Calculation of Erosion Rates Based on Remnants of Monogenetic Alkaline Basaltic Volcanoes in the Bakony–Balaton Highland Volcanic Field (Western Hungary) of Mio/Pliocene Age

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ABSTRACT. The Mio/Pliocene Bakony–Balaton Highland Volcanic Field (BBHVF) consists of erosional remnants of maars, tuff rings, scoria cones and lava flows. Post-volcanic erosion of ~100 m is calculated with the elevation difference between pre-volcanic and volcanic unit contacts and surroundings where subhorizontal contacts or constructional volcanic edifices were identified. Where pre-volcanic and volcanic units have steep contacts, intra-vent facies or collapsed crater rim units are identified, the post-volcanic erosion of ~200–300 m results in the elevation difference between the top of the volcanic remnant and the surrounding, corrected with an X. Estimation of X is based on: 1) pyroclastic facies, 2) field relationships, and 3) proportion and types of accidental lithic clasts. Diatreme-filling rocks with sedimentary grains derived from already eroded Pannonian sediments evidence Pannonian sedimentary cover in syn-volcanic time. Erosion between the end of the Pannonian sedimentation (~ 8 Ma) and the volcanism was calculated using two approaches: 1) the same post-volcanic erosion rates prior to volcanism, or 2) a uniform erosion rate considering field evidences (10 to 100 m/M.y.). The total thickness of Pannonian sedimentary cover is estimated to be ~250–900 m.

KEY WORDS: paleosurface, phreatomagmatic, diatreme, scoria, basaltic, fluvial, erosion, Pliocene, Pannonian Basin.

Introduction

The Bakony–Balaton Highland Volcanic Field (BBHVF) is a Mio/Pliocene (7.54 to 2.8 Ma) (Balogh et al. 1982, Borsy et al. 1986, Balogh 1995) alkaline basaltic, intracontinental, monogenetic volcanic field. It largely comprises variable eroded tuff rings, maars, scoria cones and lava flow fields with at least 50 volcanoes over an area of ~3500 km^2 (Jugovics 1969, Jámbor et al. 1981, Németh and Martin 1999a) (Fig 1). The basement of the volcanic field consists of Silurian schist, Permian Red Sandstone and Mesozoic carbonate sediments. In the Neogene, shortly before the volcanism started, a large lake occupied the Pannonian Basin (Pannonian Lake) (Kázmér 1990). This lake diminished at ~ 8 Ma from the area of the BBHVF (Magyar et al. 1999). Volcanism occurred a few million years after the Pannonian Lake disappeared.

Erosion after the end of the Pannonian sedimentation as well as the initial thickness and the maximum extent of the Pannonian sediments are key issues of the geological research in the BBHVF. Based on the erosional level of the volcanoes, an estimation of the thickness of the Pannonian sediments was made. This paper provides field evidence showing that the erosion rate could not exceed a few tens of metres per million years, and that the total thickness of the Pannonian sediments did not exceed 450 m.

Method

The calculation of erosion rate can be separated into two steps; 1) estimation of erosion since the start of volcanism, and 2) estimation of erosion between the end of Pannonian sedimentation and the start of volcanism (Fig. 2). In general, it is accepted – based on lithofacies and field relationships of lacustrine beds, seismic sections, and paleontological evidence (Magyar et al. 1999) – that sedimentation in the Pannonian Lake (<50 m water depth) terminated at 8 Ma in the BBHVF region. However, large open-surface water masses (<20 m in depth) may have existed for some time after the disappearance of the Pannonian Lake. K/Ar ages of volcanic rocks in the BBHVF suggest a long-lasting activity (7.56 to 2.8 Ma) (Balogh et al. 1982). The calculation of erosion rate was started with the estimation of erosion after the end of volcanic activity (post-volcanic erosion). Following

