Tephra Characteristics and Eruption Mechanics of the Komorní Hůrka Hill Scoria Cone, Cheb Basin, Czech Republic

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ABSTRACT. Komorní hůrka Hill scoria cone is situated in the SW of the Cheb Basin between Cheb and Františkovy Lázně in Western Bohemia, Czech Republic. The monogenetic olivine nephelinite volcano is dominated by ejected scoria that developed pyroclastic breccias. This major activity of the volcano can be attributed to Strombolian-type eruptions. The presence of xenolith-rich ash and lapilli deposits however suggests different fragmentation processes related to phreatomagmatic activity. The effusion of a blocky aa-lava flow from a flank fissure on the SW slope of the cone marked the end of the eruption. Petrographic and morphological studies on tephra were conducted to discriminate between different eruption and fragmentation procceses. In addition a detailed petrographical study of the lava flow helped to reconstruct the eruptive history of the Quaternary Komorní hůrka Hill scoria cone.

KEY WORDS: W Bohemia, Quaternary volcanism, Strombolian eruption, tephra, olivine nephelinite.

Introduction

The scoria cone of Komorní hůrka Hill is situated in the Cheb Basin, the westernmost Tertiary basin of the Ohře-(Egergraben) rift in Northern Bohemia (c.f. Fig. 1). The volcanic activity that led to the formation of the scoria cone is related to the latest eruptive episode within the Ohře Tectono-volcanic Zone (Kopecký 1986) interacting with the Mariánské Lázně Fault system during the Pliocene and Pleistocene. New preliminary radiometric data by Wagner et al. (1998) for some scoria samples from Komorní hůrka Hill revealed an age of 580–890 ka: an age consistent with data obtained from geological mapping (Gottsmann and Tobschall 1997) as the scoria overlies Pleistocene sediments that contain features of former ice-wedges. The geological framework of Komorní hůrka Hill consists of metamorphic Variscan basement and Tertiary as well as Quaternary sediments. The scoria cone is situated at the western margin of the Cheb Basin that has undergone multicyclic tectonic movements since late Variscan times (Svoboda 1966; Peterek et al. 1996; Gottsmann 1997) due to the vertical movements of faults associated with the the Ohře Tectono-volcanic Zone and deep-seated faults of the Mariánské Lázně Fault system (Kopecký 1986).

