7 Volcanic Heritage of the Carpathian–Pannonian Region in Eastern-Central Europe

Szabolcs Harangi

7.1 Introduction

The Carpathian-Pannonian region in eastern-central Europe appears to be a geologically calm area, where no disastrous earthquakes, no devastating volcanic eruptions occur. However, this is just the present status of this area; the past 20 million years were much more different (Harangi, 2011). This was the period when the Carpathian basin or Pannonian basin as the scientists call it, was formed behind the uplifting orogenic chain of the Carpathians. The reasons why this region is considered as one of the most important natural laboratories of the Earth are the supposed subduction along the foreland of the Carpathian chain with a still hanging deep vertical slab beneath the south-eastern Carpathians, the lateral movement and rotations of microplates, a dramatic thinning of the continental crust and the lithosphere, as well as major subsidence and the consequence formation of deep basins. In addition this complex tectonic progression was accompanied by varied types of volcanic activities, further subsidence and a final tectonic inversion with coeval general uplift. The long-lasting volcanism formed extended ignimbrite plateaus, large composite volcanoes, coalescing lava-dome complexes and different basaltic volcanic landforms from shield volcanoes to deep maars (Lexa et al. 2010; Harangi 2011). The extensive volcanism has gradually calmed down and the volcanic landforms have changed considerably, leaving the eroded remnants of the volcanic edifices. However, this transformation provided a unique benefit, i.e. a spectacular insight into the nature and the structure of the inner parts of the volcanoes.

There are many opportunities to start a volcano discovery tour in this region. One can begin with an amazing walk observing different types of pumiceous pyroclastic flow deposits, i.e. ignimbrites and the fabulous conical fairy chimneys or beehive stones as the local people call them. Then, the visitors can take a path along one of the most destructive volcanic deposits, formed during nuée ardente events. These valley-fill block-and-ash flow deposits are now in an inverted position and build mysterious cliff towers. Next, they could see also the scar remained after the huge sector collapse of an andesitic composite volcano. Let's have a look beneath the volcanoes! It is not so difficult in this region since many volcanoes eroded deeply exhibiting their root zones. A spectacular journey into the inside of a basaltic volcano along a volcano path starts at the gate of the first volcano park in this area.

In the Carpathian-Pannonian region, seemingly there are no active volcanoes, yet it is an open book for visitors, who want to have an exciting insight into the wide range of volcanic phenomena within short distances. Furthermore, this is the area where volcanic heritage meets historic, cultural, gastronomic and winery pleasures, among others. Nevertheless, this area is a challenging destination also for those people who want to visit only active or potentially active volcanoes. The last volcanic eruption occurred here at the dacitic Ciomadul volcano at 30 ka ago. A large subplinian eruption resulted in a deep explosion crater where now the picturesque St. Anna Lake is found. The last basaltic volcanic eruption took place at the northern part of this region within a deeply eroded andesitic volcanic area. This occurred at about 100 ka following approximately 6 Ma quiescence. Basaltic volcanic fields are unique types of volcanoes with long-lasting, but intermittent activities. It is difficult to claim that such a volcanic field is already extinct even after several 100's ka of repose time. The youngest basaltic volcanic field of this region is located close to Ciomadul. The first eruptions in the Perşani area occurred at 1.2–1.3 Ma and continued intermittently until 500–600 ka. A recent geophysical research indicates that

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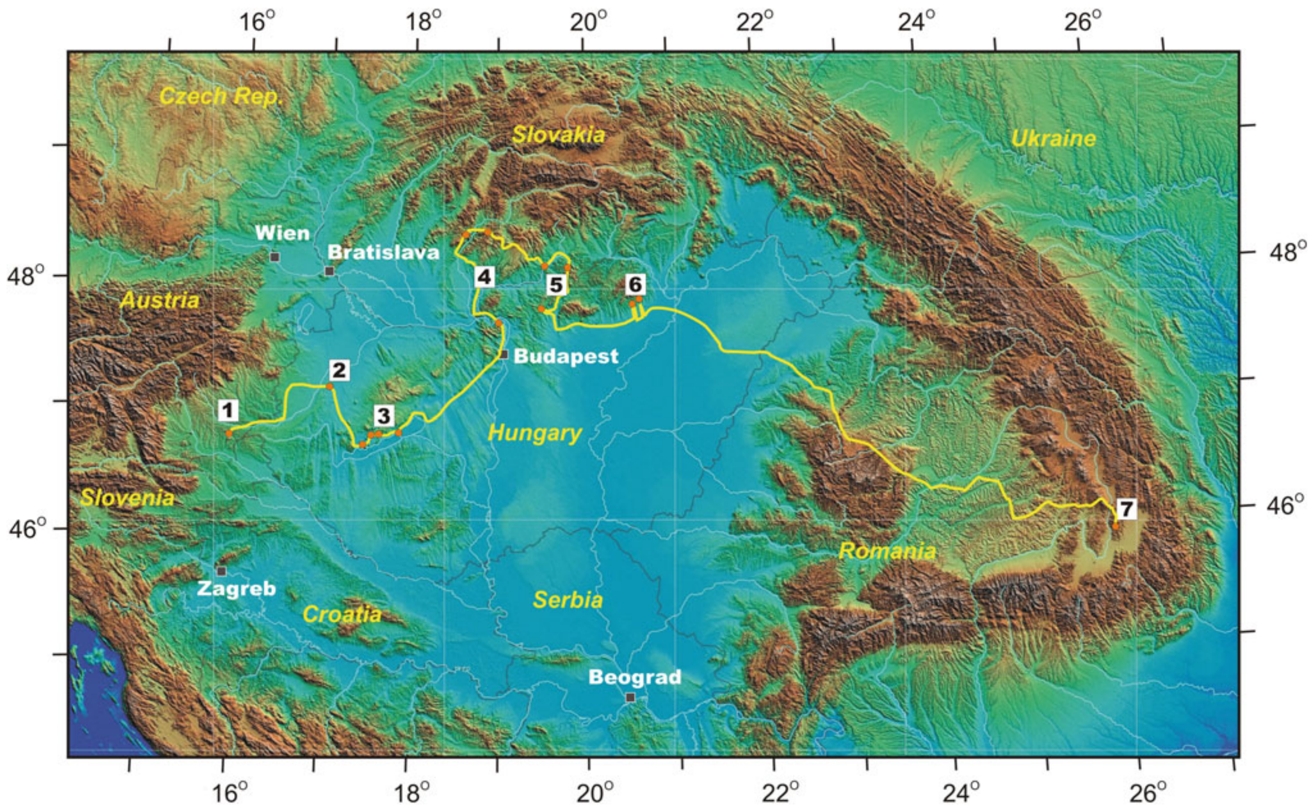

Fig. 7.1 The suggested volcano route in the Carpathian-Pannonian region with selected stops of volcanic spectacles. *1* Styrian volcanic field; *2* Kemenes Volcano Park, *3* Bakony-Balaton Geopark, *4* Visegrád Mts. and the Banska Štiavnica area, *5* Novohrad-Nógrád Geopark, *6* Bükkalja, *7* Ciomadul volcano. *Source of the topographic map* http://geophysics.elte.hu/atlas/geodin_atlas.htm

seismic anomalies could exist both beneath this volcanic field and beneath the Ciomadul volcano, so continuation of the volcanism cannot be excluded.