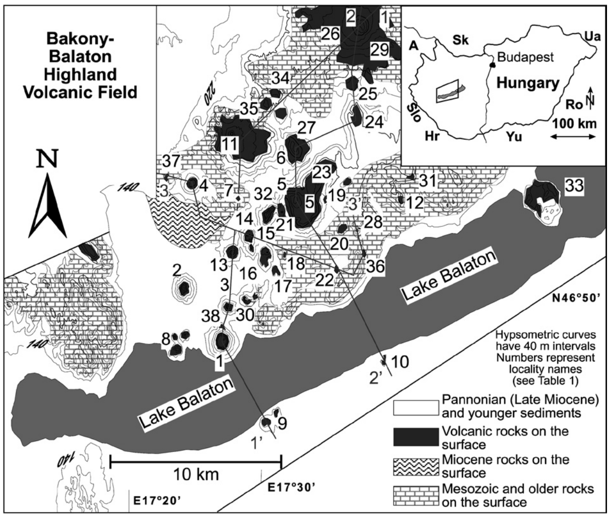

Fig. 1. Simplified geological map of the Bakony–Balaton Highland Volcanic Field (BBHVF). Numbers represent erosional remnants of volcanic edifices.

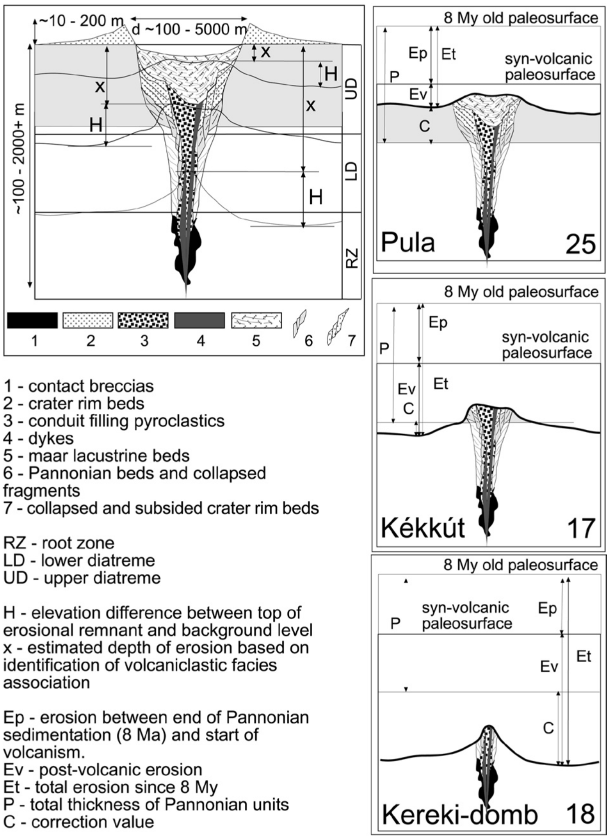

Fig. 2. Model of a monogenetic phreatomagmatic volcano. Note the 3 different stages of erosional levels that can be established by the identification of different volcanic lithofacies. Abbreviations correspond to Table 1.

this calculation, pre-volcanic erosion was calculated estimating the same erosion rate as for the post-volcanic time. For realistic estimates, a brief evaluation is given to estimate the erosion potential for each point in the BBHVF on the basis of field evidence.

Erosion rate after the end of volcanic activity – post-volcanic erosion

To estimate post-volcanic erosion, volcanic lithofacies were studied at each erosional remnant of volcanic rocks. Identification of different volcanic facies allowed to establish the level of exhumation of crater-filling deposits, vent zones or deep subsurface structures of individual volcanoes such as maars, tuff rings or scoria cones (Fig. 2). Relative proportions of different pyroclastic facies as well as the type of bedding allow to estimate the position of the present exposures below syn-volcanic paleosurface (Fig. 2). As indicated by the presence of angular sideromelane glass shards and large proportion of accidental lithic clasts in the pyroclastic rocks (Fisher and Schmincke 1984), most of the volcanic remnants were produced by subsurface phreatomagmatic explosive eruptions. Most of the original landforms are interpreted as negative forms (e.g., maars, tuff ring craters); however, most of them were subsequently filled by Strombolian scoria cones or lava lakes. Using geometrical relationships between crater depth and width as well as thickness of crater rim deposit (Lorenz 1986), an estimation for the size of the original volcanic landform and the present level of erosion was given for each site (Németh and Martin 1999b). Detailed analyses of thin sections and hand specimens of the pyroclastic units revealed quartz, quartzo-feldspatic aggregates, plastically deformed mud chunks (mm to cm scale), and mus-

