Pedogenesis on Volcanic Rocks in Protected Landscape Areas in Central and North Bohemia

Anna ŽIGOVÁ and Martin ŠŤASTNÝ

Institute of Geology, Academy of Sciences of the Czech Republic, Prague, Czech Republic

Abstract

Žigová A., Šťastný M. (2014): **Pedogenesis on volcanic rocks in protected landscape areas in Central and North Bohemia**. Soil & Water Res., **9**: 153–160.

The development of soil cover on volcanic rocks in Central and North Bohemia was analyzed. The study was performed in the protected landscape areas on basalt, andesite, and dolerite. Parent material was characterized on the basis of thin-section study. Petrography of the parent material makes it possible to document the differences in the texture, character, and amount of rock-forming minerals. All the studied sequences exhibit the same configuration of soil profiles but various thicknesses. The soil profiles were evaluated on the basis of particle size distribution, chemical properties, soil organic matter parameters, and mineral composition of clay fraction. The major specific pedogenic process in soils developed on volcanic rocks is weathering of parent material and development of the Bw horizon with the formation of mainly smectite from the group of swelling clay minerals. The results revealed differences in the formation of the Bw horizon which is significantly affected by the petrography of the parent material and local geological conditions. According to the type of volcanic rocks, the intensity of the developmental process of the Bw horizon is as follows: andesite (Týřovické skály) > dolerite (Záhrabská) > basalt (Březina).

Keywords: andesite; basalt; Bw horizon; dolerite; mineral compostion; main pedogenic process

The rock or sediment is a starting point for the soil development. In the early stages of their formation, soils are not much different from their parent materials. The character of the parent material is a base line that must be known for the evaluation of individual stages of pedogenesis. Targulian and Krasilnikov (2007) expressed that the soil formation is a transformation of the solid phase lithomatrix (parent material) of the soil system into the pedomatrix (soil body). Recent knowledge on the weathering of hard rocks and soil development, ideas about primary rock-forming minerals, nature of soil clay minerals were summarized by Wilson (2004) and Velde and Meunier (2008).

Most studies focused on soil development on volcanic rocks come from various districts – e.g. Portugal (Prudêncio *et al.* 2002), Galápagos (Stoops 2013), and Hungary (Madarász *et al.* 2013). On the territory of the Czech Republic, only selected properties of soils developed on volcanic rocks have been evaluated and described. Occurrence of light and heavy minerals in the soil profiles on weathered basalts was studied by Tomášek and Bezvodová (1969). Particle size distribution and selected chemical characteristics of soils on dolerite were described by Tomášek and Zuska (1972).

Soils on volcanic rocks are a suitable object for genetic studies mainly because initial rocks contain relatively large amounts of easily weathering minerals. The objective of this study is to compare the intensity of pedogenesis and characterize the basic properties and mineral composition of soils developed on different types of volcanic rocks from various protected areas of the Czech Republic.

MATERIAL AND METHODS

The research was conducted in the protected landscape areas. Climate was characterized by Quitt (1971). Location of soil profiles was done by GARMIN eTrex Summit in the WGS 84 system. Selection of soil profiles was guided by a soil survey. Representative soil sequences were excavated down to the parent material. Soil profiles were situated in the middle part of the slope. Soils were described according to JAHN *et al.* (2006). Individual soil profiles were classified according the World Reference Base for Soil Resources (IUSS Working Group WRB 2007). Samples were collected from all soil pits, except O horizons.

The site of Březina is located 80 km to the northwest of Prague in the České středohoří Mts. Protected Landscape Area. This locality belongs to the Tertiary volcanosedimentary complex of the České středohoří Mts. which overlies a succession of sandstones, claystones, and marlstones mainly of marine origin, several hundred metres thick, belonging to the Bohemian Cretaceous Basin. The peak of the first phase of volcanic activity ranges within the Early Miocene, during which most volcanic rocks of the České středohoří Mts. were formed. These are predominantly basaltic rocks (74%), and trachyte, phonolite, andesite, and many alkaline dyke rocks. Based on a new volcanological model and geochemical investigation, CAJZ *et al.* (1999) described basalt occurrences in the lower and uppermost formations of the volcanosedimentary complex. Data on petrography, development, and age of basaltic rocks were obtained by CAJZ *et al.* (2009).

