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Eroded porous-media aquifer controlled hydrovolcanic centers in the South Lake Balaton Region, Hungary: The Boglár Volcano

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The volcanic centers next to Balatonboglár township represent 3.5 Ma old products of post-extensional alkaline basaltic volcanism in the Pannonian Basin (eastern Central Europe). They are small, eroded volcanic centers located on the southern shore of Lake Balaton and genetically related to the Bakony–Balaton Highland Volcanic Field eruptive centers. The relatively small area (500 m x 500 m) contains at least 2 eruptive centers, which are probably related to each other and have built up a complex volcano, called the Boglár Volcano. The volcanic rocks overlie the older Pannonian clastic sedimentary sequence and represent the topographic highs in this area. The areas of lower elevation around the eruptive centers are covered by Pleistocene to Holocene swamp, lake and river clastic sediments, which strongly suggest intense erosion during the last few million years. All volcanic rocks around Balatonboglár are volcaniclastic. There is no evidence of lava flow occurrence. The volcaniclastic sediments have been divided into two lithofacies associations. The largest amount of volcaniclastic rocks is located in the center of the local hills and has been interpreted as a phreatomagmatic crater fill lapilli tuff. They contain large amphibole megacrysts and small olivine crystals. The second lithofacies association is interpreted as lahar deposits. This sequence contains an unusually large amount of fossil tree trunks, which are identified as *Abies* species. Within a small area in the western hills small outcrops show evidence of maar-lake clastic sediment occurrence. On the hilltops debris shows intimate interaction processes between clastic sediments and basaltic melt. We interpret this to mean that the eruptive centers of Boglár Volcano were formed under subaerial conditions, with explosions fueled by intensive interaction between water-saturated Pannonian sand and uprising basaltic magma.

Key words: phreatomagmatism, hydrovolcanism, diatreme, maar, strombolian, Pannonian Basin, Bakony–Balaton Highland Volcanic Field

Introduction

A wide variety of volcanic activities characterizes the Neogene in the Pannonian Basin. Following Miocene to Quaternary subduction-related calc-alkaline volcanism in the northeastern margin of the Pannonian Basin and syn-extensional Middle Miocene intermediate to acidic and potassic to ultrapotassic magmatism, widespread post-extensional alkaline basaltic volcanism occurred between the Late Miocene and the Quaternary. It is known

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that alkaline basaltic and calc-alkaline volcanism was also contemporaneous in several places, e.g. Harghita (Harangi, in press). The alkaline basaltic volcanoes can be found either near the calc-alkaline stratovolcanic complexes or far from them, at the central part of the Pannonian Basin (Szabó et al. 1992). The Bakony–Balaton Highland Volcanic Field (BBHVF) is located about 170 km southwest of Budapest (Fig. 1) and comprises more than 50 basaltic volcanoes (e.g. Jugovics 1968; Jámbor et al. 1981) including shield volcanoes, tuff rings and maars. The Boglár Volcano is genetically part of the BBHVF but is geographically separated from it by Lake Balaton. Only two areas are known as volcanic eruptive centers on the southern shoreline of Lake Balaton, Fonyód and Boglár. The few studies of the underlying thick Pleistocene and Holocene sediments in the Lake Balaton Basin show no evidence of buried volcanic edifices in the region nor is there evidence of other surface eruptive centers in the southern shoreline region. The Boglár Volcano eruptive centers probably lie on the north–south trending Tapolca Basin tectonic line (Borsy et al. 1986) and which forms elongate, young, sediment-filled basins (Tapolca Basin in the north; Nagyberek Region to the south). Fonyód and the Boglár Volcanoes represent erosional remnants above this basal geomorphologic structure. The studied area consists two of main morphological highs, Várdomb (Castle Hill) (up to 165 m a.s.l.) and the smaller Temetődomb (Graveyard Hill) (up to 145 m a.s.l.). There is a small morphological high next to the Temetődomb, called Sándordomb (Alexander Hill) (up to 128 m a.s.l.). All of the three major elevated areas are covered by volcanic rocks. K/Ar age determination of rock samples from Boglár give an age of around 3.5 Ma (Borsy et al. 1986; Balogh, pers. com.). Early geologic mapping showed this region as explosion breccia-buried hills with small-scale lava flows (e.g. Lóczy 1894, 1913).

Physical volcanology

The volcaniclastic deposits of the Boglár Volcano can be divided into three main lithofacies (associations) based on the relative amount of accidental lithic clasts, style of sedimentary structures and textural characters (both at microscopic and macroscopic scales). A fourth lithofacies can be identified as volcanogenic clastic sediment from Holocene talus debris. These lithofacies are:

1. *Phreatomagmatic crater filling coarse-grained lapilli tuff lithofacies association (PXLT)*
2. *Reworked volcaniclastic lapilli tuff (lahar?) lithofacies association (LT)*
3. *Peperite lithofacies association, mixture of lava and Pannonian clastic sediments (MX)*
4. *Maar lake sandstone lithofacies association (ML).*