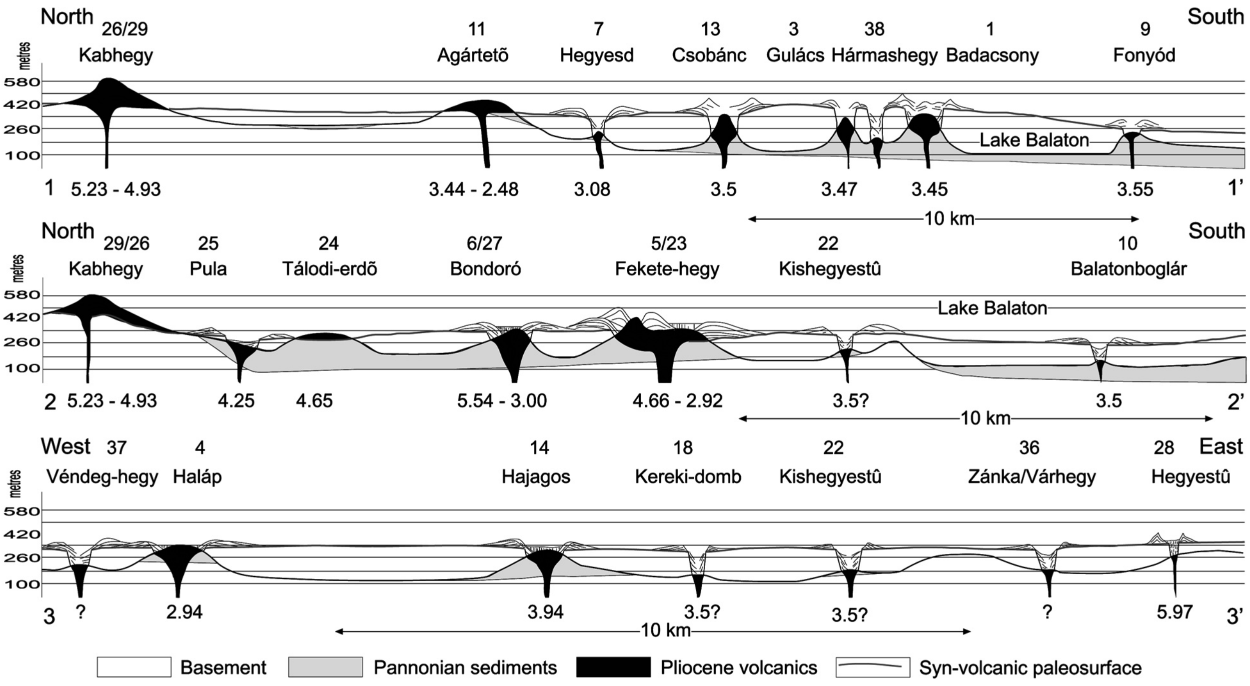

Fig. 3. Cross sections and reconstructed syn-volcanic paleosurfaces across the BBHVF.