The site of Týřovické skály lies 70 km to the southwest of Prague in the Křivoklátsko Protected Landscape Area. It is a part of the Upper Cambrian Křivoklát-Rokycany volcanic complex. Based on the rock composition, this complex can be divided into two zones. The northern part consists of dark fine-grained andesite. These terrestrial volcanic rocks attain ca. 500 m in thickness or even more. The southern part is also characterized by predominantly terrestrial volcanism, with the main rock type being rhyolite. Detailed information about the chemistry, petrography, position in the tectonomagmatic cycles, and prevailing rocks of the andesite-rhyolite assemblage at this site was published by WALDHAUSROVÁ (1971). Genetic aspects and lithology of the central and northeastern part of the Upper Cambrian Křivoklát-Rokycany volcanic complex within the regional mapping project were studied by HRADECKÝ (2008, 2010).

The site of Záhrabská is situated 35 km to the southwest of Prague in the Bohemian Karst Protected Landscape Area and located at the Hýskov volcanic centre. The maximum of volcanic activity falls within the latest Wenlock and, after a short interruption, culminates in the Early Ludlow. Typical rocks include basaltic pillow lavas and tuffs indicative of their submarine development. The main rock of this period is dolerite forming a several tens of metres thick body. Another volcanic activity occurred mainly in the very large volcanic centres of Svatý Jan pod Skalou and Řeporyje. After a short break, a new cycle of eruptions followed producing about 100 m thick coarse-grained tuffs and pillow lavas. The maximum of the Silurian volcanism dates to the Wenlock/Ludlow boundary. Silurian volcanic rocks are bound to the newly activated synsedimentary faults, especially to the intersections of faults perpendicular to the longitudinal axis of the basin. Main aspects of the Silurian volcanism at the studied site were obtained by FIALA (1970).

Analytical procedures for soil characterization followed standard methods (VALLA *et al.* 2002). Particle size distribution was determined using the pipette method. Soil pH in H_2O and in 1 mol/dm^3 KCl was measured in 1:2.5 suspension with a SenTix21 electrode (WTW GmbH, Weilheim, Germany). Determination of carbonate content was done by volumetric method using 10% HCl. The formula (S/CEC) × 100, where S denotes the sum of exchangeable bases (cmol$^{(p+)}$/kg) and CEC is cation exchange capacity (cmol$^{(p+)}$/kg), was used for the calculation of base saturation (in %). Cation exchange capacity was calculated using the method of Mehlich. Organic carbon was determined by wet combustion with a mixture of potassium dichromate and sulphuric acid and total nitrogen using the Kjeldahl method. Thin sections of parent material were examined with the OLYMPUS BX51 polarizing microscope (Olympus, Tokyo, Japan) with the DP70 digital camera (Olympus). The clay fraction of soils was prepared for the X-ray diffraction (XRD) analysis. Prior to the X-ray analysis of soil samples, organic matter was removed using 30% H_2O_2, and carbonates were removed by 0.1N monochloroacetic acid. The samples were then washed with distilled water. The clay fraction was obtained using a sedimentation method, and oriented samples were prepared by careful pipetting of the clay suspension onto a glass slide where it dried at ambient temperature. The specimens were analyzed in a natural state, then ethylene glycol-saturated at 80°C for 4 h, and heated at 550°C for another 4 h. XRD spectra were obtained on the PW3020 Philips X'Pert diffractometer with CuKa radiation. X-ray patterns were recorded at a goniometric shift 1°·min/2Θ. Semiquantitave values were calculated based on the height of individual mineral basal peaks using correction coefficients (MELKA, personal communication 2013).

RESULTS AND DISCUSSION

Petrography of the volcanic rocks and local geological conditions are site-specific. This fact, besides the different climate, makes a comparison of the development of soils in different regions more complicated.

Basic characteristics of soil profiles. The soil profile of Březina was sampled at the altitude of 675 m, with coordinates 50°32'N and 13°54'E. The studied site lies in the cold climatic region 7 (very short to short summer; moderately cold spring; mild autumn; long, mild, moderately wet winter). The whole site is covered by forest with prevalence of maple, birch, and beech with very rich herb vegetation. Parent material is Miocene basalt. The soil profile shows the following succession of horizons: O-Ah-AhBw-Bw-C.

