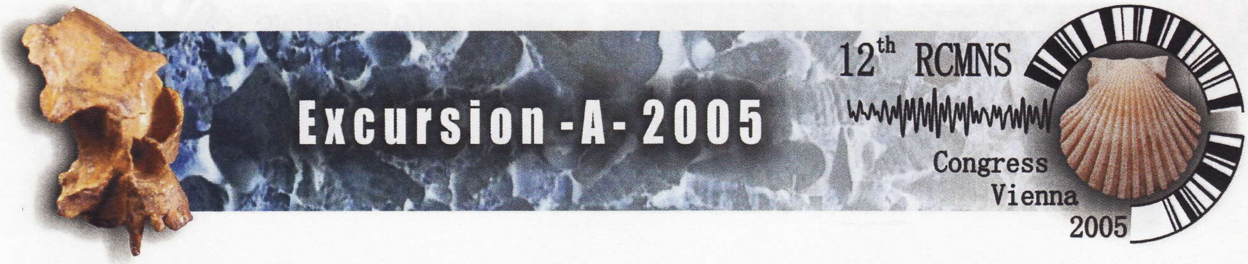

Contents

6. September 2005

7. September 2005

Neogene evolution of the Kisalföld Basin

The Kisalföld („Little Hungarian Plain" or „Danube") basin is a subbasin of the Neogene Pannonian basin system of Central Europe. The Pannonian basin is considered to be a back-arc basin with a subduction-related Neogene calk-alkaline volcanic chain along its northern and eastern margins (Horváth 1993). During the Miocene, extensional tectonic events behind the subduction zone resulted in lithospheric thinning and asthenospheric uprise (Stegena et al. 1975; Horváth 1993; Szabó et al. 2004). The structure of the Pannonian basin is the result of distinct modes of Middle and Late Miocene extension (Tari et al. 1999). The gradually diminishing extension during the Late Miocene/Pliocene could not advance to the localization of extension into narrow rift zones in the Pannonian region, except some deep subbasins, such as, among others, the Kisalföld basin (Tari et al. 1999) (Fig. 10). These basins are demonstrated to be underlain by anomalously thin crust (22.5 km) and lithosphere (45-60 km), and they are characterized by high present-day surface heat flow (c. 90 mW m2). From Late Miocene to Pliocene times, extensive alkaline basaltic volcanism characterised this region (Pécskay et al. 1995; Szabó et al. 2004), which is commonly regarded as evidence for the initiation of narrow rift zones in the Pannonian basin system (Tari et al. 1999). These proposed narrow rifts failed after the final docking of the Eastern Carpathians onto the European foreland and excluded any further extension of the back-arc region (Tari et al. 1999).

The Kisalföld Neogene basin is superimposed on the Alpine thrust-fold belts of the Eastern Alps and Western Carpathians. Following an Early to Middle Miocene, partly terrestrial, partly marine synrift stage, the bulk of the Neogene sedimentary formations were deposited in the Late Miocene brackish Lake Pannon, which flooded the area due to a widespread post-rift (thermal) subsidence. Seismic reflectors show that the Kisalföld basin was filled with sediments prevailingly from the NW, implying that the littoral zone of Lake Pannnon shifted from the NW towards the SE. Seismic profiles also suggest that at this time the Transdanubian Central Range (TCR) was a submerged sill, or a series of islands at best (Horváth et al. 1995; Magyar et al. 2000).

Recent studies showed that extensive lacustrine sedimentation in Lake Pannon ceased in the Kisalföld basin about 9 Ma BP (Magyar et al. 2000; Sacchi et al. 1999; Sacchi and Horváth 2002). During the Late Miocene, about 4000 m thick succession of basin filling deposit accumulated in the center of the Kisalföld basin, predominantly deriving from the rising Alpine-Carpathian orogen and deposited as lacustrine to delta to fluvial units (Vass et al. 1990; Horváth 1993; Lankreijer et al. 1995; Kovac et al. 1999). Due to a Late Pliocene-Quaternary tectonic inversion, the sedimentary formations of Lake Pannon, including the relatively deep water facies, became exposed and eroded along the western and eastern edges of the basin, while the central part underwent continued subsidence, and was covered by Pliocene and Quaternary terrestrial sediments (Lankreijer et al. 1995; Horváth et al. 1995; Kovac et al. 1999)

The Miocene to Pliocene alkaline volcanism in western Hungary commenced about 8 Ma and lasted until 2.3 Ma, according to high precision 40Ar/39Ar isotope age data as well as K/Ar isotope ages (Pécskay et al. 1995; Balogh and Pécskay 2001; Wijbrans et al. 2005). The volcanic fields in western Hungary consist of eroded remnants of scoria cones, tuff rings and maars (Németh and Martin 1999; Martin and Németh 2004a).

In the Little Hungarian Plain Volcanic Field (LHPVF), the basaltic volcanoes are located near the major tectonic lines, such as the Rába detachment fault and the perpendicular strike-slip faults (Tari et al. 1992)(Fig. 10). The Rába detachment fault is considered to be a major supracrustal fault zone separating distinct tectonic units (Tari et al. 1992; Horváth 1993; Tomek 1993). Magma is considered to have followed its way to the surface along the weakness zone of the lithosphere. In near surface area the melt probably break through the pre-existing pathways along the deeper brittle zone, and reached the surface more or less along the surface manifestation of the main weakness zones similar to other low density sediment filled basins such as Crater Flat in Nevada (Connor et al., 2000).