It is not easy to select only a few places which could be on the must-see list, but this chapter may serve as an introductory review to come and look around this region to discover volcanic heritage and have a rest in this area where hospitality is a tradition. This chapter provides a possible route from west to east with several suggested stops (Fig. 7.1).

7.2 Volcanoes, Chocolate, Wine and Much More: The Steirische Vulkanland

Our volcano tour starts at the Styrian monogenetic basalt volcanic field at the westernmost margin of the Pannonian basin in Austria. Eruptions occurred here from 3.7 to 1.7 Ma building small shield volcanoes, scoria cones, polygenetic basalt volcanoes and maars. Many of them contain high-quality lava rocks and therefore they are intensively quarried. The best known volcano of this area is located at Kapfenstein, where the volcanic deposits contain large amount of mantle-derived ultramafic xenoliths and olivine xenocrysts (Fig. 7.2). There are also abundant rounded quartz pebbles, while juvenile clasts are very rare. This indicates maar-forming phreatomagmatic explosive events occurring probably in a fluvial valley. The energetic explosions generated deep excavations of the subsurface rock beds while the volcanic jets accompanied radially expanding pyroclastic surges, which moved along the fluvial deposits and incorporated large amount of pebbles. A 2 km long geotrail with 11 stops provides a pleasant and easy walk around the eroded remnants of the volcano. The uniquely prepared explanation panels with German text give a brief overview of the main features of the volcanic deposits, the formation of the volcano as well as the further Styrian basaltic volcanoes close to Kapfenstein (Fig. 7.3). Olivine is a kind of trademark of this locality and therefore it is not a surprise that a local winery (Winkler-Hermaden) produces a fantastically concentrated Zweigelt called Olivin (Fig. 7.4).

The beauty of the volcanic landscape such as another remnant of a maar volcano with a castle called Riegersburg on its top (Fig. 7.5) inspired the local people to construct a common philosophy for development and that is the

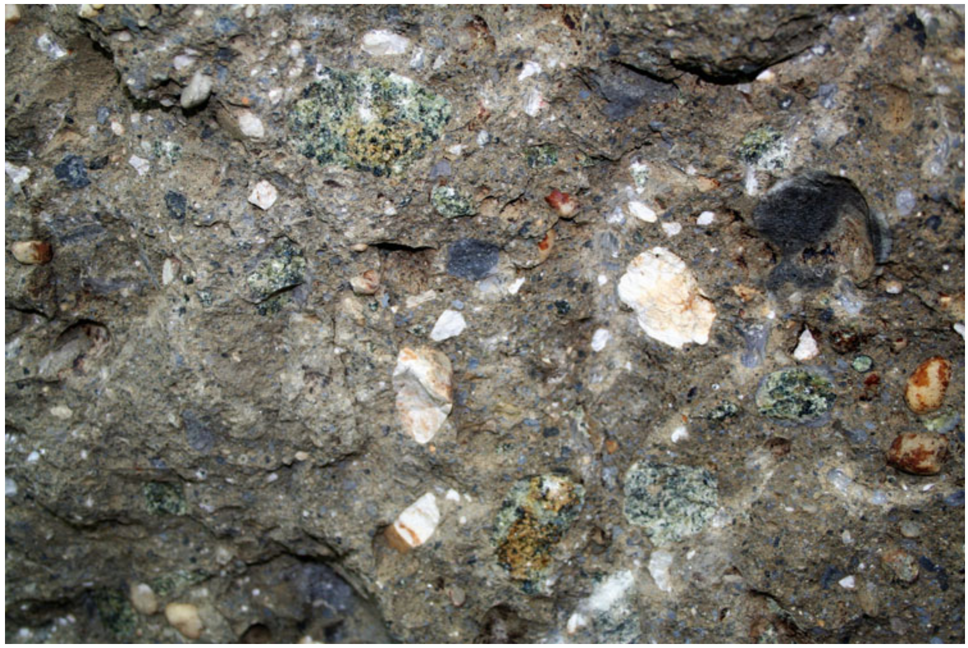

Fig. 7.2 Ultramafic xenoliths, olivine xenocrysts and abundant lithic clasts indicate a typical maar volcanic deposit in Kapfenstein. *Photo* Szabolcs Harangi

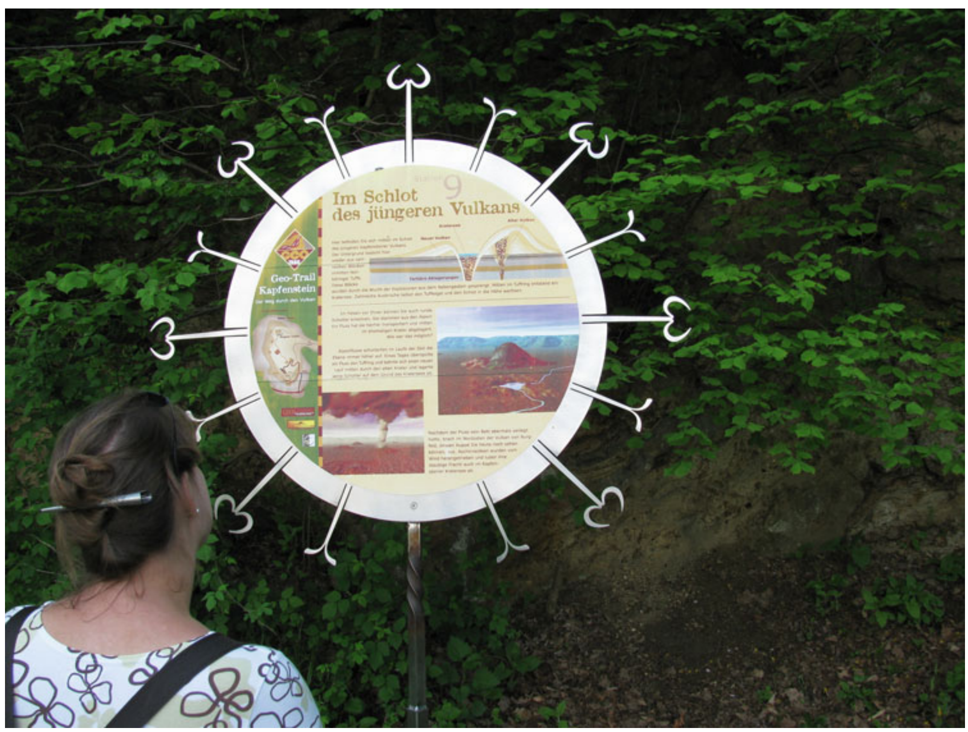

Fig. 7.3 Explanation panels with German text provide an overview of the main features of the volcanic heritage. *Photo* Szabolcs Harangi

Steirisches Vulkanland (www.vulkanland.at/). There are many tourist attractions within this framework, such as the Zotter Chocolate Manufakturer, where the visitor could get information all about chocolate, from the bean to the cult. The guided tasting tour around this special world of chocolate provides valuable information as well as numerous creatively arranged titbit/treat stations. There are many more culinary experiences in this region as well as wide range of hand-made products such as magma-slippers and volcano-hats, among other things.