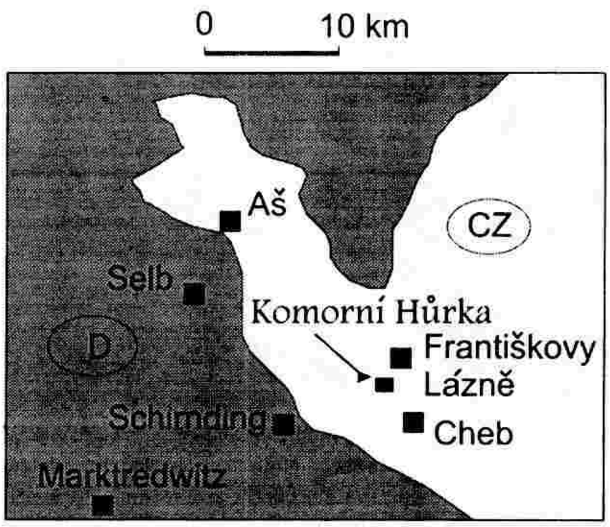


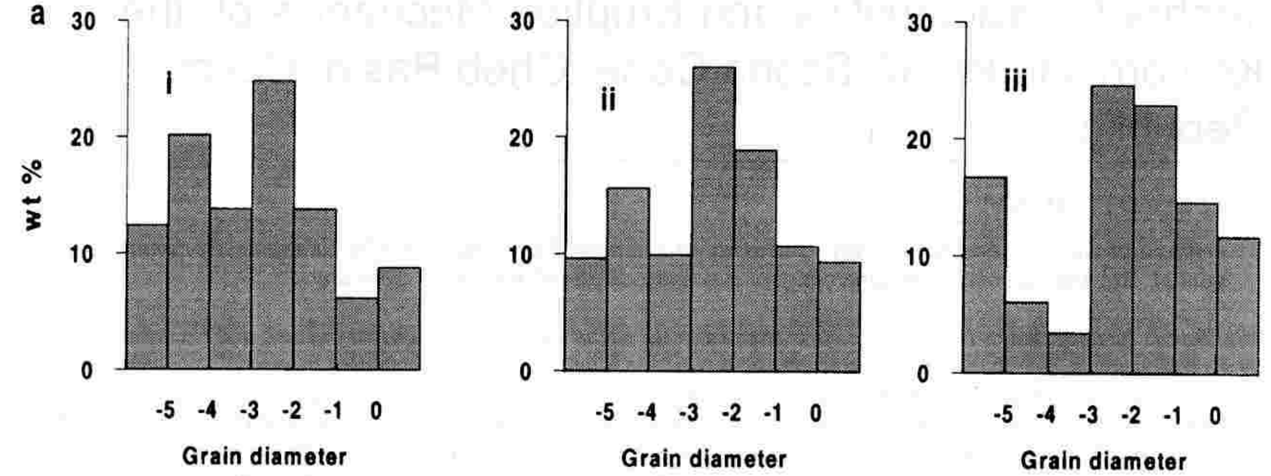
Fig. 1. Geographical sketch of the Komorní hůrka Hill scoria cone situated in the Cheb Basin, western Bohemia, Czech Republic.

The first scientific records concerning the scoria cone date back to 1773 (Kraus and Pilz 1935). During the early 19th century the German poet and scientist J.W. von Goethe visited Komorní hůrka volcano several times (v. Goethe 1823) and initiated the construction of an adit to reveal the enigmatic origin of the cone in respect to the then ongoing arguments between plutonists and neptunists.

This paper discusses new data concerning fragmentation and eruption processes at Komorní hůrka Hill. The scope of this paper is not to review the geological studies generated here throughout the last two centuries. Interested readers should refer to Kraus and Pilz (1935) and Proft (1894).

The Komorní hůrka Hill edifice

The olivine nephelinite scoria cone of Komorní hůrka Hill is mainly composed of tephra that is predominatly distributed in easterly directions to form an elliptically-shaped edifice that rises some 30 m above the surrounding topography. The dimensions of the scoria cone are 460 m (E–W) by 250 m (N–S). Geomagnetic studies reveal that the major tephra dispersal coincides with the geologically-derived outlines of the volcaniclastic rocks. A fan-shaped 90° magnetic anomaly in easterly directions may record the dispersal of fine ash. The directed scoria dispersal indicates westerly winds during the eruption. The volcanic rocks of Komorní hůrka Hill were extensively quarried throughout the centuries, leaving 2 pits to the east of the summit. Though nowadays not well exposed two different tephra lithologies can be distinguished within the larger pit. A lava flow, approximatly 90 m long, is exposed at the southwestern slope of the scoria cone where an engraved bust in honour of J.W. von Goethe can also be found. The flow bends slightly from NNE to SW. Due to the intensive quarrying of the flow a 15 m long part is missing and leaves a gap between the extrusion site and the remaining flow.



