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Interaction between a Late Miocene andesitic dyke swarm and wet sediment in the Szoros Valley, Eastern Borsod Basin, Northeast Hungary

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Magma/wet sediment interaction (e.g. autobrecciation, magma-sediment mingling, hyaloclastite and peperite-forming, etc.) is a common phenomenon, where hot magma intrudes into unconsolidated or poorly consolidated water saturated sediment. In the Eastern Borsod Basin (NE-Hungary) relatively small (2–30 m) subvolcanic bodies, sills and dykes with contact lithofacies zones were found generated by mechanical stress and quenching of the magma, and interacting with unconsolidated wet andesitic lapilli-tuff and tuff-breccia. Close to the contact between sediment and intrusions, thermal and mechanical effects may occur in the host sediment. Hydrothermal alteration and stratification of the host sediment were developed only locally along the contact zone, probably due to the paleo-hydrogeologic and paleo-rheological inhomogeneities of the lapilli-tuff–tuff-breccia deposits. Processes of magma/wet sediment interaction may be difficult to recognize because of limited exposure and/or certain similarities of the brecciated intrusions to the characteristics of the host sediment; hence detailed field work (geologic mapping or profiling) was required to demonstrate the subvolcanic origin of the brecciated andesite bodies.

Keywords: andesite, dyke, magma/wet sediment interaction, contact lithofacies, peperite

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Introduction

As early as the 1970s but mainly since the 1990s many authors have published examples of magma coming into contact with wet sediment, generating hyaloclastites, peperites, *in situ* breccias, etc. (i.e. Lydon 1968; Yamagishi 1991; Hanson and Hargrove 1999). These studies make clear that phenomena of magma/wet sediment interactions are common in geologic settings where thick sediment sequences accumulate during active volcanism. Many types of these rocks formed during the Late Miocene intermediate volcanic activity in the Eastern Borsod Basin (Hámor 2001; Püspöki et al. 2003).

The Eastern Borsod Basin (EBB), predominantly made up of Cenozoic sequences, is a hilly, slightly elevated area (max. elevation 408 m above sea level) situated between the Bükk Mts and the Sajó River (Fig. 1). Although the Lower and Middle Miocene formations of the area are well exposed by ca. 1400 boreholes, some Miocene sequences, among others the intermediate volcaniclastic deposits and subvolcanic bodies, are less known. Only few papers discussed the petrologic and volcanological interpretation of the Miocene intermediate volcanic series of the EBB (Árokszállásy 1935; Pojják 1958, 1963; Radócz and Vörös 1961).

Results of detailed geologic mapping carried out in the last decade made it clear that andesitic subvolcanic bodies, or dykes, may occur in many places in the EBB (Csámer and Kozák 2009). This paper describes an extensive, well-exposed dyke swarm complex along the Szoros Valley where detailed geologic section recording and texture analysis was performed in the field and on carefully collected samples.

Geologic settings

Regional geologic background

The EBB is situated in the northeastern part of Hungary and can be regarded as a foreland of the Bükk Mts The natural boundaries of the EBB are the Sajó River to the north and the east, the Bükk Mts to the south and the Ózd–Egercsehi Basin to the west (Fig. 1). The areal extent of the basin is approximately 250 km^2.

The Paleozoic and Mesozoic basement of the EBB is barely known because of the small number of outcrops. On the basis of geophysical investigation, the morphology of the basement is strongly dissected by deep trenches with steep margins and ridges with NE–SW strike (Szalay et al. 1976, 1979, 1989; Király 1989) and represented by limestone, siliceous shale, metavolcanite and conglomerate.

Paleogene formations are strongly eroded and usually covered by Miocene series. They are exposed in small outcrops along the southern margin of the basin. Uplifting and denudation presumably began in the Cretaceous and ended in the Middle Eocene. During this time the entire EBB, together with the Bükk and Uppony Mts, was emerged, and terrigenous clay, sand, gravel, and debris were deposited on the tectonically deformed and dissected Paleozoic–Mesozoic surface.

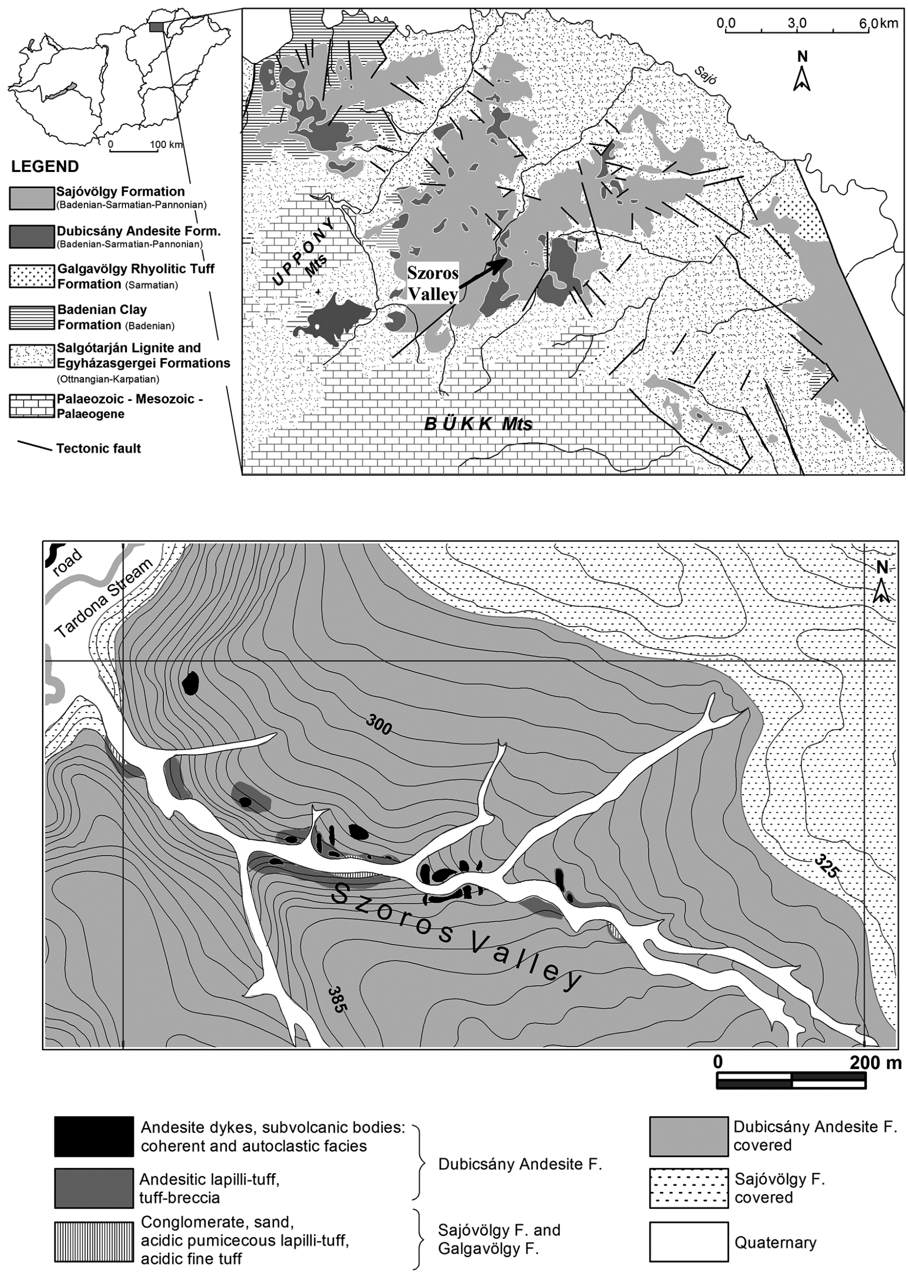

Fig. 1
Geologic map of the Eastern Borsod Basin and of the studied area (Szoros Valley)