Locality	Age [My]	Ev [m]	EvR [m/My]	T [My]	Ep1 [m]	Et1 [m]	Ep2 [m]	Et2 [m]	C [m]	P [m]
1. Badacsony	3.45	270	78	4.55	355	625	46	316	+100	725/416
2. Szt.györgy-hegy	2.80	270	96	5.20	499	769	52	322	+100	869/422
3. Gulács	3.47	260	75	4.53	340	600	45	305	+100	700/405
4. Haláp	2.94	208	71	5.06	359	567	51	259	−50	517/209
5. Fekete-hegy	2.92	210	72	5.08	367	577	51	261	−100	477/161
6. Bondoró-hegy	3.00	180	60	5.00	300	480	50	230	−50	430/180
7. Hegyesd	3.08	180	58	4.92	285	465	49	229	−100	365/129
8. Szigliget	3.40	222	65	4.60	299	521	46	268	+150	671/418
9. Fonyód	3.55	142	40	4.45	178	320	45	187	+150	470/327
10. Boglár	3.50	130	37	4.50	166	296	45	175	+150	446/225
11. Agártetõ	3.44	150	44	4.56	201	351	46	196	−100	251/96
12. Tagyon	3.26	?	?	4.74	?	?	?	?	?	?
13. Csobánc	3.50	225	64	4.50	288	513	45	270	+50	563/320
14. Hajagos-hegy	3.94	180	46	4.06	187	367	41	221	+100	467/321
15. Kopasz-hegy	3.5?	160	46	4.50	207	367	45	205	−50	317/165
16. Pipa-hegy	3.5?	160	46	4.50	207	367	45	205	−50	317/165
17. Kékkút	3.5?	160	46	4.50	207	367	45	205	−100	267/105
18. Kerekimajor	3.5?	80	23	4.50	104	184	45	125	−50	134/75
19. Öreg-hegy	3.5?	90	26	4.50	117	207	45	135	+100	307/235
20. Horog-hegy	3.5?	192	55	4.50	248	440	45	235	−100	340/135
21. Füzes-tó	3.5?	160	46	4.50	207	367	45	205	−50	317/165
22. Kishegyestû	3.5?	178	51	4.50	230	408	45	226	−50	458/276
23. Fekete-hegy N	4.66	180	39	3.34	130	310	33	213	−100	210/113
24. Tálodi-erdõ	4.65	82	18	3.35	60	142	34	116	+150	292/266
25. Pula	4.25	120	28	3.75	105	225	36	156	+100	325/256
26. Kabhegy	4.93	200	41	3.07	126	326	31	231	−100	226/131
27. Bondoró	5.54	180	32	2.46	79	259	25	205	−50	209/165
28. Hegyestû	5.97	166	28	2.03	57	223	20	186	−100	123/86
29. Kabhegy (old)	5.23	–	–	2.77	–	–	–	–	–	–
30. Tóti-hegy	5.71	256	45	2.29	104	360	23	279	+100	460/379
31. Tagyon2	5.69	229	40	2.31	92	321	23	252	−100	221/152
32. Sátorma	4.53	184	41	3.47	142	326	35	219	−50	276/169
33. Tihany	7.54	232	31	0.46	14	246	5	237	+150	396/287
34. T.dörögd	4.50	–	–	3.50	?	?	?	?	?	?
35. T.dörögd	4.50	–	–	3.50	?	?	?	?	?	?
36. Zánka/Várhegy	6.0?	160	27	2.00	54	214	20	180	−100	114/80
37. Véndeg-hegy	3.0?	140	47	5.00	235	375	50	190	−50	325/140
38. Hármashegy	3.5?	220	63	4.50	284	504	45	265	+100	604/365

Tab 1. Volcanic erosional remnants of the BBHVF. Locality numbers correspond to locations in Fig. 1. Age data from Balogh et al. (1982), Borsy et al. (1986) and Balogh (1995). Abbreviations: Ev – post-volcanic erosion, EvR – post-volcanic erosion rate, T – time between end of Pannonian sedimentation and beginning of volcanism, Ep1 – erosion between end of Pannonian sedimentation and beginning of volcanism calculated with the same erosion rate estimated for post-volcanic time, Et1 – total erosion using Ep1 and Ev, Ep2 erosion between end of Pannonian sedimentation and beginning of volcanism calculated with low erosion rates (10 m/M.y.), Et2 – total erosion using Ep2 and Ev, C – correction value, P – total thickness of Pannonian sediments.

covite. All of these components are characteristic of Pannonian sediments. They were present in each of the phreatomagmatic pyroclastic rocks studied. This observation indicates that the Pannonian sedimentary cover was still complete during volcanism in the BBHVF, and of larger areal extent than today. It is concluded that post-volcanic (Pliocene) erosion rates vary between 18 and 96 m/M.y.; however, most of the calculations fall around 50 m/M.y. (Németh and Martin 1999b). Re-establishing the syn-volcanic paleosurfaces in the region, a uniform surface can be drawn with relative elevation fluctuations below 100 m (Fig. 3). As suggested by the widespread phreatomagmatic eruptive activity in the BBHVF, most of the volcanic remnants lie in hydrogeologically active zones such as syn-volcanic valleys.