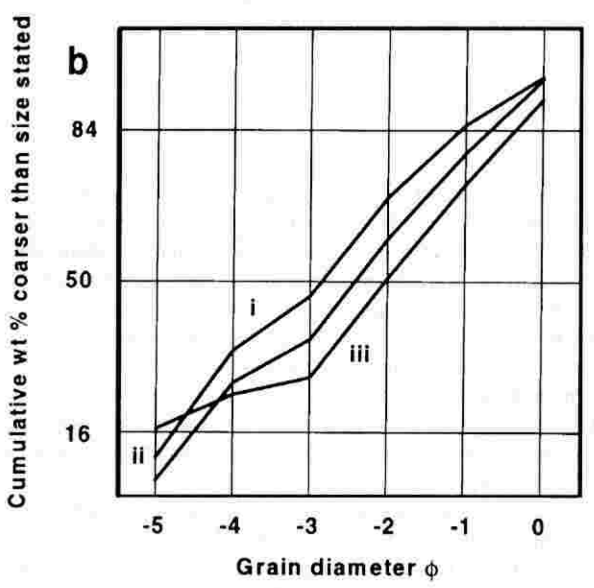


Fig. 2. Graphic representation of three grain-size analyses from samples of the Komorní hůrka Hill scoria cone. (a) Histograms for data obtained by sieve analysis of samples from (i) proximal scoria breccia exposed in the northern face of the large pit east of the summit, (ii) more distal scoria breccia in the eastern face of the large pit, (iii) xenolith-rich ash and lapilli deposit from the base of the large pit; (b) cumulative plot on a probability ordinate. 16th, 50th and 84th percentiles are shown. Their intersections with the grain-size distribution curves give the grain diameters used for the derivation of the Inman parameters in Table 1. Note: grain diameters are given in Φ (where $\Phi = -\log_2 d$, *d* being the grain size in millimetres).

Petrology

Petrography and morphology of tephra

Although the the Komorní hůrka Hill scoria comprises mainly scoria breccias, distinct layers of xenolith-rich ash and lapilli deposits (XALD) are exposed particularly towards the base of the larger pit. Apparently associated with these XALD layers are dense bombs and lapilli. The tephra in general reveals varying contents of glass ranging from interstitial matrix glass to a nearly holohyaline matrix abundance. In addition a microcrystalline recrystallization matrix sometimes dominates the texture with phenocrysts and microphenocrysts occuring randomly within the matrix. Titanaugite and olivine are present as phenocrysts and microphenocrysts. Euhedral olivine crystals are often rimmed by smaller titanaugite laths. Both minerals frequently show resorption features and glomerophyric intergrowths commonly occur. Nepheline and melilite are rare within the tephra. Iron oxides occur as inclusions in both olivine and titanaugite and are also part of the matrix, as individual minerals and as a major component of the tachylite.

The volcaniclastic rocks of Komorní hůrka Hill occur in different stratigraphic layers and reveal different fragmentation and eruption histories that are described in detail below.

Scoria breccias and bomb-fragment breccias

The major component of the tephra is composed of scoria that builds up most of the cone edifice. The scoria mantles the topography forming m-thick unwelded, coarse fall deposits with a matrix of bomb-fragments formed by clasts upon impact. The deposits are mainly composed of bomb-sized clasts and lapilli, ash particles are solely a minor component of these layers (cf. Fig. 2 (a) i,ii). Proximal welded agglutinates, somehow characteristic for scoria cones (Fisher and Schminke 1994), may be

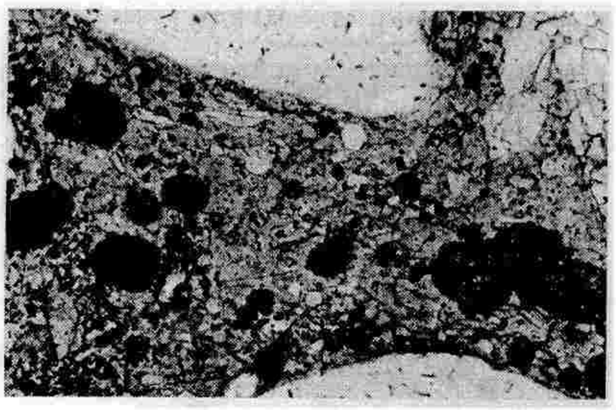


Fig. 3. Photomicrograph of highly vesicular scoria lapillus from the pyroclastic breccia. Note the irregular shape of the clast and the increasing bubble size towards the interior, partly due to bubble coalescence. Titanaugite phenocrysts are embedded in a tachylitic glass groundmass. This lapillus represents a typical clast derived from a pyroclastic fragmentation process; ppl, width of view: 4.1 mm.

