Krám et al., 1997).

Several studies have been conducted on the atmospheric depositions, cation weathering, mobility and their influences on the entire ecosystems including the vegetation(Dijkstra et al 2003).Although, there has been reasonable decline in atmospheric deposition of sulphur, recovery from acidification in soil and streamwater is still slow in Central Europe including Lysina (Hruška et al, 2002). Similar to several other granitic catchments, the depletion of exchangeable cations from Lysina soil had a critical effect in the process of acidification. In addition to acid deposition, the loss of the basic soil nutrients (especially Ca and Mg) in Lysina (**Figure 5**) was compounded by the presence of the c.100% intensive Norway spruce plantations and the leucogranite bedrock (Table 4), (Krám et al., 2012). The spruce base cation uptake was reported as the most vital net sink in 19th Century, while the bedrock slows the weathering processes in this study area (Hruška et al, 2002).

The ability of deposition and weathering to balance the input of acid pollutants and help in BC recovery is questionable in Lysina. (Figure 8). Excluding the effect of BC leaching, which might be affected by further decline in acid deposition, base saturation of Lysina soils is affected with danger because BC deposition and weathering might not meet the Norway spruce vegetation uptake (Navrátl et al 2007). In spite of recording the lowest concentrations, the BC, especially Ca and Mg displayed relatively the same vertical distribution trend throughout the profile depth(Figure 5 and Table 1). This pattern presented by Ca and Mg conformed with Augustin et al (2015) study at the Canadian Shield. There was a high concentration of Al between (c. 50,000 – 100,000 ppm) throughout the entire soil profile. The concentration of Al in the O-horizon (shallow Horizon), Middle Horizon, and the deepest horizon exceeded the total sum of all the BC concentrations combined.

Al mobilization in a Norway spruce acidified mountainous soil was recorded by previous publications (Hruška et al, 2012). Lysina with almost 100% spruce stand is threatened with unfavorably high Al concentration caused by high acidic deposition, low pH, and incapacitated ability of BC to neutralize the acidity. Independent of Sulphur and Nitrogen input, the release of Aluminium is not constant in soils with higher pH values of 5.0 and above. This is because BC input by mineral weathering and cation exchange buffers the incoming net acidity in such soils (De Vries et al 2007). Unfortunately, the soil in Lysina was not among those categories with a higher pH. Thus, the concentration of Al was significantly high in our study area.

The release rates of major BC obtained in our study (Ca > Mg ≅ K > Na) is nearly similar to those formerly documented by Hodson (2001) of Na > K ≅ Ca > Mg and Bain et al (1994) Na > Ca ≅ Mg > K for long-term weathering rates. Though Ca concentration was relatively low, its release rate exceeded that of Mg. Unlike K, Na weathering did not increase in the acidic Lysina catchment (Hruška and Krám 2003). This finding contrasted Oulehle et al (2007) results of Na slight increase from 65 ± 9.4 μmol L^{-1} between 1995 and 1999 to 74 ± 9.3 μmol L^{-1} by 2003 in Ore mts. BCs concentration, especially Ca showed a significant positive relationship with soil depth in the regression and PCA analyses (Figure 6 and Figure 7), indicating an increase in concentration with depth. Uptake by the Spruce trees and leaching to the deeper mineral zones would have contributed in the depletion of Ca from the shallow zone (Augustin et al. 2015), Mg, K and Fe pools were not significantly removed from the upper soil horizon (Oulehle et al.,2006). Fe was significant in all the horizons, especially the upper layer (Figure 5 and Figure 8).

Climate factors have been studied to partly contribute to changes in soil elements and BC concentrations (Augustin et al. 2007). On the contrary, Krám (2009) revealed that climatic roles were insignificant reasons for the observed changes in the concentration of the nutrient cations in Lysina and its neighboring catchments.