Representative soil profile of Týřovické skály is located at the altitude of 510 m, with coordinates 49°58'N and 13°48'E. This site belongs to the moderately warm climatic region 11 (long summer; moderately warm spring and autumn; short, moderately warm to very dry winter). Forest with dominance of oak, maple, and beech with relatively rich herb vegetation is typical of this site. Parent material is Cambrian andesite. The soil profile shows the following succession of horizons: O-Ah-AhBw-Bw-C.

The studied soil sequence of Záhrabská is located at the altitude of 418 m, with coordinates 49°58'N and 14°07'E. This site lies in the warm climatic region 2 (long, warm, and dry summer; warm to moderately warm spring and autumn; moderately warm, dry to very dry winter). This territory is covered by forest with prevalence of maple, beech, and oak with rich herb vegetation. Parent material is Silurian dolerite. The soil profile shows the following succession of horizons: O-Ah-AhBw$_1$-Bw$_1$-Bw$_2$-Ck.

All the studied sequences have the same configuration of soil profiles but various thicknesses of diagnostic horizons and levels of biological activity. The Ah horizon is better developed at the Týřovické skály site than at other localities. The AhBw and Bw horizons are thicker in soils on andesite and dolerite than in the soil profile on basalt. C and Ck horizons started at the depth of 82 cm in soils on andesite and dolerite. In the soil profile on basalt, C horizon occurs at the depth of 38 cm. Diagnostic criteria allowed classifying all soils as Haplic Cambisols although they showed some differences in the intensity of the soil development.

Particle size distribution. The results of particle size analysis and texture class of the soil sequences are shown in Table 1. Soil profiles have different distributions of individual particle sizes. Silt fraction dominates at the Březina site with basalt rocks. Sand fraction prevails in the whole profile except for Ah horizon at the Týřovické skály site with andesite. The elevated content of silt fraction in the upper part and sand fraction in the bottom part of soil profile on dolerite is characteristic for the Záhrabská site. Elevated content of silt in the upper part of the soil profile at this locality is probably caused by eolian transport during the Quaternary. This hypothesis is also supported by the occurrence of loess deposits within a

Table 1. Particle size distribution (%)

Locality	Depth (cm)	Clay < 0.002 mm	Silt 0.002–0.05 mm	Sand 0.05–2.00 mm	Texture class
Březina	0–6	14.1	69.5	16.4	silt loam
	6–20	11.1	71.2	17.7	silt loam
	20–38	9.6	73.5	16.9	silt loam
	38–94	14.0	62.6	23.4	silt loam
Týřovické skály	0–15	14.0	39.8	46.2	loam
	15–40	8.6	21.6	69.8	sandy loam
	40–82	15.6	20.9	63.5	sandy loam
	82–125	8.9	11.5	79.6	loamy sand
Záhrabská	0–6	16.4	47.1	36.5	loam
	6–30	27.9	42.4	29.7	clay loam
	30–60	26.8	36.3	36.9	loam
	60–82	16.5	28.7	54.8	sandy loam
	82–94	8.3	12.9	78.8	loamy sand

Table 2. Chemical properties

Locality	Depth (cm)	$CaCO_3$ (%)	pH_{H_2O}	pH_{KCl}	BS (%)	CEC (cmol$^{(p+)}$/kg)
Březina	0–6	0	3.88	3.16	31	61.43
	6–20	0	4.14	3.42	33	29.09
	20–38	0	5.63	4.84	69	29.19
	38–94	0	6.25	4.85	91	36.74
Týřovické skály	0–15	0	4.84	3.60	43	31.61
	15–40	0	5.20	3.62	64	31.73
	40–82	0	5.72	3.59	86	46.26
	82–125	0	6.19	3.98	89	36.08
Záhrabská	0–6	0	6.55	5.96	86	62.80
	6–30	0	5.63	4.16	71	45.40
	30–60	0	5.90	4.10	85	54.90
	60–82	0	6.33	4.59	83	58.20
	82–94	21	7.42	6.39	100	35.30

CEC – cation exchange capacity, BS – base saturation

radius of 5–10 km (Kovanda 2006). The particle size distribution of Haplic Cambisols is probably a function of the type of volcanic rocks and local condition development of these soils. The eolian transport could affect the particle size distribution especially in the upper part of the soil profile. Results of classification by texture classes also reflect this possibility.

Chemical properties. Data on soil chemical properties are summarized in Table 2.

The presence of carbonates was documented only in the Ck horizon at the Záhrabská site. This fact is a result of frequent carbonation of dolerite in the Barrandian area.