anticipated; however, they are not exposed at Komorní hůrka Hill. The individual clasts are highly vesicular and show irregular surfaces (cf. Fig. 3). Due to a lack of exposures a lateral correlation of individual scoria breccia layers is difficult within the tephra. Nevertheless, it is apparent that the median grain size within the scoria breccias is declining in easterly directions (cf. Fig 2 (a) ii), leaving > 20 cm clasts restricted to the central parts of the edifice. The well-sorted massive scoria deposits (cf. Tab. 1) show little evidence of stratification, xenoliths occur rarely. Depending on their degree of vesiculation the scoriae are altered in different intensities and in addition they show an oxidized, reddish-brown appearance on the surface with fresh greyish-black interiors. Olivine and titanaugite phenocrysts in mm-size within the clasts are visible with the naked eye. The clasts are predominantly fluidally shaped. The existence of cow-dung bombs can be attributed to a viscous deformation process of some clasts after impact.

Xenolith-rich ash and lapilli deposits (XALD)

Generally different features are visible in a series of cm- to dm-thick reddish, poorly sorted (cf. Tab. 1) yet well-bedded layers that alternate with dm-thick scoria breccias. The red colour of the deposits is derived from the high abundance of slightly-baked wall rocks composed of schists and quartz veins from the underlying Variscan basement. These accessory lithic components occur from sand to boulder size, with some of them reaching dimensions of up to 30 cm in diameter. A vast dimension contrast is visible comparing these lithics to the "host" matrix. The juvenile clasts merely consist of ash- and lappilli-sized particles, with median diameters of -1.9 Φ (cf. Tab. 1, Fig 2a iii, 2b). The clasts have a fresh appearance and oxidized particles are rare. Compared to the scoria breccias-forming scoria the crystal fraction is by far lower, decreasing to as low as 10 vol.%. The clasts have regular smooth surfaces and tend to have a more spherical geometry (cf. Fig. 4). Degassed co-magmatic lithoclasts are abundant within the deposits and may represent tachylitic scoriae derived from conduit walls. As in the scoria breccias, the XALD do not show any indications of welding.

Dense bombs and lapilli

The third variety of tephra does not form indvidual layers. The dense bombs and lapilli mostly occur within the XAL-deposits but are also frequently distributed around the edifice. They are therefore treated as a seperate class of tephra. These bombs and lapilli are mainly composed of an intensively recrystallized glassy matrix with minor contents of phenocrysts. The bombs occur in cm- to dm-size, the largest yet found had a diameter of 40 cm and a weight of 15 kg. Some bombs are rich in xenoliths from the underlying basement and also contain cm-sized fragments of ultrabasic rocks. The dense clasts have spherical to ellipsoidal shapes and their surfaces often show a cauliflower-like appearance. Abundand armored lapilli with interior parts composed either of juvenile lithics or wall rocks are rimmed by a recrystallized and altered glassy matrix.

Inman parameters*	proximal scoria breccia (i)	distal scoria breccia (ii)	xenolith-rich ash and lapilli deposit (iii)
Md_{Φ}	-2.90	-2.40	-1.90
$s_{\Phi}{}^{\#}$	1.80	1.85	2.45

Tab. 1. Inman (1952) grain-size parameters (median diameter and sorting) for three samples from Komorní hůrka Hill scoria cone, derived graphically from cumulative curves in Figure 4b. $*Md_{\Phi} = \Phi_{50,}$ $*\sigma_{\Phi} = (\Phi_{84}-\Phi_{16})/2$, $^{\#}\sigma_{\Phi}$: ([0–1] very well sorted; [1–2] well sorted; [2–4] poorly sorted; [>4] very poorly sorted)

Tephra glass

Although the mafic vitreous groundmass of the tephra has undergone intensive recrystallisation and alteration it is quite easy to distinguish two different glass varieties: tachylite and sideromelane. The clasts forming the scoria breccias are dominated by the tachylitic glass component (cf. Fig. 3) showing different degrees of devitrification and hence recrystallisation. Fresh tachylite has a dark brown to opaque appearance in transmitted light due to the high abundance of Fe/Ti-oxide microlites (Fisher and Schminke 1984). A patchy dirty-brown matrix is visible with increasing alteration of the tachylite. Recrystallisates are predominantly titanaugite microlites and other submicroscopic crystallites. Transparent sideromelane also occurs within the scoria breccias as a dense <50 μm thick glass rim of individual tachylite-dominated clasts, reflecting a radiative quench process during ballistic transport.