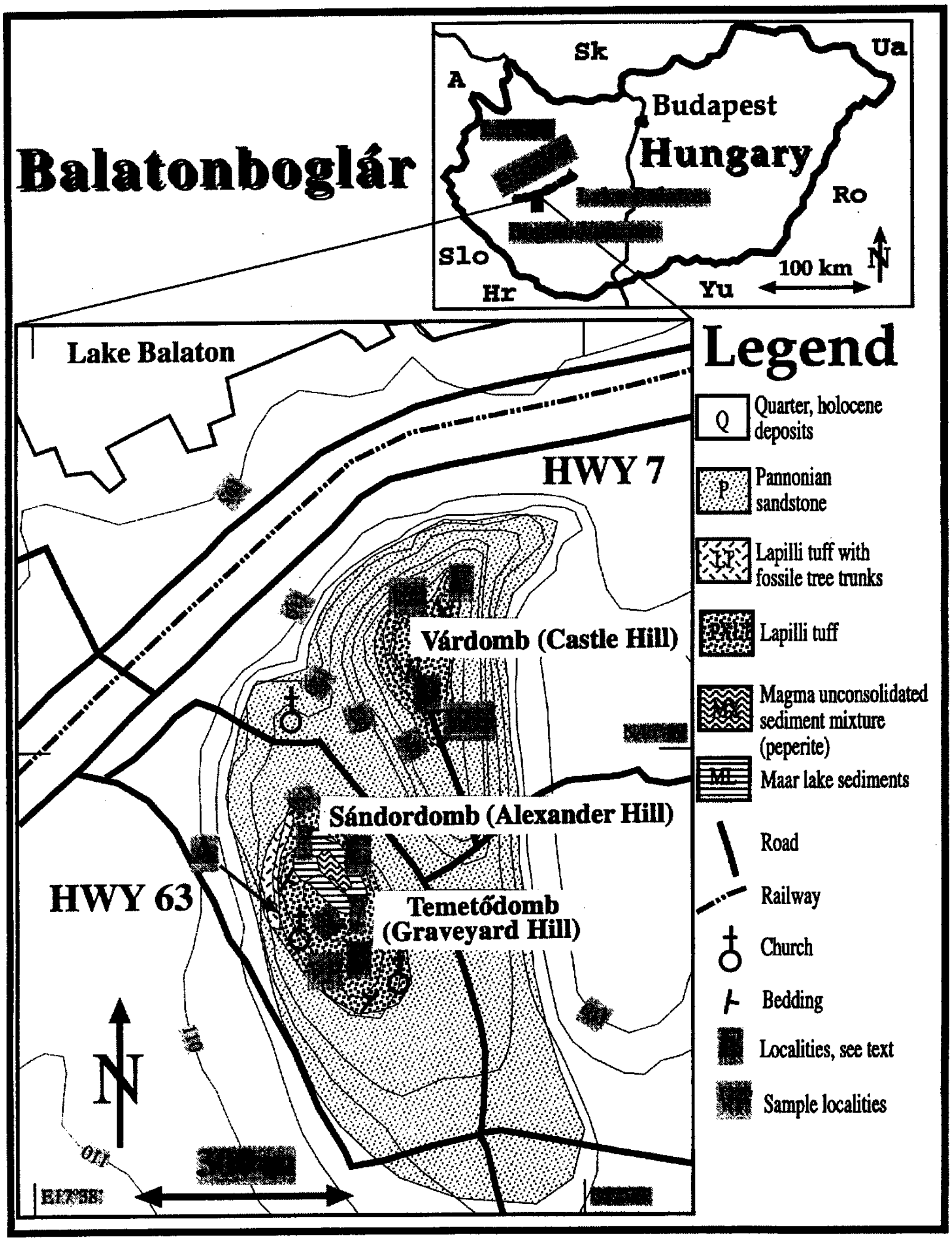

Fig. 1
Geologic map of the Boglár Volcano

Phreatomagmatic crater filling coarse-grained lapilli tuff lithofacies association (PXTL)

Description – This is the main volcanic lithofacies association in the region; it occurs on all three hilltops. The PXLT is characterized by poorly sorted, slightly bedded, brown lapilli tuff. In none of the measured sites is there any well-defined bedding. Where the bedding is relatively well developed (Várdomb, Castle Hill) measurements are always very diverse without any well-defined characteristic orientation. The dip is always steep, around 25°. In the bedded part of the sequence there is no evidence of impact sags, cross-bedding or well-defined scour fill structures. The individual beds are usually undulating with no characteristic upper and lower contact. The lithofacies contains high amounts of juvenile fragments (70 vol.-%) as unsorted vesiculated basaltic lapilli fragments which are usually palagonitized or show palagonitization processes occurring inside the clast center (Fig. 2a). Juvenile fragments can be separated into two groups. Clasts in the first group are characterized by black, highly vesiculated, usually large, rounded and semi-rounded scoriaceous lapilli. In the second group clasts are mostly light brown to yellowish, less vesiculated sideromelane fragments with small, mostly feldspathic, microliths. The vesicles are usually rounded and slightly asymmetric in shape. Often vesicles of both types of juvenile fragment are filled by secondary minerals – mostly calcite, minor zeolite – or fine grained altered sandstone fragments. There is not more than 20 vol.-% of accidental lithic fragments. Accidental lithic fragments consist mainly of sand fragments, probably from the Pannonian sandstone formations (75 vol.-% of the total accidental lithics) (Fig. 2a and Fig. 2b). There is also a low proportion of carbonate fragments (marl, limestone), probably of Mesozoic age, from depth (10–15 vol.-% of the total accidental lithics). Occasionally there are small schist fragments (probably Silurian phyllite), and a few fragments of crystalline basement rock (gneiss), but their origin is unclear because of lack of data on the basement stratigraphy of Boglár Volcano. Usually the accidental lithics are angular to semi-angular. The matrix of the samples contains strongly to slightly altered volcanic glass. Often small sandstone and silt aggregates are visible which represent intimate mixtures with the palagonitized glassy matrix. The matrix usually contains small, rounded, ovoid glauconite fragments, probably from the underlying Pannonian sandstone beds. In several samples strong carbonitization is visible. The large elongate calcite crystals occur along margins of the large clasts and show pore-fill structures. Fine-grained sand, silt and altered glass-coated lapilli are common. Free crystal proportions in the PXLT are relatively high (few vol.-% of total). They are usually brown amphibole (up to 2 cm in diameter) and altered olivine (up to 0.5 cm in diameter) in mostly idiomorphic crystals (Fig. 3).