The values of pH are strongly acidic in the upper part and acidic in the bottom part of the soil profile at Březina. Soil sequence of Týřovické skály has a strongly acid reaction. By contrast, the values of pH at the Záhrabská site range from slightly acidic in the Ah horizon and strongly acidic in the middle part of soil to nearly neutral in the bottom part of the profile.

Cation exchange capacity is the highest in the Ah horizons of the sites of Březina and Záhrabská. Values of this parameter differ at the individual sites.

Base saturation reaches high values in the bottom part of all soil profiles. Very different is this value in the Ah horizons, ranging from 31% at Březina and 43% at Týřovické skály to 86% in the Záhrabská area.

The Δ pH values in soil profiles are often > 1. Similar pH values of Cambisols were published by Gallardo Lancho (1999). The pH_{H_2O} value refers to the acidity of the soil solution. The pH_{KCl} value refers to the acidity in the soil solution, plus the reserve acidity in the colloids. On the other hand, base saturation is relatively high in the Bw and C horizons. The Δ pH values will probably also affect the quality and quantity parameters of soil organic matter.

Soil organic matter. The distribution of organic carbon, total nitrogen and C/N ratio within the profiles is presented in Table 3. The main source of biomass for the process of humification is the same but the proportion of each tree species and the amount of herb vegetation are different as shown in the descriptions of the studied areas. Values of organic carbon and total nitrogen are the highest in

Table 3. Soil organic matter composition

Locality	Depth (cm)	C_{ox} (%)	N_t (%)	C/N
Březina	0–6	20.96	1.27	16.50
	6–20	4.85	0.33	14.70
	20–38	2.58	0.19	13.58
	38–94	0.73	0.04	18.25
Týřovické skály	0–15	2.67	0.27	9.89
	15–40	0.93	0.11	8.45
	40–82	0.20	0.05	4.00
	82–125	0.12	0.05	2.40
Záhrabská	0–6	7.68	0.56	13.71
	6–30	1.36	0.12	11.33
	30–60	0.52	0.06	8.67
	60–82	0.40	0.05	8.00
	82–94	0.44	0.05	8.80

C_{ox} – organic carbon; N_t – total nitrogen

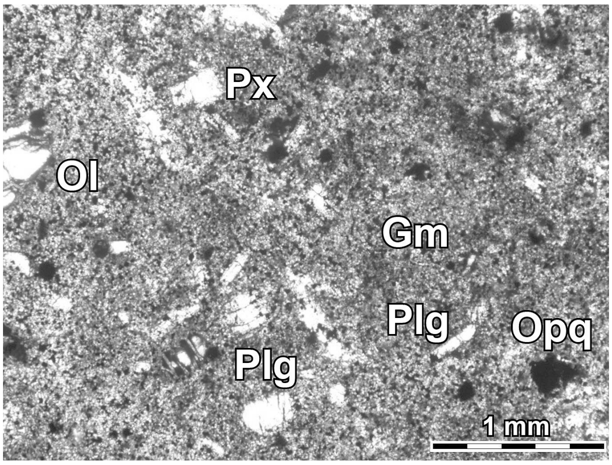

Figure 1. Microscopic detail of thin-sectioned Miocene basalt from the Březina site; Gm – glass matrix; Ol – olivine; Opq – opaque minerals; Plg – plagioclase; Px – pyroxene

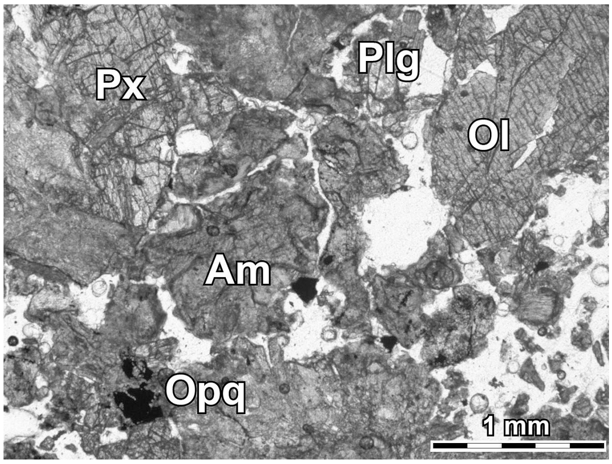

Figure 2. Microscopic detail of thin-sectioned Cambrian andesite from the Týřovické skály site; Am – amphibole; Ol – olivine; Opq – opaque minerals; Plg – plagioclase; Px – pyroxene

the upper parts of the profiles but vary among sites. The C/N value showed a variable enrichment of soil organic matter by nitrogen.