In the Late Eocene marine transgression occurred and a shallow marine carbonate platform developed, where platform carbonates, fossil-bearing clay and marl were deposited. From the Early Oligocene this Paleogene basin gradually became isolated from the world ocean, while the sea reached its maximum extension, and marl and siliciclastic sediments (sand, clay, conglomerate) were deposited in a long structural trench situated in the northern part of Hungary. By the end of the Oligocene the entire area became a continental terrain again (Pelikán 2005).

During the Miocene the area was affected by several transgression, regression and denudation phases corresponding to local tectonic movements and sea-level changes. In the Eggenburgian slow subsidence took place and at the very beginning terrestrial, later shallow marine 'molasse' formations (clayey sand, gravel) with intercalated lignite seams were deposited (Felsőnyárád Formation). During the Ottnangian and Karpatian, after a short temporal regression, a new transgression phase took place and sand, silt, clay, reworked acidic tuff, tuffitic clay and intercalated lignite seams were deposited in a near-shore–shallow marine environment (Salgótarján Lignite Formation, Egyházasgerge Formation), while in the Badenian the Miocene sea became progressively deeper and marine clay and marl were deposited (Badenian Clay Formation) (Gyalog and Budai 2004; Gyalog 2005).

During the Late Badenian–Sarmatian–Early Pannonian, sand, sandy gravel and gravel were deposited in near-shore, delta plain, delta front, prodelta or terrestrial environments (Sajóvölgy Formation), due to the next uplift of the Bükk Mts and its surroundings (Pelikán 2005; Püspöki et al. 2003). Since the Pannonian the EBB has been gradually uplifted, which led to the evolution of the present day surface and valley network in terrestrial environment.

Felsic and intermediate volcanic activity accompanied the entire Miocene geologic evolution of the EBB. Pyroclastic rocks (lapilli-tuff, tuff and tuffite) of rhyolitic and dacitic composition were deposited in three main phases during the Miocene (Pelikán 2005). The older of these was accumulated in a continental environment, approximately 18.5–21 Ma ago (Gyulakeszi Rhyolite Tuff Formation) (Gyalog 2005). The volcanic activity was renewed in the Badenian, when mainly dacitic pyroclastics were deposited in a marine environment (Tar Dacite Tuff Formation) (Gyalog 2005). The third and youngest phase of felsic volcanic activity occurred during the Sarmatian, when well-sorted pumiceous lapilli-tuff, tuff, and re-deposited tuffite and tuffitic clay (bentonite) of rhyolitic composition were formed (Galgavölgy Formation) (Gyalog 2005).

Between the Late Badenian and Pannonian andesitic volcanic activity also occurred in the territory of the EBB (Pelikán 2005; Csámer 2007). The andesitic volcaniclastic rocks, subvolcanic bodies and dykes had originally been classified as part of the Sajóvölgy Formation, but their characteristics, horizontal and lateral distribution suggested that it was preferable to distinguish them as a separate lithostratigraphic unit (i.e. Dubicsány Andesite Formation in Gyalog and Budai 2004). The Dubicsány Andesite Formation (DAF) comprises thick andesite volcaniclastic sequences (i.e. lapilli-tuff, tuff and tuff-breccia) deposited in terrestrial, deltaic and near-shore environments and penetrated by subvolcanic bodies and dykes of andesitic composition. At the margin of the dykes and the subvolcanic bodies *in situ* breccias and peperites were developed as a result of interaction between andesitic magma and wet sediment (Csámer 2007; Csámer and Kozák 2009).

The Dubicsány Andesite Formation is present only in patches on the surface, because most of it is covered by the younger part of the Sajóvölgy Formation. On the basis of well log data and field observations the average thickness of the DAF is approximately 40 m, while its volume is 2.6 km^3 (Csámer 2007). However, the formation is strongly eroded; some of the larger (30–40 m in diameter), highly-brecciated andesite pipe structures could be regarded as volcanic conduits.

The age of the intermediate volcanic activity in the EBB ranges from 9.5 to 13.73 Ma (Late Badenian–Sarmatian–Pannonian) according to K/Ar radiometric data (Árva-Sós et al. 1983; Balogh 1984; Püspöki et al. 2003; Csámer 2007).

Geologic setting of the Szoros Valley

The Szoros Valley is situated 1.5 km north of the village of Tardona on the right side of the Tardona Stream. The length of the main valley, striking roughly northwest-southeast is approximately 1.2 km. Genetically it can be regarded as a tectonically pre-formed epigenetic erosional valley with very steep slopes at some locations. The valley bottom is 5–15 m wide and is filled with Quaternary alluvium of variable grain-size and composition (Fig. 1).

Almost the entire Late Miocene intermediate volcanic and subvolcanic succession (i.e. Dubicsány Andesite Formation), including overlying and underlying sediment sequences, is exposed in numerous outcrops along the valley. At the base of the DAF coarse-grained tuffaceous sedimentary rocks (conglomerate, sandstone), fine felsic bentonitic tuff and pumiceous lapilli-tuff occur, overlain by andesitic lapilli-tuff and tuff-breccia of a thickness of about 70 m. The volcaniclastic unit is intruded by andesitic subvolcanic bodies, dykes and sills.

K/Ar radiometric dating, carried out on an andesite dyke sample collected from the Szoros Valley, yields an age of 13.73 ± 0.76 Ma (Late Badenian–Sarmatian) (Csámer 2007).

Analytical methods

Detailed geologic sections were recorded on well-exposed rock surfaces of the Szoros Valley by careful examination, description and interpretation of textural features in the field. Rock samples were collected and thin sections were made to achieve detailed petrographic descriptions by polarized microscopic examination. In this paper the results of the field work and microscopic texture analysis of the collected samples are described.

Major element composition of the samples was determined by classic chemical analysis methods in the Department of Mineralogy and Geology, University of Debrecen, after sample powdering, homogenizing and decomposition by HF.

X-ray powder diffraction measurements of samples were carried out in the X-ray Laboratory of the Geological and Geophysical Institute of Hungary with a PC-controlled Philips PW1730 powder diffractometer using Cu anticathode 40 kV and 30 mA current, graphite monochromator and goniometer velocity of 2°/min.

Thermal analyses were made using Derivatograph-PC with simultaneous TG, DTG and DTA set in a corundum crucible with a heating speed of 10 °C/min up to 1000 °C, under atmospheric pressure. The analyses were performed in the Thermal Analytical Laboratory of the Department of Mineralogy and Geology, University of Debrecen, Debrecen, Hungary.