The juvenile glass shards are very fresh, and their composition is trachy basalt from each locality (Table 1), according to electron microprobe analyses

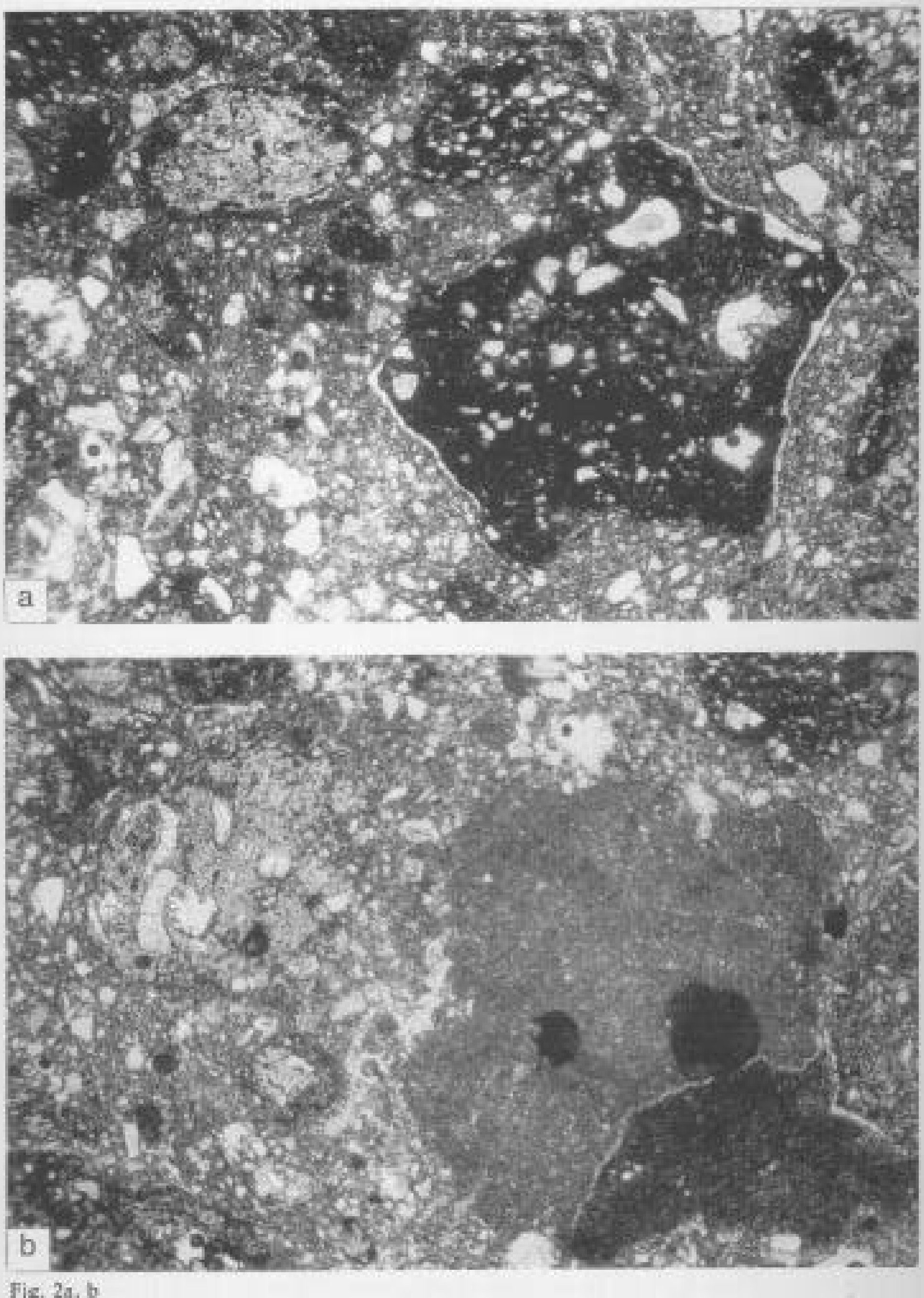

Fig. 2a, b
Photomicrographs of the PXLT lithofacies from locality D (see Fig. 1). In both pictures the shorter side of the picture is 2 mm. Note the bright, white-colored, small, angular fragments. They are quartz fragments derived from the Pannonian clastic deposits. In Fig. 2a note the difference between sideromelane (small, microvesiculated, slightly rounded, elongate lighter colored shard in the top/left corner) and tachylite glass shards (large, angular black fragment in the middle of the picture)

Table 1
Geochemical composition of volcanic glass shards from pyroclastic rock samples from three different localities. Locality names are shown in Fig. 1. Electron microprobe analyses were carried out on JEOL 8600 Superprobe, 15 kV acceleration voltage, 10–20 μm beam diameter on polished thin sections, OXIDE9 standard. $Fe_2O_3/FeO = 0.3$ using Middlemost (1989) classification