The results indicate that the quality of soil organic matter was probably closely connected with the source of biomass and climatic conditions of the individual sites.

Petrography of parent material. Parent material of the individual soil profiles underwent petrographic studies. Thin sections of basalt from the Březina site (Figure 1) showed glass matrix which predominantly contains lath-shaped plagioclase crystals up to 0.2 mm in size and pyroxene phenocrysts 0.2–0.4 mm in size, and also olivine grains. The groundmass also contains opaque minerals. Texture of basalt is hemicrystalline to porphyritic.

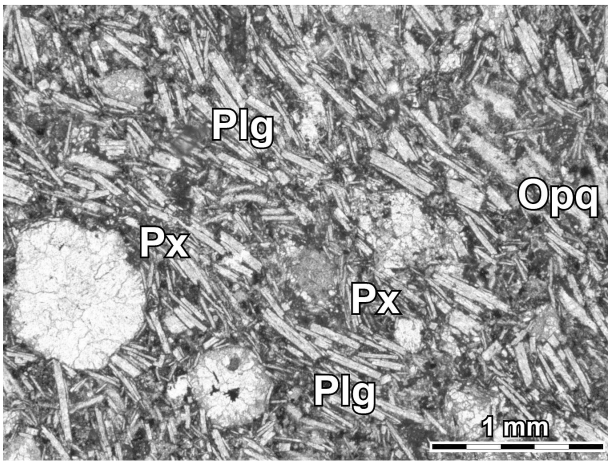

Figure 3. Microscopic detail of thin-sectioned Silurian dolerite from Záhrabská sit; Opq – opaque minerals; Plg – plagioclase; Px – pyroxene

Thin sections of andesite from the Týřovické skály site (Figure 2) show phenocrysts of pyroxene, amphibole, and olivine up to 1 mm in size and dominance of lath-shaped plagioclase crystals. Disseminated quartz and plagioclase are scarce. Grains of opaque minerals 0.2 mm in size occur between amphibole crystals. The texture of andesite is granular.

Thin sections of dolerite from the Záhrabská site (Figure 3) display groundmass composed of minute

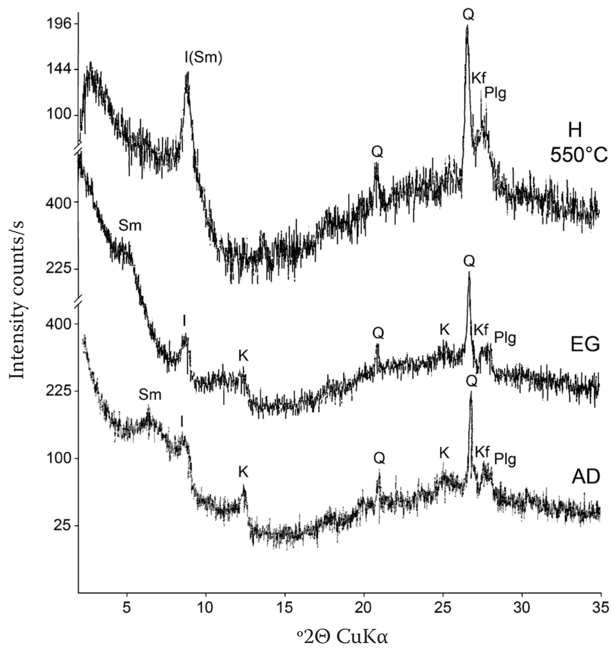

Figure 4. X-ray diffractogram of clay fraction of the Bw horizon from Březina site; AD – air-dried; EG – ethylene glycol solvated; H – heating; I – illite; K – kaolinite; Kf – K-feldspar; Plg – plagioclase; Q – quartz; Sm – smectite

Table 4. Mineral composition of the clay fraction

Locality	Depth (cm)	Am	Ch	I	K	Kf	Plg	Q	Sm
		(%)							
Březina	0–6	0	2	9	4	22	21	40	2
	6–20	0	0	18	9	13	11	26	23
	20–38	0	0	18	7	10	5	29	31
	38–94	0	0	15	2	11	14	36	22
Týřovické skály	0–15	4	6	7	0	3	4	13	63
	15–40	4	8	5	0	6	12	15	50
	40–82	4	3	6	0	6	0	7	74
	82–125	7	0	3	0	0	2	6	82
Záhrabská	0–6	0	6	0	1	0	51	41	1
	6–30	0	8	0	2	0	24	48	18
	30–60	0	0	0	2	0	14	38	46
	60–82	0	0	0	4	0	16	13	67
	82–94	0	0	0	2	0	14	12	72