Fig. 7.4 The famous Zweigelt called Olivin provided by the local Winkler-Hermaden winery. *Photo* Szabolcs Harangi

Fig. 7.5 A beauty of the Steirisches Vulkanland: the Riegersburg Castle is sitting on the eroded remnant of a maar volcano. *Photo* Szabolcs Harangi

7.3 A Journey into the Inside of a Basaltic Volcano: The Kemenes Volcano Park

About 130 km from Kapfenstein, a newly developed volcano park called Kemenes Volcano Park (www.kemenesvulkanpark.hu/) which opened officially in 2013 provides a must-see stop for volcano lovers. The idea for the construction of a volcano park in the middle of a flat plain (called Kisalföld, i.e. Little Hungarian Plain) was raised in the 1990s, when intense volcanological research of the basaltic volcanoes commenced in Hungary. This started with the study of the Ság volcano by the researchers and students of the Department of Petrology and Geochemistry, Eötvös University. The Ság hill was extensively quarried for the high quality basalts (many of the roads in Vienna and in Budapest were made by these cube-shaped basalt

Fig. 7.6 The main crater of the 5 Ma old Ság volcano, with irregular fan-shaped basalt columns and red spatter deposit on the top. *Photo* Szabolcs Harangi

blocks) and as a result, the inner part of the 5.3 Ma old basalt volcano has been exposed (Fig. 7.6). The unique remaining cliff walls convey the great moments of the volcanic history. The birth of the Ság volcano started with phreatomagmatic eruptions in a fluvial-marshy environment and this resulted in the formation of a wide tuff ring. Subsequently the role of mixing with external water-rich sediments decreased significantly and the style of volcanism changed to pure magmatic explosive type (Strombolian to Hawaiian). Scoria cones developed within the tuff ring and later on fire fountains were spewing along a 400 m long fissure. The accompanying lava flows filled slowly the crater of the volcano and formed finally a lava lake without breaching the tuff ring wall. In summary, the volcanic history of Ság hill involves all the principal types of basaltic volcanic activity and left a wide variety of basaltic volcanic products. The more then 50 years long quarrying revealed not only this volcanic heritage, but exposed additional spectacular volcanic phenomena such as impact sags beneath ballistic blocks (Fig. 7.7), peperites, i.e. intimate mixture of basaltic magma fragments and fine-grained volcaniclastic sediments along the contact of a feeding dyke, funnel–shaped vents and peculiar bread-structured basalt spatters, among others.

A volcano path with 12 stops including instructive explanation panels (with Hungarian text, but guides with English and German language could be obtained at the Ság Museum) helps the visitors to understand the main volcanic phenomena and the formation of a basaltic volcano (Fig. 7.8).

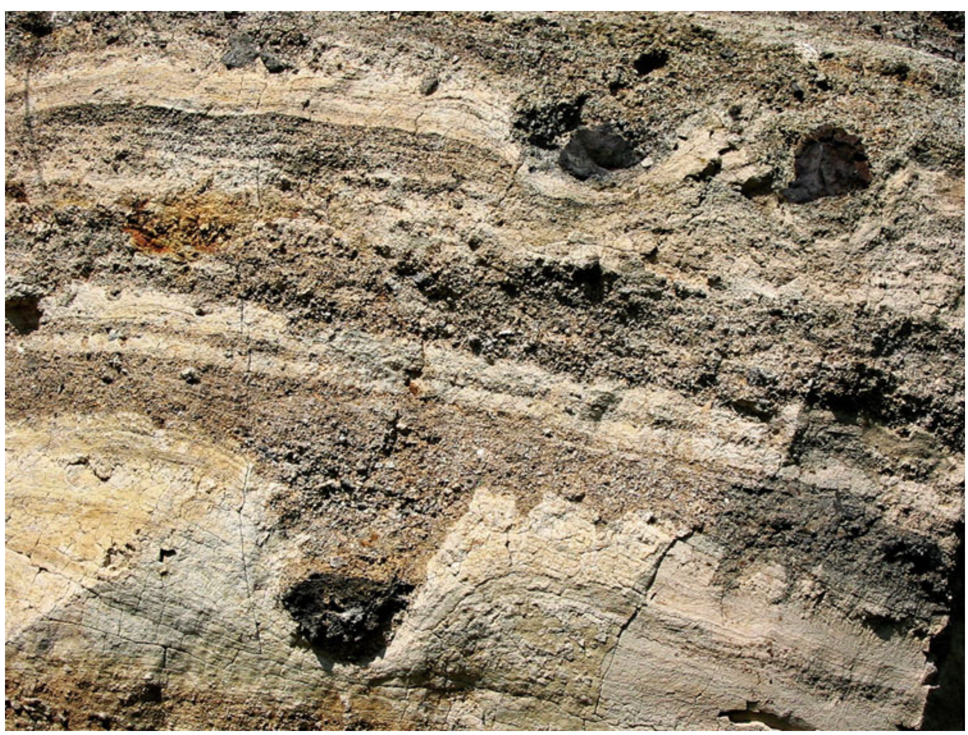

Fig. 7.7 Detail of the initial phreatomagmatic volcanic activity—alternation of base surge and fall deposits with ballistic bombs. *Photo* Szabolcs Harangi

Fig. 7.8 Walk on the new Volcano path with explanation panels. *Photo* Szabolcs Harangi

Fig. 7.9 An out-door activity place with plate tectonic puzzle and volcano columns at the Ság Museum. *Photo* Szabolcs Harangi

Each panel provides a question related to the relevant stop and the answer can be found on the following panel. In addition, the cartoons showing Volcano-Fellow, the symbol of the volcano path, in the explanation panels nicely reflect the main volcanic feature at each stop. Immediately at the foot of the volcano is a newly renovated museum with an interactive exhibition, which shows the volcanological, historical, botanical, ornithological and winery aspects as well as the quarrying techniques performed in the Ság hill. Around the Ság Museum a small play-ground provides a good place for the children, where they can test their knowledge on volcanoes by using the rotatable cubes of the volcano columns and where they can use a large wooden-puzzle to set up the plate tectonic picture of the Earth (Fig. 7.9). The outdoor rock-exhibition shows the most common volcanic and plutonic rocks of Hungary with the explanation plates telling of their age, locations and origin. But there is still more to visit here!