Erosion rate between end of Pannonian sedimentation and volcanism – pre-volcanic erosion

Calculation of the pre-volcanic erosion rate in the area is problematic. Little direct field evidence is available to help reconstructing paleosurfaces for times prior to 8 Ma. The use of the same erosion rates for pre-volcanic times as for post-volcanic times would imply that the erosional potential was the same ever since the end of Pannonian sedimentation. Based on this simplification, the amount of erosion since the end of the Pannonian sedimentation would be more than twice larger than the amount of erosion since the end of volcanic activity. The total thickness of accumulated Pannonian sediments in the area would have exceeded 800 m in basins with an estimated erosion of more than 600 m (Table 1). However, the field evidence indicates that erosion rates must have been lower before the volcanism than after the end of volcanic activity.

The youngest deposits of Pannonian age in the BBHVF are lacustrine limestones (Nagyvázsony Mészkõ Formation – NMF). These are intercalated with strongly altered basaltic tuff (Budai and Csillag 1998) inferred to be deposited from phreatomagmatic eruptions of the oldest volcanoes of the region (Tihany, 7.54 Ma) on the basis of its textural characteristics. The limestones tend to form an extensive plateau, marking the aerial distribution of a closed laguna developed in the final stage of Pannonian sedimentation. Extensive lava flows derived from the volumetrically largest volcano of the BBHVF (Kabhegy, scutulum-type shield) were observed to overlie the youngest Pannonian units (NMF) at uniform elevation (~300 m a.s.l.). As indicated by the K/Ar age, textural and compositional similarities, mineral orientation and drill core data, lava sheets of the major shield volcano (Kabhegy) can be correlated with dissected lava sheets located south of this center (Tálodi erdõ)(Jámbor et al. 1981). The large (10 km-scale) extent of lava on a uniform elevation and the undisturbed contact between lava and limestone suggest that the paleosurface on which the lava erupted was flat with insignificant fluvial incision and poorly developed valleys. The age difference between these lavas (~5 Ma) and the cessation of Pannonian sedimentation (~8 Ma) suggests that the interval of ~3 M.y. was not long enough to develop a significant valley system. A low erosion rate of e.g. ~10 m/M.y. was inferred for the region in pre-volcanic times (Table 1). Based on these calculations, the total erosion after the end of the Pannonian sedimentation can be maximalized to ~300 m, while the total thickness of the Pannonian sediments accumulated in the region was calculated at ~450 m (Table 1).

Conclusion

Based on the analyses of the erosional remnants of monogenetic volcanoes, the following conclusions can be made:

1) the post-Pannonian erosion must be separated into two stages; a) prior to the start of Mio/Pliocene volcanism, and b) between the Mio/Pliocene volcanism and present;
2) post-volcanic erosion rates vary between ~20 and 100 m/M.y., resulting in a total erosion of 80 to 270 m of predominantly Pannonian sediments;
3) by reconstructing the Pliocene syn-volcanic paleosurface, a remarkable flat landscape can be drawn with a total geomorphic relief of less than ~100 m;
4) considering that most of the volcanoes had at least an initial phreatomagmatic eruptive phase, their position marks local lowlands;
5) the total thickness of the Pannonian sedimentary cover is estimated at 250 to 900 metres prior to erosion starting at ~8 Ma, most realistically being not higher than 450 m;
6) Pannonian sedimentary cover must have been still widespread in the region before volcanism started. Pannonian sediments were only stripped away from elevated ridges.

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