Am – amphibole; Ch – chlorite; I – illite; K – kaolinite; Kf – K-feldspar; Plg – plagioclase; Q – quartz; Sm – smectite

lath-shaped plagioclase crystals 0.4 mm in length, small grains of opaque minerals, and phenocrysts of olivine and pyroxene of different size. The texture of dolerite is hemicrystalline. Petrography of parent material allows to document differences in the texture, character, and amount of rock-forming minerals.

Mineralogy of clay fraction of soils. The most common minerals of volcanic rocks are feldspars and pyroxenes which become transformed into new mineral phases during the weathering and pedogenesis processes. Mineral composition of the clay fraction of soils is given in Table 4. X-ray diffractograms of the clay fraction from the Bw horizons are presented in Figure 4 (Březina), Figure 5 (Týřovické skály), and Figure 6 (Záhrabská).

In the soil profile of Březina, the influence of the parent material (basalt) is combined with that of the surrounding Cretaceous sediments. The latter is indicated primarily by the higher contents of K-feldspar (3.23 Å) and quartz (4.24, 3.32 Å). Elevated is also the content of illite (10.0, 4.49, 3.32 Å) in amounts up to 18% in the Ah and Bw horizons, then of kaolinite (7.12, 3.54 Å). The weathering intensity in the soil profile is lower. This fact is documented by the relatively high content of feldspars in the clay fraction of soils along with lower (22–31%) contents of smectite (13.91 Å, ethylene glycol solvated 16.64 Å). Basal reflections of clay minerals have low intensities and are not too sharp. This reflects a low crystallinity of clay minerals and a lower degree of weathering.

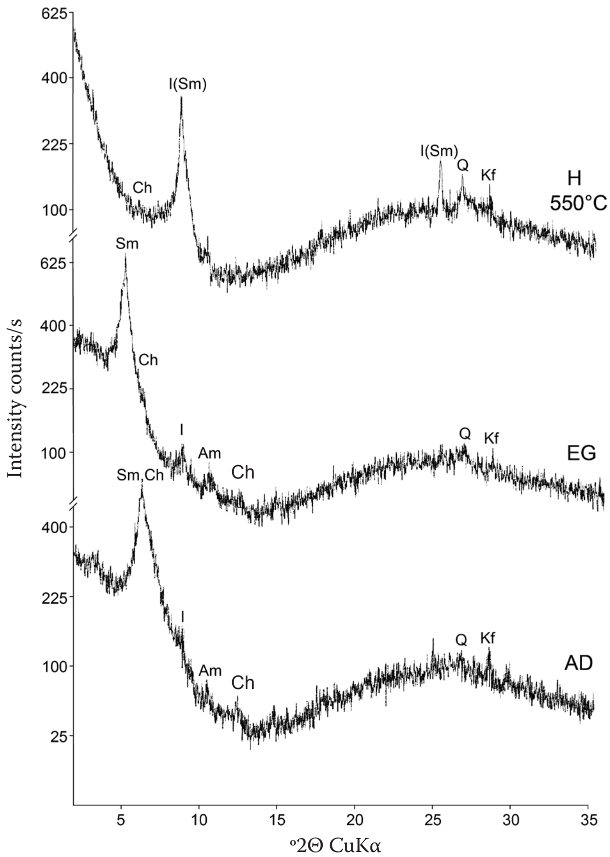

Figure 5. X-ray diffractogram of clay fraction of the Bw horizon from Týřovické skály site; AD – air-dried; EG – ethylene glycol solvated; H – heating; Am – amphibole; Ch – chlorite; I – illite; Kf – K-feldspar; Q – quartz; Sm – smectite