Table 3: Descriptive Statistics of the soil elements concentration at from the depth of 0 to 2400 cm

Depth of 0-500cm [Shallow Horizon (SH)]

stat	*Ca*	*Mg*	*K*	*Na*	*Fe*	*Al*
Mean	1533	1434	24118	14802	9745	70779
SE	139	214	636	553	599	1921
Med	1581	1214	25034	15314	8990	71027
SD	591	907	2696	2346	2542	8149
SV	348864	821941	7270157	5503677	6463739	66404892
Range	1788	3467	10929	8888	9939	39975
Min.	631	622	16670	8466	5722	47842
Max.	2419	4089	27599	17353	15661	87817
Sum	27597	25805	434127	266433	175403	1274017

Depth (501-1500 cm): Middle Horizon (MI)

stat	*Ca*	*Mg*	*K*	*Na*	*Fe*	*Al*
Mean	2839	853	25090	17914	7293	69693
SE	176	40	403	310	197	1070
Med	2704	868	25066	18003	7115	70203
SD	786	178	1801	1385	881	4786
SV	617926	31755	3243532	1919426	775571	22901289
Range	3923	651	9085	6871	3361	24940
Min.	1661	519	19769	13132	6059	51337
Max.	5583	1169	28854	20003	9420	76276
Sum	56786	17062	501807	358274	145853	1393869

Depth (1501-2400 cm): Deepest Horizon (DE)

stat	*Ca*	*Mg*	*K*	*Na*	*Fe*	*Al*
Mean	4590	1109	25826	14304	7608	73416
SE	553	74	1578	1126	461	2080
Med	3903	1116	25376	16582	7228	72767
SD	2279	305	6508	4642	1900	8574
SV	5193320	93190	42350973	21549891	3610798	73520777
Range	9128	1045	29364	16541	7091	38099
Min.	2691	567	16085	1957	4662	59025
Max.	11819	1612	45449	18497	11753	97124
Sum	78033	18860	439043	243160	129336	1248078

*Stat=Statistics; SE=Standard Error; Med=Median; SD=Standard Deviation; SV=Sample Variance; Min/Max.=Minimum/Maximum

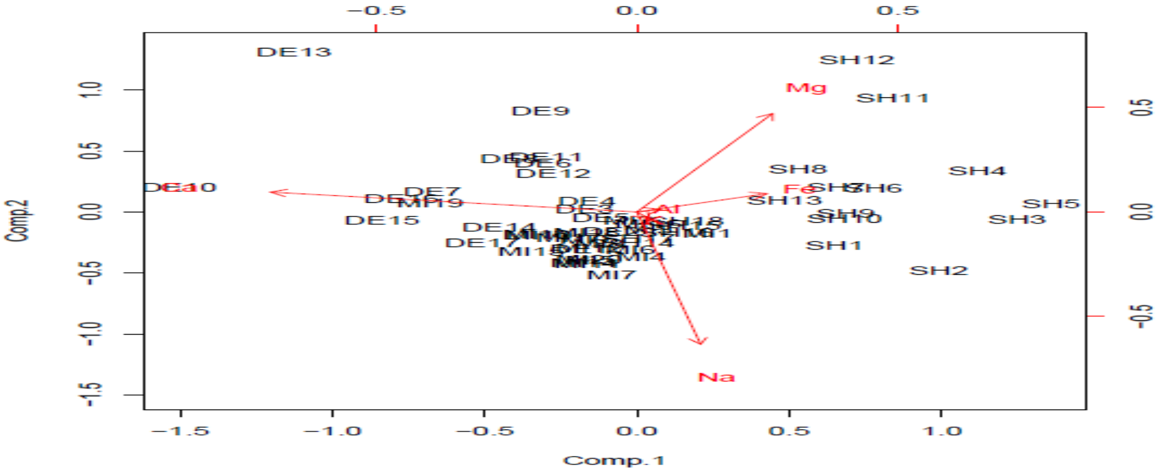


Figure 7: Ordination PCA of Soil elemental concentrations (Ca, Mg, Fe, Na, K, Al) as function of weathering/soil profile depth (cm). **SH**=Shallow Horizon (above 500cm) ranked from SH1-18,; MI = Mid or Middle Horizon (501-1500cm), classified MI1-20; DE=Deepest Horizon (1501cm and beneath), rated DE 1-17. [Note: SH1 is the top most layer of the weathering profile while, DE 17 is the deepest]