The glass component of the XALD is mostly yellowish, transparent sideromelane. Tachylite occurs merely as the matrix of of the co-magmatic cognate clasts. The matrix of the XALD-clasts is also glassy, microlites are less abundant. The sideromelane glass matrix is marked by jigsaw cracks, resulting in equantly shaped glass shards of predominatly triangular and quadrangular geometry (cf. Fig. 4). The sideromelane shows various degrees of alteration. The glass undergoes palagonitisation concomitant with a change to a dull yellowish-brown colour. The transition of fresh sideromelane to palagonite is marked by a sharp boundary within the clasts. Palagonitisation also affects the sideromelane rim of some scoria breccia fragments.

The average glass content of the scoria forming the breccias is 30 vol.%, though its accurate estimation is difficult due to varying degrees of recrystallisation and alteration. By contrast the average XALD glass content reaches about 80 vol.%.

With an average of 15 vol.% the dense bombs and lapilli

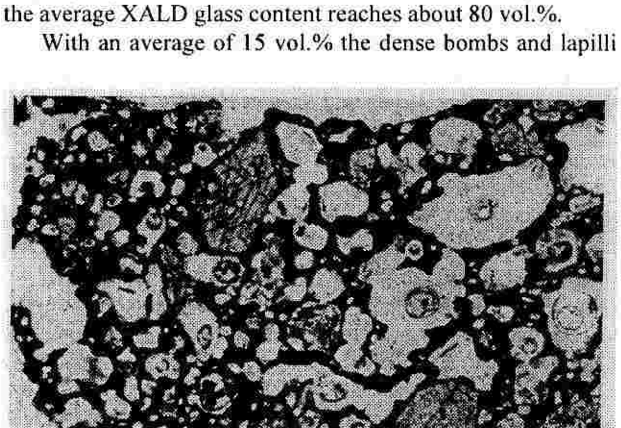


Fig. 4. Photomicrograph of a typical ash particle from the xenolith-rich ash and lapilli deposits (XALD) of the Komorní hůrka Hill scoria cone. The sideromelane glass matrix is highly palagonitised. Note the low vesicularity of the fragment in contrast to the clast shown in Fig. 3 and the smooth, regular surface. The ash fragment has an equant shape and jigsaw-cracks indicate a rapid chilling of the particle. The presence of these distinct clasts suggests a phreatomagmatic origin of the XALD; ppl, width of view: 0.6 mm.

reflect the lowest glass content of the Komorní hůrka Hill tephra. Tachylite is the dominant glass variety by far in these dense clasts. Sideromelane, though highly palagonitized, occurs as dense, fine-grained ash rims of spherical lapilli, resembling armored lappilli (Schminke 1977; Fisher and Schminke 1984, 1994).

Vesicularity of tephra

Komorní hůrka Hill tephra shows a large variety of vesicularity. Clasts of the scoria breccias reflect the highest degree of vesiculation. The vesicle size within the individual scoria types decreases from the central parts to rims of the clasts. Towards the rims of the clasts, spherical bubble geometries dominate, whereas bubble coalesence within the interior of the clasts results in different bubble geometries reflecting bubble expansion both before and after deposition. The high average vesicularity of 65 vol.% results in an open framework of the scoria (cf. Fig. 3). Individual vesicles can reach diameters of up to 2 cm. Cow-dung bombs underwent a process of viscous deformation and gravitational collapse after emplacement. Bubble collapse followed once an open vesicularity permitted the trapped volatiles to escape.

A marked contrast concerning the degree of vesiculation is obvious in the individual clasts of the XALD as the average porosity reaches merely 8 vol.% (cf. Fig. 4). In addition, the cognate tachylite clasts also show very low porosities due to a degassing process inside the conduit.