Observational and analytical results

Volcaniclastic host rock

Andesitic volcaniclastic rocks exposed in the Szoros Valley are usually drab or grey in color, poorly bedded or unbedded, massive, matrix and lithic-rich lapilli-tuffs and tuff-breccias containing abundant lithic fragments (40–50 percent in volume by visual observation). Traces of short-distance reworking may appear. In that cases tuffaceous gravel, conglomerate and sand deposits occur showing cross bedding and some sorting.

The main components of the tuffaceous matrix are crystals and glass shards, but lithics may also occur in a significant amount. Two types of glass shards may occur in the tuffaceous matrix. First one is represented by yellow-colored, slightly or moderately vesicular, blocky volcanic glass particles, which may be either microlite-free or -rich in their texture. Microlites are feldspars, pyroxenes and rarely amphiboles. On the basis of color and refraction index the glass composition can be regarded as andesitic. The other type of volcanic glass is represented by cuspate, blade-like glass shards and pumice clasts of felsic composition on the basis of their refraction index. Dark brown vesicular, optically opaque tachylites with feldspar and pyroxene microlites may also occur.

Free juvenile crystals also may occur in the tuffaceous matrix. Approximately 45–50 percent of the crystals are euhedral or subhedral feldspars, which can be regarded as juvenile components. Subhedral and anhedral pyroxenes and anhedral amphiboles may also occur. Non-magmatic anhedral mono- or polycrystalline quartz, white mica and rounded aggregates of glauconite, can also be found in every sample in variable amount. X-ray powder diffraction analysis shows the presence of montmorillonite (20–25%), illite (6–7%), cristobalite (13%), goethite (6%), K-feldspar (5%) and opal (traces).

The lithic fragments' shape, size and composition exhibit high variety. Lithoclasts may occur equally in ash, lapilli or block fractions, with igneous (pyroxene andesite, garnet-bearing amphibole dacite, granitoid), sedimentary (limestone, sandstone, claystone) or metamorphic (phyllite, gneiss, quartzite) origin, and with angular, partly or well-rounded shapes. The texture of andesitic lithic fragments is highly porphyritic (microholocrystalline-porphyritic or pilotaxitic). The phenocrysts are plagioclases, orthopyroxenes (ferrosilite), clinopyroxenes (augite), while the felsitic groundmass contains a mineral assemblage of plagioclase, orthopyroxene, clinopyroxene, magnetite and titanomagnetite. In the case of certain type of volcanic (andesitic) lithic clasts, vesiculation may occur.

On the basis of the chemical analysis of the tuffaceous matrix, the lapilli-tuff and tuff-breccia belong to the calc-alkaline series (Tables 1 and 2, Fig. 2). There are no significant differences in the major element composition of the andesitic volcaniclastite samples collected from the EBB. The relative high LOI and low Al_2O_3 and alkali content are due to the weathering and clay transformation of the unstable phases (mainly the volcanic glass shards). The presence of non-magmatic minerals in the matrix also can cause a high LOI value. The representativeness of this sample for the magma composition is quite problematic.

Table 1
Major element content of rock samples derived from the Szoros Valley

Sample name	**117 m volcaniclastite**	**585 m dyke East**	**585 m dyke West**	**250 m reddish scoriaceous autoclastite**	**250 m dyke**
facies	*host sediment*	*slab jointed coherent*		*autoclastic breccia*	*large blocky coherent*
SiO_2	60.62	59.33	59.55	51.10	52.30
TiO_2	0.77	0.71	0.74	1.01	0.91
Al_2O_3	15.34	17.89	18.60	18.50	18.30
Fe_2O_3	3.06	3.05	3.15	9.24	5.38
FeO	2.66	1.60	0.91	0.01	2.06
MnO	0.11	0.06	0.04	0.54	0.30
MgO	2.71	1.09	0.67	1.13	1.99
CaO	7.78	10.12	10.23	8.13	10.90
NA_2O	1.47	2.22	2.30	2.63	2.77
K_2O	2.46	2.93	2.91	0.65	1.23
P_2O_5	0.14	0.19	0.21	0.40	0.16
CO_2	0.28	0.30	0.72		
$(+)H_2O$	2.40	0.39	0.00		
$(–)H_2O$	2.63	0.89	0.84	3.65	0.47
LOI				2.76	2.82
Sum	102.42	100.77	100.86	99.75	99.58

Table 2
Major element content of rock samples derived from the Szoros Valley (recalculated, volatile-free)

Sample name	**117 m volcaniclastite**	**585 m dyke East**	**585 m dyke West**	**250 m reddish scoriaceous autoclastite**	**250 m dyke**
facies	*host sediment*	*slab jointed coherent*		*autoclastic breccia*	*large blocky coherent*
SiO_2	62.42	59.82	59.96	54.75	54.31
TiO_2	0.80	0.71	0.74	1.08	0.94
Al_2O_3	15.80	18.04	18.73	19.82	19.00
Fe_2O_3	3.15	3.07	3.17	9.90	5.59
FeO	2.74	1.61	0.92	0.01	2.14
MnO	0.12	0.06	0.04	0.58	0.31
MgO	2.79	1.10	0.67	1.21	2.07
CaO	8.01	10.20	10.30	8.71	11.32
NA_2O	1.52	2.24	2.32	2.82	2.88
K_2O	2.53	2.95	2.94	0.69	1.28
P_2O_5	0.14	0.19	0.21	0.43	0.16
Sum	100	100	100	100	100

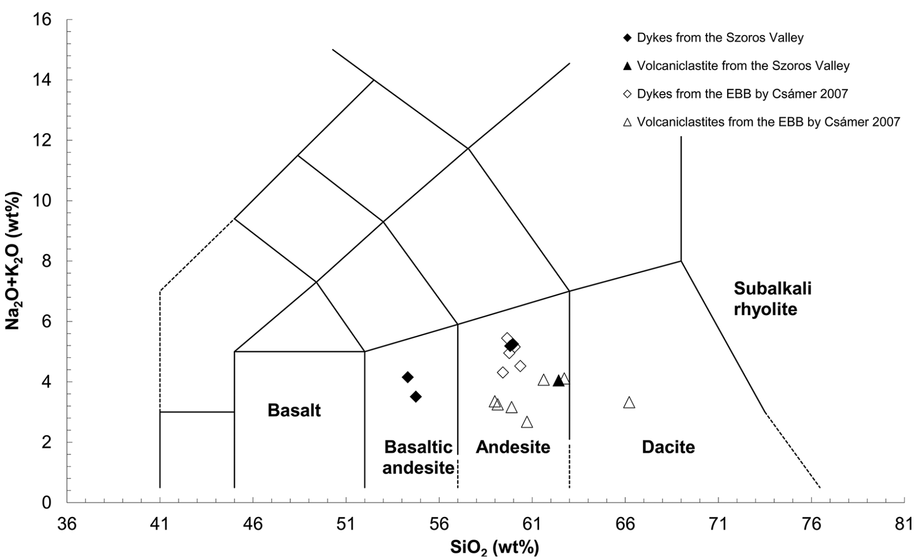

Fig. 2
Chemical classification of the rock samples from Szoros Valley using a total alkali silica diagram (after le Bas et al. 1986)