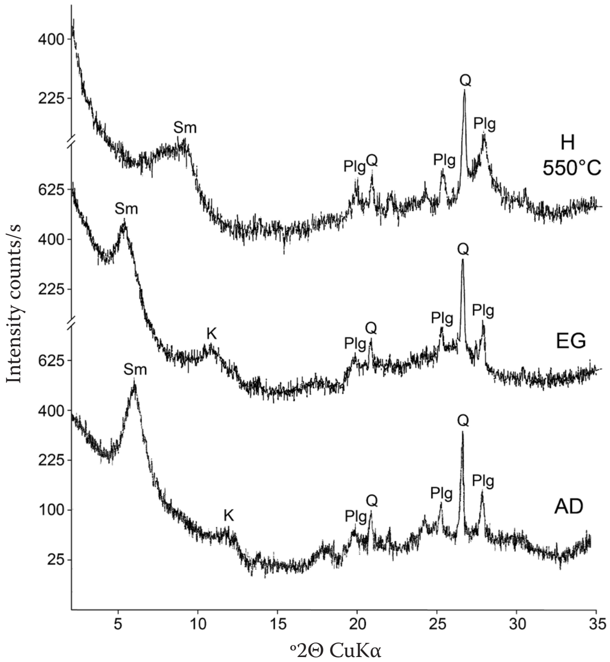

Figure 6. X-ray diffractogram of clay fraction of the Bw_1 horizon from Záhrabská site; AD – air-dried; EG – ethylene glycol solvated; H – heating; K – kaolinite; Plg – plagioclase; Q – quartz; Sm – smectite

The dominant clay mineral of the soil profile developed on andesite at the Týřovické skály site is smectite (14.07 Å, ethylene glycol solvated 16.14 Å). This clay mineral has a sharp basal peak indicating its good crystallinity. Smectite originates not only from weathering of feldspars and pyroxene, but also of olivine which is present in the parent rock. Amorphous glassy minerals are indicated by a protracted, rounded maximum in the range of 15–35° 2Θ on the X-ray diffractogram. High contents of smectite (50–82%) suggest a strong weathering process. Chlorite and illite are also present among clay minerals. The other minerals present are quartz, feldspars, and amphibole, which are accessory minerals of andesite. Feldspars are almost totally decomposed in the Bw and C horizons.

The clay fraction in the profile developed on dolerite at the Záhrabská site is dominated by smectite (14.75 Å, ethylene glycol solvated 16.22 Å) especially in the Bw_1, Bw_2, and C horizons. Small portion of chlorite (14.33, 7.10 and 3.51 Å) occurs in the Ah and $AhBw_1$ horizons. Accessory kaolinite (7.13, 3.56 Å after heating to 550°C reflection disappears) is present throughout the profile. The content of smectite increases with depth which is a result of plagioclase decomposition. Higher contents of quartz (4.25, 3.34 Å) in the upper part of the soil profile probably reflect the presence of quartz of eolian origin. Intensity of the weathering process is lower than in the soil profile on andesite.

Smectite is the most characteristic clay mineral of the analyzed Haplic Cambisols on volcanic rocks.

Under various alkaline conditions, feldspars may be transformed into various weathering products For example, Wilson *et al.* (1971) showed that in deeply weathered parent rock all K-feldspar and plagioclases were converted to Cheto-type montmorillonite poor in Fe. Most feldspars are decomposed at pH 4–7. However, it was also found out that the dissolution rate may be independent of the pH value in this range.

CONCLUSIONS

The main pedogenic process in soils developed on volcanic rocks is weathering of parent material and development of the Bw horizon. The thicknesses of the soil profiles and Bw horizons are higher in soils on andesite and dolerite than in soils on basalt.

The particle size distribution of soils is connected with the type of volcanic rocks and, in the case of the site Záhrabská, probably with the eolian transport during the Quaternary.

Chemical properties of soils are affected by the type of parent material, and values of pH also by the composition of the soil organic matter.

The content and quality of the soil organic matter are influenced by the source of biomass and climatic conditions at the individual sites.

Variations in the formation of the Bw horizon are controlled by the character of parent material. The results revealed differences in the parameters of the individual Bw horizons. The most characteristic clay mineral in soils developed on volcanic rocks is smectite. The soil profile at Březina on basalts has a relatively high content of minerals which is probably connected with the occurrence of the surrounding Cretaceous sediments. High contents of smectite in soil developed on andesite at the Týřovické skály site indicate the highest intensity of weathering. The characteristic process of weathering on soil developed on dolerite at the Záhrabská site is partly disturbed by deposition of quartz probably of eolian origin in the upper part of the profile. According to the type of volcanic rocks, the intensity of the process of the Bw horizon development is as follows: andesite (Týřovické skály) > dolerite (Záhrabská) > basalt (Březina).