The nearby Volcano House (Fig. 7.10) was opened in 2013 and this is the first permanent interactive exhibition devoted to volcanoes in Eastern Central Europe. The visitors

Fig. 7.10 The Volcano House at the foot of the Ság hill provides an instructive insight into the nature of volcanic processes. *Photo* Szabolcs Harangi

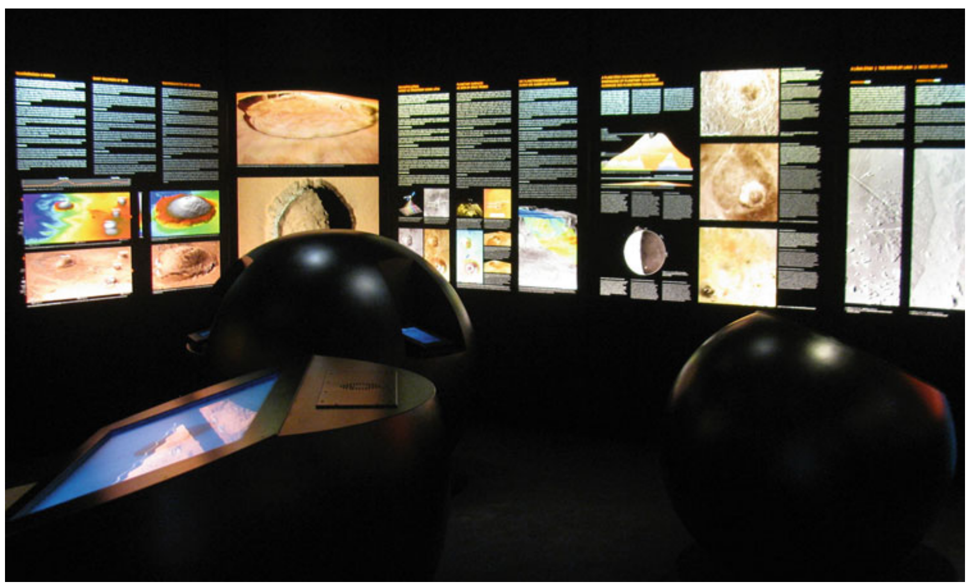

Fig. 7.11 One of the most attractive parts of the exhibition in the Volcano House of the Kemenes Volcano Park shows the hidden secret of the extraterrestrial volcanoes. *Photo* Szabolcs Harangi

can test how is a walk on different types of lava flows and can see 3D maquette of the Etna and the volcanic areas of the Carpathian-Pannonian region. The exhibition provides an interesting tour in the world of volcanoes with explanation panels in English and German. One of the main attractions is a visual journey into the extraterrestrial volcanoes (Fig. 7.11). All in all, it is an intense full day program for volcano friends! In addition, there are more tourist destinations around the Kemenes Volcano Park. The famous Spa and Wellness Centre of Sárvár is only 20 km away, whereas Kissomlyó (10 km from Ság) provides a nice quiet place to experience the country life and go on a short walk along another volcano path of the nearby basaltic hill.

7.4 The Land of Calmed-down Volcanoes and Dinosaurs: The Bakony-Balaton Geopark

The heart of the Bakony-Balaton Geopark (www.bakony-balaton-geopark.hu/) area is only an 80 km easy drive (along the Route 84) from the Ság hill. The first unique

Fig. 7.12 The beautiful volcanic landscape of the Tapolca basin in the Bakony-Balaton geopark: eroded remnants of various basaltic volcanoes. *Photo* Szabolcs Harangi

Fig. 7.13 Cross-stratified base surge deposit at the wall of the Barátlakások of the Tihany maar volcano. *Photo* Szabolcs Harangi

place along the road, where the visitor has to stop is the beautiful medieval Sümeg castle sitting on a steep conical Cretaceous reef-limestone. The Geopark has an extent of 3100 km^2 and comprises 171 different geological formations of various ages. One of the main geologic attractions of this area is the spectacular basalt volcanic field formed from 7.9 to 2.6 Ma. More than 50 basaltic volcanoes developed during this time range from shield volcanoes (e.g. Kab-hill, Agár-tető) through complex polygenetic volcanoes (e.g. Badacsony, Szent-György hill) to maar volcanic complexes (e.g. Tihany, Pula; Martin and Németh 2004). The original volcanic edifices however are strongly affected by the climatic fluctuations during the Pleistocene. Wind erosion and frost disintegration, accompanied by watercourses fed by abundant rainfall during the interglacial periods, carried away a significant amount of loose sediments, mostly consisting of phreatomagmatic deposits of the initial tuff rings. As a result of this strong erosional impact, only basalt-capped volcanic hills (butte) have remained, providing the unique landscape such as seen in the Tapolca basin (Fig. 7.12).

The volcanism took place mostly in a marshy environment following the long period, when the entire area was covered by an extensive lake (Pannon Lake). Semi-consolidated, water-saturated sediments were widespread and as hot basaltic magma mixed with them at shallow depth, violent phreatomagmatic explosions occurred. Occasionally, this magma-water interaction was taking place gradually at deeper level as diatremes propagated downwards. There, the type of water-storage system, i.e. the hydrological condition, changed from the upper porous media aquifer to karst fracture-filling aquifer. That means increasing amount of water mixed to the uprising basaltic magma. In this condition, the eruption jets were loaded by abundant fragments of deep-seated basement rocks, such as

Fig. 7.14 From (*left*) The Lavender House in Tihany is the central interpretive site of the Bakony-Balaton geopark. Pushing a button and you can see how an impact sag is formed beneath a ballistic block. A scoria cone at the corner of the Lavender House, where occasional eruptions occur. *Photos* Szabolcs Harangi

the Permian red sandstone and the Silurian schist. This unique change of the explosion locus can be intimately followed in the maar volcanic sequence of the Barátlakások (Monks cells) at the north-eastern margin of the Tihany peninsula (Fig. 7.13). Cells and a cave-church were carved out here in the phreatomagmatic sequence by Greek monks in the tenth to eleventh centuries and as a result this place offers a fine three-dimensional view of the volcanic formations. In this unique outcrop, the cross-layered structure of the base surge deposits and the asymmetrical impact sags present a special opportunity to reconstruct the former vents (eruptions occurred both at the present position of the Külső-tó, i.e., Outer lake and at the present Füredi-öböl, i.e. Füred bay; note that at that time Lake Balaton did not exist, it formed only about ten thousand years ago). The Tihany peninsula provides further beautiful attractions such as the post-volcanic hot-spring deposits, generally classed as geyserites, which are found mostly at the south-eastern and southern parts of the peninsula. A good walking path, called Lóczy-Geyser Nature Trail, guides visitors to these peculiar formations. Information about the zoological, botanical and landscape values along the path can be read in the explanation boards, both in English and Hungarian. The main visitor centre of the Geopark, the Lavender House, was also built in Tihany and was opened in 2011 and offers a highly instructive exhibition about the volcanic phenomena as well as the cultural and biological diversities of the area (Fig. 7.14).