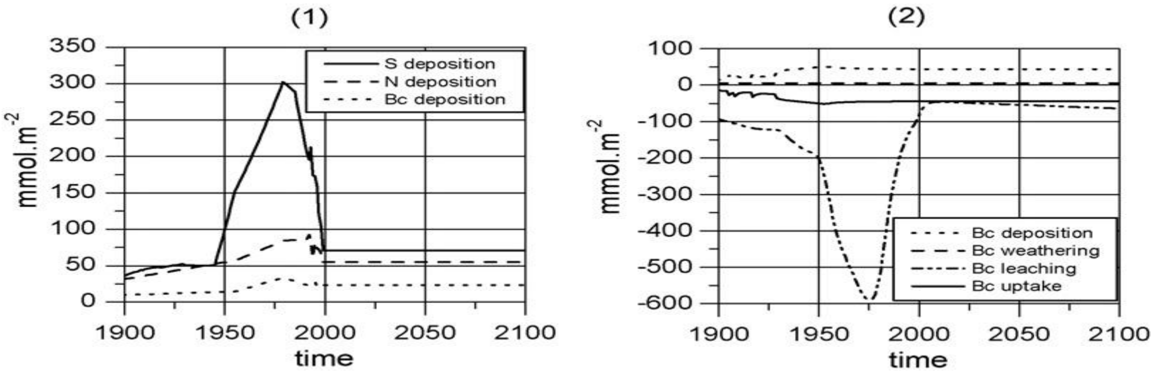
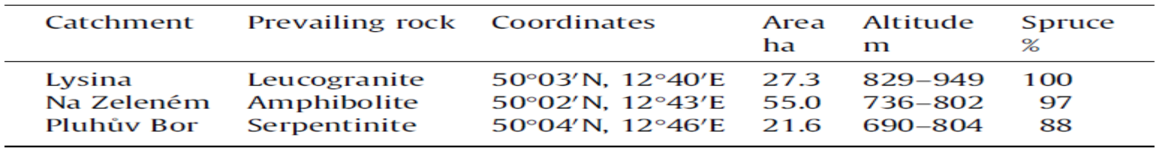


Figure 8: (1) The deposition scenarios used for sulfate, nitrogen and nutrient base cations (Bc = Ca +Mg + K); (2) comparison of inputs (weathering and deposition) and losses of base cations (uptake and leaching) at the Lysina catchment.[After Navrátl *et al., 2007]*

Table 4: Characteristics of the Lysina and other surrounding catchments in the Slavkov Forest



Catchment	Prevailing rock	Coordinates	Area ha	Altitude m	Spruce %
Lysina	Leucogranite	50°03′N, 12°40′E	27.3	829–949	100
Na Zeleném	Amphibolite	50°02′N, 12°43′E	55.0	736–802	97
Pluhův Bor	Serpentinite	50°04′N, 12°46′E	21.6	690–804	88

(Kram et al. 2012)

5.0. CONCLUSIONS

Although there has been an enormous decrease in acid deposition, low mineral weathering rates and unfavorable leaching of cation nutrients from the soil have remained mainly because of the release of S and N accumulated in the past. Soil formed under limited weathering granite catchments are vulnerable to small pools of exchangeable base cation nutrients, low pH in soil, and soil solution.

Due to low weathering and insignificant exchange processes, Lysina catchment has been incapable of neutralizing the excessive inputs of acid deposition. Consequently, this resulted in accelerated H+ and Al concentrations. At the shallow soil horizon, there was a decline in Ca and Mg concentrations compared to K, Na, and Fe. Reasons for this include: (i) a significant decline in atmospheric deposition of Ca and Mg; (ii) domination of Ca and Mg by changes in strong anions; (iii) more uptake by spruce plants; (iv) Ca concentration tends to increase with depth; therefore, leaching cannot be neglected as a factor. Above all, more pronounced Al mobilization in Lysina Norway spruce forest was caused by elevated deposition of acid, which resulted in higher anion concentration and very low pH. The scope of this study excluded the possible impacts of weather-seasonality on weathering and mineralization, as well as plant management, which, to a large extent, could influence the dynamics and mobility of base soil nutrients in such an ecosystem.

Acknowledgement

This research was financially and materially supported by the Czech University of Life Sciences (CULS) internal grant (KGEV 42400/1312/3177) and the European Commission Project through Czech Geological Survey (FP7 SoilTrEC 244118). Technical help of Šillerová H.(CULS), Kminek V.(Kladská), Vaclavek J. (Teplá), numerous co-operators from Czech Geological Survey and CULS, and anonymous reviewers who made valuable suggestions are acknowledged.

Competing Interest

The Author declares that no conflicting interest exist in this manuscript/.

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