Acknowledgments. Supported by the RVO 67985831 (Institute of Geology, Academy of Sciences of the Czech Republic, v.v.i., Prague).

References

Cajz V., Vokurka K., Balogh K., Lang M., Ulrych J. (1999): The České středohoří Mts.: Volcanostratigraphy and Geochemistry. Geolines, **9**: 21–28.

Cajz V., Rapprich V., Erban V., Pécskay Z., Radoň M. (2009): Late Miocene volcanic activity in the České středohoří Mountains (Ohře/Eger Graben, northern Bohemia). Geologica Carpathica, **60**: 519–533.

Fiala F. (1970): Silurian and Devonian diabases of the Barrandian Basin. Sborník geologických věd, **G**: 7–89. (in Czech)

Gallardo Lancho J.F. (1999): Relationships between total extractable organic carbon and some parameters of soils from Western Spain. Humic Substances in the Environment, **1**: 15–20.

Hradecký P. (2008): Genetic aspects of the Upper Cambrian Křivoklát-Rokycany volcanic complex. Zprávy o geologických výzkumech v roce 2007, 24–26. (in Czech)

Hradecký P. (2010): Lithology of the Furongian volcanic rocks, central part of the Křivoklát-Rokycany complex, W-Bohemia. Zprávy o geologických výzkumech v roce 2009, 215–219. (in Czech)

IUSS Working Group WRB (2007): World Reference Base for Soil Resources 2006, 1st update 2007. World Soil Resources Reports, **103**: 1–116.

Jahn R., Blume H.P., Asio V.B., Spaargaren O., Schad P. (2006): Guidelines for Soil Description. 4th Ed., FAO, Rome.

Kovanda J. (2006): A temporary outcrop in a loess drift on the southeast slope of the Damil hill (396 m a.s.l.). Český kras, **32**: 13–16. (in Czech)

Madarázs B., Németh T., Jakab G., Szalai Z. (2013): The erubáz volcanic soil of Hungary: Mineralogy and classification. Catena, **107**: 46–56.

Prudêncio M.I., Braga M.A.S., Paquet H., Waerenborgh J.C., Pereira L.C.J., Gouveia M.A. (2002): Clay mineral assemblages in weathered basalt profiles from central and southern Portugal: climatic significance. Catena, **49**: 77–89.

Quitt E. (1971): Climatic regions of Czechoslovakia. Studia Geographica **16**: 1–82. (in Czech)

Stoops G. (2013): A micromorphological evaluation of pedogenesis on Isla Santa Cruz (Galápagos). Spanish Journal of Soil Science, **3**: 14–37.

Targulian V.O., Krasilnikov P.V. (2007): Soil system and pedogenic processes: Self-organization, time scales, and environmental significance. Catena, **71**: 373–381.

Tomášek M., Bezvodová B. (1969): Mineralogical composition of selected soil profiles on weathered basalts. Scientia Agriculturae Bohemoslovaca – Pedologia et Meliorationes, **18**: 117–126.

Tomášek M., Zuska V. (1972): Soils on Wheathered Diabases in Central Bohemia. Rostlinná výroba, **18**: 333–340. (in Czech).

Valla M., Kozák J., Němeček J., Matula S., Borůvka L., Drábek O. (2002): Soil Science Practicum. Česká zemědělská univerzita, Praha. (in Czech).

Velde B., Meunier A. (2008): The Origin of Clay Minerals in Soils and Weathered Rocks. Springer-Verlag, Berlin, Heidelberg.

Waldhausrová J. (1971): The chemistry of the Cambrian volcanics in the Barrandian Area. Krystalinikum, **8**: 45–75.

Wilson M.J. (2004): Weathering of the primary rock-forming minerals: processes, products and rates. Clay Minerals, **39**: 233–266.

Wilson M.J., Bain D.C., McHardy W.J. (1971): Clay mineral formation in a deeply weathered boulder conglomerate in north east Scotland. Clays and Clay Minerals, **19**: 345–352.

Received for publication January 29, 2014
Accepted after corrections May 26, 2014

Corresponding author:

RNDr. Anna Žigová, CSc., Geologický ústav AV ČR, v.v.i., Rozvojová 269, 165 00 Praha 6-Lysolaje, Česká republika; e-mail: zigova@gli.cas.cz