In addition to Tihany, there are many other spectacular places of volcanic heritage in this new Geopark. The beautiful landscape of the Tapolca basin shows the typical erosional remnants of the former basaltic volcanoes (Fig. 7.12). The basalt-capped butte was formed where lava lakes filled the wide craters of initial tuff rings and this hard rock was resistant against the subsequent erosion (Fig. 7.15). The soft pyroclastic rocks eroded and as a result the columnar jointed structure of these lava lake rocks has been exposed. The tall

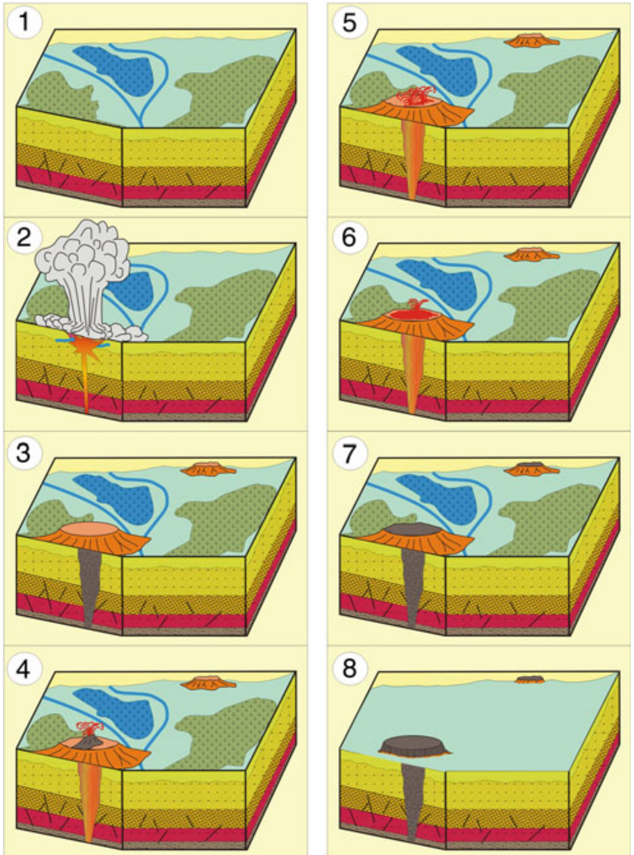

Fig. 7.15 Formation of the typical basalt-capped volcanic hills (*butte*) of the Kemenes and Tapolca basin. *1* Fluvial-marshy environment, *2* and *3* Violent phratomagmatic eruptions due to magma-water interaction forming tuff rings with wide craters, *4* and *5* Strombolian and Hawaiian explosive eruptions within the tuff ring, *6* Formation of lava lake, *7* Termination of the volcanism, *8* Subsequent erosion removed the loose pyroclastic deposits of the volcanoes and only the inner hard basalt lava lake rocks resisted and remained forming the present typical landform. *Source* Harangi (2011)

basalt columns were rounded primarily due to the frost disintegration and they look like giant organ pipes, as local people call them. The most famous ones can be seen at the Badacsony and at the Szent György hill (Fig. 7.16). Good walking trails at both hills make it easy for visitors to see these particular creations of nature and which lead to viewing points, where the panorama of the unique volcanic landscape of the Tapolca basin can be seen.

The nearby Káli basin offers at least two must-see places for volcano-friends. Szentbékkálla is a picturesque small village at the northern margin of the basin. It is famous for the abundance of mantle-derived ultramafic xenoliths found in the phreatomagmatic volcanic products (Fig. 7.17). However, just next to the old church at the northern part of the village a peculiar outcrop is found. In the lower part, a massive basaltic hydrovolcanic flow deposit is exposed with gas segregation pipes and with a wide range of colourful rock fragments. They are mostly lithic clasts, which represent almost the whole lithosphere from the upper mantle part (green-coloured peridotites) through rare granulites from the lower crust to the many rock types of the shallower crust. There are also rounded quartz pebbles indicating that the pyroclastic flow swept a gravely fluvial deposit in a paleo-valley. The steam of the water of that creek penetrated through the pyroclastic flow deposit forming the gas segregation pipes. This massive rock unit is overlain by cross-laminated deposit representing the diluted overbank facies (i.e. pyroclastic surge) of the flow. In addition to this peculiar volcanic formation, there is another geological spectacle west to the village. This is called 'Sea of stones' and contains big boulders and groups of rocky cliffs formed along the shoreline of the Lake Pannon. The sand, pebbly sand and gravel beds were cemented by silica. These blocks have been tilted frequently from their original position with one of them resulted in a specific balanced rock.

The half-cut hill of Hegyestű at the eastern margin of the Káli basin can be seen from far and presents another breath-taking exposure of the tall basalt columns. It is a deeply eroded neck of a 7.9 Ma old basaltic volcano and has remained after the quarrying of the basalts. The abandoned quarry serves now as one of the most important geological exhibition sites of the Geopark. The 336 m peak of the Hegyestű rises more than 200 m high above the shore of Lake Balaton and therefore its top is an excellent viewing point with a 360° panoramic view. A small exhibition shows the basic geology of the Balaton Upland area and the history of quarrying with a picnic area next to it.

Last but not least, from a palaeontological point of view one of the most valuable sites of the Geopark is a dinosaur locality at Iharkút (High Bakony), which was discovered in the early 2000s. Fossil vertebrate remains found here are unique in the world. Based on more than 10,000 isolated bone and tooth fossils, the presence of 30 vertebrate groups was revealed in the Late Cretaceous (85 million years old) sandy-clayey sediments of fluvial–alluvial plain facies.

Fig. 7.16 Variations of columnar jointing: the volcanic neck at Hegyestű and the so-called basalt organs representing the margin of a lava lake rock body at Szent György hill. *Photos* Szabolcs Harangi

Fig. 7.17 Colourful rock fragments in the unique basaltic hydroclastic flow deposit at Szentbékkálla: note the abundance of mantle derived ultramafic xenoliths. *Photo* Szabolcs Harangi