Andesite subvolcanic bodies

Dark or medium grey-colored andesitic subvolcanic bodies, dykes and sills are small-sized (max. 30 m width), and often show close-fitting columnar, platy or blocky jointing in their inner part (Figs 3 and 4). They can be regarded as a coherent facies of syn-volcanic shallow intrusion (McPhie et al. 1993). The fitting of the columns, slabs and blocks is close. The texture is usually porphyritic-transitional, whereas micro-vesiculation may occur. At the margins of the dykes a zone consisting of angular andesite fragments and slightly weathered volcanic glass matrix may occur, which can be regarded as the autoclastic facies of the intrusive rock. It is represented by angular andesite fragments of 2–30 cm in diameter. Clusters of angular andesite fragments often show jigsaw-fit texture indicating *in situ* fragmentation. Initial brecciation caused by mechanical stress was observed on a polished hand specimen collected from an intrusion, where a dark, less crystallized 'fresh' magma vein intruded into a light grey, fine-grained, crystal-rich andesite (Fig. 5).

Close to the contact of the host sediment and the intrusive autoclastic facies, a margin consisting of reddish, scoriaceous andesitic fragments developed. Two types

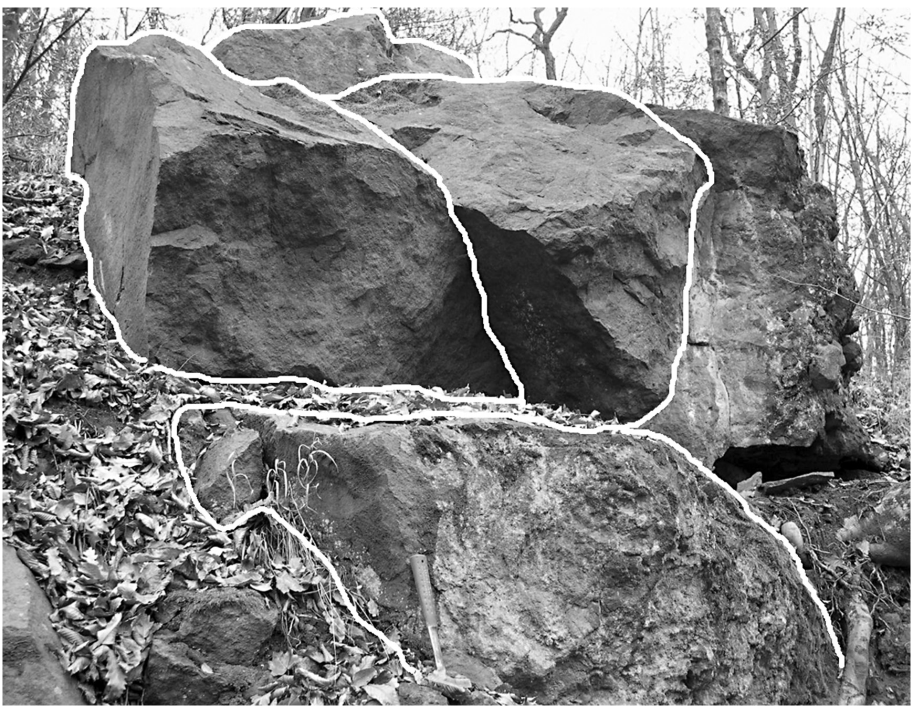

Fig. 3
Large fragments of the blocky-jointed andesite body in the Szoros Valley at 250 m distance from the valley mouth. Note the close fitting of the large fragments

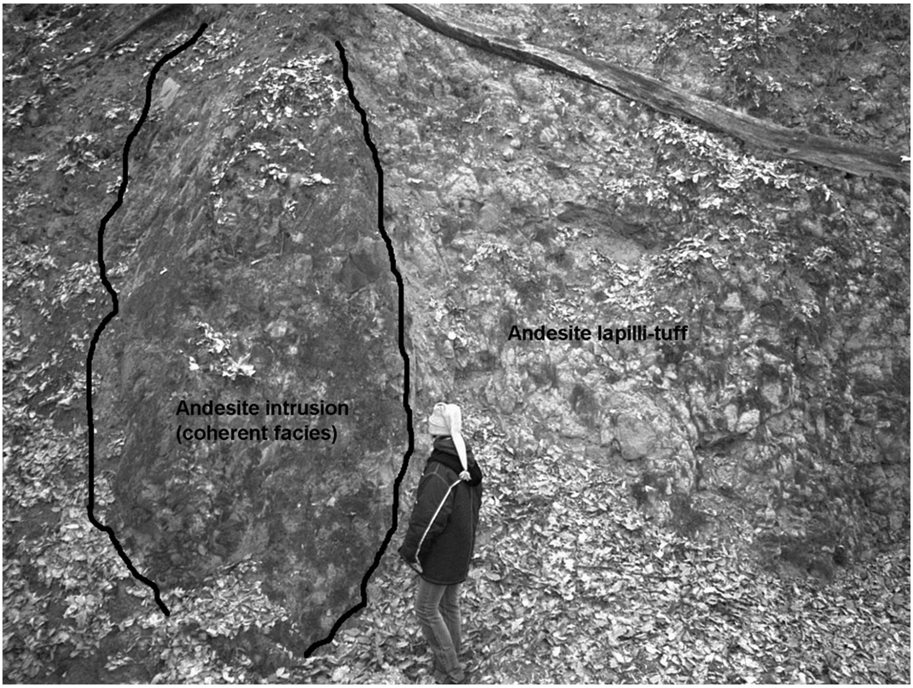

Fig. 4
Subvertical slab-jointed andesite dyke in andesite lapilli-tuff with sharp contact

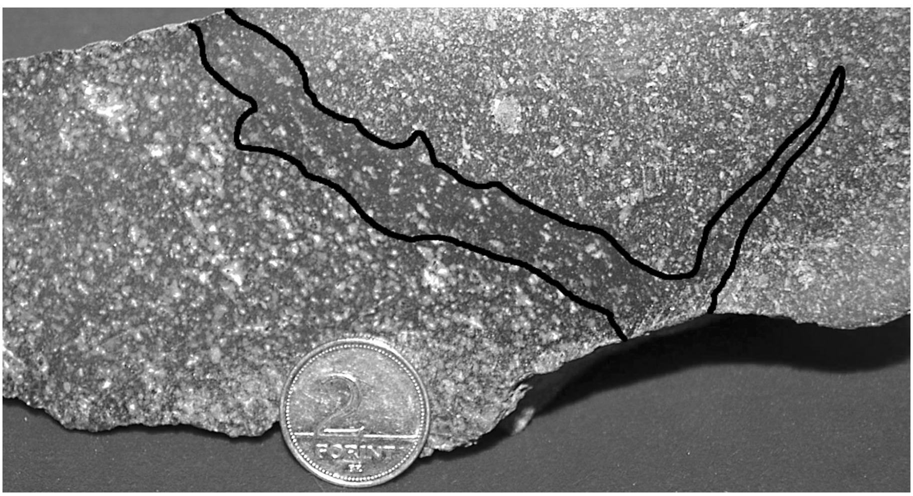

Fig. 5
Less crystallized vein on the surface of a polished pyroxene andesite sample from the coherent facies of a dyke; Szoros Valley, at 250 m distance from the valley mouth

of andesitic clasts of this sub-lithofacies were recognized in thin section. One type of clast contains skeletal feldspar crystals in large, as well as pyroxene, amphibole and plagioclase phenocrysts in smaller amounts (Fig. 6). The andesite is highly vesicular and the glassy groundmass contains Fe–Ti-oxide minerals. The second type of andesite fragment is almost completely crystallized, non-vesicular, the groundmass is felsitic, and large plagioclase and pyroxene phenocrysts may occur. The margin of the clasts is red-colored and oxidized due to the thermal effect of the hot magma. Thin andesite veins of low crystallinity cross the clasts, while the space between the lithic clasts is filled with light brown, slightly devitrified volcanic glass consisting of plagioclase and pyroxene microlites.