The dense bombs and lapilli show average porosities of 12 vol.%. Cauliflower-shaped bombs however show higher porosities towards the interior of the clasts. These distinct surface textures are associated with the expansion of gas inside the bomb resulting in the brittle failure of the quenched surface of the clasts.

The Komorní hůrka Hill lava flow

The volcanic activity of Komorní hůrka Hill also led to the extrusion of a blocky lava flow with a near-surface clinker top (Cas and Wright 1988). The fissure-fed flow extruded from the southwestern flank of the edifice and is hence not derived from the central crater (Ulrych and Kopeckýý 1991).

Towards the extrusion site a porous aa-lava-like appearance is visible as well as dense, degassed, m-sized angular nephelinite blocks within vesicular matrix. The maximum exposed flow thickness is 7 m. Due to the intensive quarrying of nephelinite throughout the centuries there is little control on the original dimensions of the lava flow. Nevertheless, an apparent increase in porosity towards the flow-top and the scoriaceous clinker-top-resembling surface of the flow suggest an original thickness of not more than 10 m. The larger vesicles show an elongation in flow direction towards the SW. In addition, cm-sized cavities sometimes show a yellowish-green microcrystalline mineral matrix that may represent an alteration mineral admixture. Proft (1898) suggested this mineral assemblage to be the remnant of the assimilation process of quartz-rich wall rocks. However, detailed microscopic studies revealed serpentinized olivine and clinopyroxenes and also calcium carbonate as major components. Sparsely found enclaves of cm-sized clinopyroxenites within the flow may represent unaltered xenoliths of this very fine-grained gel-like mineral assemblage. Major modal components of the flow are titanaugite, olivine, iron oxides, nepheline, melilite and tachylite. The lower, central and upper parts of the lava flow are holocrystalline with olivine and titanaugite as predominant phenocryst assemblages. Towards the flow-top, the glass content increases with decreasing nepheline content. Olivine is most abundant in the lower parts of the flow, titanaugite seems to be more ftrequent in the central parts of the flow indicating a vertical zonation due to a gravitatonal segregation process. The segregation may have occurred during progressive flow of the lava (Wilson 1989). No significant change in the modal composition was observed along flow drection. The glass at the near-surface part of the flow is highly altered with a dirty brownish (sub)-microcrystalline mineral admixture. The increasing glass content towards the upper part of the flow indicates an increased cooling of the flow surface due to radiation and forced convection as one might expect. The interior of the flow retained enough heat, probably enhanced by an insulating effect of the vesicular scoriaceous flow surface, for crystallisation of the central parts of the lava flow. The latent heat additionally kept temperatures high and thus viscosities low enough within the main body of the flow. Low viscosities are a major control on flow rheologies influencing e.g. diffusion kinetics and volatile exsolution during magmatic processes (Perlaki 1966; Chakraborty 1995; Dingwell 1995). Low viscosities may also account for a substantial degassing of the flow as porosities of the main body are as low as 10 vol.%, a marked contrast compared to up to 60 vol.% vesicularity of the flow surface.

Fragmentation and eruption mechanics

Two significantly different fragmentation processes led to the formation of the mogenetic scoria cone. The morphology and the high vesicularity of the scoria suggest a pyroclastic fragmentation process prior to the emplacement as scoria breccias. This process can be attributed to the violent near-surface bubble disruption within a rising magma column, where jets of melts accelerated by gas thrusts break up into clusters of pyroclasts of various size (McGetchin et al. 1974). The unbedded scoria breccias represent typical deposits of Strombolian-type activity, where the exsolution of the gas phase and its rapid ascent due to the low viscosity of the nephelinitic magma triggered fountain-fed eruptions at Komorní hůrka Hill. During their ballistic transport the fragmented clasts rapidly cooled, preventing substantial crystallisation and leading to the high abundance of tachylitic glass. Yet, cooling of some clasts was slow enough to allow viscous deformation upon impact resulting in cow-dung-shaped fragments.

