Calculating Geochemical Weathering Rates Of Three Different Catchments In The Czech Republic

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Abstract-The studied catchments are Hartvikov, Salacova Lhota and Jezeri. They are labeled (X-02), (X-8) and (X-16), respectively. The three studied catchments belong to different geological units of the Bohemian Massive. The major difference between the catchments X-02, X-8 and the catchment X-16 is that the catchment Jezeri (X-16) receives high input of SO_2 and NO_x from atmosphere.

We calculated the depletion rates of cations from soils to better understand the problems of local soil fertility, plant nutrient supply and to determine the sensitivity of the ecosystem to enhanced acidification resulting from acid deposition. We determined the field chemical weathering rates in the three catchments from the long-term monitoring of the mass balance of cations and silica to quantify the rate of leaching of exchangeable base cations from soils. The depletion rates of exchangeable cations are higher in all sites than the production of base cations by weathering.

The chemical weathering rates calculated for idealized profiles using PROFILE model vary in moderately acidified catchments from 0.27 keq ha^{-1} yr^{-1} in X-02 to 0.36 keq ha^{-1} yr^{-1} in X-8. In extremely acidified catchment X-16, the chemical weathering rate of soil is 0.5 keq ha^{-1} yr^{-1}.

Oligoclase, biotite, K-feldspar, muscovite and chlorite are the main contributors to the rate of weathering ranging from 84 % to 89 % of total chemical weathering in most soils of biotitic gneiss in the three representative catchments in The Czech Republic.

Keywords- Weathering, Acidification, Cations, Depletion rate, mass balance, Profile model, The Czech Republic.

I. INTRODUCTION

Central Europe is a region seriously damaged by acid industrial emissions [1](Ulrich, 1983). Troubling associated with acidic atmospheric deposition is severe in the "Black Triangle" of northern part of Bohemia Massif. This region is located in central Europe along the borders between Germany, Czech Republic and Poland [2-4] (Paces, 1995; Cerny, 1995; Hruska et al., 1996). Human activities and their impact such as increased acidity of rain and deposition of acidifying oxides such as SO_2 and NO_x may have a profound effect on weathering [5-7] (Paces, 1985; Bain et al., 1994; Melegy, 1998).

The advance of the weathering front at depth is thus coupled to surface denudation [8] (Brantley and Lebeveda, 2011). It has been hypothesised that biotic processes contribute towards this coupling [9] (Brantley et al., 2011). Plants and soil microbiota play an active role in rock weathering and potentially couple weathering at depth with erosion at the soil surface [10] (Uhlig et al., 2017).

Chemical weathering plays an important role in global geochemical cycles of elements [11] (Melegy et al., 2011). The balance between the base cation release through chemical weathering of soil parent materials and loss of the base cations by biological uptake and leaching determines the sensitivity of the ecosystem to enhance acidification resulting from acid deposition. Most notable models are weathering and erosion model [5](Paces, 1985) and a steady state PROFILE model [12](Sverdrup and Warfvinge,1988) for small catchments.

The major aims of this paper are to,

- calculate geochemical mass balances of chemical elements in small drainage catchments for evaluating weathering and mechanical erosion rates,
- calculate chemical and mineralogical weathering by the application of the biogeochemical PROFILE model for understanding of soil fertility and plant nutrient supply.

II. GEOLOGICAL AND HYDROLOGICAL CHARACTERISTICS OF SMALL CATCHMENTS

The studied catchments are Hartvikov, Salacova Lhota and Jezeri. They are labeled (X-02), (X-8) and (X-16), respectively (Figure 1). Catchment Hartvikov (X-02), is located at latitude 49° 30´ N and longitude 14° 50´ while catchment Salacova Lhota (X-8), is located at latitude 49° 31´ N and longitude 14° 59´. Catchment Jezeri (X-16) is located at slopes of the Krusne hory mountains (50° 33´ N, 13° 30´ E). Major characteristics of three studied catchments are given in Table (1).
The three studied catchments belong to different geological units of the Bohemian Massive. Two catchments Hartvikov and Salacova Lhota belong to the monotonous metamorphic complex of Moldanubicum. Jezeri catchment belongs to the Saxothuringicum. It is composed of high-grade metamorphic rocks of Proterozoic and Palaeozoic [13] (Suk et al., 1984).