X-ray powder diffraction analysis carried out on a sample of the red scoriaceous sub-lithofacies indicated the presence of 22% of montmorillonite, 15% of hematite, 5% of K-feldspar and traces of quartz and opal.

Chemical and mineralogical composition of the subvolcanic bodies are very similar to the lithic clasts of the host lapilli-tuff and tuff-breccia layers (Csámer 2007),

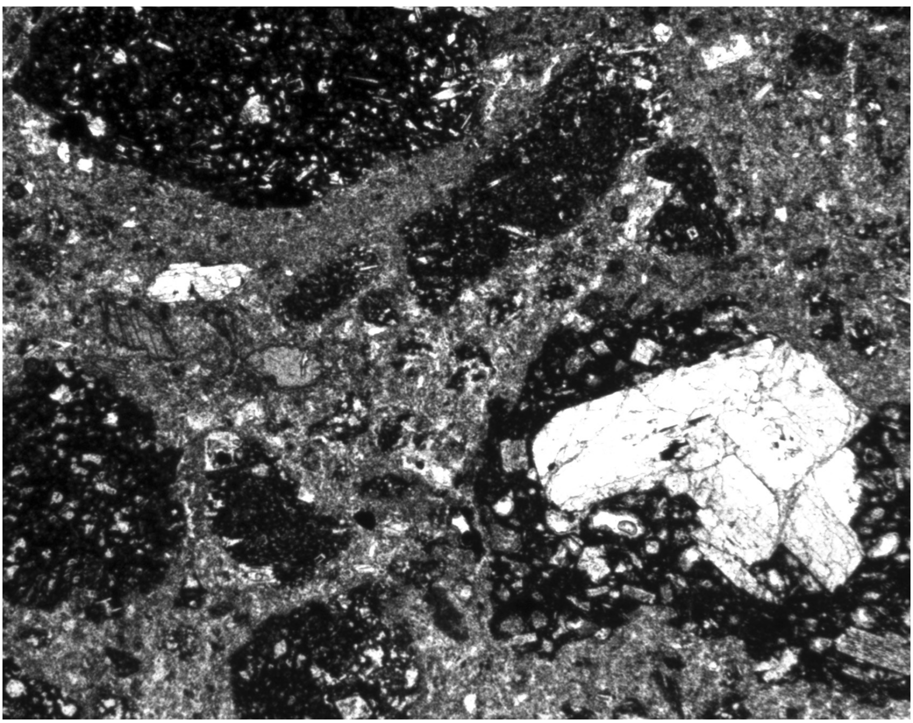

Fig. 6
Microphotograph of oxidized andesite breccia from autoclastic facies of a dyke. Note the dark vesicular and oxidized particles containing small plagioclase skeletal crystals and the lighter, slightly altered microlite-poor glassy matrix (1 Nicol, the shorter side of the photo is 2.75 mm long)

although some differences may occur due to hydrothermal alteration (Tables 1 and 2; Fig. 2). The inner, hydrothermally unaltered, coherent part of the magmatic bodies is represented by samples taken from a dyke crossed and cut off by the Szoros Valley at 585 m from the mouth of the valley. Hydrothermally slightly altered blocky andesite was collected from an exposure at 250 m from the mouth of the valley (Fig. 3), while hydrothermally altered, reddish, scoriaceous autoclastic andesitic breccia was collected at the same location. Major element composition of hydrothermally altered rock samples shows decreased SiO_2, K_2O and CaO, and increased MnO, Fe_2O and Fe_{total} content compared to the unaltered coherent type.

Andesite–host rock contact zone

The contact zone developed in the andesitic volcaniclastic host sediment along the margin of andesitic subvolcanic bodies is approximately 1.5–3 m wide, wavy and sharp. The originally deposited lapilli-tuff and tuff-breccia layers are massive and show no internal bedding throughout the EBB. In contrast, along the contact

Fig. 7
Fissure system in the lapilli-tuff host deposit. The matrix of the rock is light blue because of a thin chalcedony film

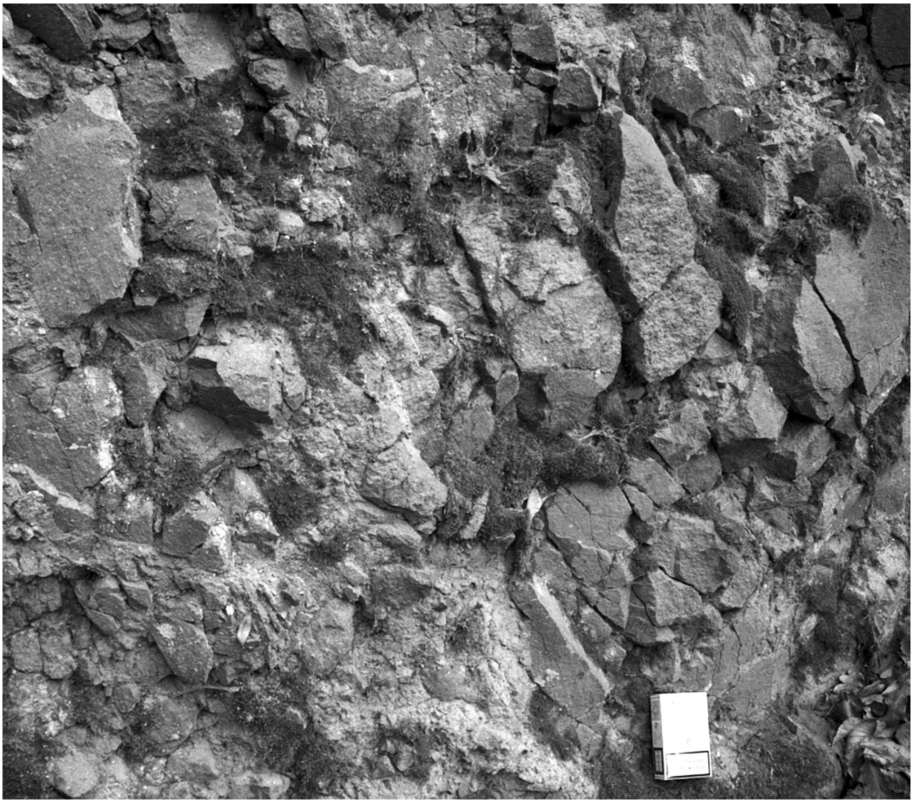

Fig. 8
Jigsaw-fit texture in blocky peperite. Note the cluster of angular andesite fragments

zone the volcaniclastic deposit is strongly cemented by a combination of silica and clay minerals; moreover, along the contact fissures and cracks developed, resulting in stratification, even though the adjacent volcaniclastic host is massive (Fig. 7). The originally drab or light grey matrix of the volcaniclastic rock was discolored by a thin, light-blue chalcedony film generated around the particles, while the andesitic lithic fragments almost completely altered to a yellowish-white clay mineral assemblage. In contrast, the non-volcanic lithics, like quartzite and meta-siltstone, appear to be unaltered.