7.5 Andesitic Volcanoes of Northern Hungary and Southern Slovakia

7.5.1 Royal Palace on a Huge Volcanic Avalanche Deposit and Walks in the Roots of the Volcanoes

The formation of the Pannonian basin was accompanied by extensive calc-alkaline andesitic-dacitic volcanic activity, mostly along the inner side of the Carpathians. They are traditionally thought to be related by subduction of an oceanic plate; however, there is a lack of corroborated geological and geophysical evidence for this. Alternatively, they could have been related to the main extensional phase (12–18 Ma) of the evolution of the Pannonian basin, when partial melting of metasomatized lithospheric mantle and mixing of mantle-derived mafic magmas and crustal derived silicic melts resulted in the formation of calc-alkaline intermediate magmas. This volcanism commenced at about 16 Ma and terminated at 10 Ma in the northern part of the region, whereas at the east it lasted from 12 up to 30 ka. The volcanic activity built up groups of composite volcanoes mostly by summit lava dome outpourings and associated pyroclastic flows such as can be seen presently at Merapi or at the Kamchatkan volcanoes. As a result, steep-sided conical volcanoes developed that were subsequently undergoing catastrophic sector collapses (Karátson 2007). The remnant of one of these associated landslide-debris avalanche deposits can be seen superbly just beneath the walls of the Royal palace at Visegrád in the picturesque Danube-bend. The Visegrád Mountains however offer even more points of volcanological interest. The highest point of the mountain is Dobogókő (700 m a.s.l.), which is a place of cultic significance for some Hungarians. Just beneath this ridge are fabulous tall cliffs standing steeply in the thick forest and represent the deposits of devastating nuée ardente block-and-ash flows. Thus, the current highest point once was a deep valley, where such pyroclastic flows could rush down. This also indicates that at that time (at about 15–16 Ma) a volcanic cone developed in this area, the Keserűs volcano. After a sector collapse, further erosion revealed the deeper structure of this volcano. The deep ravines bordered by narrow cliffs of volcaniclastic deposits such as the Rám-gorge offer challenging excursions inside the volcanic heritage (Fig. 7.18). Another unique product of the erosion can be seen in Kő-hill at the eastern margin of the Visegrád hill, where big andesite blocks are sitting amazingly on the top of narrow rock columns (Fig. 7.19).

An additional spectacular place to visit and see what is under the large calc-alkaline andesitic composite volcanoes is in Southern Slovakia. The Banska Štiavnica and Kremnica areas are famous for their ore deposits. Their history is closely linked to the exploitation of its abundant resources such as silver and gold. The first mining settlement was founded by Celts in the 3rd century. In the Middle Ages, this area was the main producer of silver and gold in the Kingdom of Hungary and in 1735, one of the first mining schools in the World was founded in Banska Štiavnica (Fig. 7.20). The Banska Štiavnica Geopark (www.

Fig. 7.18 The Rám-gorge provides challenging excursions within deeply eroded volcaniclastic deposits. *Photo* Szabolcs Harangi

Fig. 7.19 An amazing product of erosion: spectacular 'rock tables' in Kő-hill. Big andesite blocks are sitting on narrow rock columns. *Photo* Szabolcs Harangi

Fig. 7.20 Banska Štiavnica, an old mining town is hidden in the erosional remnant of a calc-alkaline volcanic complex. Within the town, the eroded neck of a 6 Ma old basaltic volcano is found (Kálvária-hill, i.e. the Calvary hill) where volcanic and cultural heritage meets. *Photo* Szabolcs Harangi

geoparkbs.sk), which is presently not an official member of the European Geopark Network, offers an excellent educational outline about volcanism and its related ore generation and mining history of the area. A part of this history is found within the town in the rich Mining Museum; however, there is also an instructive geological path with 19 stops starting in the Červená studňa saddle in the Paradajs Mountain. The explanation boards provide a broad insight into the formation of the Štiavnický stratovolcano. There is a marked green touristic sign leading from the Square of St. Trinity which connects with the sign of the instructive path in Červená studňa. The undemanding route (about 2.5 h long) is also suitable for children and elderly people, free from any orientation problems and it is conceived in the form of circuit around the Paradajs Mountain. Finally, it is worth to mention that the youngest basaltic volcano of the entire Carpathian-Pannonian region is found close to Banska Štiavnica. The Putikov volcano formed at about 100 ka near the present village of Nová Baňa. Presumably tall lava fountains built a spatter cone within the erosional remnant of the andesitic volcanic landscape and finally the basaltic lava travelled several kilometres burying the older terraces of the river Hron. It is noteworthy that this volcanic activity is suggested to have occurred after several million years of quiescence in this area.

7.6 Where Volcanic Heritage meets Historic and Cultural Events: The Novohrad-Nógrád Geopark

The Novohrad-Nógrád Geopark (www.nogradgeopark.eu/) is the first 'across border' geopark situated in northern Hungary and southern Slovakia. One of the main driving forces for the application to become officially recognised as a geopark was the rich volcanic heritage of this area which includes:

- damaging pumiceous ash-flows;
- submarine and subaerial lava flows;
- one of Europe's largest coherent lava plateaus;
- exposed subvolcanic bodies and volcanic vents, maars and diatremes;
- 'petrified' gas bubbles and lava spatters;
- platy and columnar jointed basalts and andesites including a unique 'andesite-slide';
- garnet in the volcanic rocks, and
- fragments from the upper mantle.

All of this within a restricted, small area makes it without doubt an excellent place to gain a unique insight into volcanogenic processes. The volcanic phenomena here are strongly linked to cultural and historical heritage of the region. Beautiful medieval castles (e.g. Fiľakovo, Somoskő, Salgó and Hollókő) are built on top of the former vents of the basalt and andesite volcanoes and contribute to the rich cultural tradition of the area (Fig. 7.21).

While not all the spectacular sites can be discussed here, there are a few must-to-see places that are certainly unique, such as the Nature Reserve of the Ipolytarnóc fossils and the curvilinear columns of basalts and andesites at Somoskő and Bér, respectively. The name of Ipolytarnóc became famous after a petrified tree that is almost 100 m long and has a circumference of eight metres. This makes it probably one of the largest petrified pine trees in the world. The tree was washed out from a volcanic layer deposited following a large devastating eruption at about 17.5 Ma. Hot pumiceous ash layers buried a vast area and destroyed the subtropic vegetation, but on the other hand, remnants of the rich flora as well as many footprints of various animals at a watering place were nicely preserved. Based on this particular preservation, and the intricate research work, which reconstructed this unique place, the Ipolytarnóc Paleontological Site protected area (http://osmaradvanyok.hu/index.php?p=hu_home) received the European Diploma in 1995. The newly reshaped visitor centre close to the village offers an interesting outline of this geological heritage and a movie theatre with world-class 3D animation introduces visitors to the prehistoric past. The associated trail network consists of five introductory study paths starting from the visitor centre with guided tours available. The geological study path in the Borókás creek reveals a treasure of paleontology, including shark teeth in the shallow sea sediments, the palaeosurface of an ancient dry land dotted by thousands of footprints of mysterious creatures and remnants of a petrified forest, all recalling the memories of a prehistoric past. The trail is accessible even in rainy weather, including by wheelchair. The pumiceous ignimbrite is well exposed above the footprint sandstone and contains many charcoal fragments indicating the high temperatures at the time of deposition. The footprint sandstone as well as part of the large petrified pine tree is exposed in covered exhibition halls and in a protective cellar. At the end of the trail, the Tasnadi Kubacska Hall provides a spectacular outline of the richness of the various footprints and the high-tech 3D movie projecting the prehistoric track gives a unique interpretation of a vanished era.