VD		CIPW Norm		$Fe_2O_3/Fe) = 0.3$			
SiO_2	49.53	Q		ns		cs	
TiO_2	3.03	C		ks		mt	3.09
Al_2O_3	19.19	Z		di	9.99	cm	
Fe_2O_3	2.13	or	21.39	*wo*	5.10	il	5.75
FeO	7.11	ab	18.36	*en*	2.89	hm	
MnO	0.13	an	31.93	*fs*	2.00	tn	
MgO	3.79	lc		wo		pf	
CaO	8.90	ne		hy	3.66	ru	
Na_2O	2.17	kp		*en*	2.16	ap	
K_2O	3.62	hl		*fs*	1.50	fr	
P_2O_5	n.m	th		ol	5.42	pr	
H_2O	n.m	nc		*fo*	3.07	cc	
Total	99.60	ac		*fa*	2.34	H_2O	
							Trachy-basalt
VD3		CIPW Norm		$Fe_2O_3/Fe) = 0.3$			
SiO_2	49.29	Q		ns		cs	
TiO_2	3.26	C		ks		mt	3.41
Al_2O_3	17.48	Z		di	18.03	cm	
Fe_2O_3	2.35	or	19.86	*wo*	9.14	il	6.19
FeO	7.82	ab	19.31	*en*	4.77	hm	
MnO	0.12	an	26.82	*fs*	4.11	tn	
MgO	3.38	lc		wo		pf	
CaO	9.82	ne	0.72	hy		ru	
Na_2O	2.44	kp		*en*		ap	
K_2O	3.36	hl		*fs*		fr	
P_2O_5	n.m	th		ol	4.98	pr	
H_2O	n.m	nc		*fo*	2.56	cc	
Total	99.32	ac		*fa*	2.43	H_2O	
							Trachy-basalt
VF		CIPW Norm		$Fe_2O_3/Fe) = 0.3$			
SiO_2	49.87	Q	0.18	ns		cs	
TiO_2	3.24	C		ks		mt	3.28
Al_2O_3	18.17	Z		di	13.65	cm	
Fe_2O_3	2.26	or	18.26	*wo*	6.94	il	6.15
FeO	7.55	ab	18.11	*en*	3.78	hm	
MnO	0.15	an	30.85	*fs*	2.92	tn	
MgO	3.59	lc		wo		pf	
CaO	9.57	ne		hy	9.17	ru	
Na_2O	2.14	kp		*en*	5.17	ap	
K_2O	3.09	hl		*fs*	4.00	fr	
P_2O_5	n.m	th		ol	5.42	pr	
H_2O	n.m	nc		*fo*	3.07	cc	
Total	99.63	ac		*fa*	2.34	H_2O	

Fig. 3
Photomicrograph of the amphibole crystals in the pyroclastic sample from the PXLT lithofacies association at locality D (see Fig. 1). The shorter side of the picture is 2 mm

(Jeol 8600 Superprobe, 15 kV acceleration, 10–20 μm beam diameter, polished thin section, OXIDE9 standard) of fresh glass shards (98 vol.-% of total).

Interpretation – The PXTL lithofacies association is interpreted as crater-filling, coarse-grained lapilli tuff. The two major kinds of juvenile fragment (sideromelane and tachylite glass) show evidence of phreatomagmatic explosive processes during the eruptive history with strong magmatic influence. The lighter colored volcanic glass (sideromelane) originated from the magma-water interaction (Wohletz and Sheridan 1983; Sheridan and Wohletz 1983; Houghton and Hackett 1984; Houghton and Schmincke 1985; Fisher and Schmincke 1994) but the black scoriaceous fragments are more likely to be Strombolian magmatic explosive products (Houghton and Schmincke 1985; Houghton and Hackett 1984). The steeply dipping beds, the wide variety of dip direction in a small area, the very steep contact zone with the underlying Pannonian sandstone beds with small microfaults and the circular distribution of the lithofacies strongly suggests a near vent situation. This agrees with the descriptions of Lorenz (1986), Cas and Wright (1987) and White (1991b) of near vent deposits related to small monogenetic alkaline basaltic volcanic centers. The high amount of sandstone, siltstone fragments in the matrix, and intimate mixing with the altered glass matrix infers intimate mixing of probably water saturated unconsolidated sand and uprising basaltic magma, leading to phreatomagmatic explosions. The presence of large amounts of vesiculated sideromelane glass and scoriaceous tachylite fragments is suggestive of subaerial conditions during eruption according to Cas and Wright (1987), Fisher and Schmincke (1984) and McPhie et al. (1993). The diffuse bedding and geometrically well-defined altered zones in single rock fragments indicate some thermal, and probably hydrothermal, disturbance which could also be interpreted as a near vent depositional environment. The very strong carbonitization and palagonitization could be related to wet and probably hot environments, such as the vent zone of eruptive centers. The low proportion of deep-seated lithic fragments indicates that the Pannonian sand column was high, resulting in the explosive process controlled by the water content of the porous-media aquifer, producing normal maar volcanic centers as described by Lorenz's (1986) model. Following continuous drying of the porous-media aquifer, Strombolian magmatic explosive activity took place inside the local maar basin(s), a process well known in other maar volcanic fields where the maars are developed on thick clastic (porous media aquifer) beds (e.g. Lorenz 1986; White 1991b). In these zones strong reworking occurred, mixing primary hydrovolcanic explosion-generated fragments (sideromelane glass shards) with magmatic ones (tachylite glass shards), a similar process to that described by Houghton and Smith (1993).

The PXTL lithofacies association is located on the upper slopes of each hillside. There are no significant petrographic, petrological, textural and compositional differences between samples from these three localities. Because two of these hillsides are separated from each other by Pannonian clastic deposits outcropping in-between they can be interpreted as remnants of individual eruptive centers, but there is not enough field evidence to reconstruct the exact locality and number of eruptive centers. The similar characteristics of the deposits on each hillside also suggest that there was a volcanic complex with individual vent sites which, following erosion, now represent the hills around Boglár.