III. METHODS AND MATERIALS

Forty-six samples - nearly 7 kg for each sample - from different soil horizons were collected in spring of 1995. These samples include 36 samples from Hartvikov and Salacova Lhota catchments, and 10 samples from Jezeri catchment. The collected soil samples are dried and separated into different size and density fractions as described in details by Melegy [7] (1998). The method depends on the fractionation of each soil sample by sieving and gravity sedimentation into five parts: Fraction A contains grain size <2 μm, fraction B contains grain size 2-500 μm, with density < 2.7 gm/cm^3, fraction C contains grain size 2-500 μm with density 2.7-3.2 gm/cm^3, fraction D contains grain size 2-500 μm with density > 3.2 gm/cm^3 and fraction E contains grain size > 5000 μm. The application of the RECAI program [14] (Ondrus and Veselovsky, 1995) was used to calculate mineralogical composition of soils by combining the qualitative and quantitative X-ray analyses with chemical analysis of major ions of soil. Bulk precipitation, throughfall depositions and runoff data were monitored by the staff members of the Czech Geological Survey. Soil and water samples were analyzed in the Czech Geological Survey's Laboratory.

3.1 Application Of Geochemical Mass Balance

An equation of mass balance [5] (Paces, 1985, 1986) of element "i" in a drainage basin is

$$W_i + P_i + A_i - R_i - M_i - B_i = \sum_I \quad (1)$$

where W_i is the input of the element "i" due to the total weathering of bedrock, P_i is the input of chemical element "i" by atmospheric deposition, A_i is anthropogenic input of element "i", R_i is the output of element "i" via runoff from drainage basin, M_i is output of element "i" by mechanical erosion of weathered material, B_i is output of element "i" fixed in biomass by harvesting crops and lumbering timber, and $\sum_i$ is the net accumulation or depletion of the element "i" in the weathered layer (i.e. regolith).
The rate of decomposition of bedrock by total weathering, W_{rock}, and the rate of mechanical erosion of regolith, M_{rglth}, are related to the release and mechanical erosion of an element "i" by the following equations;

$$W_{rock} = W_i \ / \ X_{i,rock} \quad (2)$$

$$M_{rglth} = M_i \ / \ X_{i,rglth} \quad (3)$$

where $X_{i,rock}$ and $X_{i,rglth}$ are dimensionless concentrations (g g^{-1}) of the element "i" in bedrock and its regolith respectively.
The mechanical erosion of regolith, $M_{rglth,}$ and the total weathering of bedrock, W_{rock}, can be calculated from equations (1) to (3) written for sodium and silicon (Paces, 1985, 1986). The assumption of the calculation is that Na and Si are in a steady state ($\sum_{Na} = \sum_{Si} = 0$). Then;

$$M_{rglth} = \{[(P_{Na} + A_{Na} - R_{Na} - B_{Na}) / X_{Na,rock}] - [(P_{Si} + A_{Si} - R_{Si} - B_{Si}) / X_{Si,rock}]\} / [(X_{Na,rglth} / X_{Na,rock}) - (X_{Si,rglth} / X_{Si,rock})] \quad (4)$$

The depletion of exchangeable cations is defined by a mass-balance equation;

$$W_i + P_i + A_i - R_i - M_i - B_i = -EX_i \quad (5)$$

3.2 Application Of Geochemical Weathering Of Kinetic Model

The kinetic equation for weathering rate in the PROFILE model, R_W (keq ha^{-1} yr^{-1}), of the whole soil profile is:
where:
r_i = dissolution rate of mineral i (keq m^{-2} s^{-1}),
A_W = total exposed surface area of the mineral fraction (m^2 m^{-3} soil),

$$R_w = \sum^{\text{horizon}} \sum_i^{\text{minerals}} r_i \,.\, A_w \,.\, X_i \,.\, \theta \,.\, Z \quad (6)$$

X_i = the surface area fraction of mineral i in the soil (m^2 kg^{-1}),
θ = soil moisture saturation, kg m^{-3},
Z = thickness of soil layer (m).