The major volatile of the upper mantle-derived nephelinitic magma of Komorní hůrka Hill (Gottsmann and Tobschall 1997) is presumed to be CO_2. Carbon dioxide is assumed to be the most abundant volatile in the upper mantle, as f_{CO_2} is believed to be larger than f_{H_2O} (Wilson 1989). At near-surface levels CO_2 readily partitions into the gas phase due to its low solubility (Spera and Bergman 1980), an effect that represents the major criterion for carbon dioxide gas thrust-accelerated magma fragmentation during mafic volcanic eruptions.

The clasts of the XALD show significantly different morphologies, vesicularities and crystal fractions as outlined above. The presence of a low vesicular sideromelane matrix suggests a rapid quench process for these particles. Decreasing median grain sizes, the poor sorting of the deposits and the high abundance of wall rock components as well as xenolith-rich dense bombs and lapilli may be attributed to a phreatomagmatic fragmentation process (Schminke 1977; Lorenz 1973). Unlike the pure pyroclastic fragmentation, phreatomagmatic eruptions are assigned to a magma/external water interaction. This interaction leads to a rapid chilling of the upper part of a rising magma column and a subsequent fragmentation process producing smallgrained individual clasts, represented in the equantly shaped microlite-poor sideromelane shards of the XALD. The magma/water contact leads to violent eruptions due to the sudden water vapour generation and associated gas volume expansion. This increasing explosiveness is documented by the presence of large dense blocks and cognate lithics presumably from the conduit walls. Another feature of the XALD is their small-scale stratification and thin bedding, typical for phreatomagmatic deposits (Schminke 1977; Fisher and Schminke 1984). Though not very well exposed an alternating bedding succession of cm-thick XALD and dm-thick scoria breccias at the base of the large pit at the eastern flank of the cone may reflect repeated magma/water interaction followed by pyroclastic fragmentation. Increasing eruption rates may have resulted in the sealing off of the magma column against external water progression and a shift to fully pyroclastic fragmentation processes that dominated the scoria cone build-up. The phreatomagmatic eruptions may have dominated the initial phase of the volcanic activity at Komorní hůrka Hill, as v. Goethe (1823) reports up to 40 reddish layers at the base of the tephra succession. Geological mapping of the area (Gottsmann and Tobschall 1997) revealed that the tephra overlies Pleistocene sands and gravels. Therefore the magma/water interaction may be attributed to the contact of the rising magma column with a permafrost horizon or an aquifer beneath a permafrost horizon. Both scenarios can generate phreatomagmatic eruptions (Lorenz 1973; Kienle et al. 1980)

The third eruptive process associated with the genesis of the Komorní hůrka Hill edifice is the effusion of the lava flow from an open flank fissure. This extrusion may have occured as a subterminal eruption towards the end of the volcanic activity when highly degassed and hence more viscous lava extruded from an open fissure, probably simultaniously with crater-based Strombolian activity. This combined activity is typical of mafic bocca eruption of, for example, Mt. Etna (Pichler and Schick 1985).

Conclusions

Summary of volcanic activity

The initial volcanic activity of the Komorní hůrka Hill scoria cone began with phreatomagmatic eruptions forming xenolith-rich ash and lapilli deposits as well as dense (cauliflower-) bombs and spherical dense lapilli. The alternating succession of phreatomagmatic layers with scoria breccias suggest repeated magma/external water contact followed by pyroclastic processes. At a certain stage the conduit walls of the volcano were sealed against water penetration. Pyroclastic fragmentation associated with Strombolian-type eruptions led to the construction of the scoria cone. Ballistic transport of the pyroclasts resulted in the emplacement of m-thick unwelded scoria breccias with bomb-fragment matrix. The effusion of a blocky aa-lava flow marked the waning of the volcanic activity. Geological and magnetic studies emphasize the generation of the fissure-fed scoria cone as one single eruptive event perhaps lasting hours or days, a time frame that also accounts for mafic eruptions of similar size (Heiken, 1978; Fisher and Schminke, 1984; Cas and Wright, 1987).

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