Reworked volcaniclastic lapilli tuff (lahar?) lithofacies association (LT)

Description – It is a max. 10–15 m thick (visible thickness) lithofacies in the western corner of the Temetődomb (Graveyard Hill) which consists of a very chaotic, structureless, light brown, sandy lapilli tuff. This lithofacies contains, high proportion of unsorted fine to coarse-grained, light yellowish sand matrix (70 vol.-% of total volume), comprised of a mixture of altered volcanic glass and Pannonian sands. There are no signs of well-defined bedding or of any systematic distribution of large clasts. The matrix of the lithofacies is weakly cemented and friable. The upper and lower contacts are not currently exposed, but there is strong evidence for identifying this lithofacies as that described as chaotic explosion breccia by Lóczy (1894, 1913). That description reports that the volcaniclastics have a sharp contact with the Pannonian sandstone, with abundant microtectonic features. The lithofacies association is dominantly composed of accidental lithic fragments (visual estimation: 90 vol.-% of total volume). The lithofacies association contains a high proportion of rounded, semi-rounded, thermally affected Pannonian sandstone pebbles (visual estimation: 75 vol.-% of the total volume of large – 1 cm clasts, up to 10 cm in diameter). The Pannonian sandstone pebbles have no impact character or string orientations. A few large (up to 10 cm in diameter) altered, palagonitized, micro-vesicular basaltic fragments also occur in this lithofacies. The tree trunks are usually covered by greenish, strongly altered tuffs (Fig. 4). The high amount of tree trunk fossils have a wide size range, from 1–2 cm in length to pieces up to 40–50 cm long and 10–15 cm wide (Fig. 5). The larger, concave shape juvenile or lithic fragments also contain altered fine-grained rims of varying thickness.

Interpretation – The chaotic structure of different lithologies in a very altered sandy matrix, and presence of altered tuff rimmed larger fragments, strongly suggests reworking processes, for instance deposition by lahars. The characteristic

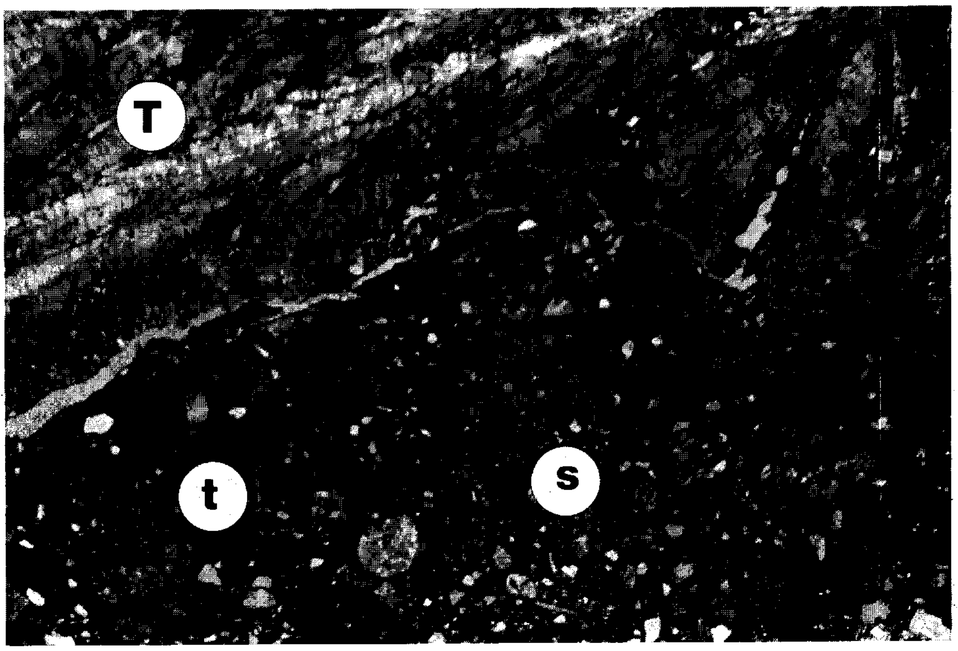

Fig. 4
Photomicrograph of the tree trunk and host rock in thin-section. The shorter side of the picture is 2 mm. T – tree fossile, t – trachylite, s – sideromelane

Fig. 5
Photo of the lahar deposit with tree trunks at locality A (see Fig. 1)

sharp contact of the Pannonian clastic sediments result from valley fill deposition of the sediment, or of a small volume of strongly reworked-recycled, vent-filling deposits of a local basically phreatic explosion center. The large amount of sandy matrix and matrix-supported large clast-bearing character is interpreted as a cohesive debris-flow deposit in which the massive, matrix-supported pebbly mudstone (thermally affected Pannonian sandstone fragments) and tree trunk fragments were suspended in and supported by the matrix according to Lowe's (1982) model. In this interpretation we describe this lithofacies as a lahar deposit, which means rapid water-supported flows of volcaniclastic particles generated on volcanoes (Smith and Lowe 1991; McPhie et al. 1993).

Peperite lithofacies, mixture of lava and Pannonian clastic sediments (MX)

Description – In a very small area on the top of the Temetődomb (Graveyard Hill) several unusual rock samples (with 10–35 cm diameter) were found (Fig. 6). The original source of the samples is unknown but is probably not far away from the locality where they are found, because this is locally the highest elevated area in the region. The samples consist of a mixture of fine-grained sand and scoriaceous juvenile fragments. The juvenile fragments are black, highly vesiculated, and very glassy. The vesicles reach 1 cm in diameter and are usually rounded with a smooth inside surface. The contact between the original sand/silt region and the original juvenile fragments is diffuse. Several alignments are clearly visible as a string of small vesicles and fresh sandy or muddy, "untouched" relict sand fragments. The transition between the juvenile fragments and the sandstone is usually continuous. Next to the large juvenile fragments the original sandstone/siltstone fragments are melted and probably mingled together with the original basaltic melt.