The next site recommended for a visit is located just at the Hungarian-Slovakian border, which is now free to cross. The medieval castle of Somoskő was built on a volcanic neck of a 3 Ma old basaltic volcano with exposed convex curvilinear columns which are likely to represent the outer margin of the neck (Fig. 7.22). Beneath the 'rock-cascade' is a wide 'stone-sea', where the eroded fragments of the steep cliff have accumulated. A short study path (free of charge) with explanation panels guides the visitors explaining both the main geological and the biological features. There is no entrance fee either to visit the ruins of

Fig. 7.21 Castles on volcanoes: Somoskő (**a**) and Filakovo (**b**). *Photo* Szabolcs Harangi

the medieval castle of Somoskő. Another unique curvilinear columnar jointed rock is exposed 60 km further south close to the village of Bér (Fig. 7.22). As far as we know, there are only a few examples in the world where such a good example of a concave curvilinear columnar jointed structure is preserved. It is locally known as the 'andesite-slide' and is exposed in the Nagy-hill, where a short path leads visitors to the site. This structure could have formed either in a volcanic neck or in a lava flow burying a narrow deep valley as the andesitic magma slowly cooled down.

Fig. 7.22 Variation of curvilinear columns: convex (**a**) and concave (**b**) columnar jointed rocks. The basaltic rock-cascade in Somoskő and the andesite-slide in Bér. *Photo* Szabolcs Harangi

7.7 The Land of Devastating Ignimbrite Deposits, Inviting Wine Cellars and the Fabulous Fairy Chimneys: The Bükkalja Area

The Miocene to Quaternary volcanism of the Carpathian-Pannonian region started with explosive eruptions of large volume silicic magmas. This volcanic activity coincided with the initial thinning of the continental crust and lithosphere beneath the area. The caldera-forming eruptions resulted in dominantly thick pumiceous pyroclastic flow deposits, called ignimbrite. In some places the thickness of the ignimbrite unit exceeds 200 m! In such thick ignimbrite sequences welded facies were often formed by sintering of pumices and silicic glass shards at high temperature and compressive loads. As a result, elongated fiamme occurs frequently in volcaniclastic rocks. The southern foreland of the Bükk Mountains (called Bükkalja) provides an excellent insight into the nature of the ignimbrite deposits. It is indeed a volcanological paradise of ignimbrites showing various facies, i.e. non-welded to welded types of such silicic pyroclastic flow deposits. The repetitive violent eruptions for an about 7 million year long period (from 20 to 13 Ma) could have resulted in an ignimbrite plateau. The subsequent erosion dissected this plateau and deep creeks were formed (a good example of this bad-land landscape can be seen at Kazár, close to Somoskő) which then widened, becoming broad valleys and decreasing significantly the extent of the ignimbrite surface. One of the peculiar results of such erosion is the formation of fabulous fairy chimneys at the retreating steep margins of the valleys. These conical geomorphologic features are locally called beehive stones (Fig. 7.23), because of the rectangular 'windows' carved into them up to heights of 10–12 m. There are dozens of such conical cliffs in Bükkalja (72 beehive stones with 473 chambers are currently known in this area) and almost all include the enigmatic carved 'windows'. The origin of these 'windows' is still unclear and highly debated, but the most

Fig. 7.23 The land of devastating ignimbrite deposits: (*left*) A fabulous conical fairy chimney in Bükkalja—typical erosional forms of the un-welded ignimbrites. (*right*) Fairy chimney castle of un-welded ignimbrite at Szomolya, one of the most spectacular places of beehive stones in Bükkalja. *Photo* Szabolcs Harangi

Fig. 7.24 Wine cellars in the ignimbrite. They hide barrels of well-known wines of the Eger area. *Photo* Szabolcs Harangi

widely supported view is that the carved compartments were used for beekeeping. The local name of these fairy chimneys refers to this supposed origin of the 'windows'. Another idea for their mysterious origin suggests that idol statues were placed into them, or they were used as an urn cemetery. The most beautiful group of beehive stones in Bükkalja is found at the northern edge of the village of Szomolya. Explanation boards and direction indicators clearly show the location of the exceptional site right from the centre of the village. Along the road, wine cellars excavated in the ignimbrite can be seen that are another typical feature of this volcanic area (Fig. 7.24).

Fig. 7.25 The cave-dwellings of the Little America at Cserépfalu. *Photo* Szabolcs Harangi

The local wine is widely respected. Viticulture began in the region as early as the eleventh century. The cultivation of wine was not interrupted even during the 91 years of Turkish occupation, when wine was an important source of income for the Turks. The typical wines of the Bükkalja (or Eger) region is called Leányka, Királyleányka, Hárslevelű (Linden-Leaf), Olaszrizling (Italian Riesling), Muskotály (Muscatel), Tramini, Szürkebarát and Chardonnay. The spiciness, fieriness and relatively high acidity of the red wines of Eger is what typifies Bikavér (Bull's Blood) which is why local wine-growers put most of their energy into producing it. The method of preparing this noble wine is based on age-old traditions and was finally set down in the Bikavér Codex. Walking in this ignimbrite field, one can often find wine-cellars carved into the ignimbrite at the outer parts of the villages and towns and one has a good chance to find them open for a quick (or long?) wine-tasting.

In order to have a good outline of the various types of ignimbrite facies (unwelded and welded), probably the best is to take a short route from the northern edge of Bogács (where of course excellent wine cellars are also found) to north to the village of Cserépfalu. Just above the wine-cellars of Bogács (carved into unwelded ignimbrite), good outcrops of fiamme-bearing welded ignimbrite can be found following the tourist path indicated by a red line. Further north, leaving the village of Cserépfalu, a dirt road leads to the Mész-hegy hill, where an explanation board indicates the direction of a forest nature trail where good examples of beehive stones can be found with the so-called famous 'Devilstower'. Just at the other side of the dirt road, another small forested hill, called Túrbucka, offers a good opportunity to have a closer look at shiny, fiamme-bearing welded ignimbrite rocks. Back to Cserépfalu, it is recommended to visit the so-called Little America (eastern side of the village at Berezdi walk; the direction is marked from the village centre). These cave-dwellings (Fig. 7.25) served as home for poor people, who could not immigrate to the American continent during the economic crisis which affected the world during the beginning of the twentieth century. They could reach only this place instead of America and therefore people said that they were able to emigrate only to 'Little America'.