At the contact zones, intermingling of the magma and its volcaniclastic host took place resulting in a specific mixed rock called peperite.

Based on field observation and detailed textural analysis of the studied exposures, the juvenile andesite fragments derived from the dykes are angular and show jigsaw-fit texture. This type of peperite can be recognized as a blocky peperite facies (Fig. 8).

Discussion

Genesis of the host volcaniclastic rocks

Detailed texture analyses were carried out along the Szoros Valley, where the Late Badenian–Sarmatian Dubicsány Andesite Formation is exposed. The total thickness of the formation here is more than 70 m. The greater part of the DAF is built up by very poorly sorted, massive andesitic lapilli-tuff and tuff-breccia, containing lithic fragments in very large amounts and various sizes. The lack of internal gradation, bedding, and massive appearance suggests that the volcaniclastic unit is not reworked by post-volcanic erosional processes; however, interbedded tuffaceous sand and gravel deposits may occur, which may have been generated when the volcanic activity ceased. Non-vesicular, angular lithoclasts with andesitic composition may be fragmented co-magmatic volcanic rocks from a previous eruption of the same volcano. The Paleozoic and Mesozoic basement is built up by carbonates and metamorphic rocks; thus the angular phyllite, gneiss, and limestone lithics are possibly derived from the deeper-seated pre-volcanic basement. Granite lithics came from the basement as well. Sandstone, siltstone,

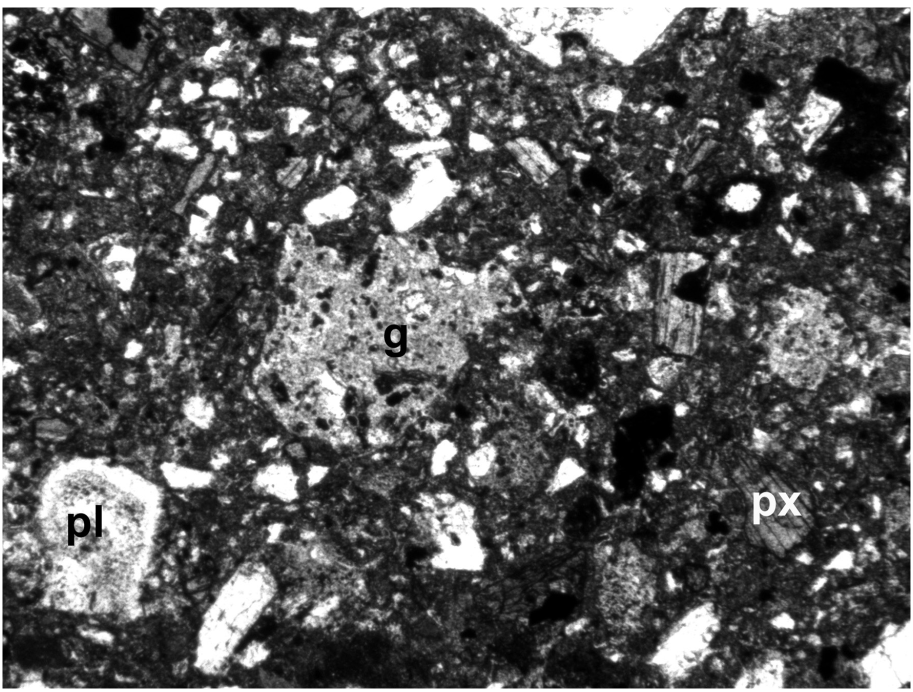

Fig. 9
Photomicrograph of microlite-poor, slightly vesicular, blocky volcanic glass fragment (g) with plagioclase (pl) and pyroxene (px) phenocrysts (1 Nicol, the shorter side of the photo is 2.5 mm long)

clay, and tuffitic claystone (bentonite) lithics are fragmented from the shallow-seated Paleocene–Middle Miocene pre-volcanic basement, just like the rounded quartzite, andesite, dacite, limestone, and granite clasts, which were explosively ejected from the underlying Miocene coarse-grained pebble and conglomerate sequences. As was mentioned earlier the volcaniclastic unit is not reworked or resedimented, which excludes an epiclastic origin of the lithic fragments. The amount of the accessory and accidental lithic clasts in the volcaniclastic deposit indicates subsurface explosive fragmentation.

Volcanic glass shards of andesitic and felsic composition were found in every thin section. Two types of glass shards may have derived from different sources. Yellow-colored, slightly or moderately vesicular, blocky volcanic glass particles of andesitic composition can be regarded as juvenile fragments (Fig. 9), while the acidic glass shards, pumice and micropumice clasts (Fig. 10) are derived from the Miocene felsic pyroclastic formations of the pre-volcanic basement, and thus cannot be considered as juvenile components.

Free crystals of the tuffaceous matrix are of diverse origin. Free juvenile crystals are released during the explosive disruption and breakage of crystal-rich magma and juvenile fragments. On the basis of the microlite contents of the blocky volcanic glass

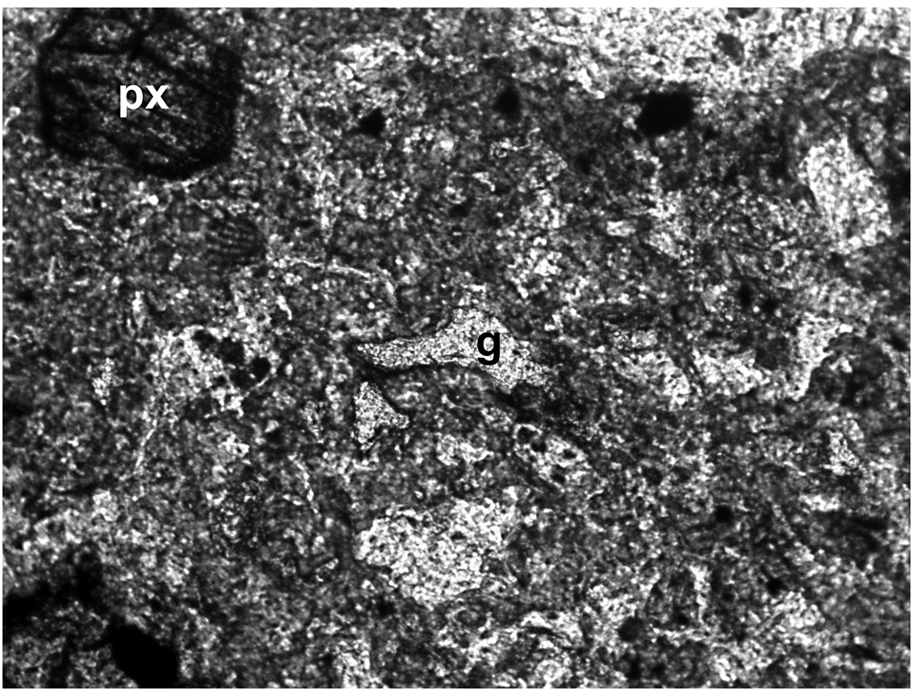

Fig. 10
Photomicrograph of a small cuspate volcanic glass shard (g) and a pyroxene crystal fragment (px) (1 Nicol, the shorter side of the photo is 0.48 mm long)