Interpretation – The wide range of characteristic fragments on top of Temetődomb (Graveyard Hill) are interpreted as peperite fragments. Peperites form when hot lava intrudes into wet unconsolidated sediments (Fisher 1960; Williams and

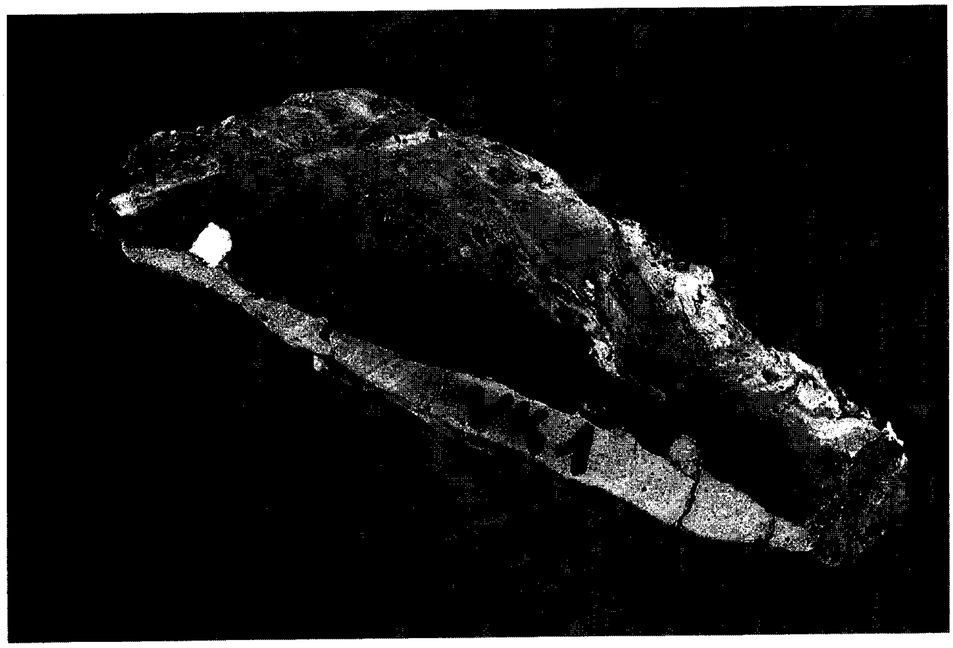

Fig. 6
Picture of the peperite. The shorter side of the picture is 15 cm. Note the irregular shaped dark, scoriaceous fragment in the middle of the sample in a light color sand matrix

McBirney 1979; Busby-Spera and White 1987). They are characterized by a clastic texture in which either component may form the matrix. This description clearly fits the observed character of samples from Temetődomb (Graveyard Hill). Using the classification of Busby-Spera and White (1987) we can classify the peperite from Boglár as globular-type peperite, where the host sediment was probably unconsolidated water-saturated and fine-grained, as the Pannonian sand must have been during the eruptive history of the Boglár Volcano.

Maar lake sandstone lithofacies (ML)

Description – There are several intercalated, thin (5–25 cm), well-cemented sandstone beds in the northern sector of the Temetődomb (Graveyard Hill) area. The sandstone beds are more abundant toward the upper part of the theoretical stratigraphic column. There is no well-exposed section where the stratigraphic section is easily measurable. The deposits in several cases contain large amounts of carbonate matrix and become laminated, coarse-grained, and unsorted. The sandstone is pink to light gray. The matrix of the sandstone contains small altered volcanic glass shards with feldspathic microliths, free broken brown amphibole, feldspar fragments and several small rounded tuff fragments. Rounded glauconite clasts are also present.

Interpretation – The intercalated sedimentary layers, which contain several clasts of volcanic origin, suggest that the sediment is a post-eruptive, probably maar lake sediment. The large amount of quartz fragments implies an abundant sand source from the Pannonian sand beds, which makes up a large part of the volcaniclastic products.

Paleobotany

The fossil trees are unsorted and unoriented in the volcaniclastic matrix. The studied sample is angular in shape, with numerous cracks filled either by iron hydroxides or matrix of the host rock. It is a decimeter size fragment of secondary xylem, strongly deformed. Hence, its shape does not allow any inferences about the original size of the tree. It has been studied under the number MP 917. The preservation is poor. The wood is epigenized by hyperblastic calcite. Locally however, in the cracks, some tracheids have been epigenized by pyrite and subsequently oxidized into iron hydroxides. These processes preserve the original wood structure quite well. However, pits were observed only in a small area. Some other tracheids have been cast by the matrix, but not delicately enough to preserve the tracheid pits. It has been studied with Collodion casts. The Tracheidoxyl (i.e. an isolated secondary xylem compound unique to tracheids) has faint but marked growth rings. Radial pitting is typically abietinean with either spaced round pits or biseriate opposite ones. Quite frequently pits are in contact, somewhat flattened. Rays are heterogeneous including tracheids at their edges. The ray cell walls are quite thick and the transversal ones are pitted. The cross-fields are occupied by two oculipores. Axial parenchyma and resin channels have not been observed. Although observations were possible in only a very small area (2 x 1 mm), because of the poor preservation, the general pattern indicate quite safely the genus *Abies*. The genus *Abies* is a frequent component of paleoarctic biota, particularly fresh and temperate settings. It has been reported from the entire Neogene. It is thus not a very good indicator, either from a paleoecological or a stratigraphic point of view. Extant Abies, at least in Europe, prefer temperate to fresh temperate climates with a regular water supply. They are often found in mountains. Although they can grow on boggy grounds, they usually avoid wet areas. There is no hint of charcoal on the surface of the wood, nor any burns (Fig. 4 and Fig. 5). This suggests a low temperature deposition history of the host sediment. On the other hand, the original epigeny through pyrite implies fossilization under reductive conditions.