7.8 The Youngest Volcano of the Region: The Ciomadul

It is about 650 km (about 9 h) drive from the Bükkalja region to reach the youngest volcano of the Carpathian-Pannonian region, near the village Tusnádfürdő (or Baile Tusnad, an area in Romania where mostly Hungarian people called Székely are living. Therefore we give both the Hungarian and Romanian name of the geographic places). This volcano is called Ciomadul (or Csomád in Hungarian), a dacitic lava dome complex with two picturesque craters in the central part (Fig. 7.26). The older one (Mohos swamp) is covered by a 10-meter-thick peat layer and contains numerous colourful tiny pools of water. Entrance is only permitted for guided tours and visitors can follow a wooden boardwalk just above the swamp. The younger crater is filled by the 6 m deep St Anna Lake, the best preserved crater lake of Europe. This is an explosion crater formed presumably by a violent subplinian eruption at about 30 ka. The eruption cloud shifted south-eastwards and deposited a

Fig. 7.26 The youngest volcano of the region, the Ciomadul—could it be reactivated in the future? The Ciomadul lava dome complex from north. *Photo* Szabolcs Harangi

Fig. 7.27 The colourful Mohos swamp, the older crater of the Ciomadul formed by phreatomagmatic eruption. *Photo* Szabolcs Harangi

15 cm thick layer of 2–3 cm sized pumice clasts as far away as 20 km (the outcrop is found in an abandoned sand quarry at Kézdivásárhely/Târgu Secuiesc). The proximal deposits of 1–2 m thick pumiceous fallout layers are found mostly around the Mohos swamp (Fig. 7.27).

The volcanic activity of Ciomadul started about 150 ka and occurred intermittently with fairly long quiescence periods. Outpourings of viscous, crystal-rich dacitic magma formed steep-sided lava domes, which coalesced into a larger volcanic edifice. This kind of volcanism was occasionally interrupted by explosive eruptions which formed the two craters. Explosive and gravitational collapse of lava domes resulted in devastating nuée ardentes. Their block-and-ash flow deposits may contain charcoal fragments allowing the determination of their formation age. These outcrops are found mostly at the southern periphery of the volcano along the dirt road from Sepsibükszád (Bixad) to the St. Anna Lake (Fig. 7.28). There are many forest tourist paths around the craters, where one can observe the huge blocks of the lava dome rocks. Note, that bears are living in the forests of this area and therefore certain precautions are needed, although the danger is limited.

The present state of the Ciomadul volcano is unclear regarding whether further eruptions can be expected. In fact, there are many signs suggesting that this volcano could be potentially active, even though the last eruption occurred at about 30 ka. Geophysical research indicates that the magmatic body beneath the volcano could contain some amount of silicic liquid. Furthermore, there are intense gas emissions (mostly CO_2 with some H_2S) around the volcano. One

Fig. 7.28 St Anna Lake—a deep explosion crater formed by a subplinian eruption at 30 ka. *Photo* Szabolcs Harangi

Fig. 7.29 One of the mofettes around Ciomadul, where CO_2 gases are emitted. Their isotope composition suggests magmatic origin. *Photo* Szabolcs Harangi

peculiar site is located a couple of kilometres south of the Ciomadul volcano (Büdös/Potorusu-Bálványos/Balvanyos hills) where abundant mofettes and CO_2-rich springs are found (Fig. 7.29). Many of them are utilised for therapeutic purposes in nice wooden houses. The Smelly/Stinking or Sulphurous cave (Büdös-barlang) is a unique place of such gas emanation. Jókai, the famous Hungarian writer called it as the 'Portico of Hell'. It is located at the south-eastern slope of the Büdös-hill just above the Hotel Bálványos, which was once a sanatorium for tuberculosis patients.

Several relatively steep tourist trails are marked with blue and red spots leading from the hotel to a cave that was formerly the entrance to a sulphur mine. The upper level of the CO_2 gas accumulation is clearly indicated by the yellow colouring of the cave wall and can be unambiguously checked using a pocket-lighter or match-stick. The strong odour which can be smelled even far from the cave is caused by the 0.38 % of sulphurous hydrogen in the emitted gas. There are more such caves around the hill, including the Alum (Timsós) Cave and the Killer Cave, which can be visited following the blue trail. However, one should keep in mind that entering into these caves is highly dangerous! Close to the Killer Cave, there is a depression filled with gas, which is known to cause the death of wild animals (therefore it is called as the Birds' Cemetery). At the end of the trail, there is a small peat bog, called Buffogó-láp. The maximum thickness of the peat is around 4 m. There are smaller and bigger pools of water girded with grass and flossy sphagnum and carbon-dioxide gas emissions can be also recognized here as continuous bubbling. Geochemical investigation of the gas emissions revealed, that it has a magmatic component that also underlines the notion that although this area is seemingly quiet, renewal of volcanism cannot be unambiguously excluded in the future.

In conclusion it can be said that the Carpathian-Pannonian Region is indeed akin to a natural laboratory where the present state of the tectonic environment allows us to gain an insight into the volcanic processes of the past. The sheer abundance of volcanic features and their integration into the historic and cultural traditions offers volcano tourists an extensive geodiversity to explore. The remarkable volcanic heritage has been embraced by the tourism industry and includes not only the dormant volcanic landscapes, but also attractions such as the local historic architecture, the vineyards established on the fertile volcanic soils as well as the natural mineral springs, which are utilised for health and wellness purposes.

References and Further Reading

Bakony-Balaton Geopark (2013). Where to find the Bakony-Balaton Geopark? http://www.bakony-balaton-geopark.hu/home/bakony-balaton-geopark/bevezetes. Accessed 23 July 2013.

Geodynamic Atlas of the Pannonian Basin (2013). http://geophysics.elte.hu/atlas/geodin_atlas.htm. Accessed 30 July 2013.

Geopark Banská Štiavnica (2013). http://www.geoparkbs.sk/geopark-banska-stiavnica.html. Accessed 23 July 2013.

Harangi, Sz. (2011). Vulkánok. A Kárpát-Pannon térség tűzhányói. [Volcanoes. The Volcanoes of the Carpathian-Pannonian region] (p. 440). Geolitera Szeged, ISBN: 978-963-306-110-7. [in Hungarian].

Ipolytarnóc Paleontological Site (2013). Üdvözöljük honlapunkon! http://osmaradvanyok.hu/index.php?p=hu_home. Accessed 23 July 2013.

Karátson, D. (2007). A Börzsönytől a Hargitáig—Vulkanológia, felszínfejlődés, ősföldrajz. [From the Börzsöny to the Hargita—Volcanology, landscape evolution and paleogeography] (p. 463). Budapest: Typotex Kiadó, ISBN 978-963-9664-66-1 [in Hungarian].

Kemenes Vulkánpark (2013). http://www.kemenesvulkanpark.hu/. Accessed 23 July 2013.

Lexa, J., Seghedi, I., Németh, K., Szakács, A., Koneĉny, V., Pécskay, Z., et al. (2010). Neogene-Quaternary volcanic forms in the Carpathian-Pannonian region: A review. *Central European Journal of Geosciences, 2*, 207–270.

Martin, U. & Németh, K. (2004). Mio/Pliocene phreatomagmatic volcanism in the Western Pannonian Basin. Geologica Hungarica, Series Geologica tomus 26 (p. 191). Budapest, ISBN:963-671-238-7.

Novohrad-Nógrád Geopark (2013). http://www.nogradgeopark.eu/. Accessed 23 July 2013.

Steirisches Vulkanland (2013). Region Steirisches Vulkanland. http://www.vulkanland.at/. Accessed 23 July 2013.