shards, the feldspars, pyroxenes and amphiboles originated by fragmentation of the ascending magma, while quartz, white mica and glauconite crystals are xenocrysts. Broken phenocrysts and xenocrysts are thought to be products of magmatic (phreatomagmatic) fragmentation, rather than weathering or reworking processes.

Despite the detailed field work and textural analysis several aspects of the host volcaniclastic rock and its formation are poorly understood, including the condition of transportation and deposition. The textural characteristics of the andesite volcaniclastic succession (i.e. vesiculation and shape of the juvenile glass shards) suggest that groundwater of the pre-volcanic basement, beside the magmatic volatiles, played a significant role in the fragmentation of the magma. The presence of slightly vesicular blocky glass shards as juvenile fragments in the volcaniclastic rocks indicates that the fragmentation of magma was mainly driven by magma/water interaction, when the andesitic magma was emplaced into water-saturated, poorly consolidated, ‘soft’ sediments of the pre-volcanic basement.

Slightly or non-vesicular volcanic glass shard can form by quench fragmentation of magma under water or at a subsurface contact between magma and water-saturated sediment, or by explosive phreatomagmatic eruption. Andesitic blocky glass shards are characteristic of the entire host volcaniclastic sediment (Csámer and Kozák 2009) suggesting that they can be interpreted as a result of predominantly eruptive processes. Intrusion-related magma-sediment interaction also could have played a role in the formation of the blocky volcanic glass shards; however, to clarify this question, further research is required.

Phreatomagmatic eruption is caused by mixing of ascending magma with groundwater, when the thermal energy of the magma is transformed into the mechanical energy driving explosions (Cas and Wright 1988). The large amount and variable size of the accessory lithic clasts (e.g. sandstone, claystone, rounded andesite, and dacite fragments) indicate that the subsurface explosive fragmentation took place predominantly at shallow depth (a few hundred meters) (Lorenz 1985, 1986; Németh et al. 2003; Németh and Martin 2007). However, large angular phyllite and granitoid clasts may have been derived from the deeper Paleozoic–Mesozoic basement by expansion of magmatic volatiles or karst water mixing with the ascending magma. The considerable amount of accessory lithics and xenocrysts in the tuffaceous matrix suggests that the formations of the shallow pre-volcanic basement were probably unconsolidated and water-saturated.

Csámer and Kozák (2009) suggested that the fresh volcanic material may have intermixed with loose sedimentary material of the shallow basement during the phreatomagmatic explosion, which created an eruption column of high particle density. Due to the large particle concentration of the eruption column it seems to be more likely that gravitational collapse occurred, generating a poorly sorted, non-bedded, massive flow deposit.

On the basis of White and Busby-Spera (1987) the description of an alternative possibility of the formation of andesitic volcaniclastic deposits of the EBB may arise. In this case subaqueous volcaniclastic processes may occur in relation with an intruding andesitic dyke in a shallow marine–near-shore environment. The intrusion destabilized and remobilized the sedimentary pile, a large slump formed and subaqueous volcaniclastic mass flow developed. In this case, according to the classification of volcanic processes created by McPhie et al. (1993) the host andesitic volcaniclastic deposit be regarded as a resedimented syn-eruptive volcaniclastic deposit.

Genesis of the andesite intrusive bodies and magma–sediment interaction

A short time after deposition, andesite subvolcanic bodies were emplaced into the loose, unconsolidated, probably wet debris. When magma interacts with water-saturated sediment it may have thermal and mechanical effects on the host deposit such as dewatering, textural homogenization, vesiculation, fluidization, folding, compaction, cementation, melting and alteration (Skilling et al. 2002).

Along the contact of the magma and the wet volcaniclastic sediment intensive magma/wet sediment interaction occurred, resulting in a contact lithofacies zone at the margins of the subvolcanic bodies (Fig. 11).

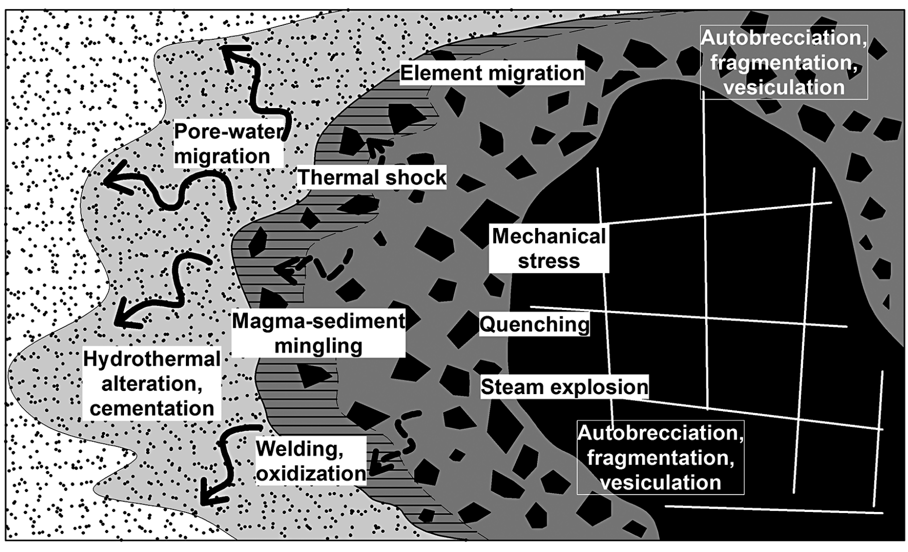

Fig. 11
Sketch model of development of contact lithofacies of andesitic intrusion. At the margin of a massive intrusion, autobrecciation, fragmentation and vesiculation occur due to mechanical stress, quenching and steam explosion of volatiles, which lead to the formation of an autoclastic facies consisting of angular andesite fragments and quenched glassy matrix. Along the contact of the host sediment and autoclastic facies, oxidization, welding and magma-sediment mingling may occur, while thermal and mechanical effects (alteration, cementation, fracturing) can result for host sediment accompanying dewatering and pore-water migration