IV. RESULTS AND DISCUSSION

4.1 Evaluation Of Residual Mineral Phases

Ninety two samples of soil from Hartvikov, 48 samples from Salacova Lhota, and 32 samples from Jezeri catchments were investigated by X-ray. Chemical silicate analyses of four fractions (A, B, C, and D) with different density and grain size were performed for seventeen major and minor elements [6] (Melegy, 1998). The coarse fraction E was discarded as a nonreactive residuum with very small specific surface of particles. The whole method was computer-controlled with the use of the RECAl program [14] (Ondrus and Veselovsky, 1995). Calculation of mineral phases by this model is based on the combination of qualitative and quantitative X-ray analyses with the data from silicate chemical analyses. The mineralogical compositions in the three studied catchments are listed in Table 2. Quantitative mineralogy of particle-size distribution in the three representative catchments is used as the input to PROFILE model for calculating weathering rates.

4.2 Geochemical Mass Balance Of Chemical Fluxes

The data obtained from the field include wet precipitation (Pi), runoff (Ri) and biological output (Bi). Annual mean of wet precipitation was calculated from concentrations of elements in individual precipitation events by multiplying them with water quantity of the precipitation. Mass fluxes of stream water for individual solutes were calculated by multiplying annual discharge-weighted average solute concentrations with annual water discharge (Table 3).

The rate of total weathering of bedrock and of mechanical erosion of regolith are calculated according to a steady-state mass-balance model (Table 4). The highest rates of weathering and erosion from the three catchments are documented in the catchment X-16. The total weathering rate of gneisses in slightly acidified two catchments increases from 291 kg h^{-1} yr^{-1} in X-02 to 468 kg h^{-1} yr^{-1} in X-8 depending on slope. In the damaged forest X-16, the rate of chemical weathering is 1206 kg h^{-1} yr^{-1} and mechanical erosion is 1712 kg h^{-1} yr^{-1}. The increase in the mechanical erosion is probably due to deforestation. The depletion rates of exchangeable cations are higher in all sites than the production of base cations by weathering. The rate of depletion of basic exchangeable cations reached recently –85.1 kg h^{-1} yr^{-1} in the damaged forest X-16.

4.3 Chemical Weathering Rate

The weathering PROFILE model was used to calculate soil weathering rates under different rates of atmospheric deposition. The resulting chemical weathering rates from idealized profiles (Table 5) are in moderately acidified catchments 0.27 keq ha^{-1} yr^{-1} in X-02 and 0.36 keq ha^{-1} yr^{-1} in X-8. In the extremely acidified catchment X-16, the chemical weathering rate of soil was 0.5 keq ha^{-1} yr^{-1}. Part of the increase in chemical weathering is caused by a steeper slope as in X-8 and X-16 and by acid deposition as in X-16.

For the studied site, a few minerals are major controlling importance for the weathering rate in the field, compared with other minerals [15] (Melegy, 2004). The weathering rates per mineral are shown in Table 6. It can be seen that oligoclase, biotite, K-feldspar, muscovite and chlorite are the main contributors to the total rate of weathering ranging from 84 % to 89 % of total chemical weathering in most soils of biotitic gneiss in the representative catchments.

V. CONCLUSIONS

In the damaged forest X-16, mechanical erosion of the weathered layer has increased by factor 3. The increase in the mechanical erosion is probably due to deforestation.

In extremely acidified catchment X-16, the chemical weathering rate of soil is higher than in slightly acidified two catchments (X-02 & X-8). Oligoclase, biotite, K-feldspar, muscovite and chlorite are the main contributors to the rate of weathering.

The depletion rates of exchangeable cations are higher in all sites than the production of base cations by weathering. This phenomenon indicates that the depletion of the exchangeable pool of biologically essential cations in soils of central Europe is alarmingly fast and much faster than its formation by weathering of bedrock.

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