Conclusion

Our study is based on several key field observations and detailed descriptions of the different lithofacies (associations) around the hill area of Balatonboglár township. We have concluded that the main volcanic lithofacies on the three hilltops show similar sedimentological and petrological characteristics. We interpret these volcaniclastic rocks as the products of a phreatomagmatic explosive eruption. The large amount of quartzofeldspathic fragments in the matrix in the volcaniclastic sequences strongly suggest the importance of magma and unconsolidated water-saturated sediment mixing processes during the eruptive history. This conclusion is supported by the occurrence of globular peperite in the region. Probably peperite was formed when magma intruded into wet maar lake sediment and/or Pannonian clastic sediment. The eruptions took place under subaerial conditions (high vesicularity of juvenile fragments, no pillow structures), in which the main water supply for the phreatomagmatic explosions was the water saturated clastic Pannonian sediments (Fig. 7a).

The steeply dipping and chaotic structural position of pyroclastic deposits suggest that they were in a near vent position where syn-eruptive movements (Fig. 7b and c), thermal effects, and hot springs were important during and after the eruptions, as reported by White (1991a, b) from near vent deposits of Hopi Buttes volcanic field. Repeated explosions might be responsible for the intensive reworking/recycling process of juvenile and sedimentary fragments in the vent zone similar to the model of Houghton and Smith (1993). The phreatomagmatic explosions probably caused maar depression(s) which was/were filled by water and in which maar lake sedimentation could have occurred (Fig. 7b). With decreasing pore-water supply from the porous-media aquifer, Pannonian sand, dryer explosive events took place, building up small Strombolian scoria cones and adding more magmatic juvenile shards (tachyilite)

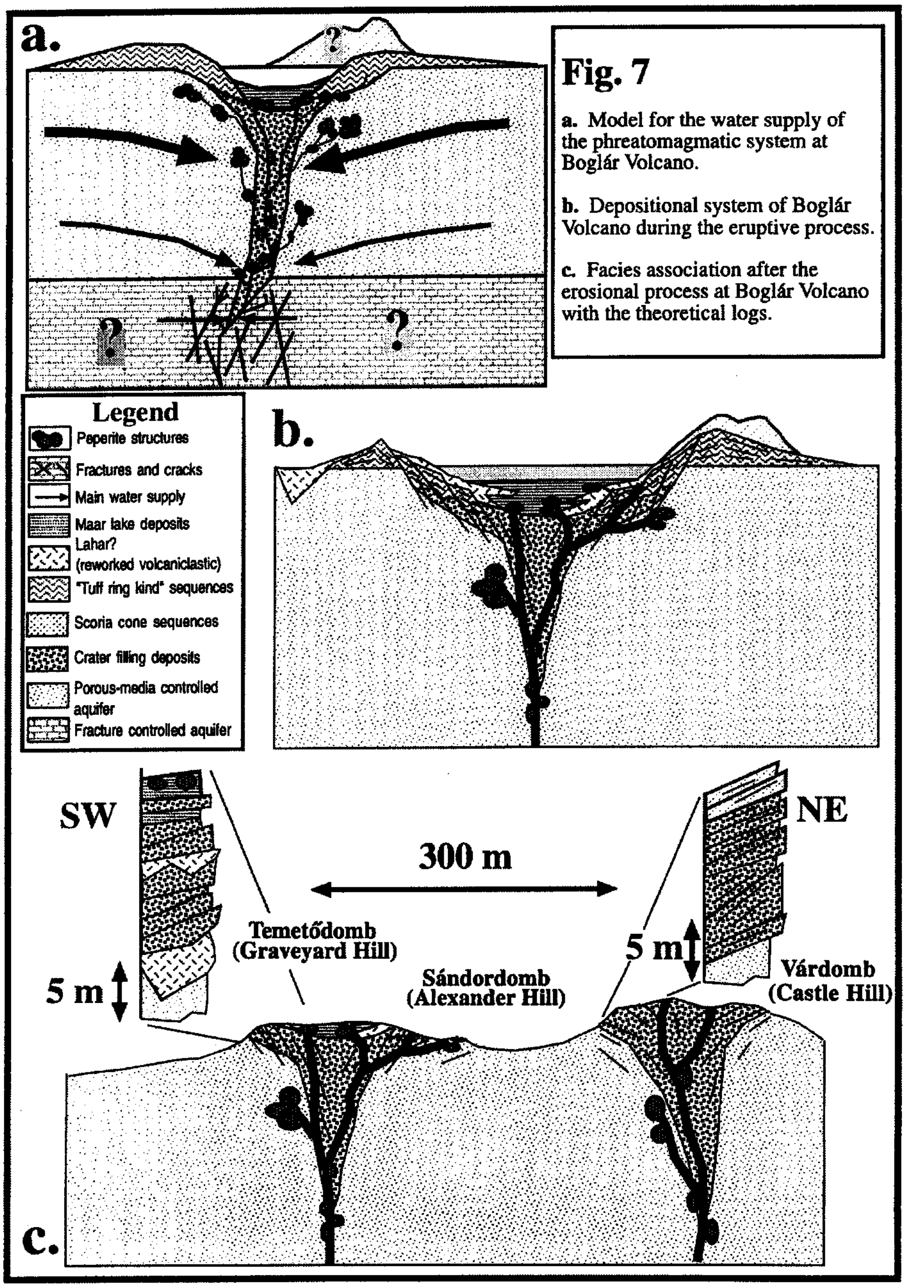

Fig. 7
Composite picture of the eruptive mechanism (a. and b.), theoretical stratigraphic columns (c.) and reconstruction of lithofacies relations after erosion (c.) of the Boglár Volcano

to the deposits. This process is well known from other volcanic fields where the main water source of the phreatomagmatic explosions was porous-media aquifer (e.g. in Hopi Buttes, Arizona, White 1991a; 1991b, Western Snake Rivers, Godchaux et al. 1992; Eifel, Germany, Büchel 1993). The new tree fossil suggests that the eruptions took place under subaerial conditions, and that probably all the volcanic processes were low temperature, which fits with the low-temperature phreatomagmatic, phreatic explosive history.