On the basis of the volcanological interpretation of the field observation and microscopic textural analysis, the genesis of contact lithofacies zones can be drawn as follows. Newly deposited andesite lapilli-tuff and tuff-breccia layers were unconsolidated and probably wet. On the basis of the structural and textural characteristics of the massive, coherent facies the andesitic magma intruded into the host sediment at shallow depth. The hot andesitic magma heated the pore water stored in the interstitial space of the host, which thereupon resulted in a local hydrothermal system and thermal anomaly, when intensive fluid migration generated by hot andesitic magma caused massive hydrothermal alteration of the host and the andesite at the contact zone (Fig. 11). The hydrothermal fluid, of increased solubility, migrated toward the host sediment, and caused silica (chalcedony) and clay mineral cementation in the lapilli-tuff, while the SiO_2 and K_2O content of the magmatic body notably decreased (see Table 1). The emplacement of magma may have resulted in mechanical effects on the host sediment, such as stratification of the host and mixing it with the andesitic magma (blocky peperite facies). Blocky peperite developed along the margin of the intrusion only in a few cases, which indicates that the host was not water-saturated; the relatively high permeability allowed rapid escape of heated pore fluids. The escaping pore fluid transferred thermal energy from the margin of the intrusion, which caused quench fragmentation of the magma near the contact, while mechanical stress, autobrecciation and thermal effects also occurred (e.g. welding, oxidizing of the autoclastic facies) (Fig. 12).

The volume of intruded andesitic magma was relatively small and insufficient in many cases, thus a peperitic or welded, oxidized autoclastic margin could not have always developed. Moreover, the width of the greater dykes and sills is only few tens of meters, probably due to the branching of the main magmatic body at shallow depth; thus the shallow subvolcanic complexes could show a complex architecture and geometry.

Csámer and Kozák (2009) described well-developed contact lithofacies zones and blocky and fluidal peperites in the EBB from the Özvény Valley. Peperite has been commonly described as a morphologically blocky or globular (fluidal) rock (Busby-Spera and White 1987), which developed in response to physical properties of the host sediment and the magma (e.g. Busby-Spera and White 1987; Kano 1989; Hanson and Wilson 1993; Doyle and McPhie 2000; Martin and Németh 2007). Formation of blocky peperite involves brittle fragmentation of magma due to the quenching and mechanical stresses to form blocky juvenile clasts dispersed in the host sediment. Based on field observation and detailed textural analysis of the exposures along the Szoros Valley, the blocky peperite facies can be described by arrangement of the juvenile angular andesite fragments in jigsaw-fit texture (Fig. 8), which indicates roughly contemporaneous sedimentation and volcanism. Peperite forming along the contacts of subvolcanic bodies indicates that the host sediment was unconsolidated and probably in wet condition during magma emplacement. However, in contrast to the other well-exposed locality in the Özvény Valley (Csámer and Kozák 2009), globular or fluidal peperites were not identified

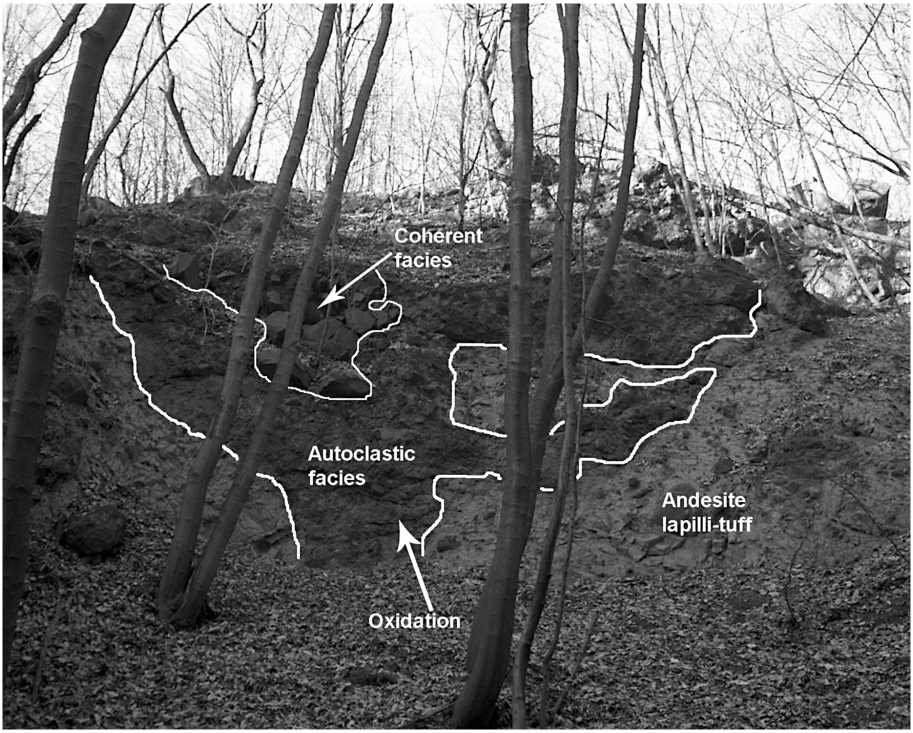

Fig. 12
Brecciated andesitic subvolcanic body intruded into lapilli-tuff host. The margin is oxidized, while the inner part is blocky-jointed

along the Szoros Valley. This indicates that there may have been some heterogeneities in the physical properties of the host deposit (such as in pore water content, sediment rheology, permeability, sorting, grain size, etc.) or the andesitic magma (temperature, viscosity, etc.) compared to the Özvény Valley, which may have affected the development of the contact lithofacies (Skilling et al. 2002; Martin and Németh 2007). Most of these factors could have varied spatially and temporally during the lithofacies generation.

Conclusions

Only few previous papers discussed the petrologic and volcanological interpretation of the Miocene intermediate volcanic series of the EBB (NE Hungary); thus the Dubicsány Andesite Formation can be regarded as one of the less known lithostratigraphic units of the region. Detailed field work (geologic mapping and recording of sections) and micro- and macroscopic textural analyses were carried out at natural exposures of the Szoros Valley, where numerous andesitic subvolcanic bodies in the form of a dyke and sill complex intruded into andesitic lapilli-tuff and tuff-breccia deposits.

The laterally widespread andesitic volcaniclastic rocks are rich in accidental lithics of variable size and composition as well as in non- or slightly vesicular blocky volcanic glass fragments, which indicate that magma and groundwater interaction may have played a significant role in the fragmentation of the magma, resulting in phreatomagmatic explosions in the shallow pre-volcanic basement. Shortly after the deposition of the lithic-rich volcaniclastic unit, shallow subvolcanic bodies of andesitic composition were emplaced into the soft, unconsolidated and probably wet sediment. Along the contact of the magma and host sediment, thermal and mechanical effects indicating magma and wet sediment interaction occurred at shallow subvolcanic depth. Either peperitic or welded, an oxidized autoclastic margin could not always have been developed, which shows that there could have been some inhomogeneities in the pore water content, permeability, sorting of the host sediment and differences in magma volume and injection velocity, which affected the development of the contact lithofacies zones. Certain physical properties of the magmatic bodies and host sediment deposits (e.g. magma volume, water saturation, sorting) may have varied spatially and temporally within a relatively short distance. Identification of the contact lihofacies zones and distinction from the volcaniclastic deposits could be quite difficult without detailed field observation and textural analysis; however, it could be a significant indicator of the paleo-environmental settings.

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