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References

Borsy, Z., K. Balogh, M. Kozák, Z. Pécskay 1986: Újabb adatok a Tapolcai-medence fejlődéstörténetéhez (New data for the evolution of the Tapolca Basin). – Acta Geogr. Debrecina, 23, pp. 79–104 (in Hungarian).

Busby-Spera, C.J., J.D.L. White 1987: Variation in peperite textures associated with differing host-sediment properties. – Bull. Volcanol., 49, pp. 765–775.

Büchel, G. 1993, Maars of the Westeifel, Germany. – In: J. F. Negendank, B. Zolitschka (Eds): Paleolimnology of European Maar Lakes – Lecture Notes in Earth Sciences, vol. 49, Springer-Verlag, Berlin, Heidelberg, pp. 1–13.

Cas, R.A.F., J.V. Wright 1987: Volcanic succesions, modern and ancient. – Unwin Hyman, London, 528 p.

Fisher, R.V. 1960: Classification of volcanic breccias. – Geol. Soc. Am. Bull., 71, pp. 973–982.

Fisher, R.V., H-U. Schmincke 1984: Pyroclastic rocks. – Springer Berlin, Heidelberg, New York

Fisher, R.V., H-U. Schmincke 1994: Volcanic sediment transport and deposition. – In: Pye, K. (Ed.): Sedimentary Processes. – Blackwell Oxford, pp. 349–386.

Godchaux, M.M., B. Bonnichsen, M.D. Jenk 1992: Types of phreatomagmatic volcanoes in the western Snake River Plain, Idaho, USA. – J. Volcanol. Geotherm. Res., 52, pp. 1–25.

Harangi, Sz. in press: Neogene magmatism in the Alpine-Pannonian Transition Zone – a model for melt generation in the western Pannonian basin. – Geol. Soc. Am. Spec. Publ. (submitted)

Houghton, B.F., W.R. Hackett 1984: Strombolian and phreatomagmatic deposits of Ohakune Craters, Ruapehu, New Zealand, a complex interaction between external water and rising basaltic magma. – J. Volcanol. Geotherm. Res., 21, pp. 207–231.

Houghton, B.F., H-U. Schmincke 1985: Mixed deposits of simultaneous strombolian and phreatic volcanism, Rothenberg Volcano, East Eifel Volcanic Field. – J. Volcanol. Geotherm. Res., 25, pp. 117–130.

Houghton, B.F., R.T. Smith 1993: Recycling of magmatic clasts during explosive eruptions: estimating the true juvenile content of phreatomagmatic volcanic deposits. – Bull. Volcanol., 55, pp. 414–420.

Jámbor, Á., Z. Partényi, G. Solti 1981: A dunántúli bazaltvulkanitok földtani jellegei (Geologic characteristics of the basaltic volcanic rocks of the Transdanubia Region). – MÁFI Évi Jel. 1979-ről, pp. 225–239 (in Hungarian).
Jugovics, L. 1968: A Balatonfelvidék és a Tapolcai-medence bazaltvidékének földtani jellegei (Geologic characteristics of the Balaton Highland and the Tapolca Basin basalt province). – MÁFI Évi Jel. 1968-ról, pp. 223–243 (in Hungarian).
Lóczy, L. 1894: A Balaton geológiai története és jelenlegi geológiai jelentősége (The geologic history of Lake Balaton and its geologic importance). – Földrajzi Közl., XXII. volume (in Hungarian).
Lóczy, L. 1913: A Balaton környékének geológiai képződményei és ezeknek vidékek szerinti telepedése (Geologic features of the land around Lake Balaton, and their stratigraphy site by site). – Balaton Tud. Tan. Eredm. I. (in Hungarian).
Lorenz, V. 1986: On the growth of maars and diatremes and its relevance to the formation of tuff rings. – Bull. Volcanol., 48, pp. 265–274.
Lowe, D.R. 1982: Sediment gravity flows: II., Depositional models with special reference to the deposits of high-density turbidity currents. – J. Sed. Petrology., 52, pp. 279–297.
McPhie, J., M. Doyle, R. Allen 1993, Volcanic textures. – CODES, University of Tasmania, 198 p.
Middlemost, E.A.K. 1989: Iron oxidation ratios, norms and the classification of volcanic rocks. – Chemical Geol., 77, pp. 19–26.
Sheridan, M.F, K.H. Wohletz 1983, Hydrovolcanism: basic considerations and review. – J. Volcanol. Geotherm. Res., 17, pp. 1–29.
Smith, G.A., D.R. Lowe 1991: Lahars: volcano-hydrologic events and deposition in the debris flow – hyperconcentrated flow continuum. – Sedimentation in Volcanic Settings, SEPM Special Publication No. 45, pp. 59–70.
Szabó, Cs., Sz. Harangi, L. Csontos 1992: Review of Neogene and Quaternary volcanism of the Carpathian-Pannonian Region. – In: Ziegler, P.A. (Ed.): Geodynamics of rifting. Vol. 1. Case studies on rifts: Europe and Asia. Tectonophysics, 208, pp. 243–256
White, J.D.L. 1991a: The depositional record of small, monogenetic volcanoes within terrestrial basins, Sedimentation in Volcanic Settings. – SEPM Special Publication No. 45, pp. 155–171.
White, J.D.L. 1991b: Maar-diatreme phreatomagmatism at Hopi Buttes, Navajo Nation (Arizona), USA. – Bull. Volcanol., 53. pp. 239–258.
Williams, H., A.R. McBirney 1979: Volcanology. – Freeman, Cooper and Company, San Francisco, 397 p.
Wohletz, K.H., M.F. Sheridan 1983: Hydrovolcanic explosions II. Evolution of basaltic tuff rings and tuff cones. – Am. J. Sci., 283, pp. 385–413.

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