The alkaline basaltic volcanism of the LHPVF occurred about 4 - 6 Ma according to the wide range of K/Ar and occasional 40Ar/39Ar dates (Balogh et al. 1986; Balogh and Pécskay 2001; Wijbrans et al. 2005). The alkaline basaltic volcanism in the LHPVF is characterised by predominantly mafic rocks ranging from basanite to alkali basalts and trachybasalts with minor basaltic trachyandesites from the Ság-hegy (Fig. 1) (Embey-Isztin et al. 1993; Harangi et al. 1995; Harangi 2001). Ultramafic xenoliths are common from pyroclastic successions of the Gérce N (Hercseg-hegy) and Gérce E tuff ring remnants (Fig. 10) (Harangi et al. 1995; Szabó et al. 1995).

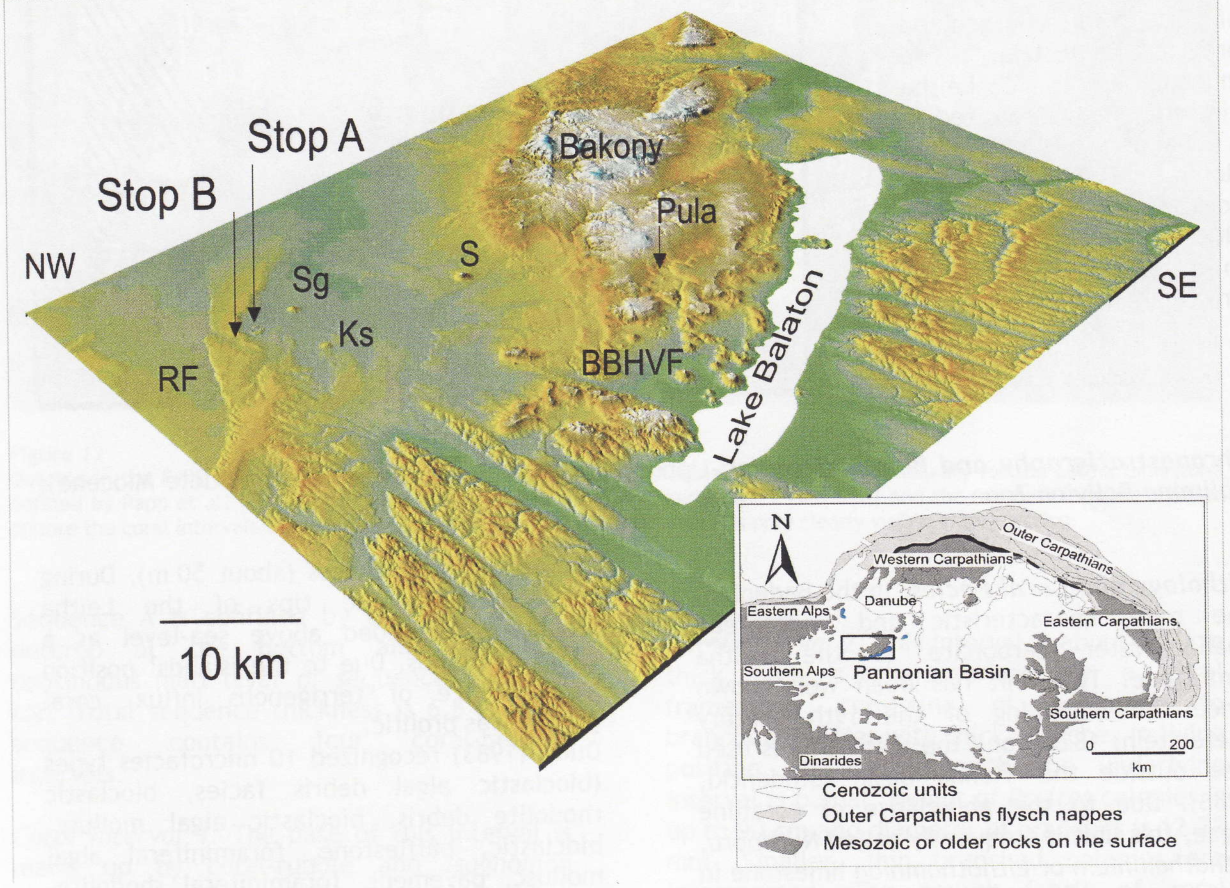

Figure 10
Oblique view of western Hungary on a Digital Terrain Model. Abbreviations: RF - Rába Fault Zone, Sg - Ság-hegy, Ks - Kissomlyó, S - Somló, BBHVF - Bakony- Balaton Highland Volcanic Field. A and B are the visited sites - see stop *Gerce* for details.

KISAFÖLD BASIN (= DANUBE BASIN)

Stop 3: Gérce, Hungary - Tapolca Basalt Formation (A) and Pula Alginite Formation (B), ~5 my

In a relatively small area along the Rába fault zone in western Hungary, an alkaline basaltic volcanic field was active in the latest Miocene/early Pliocene (Fig. 23). The largest volcanoes, such as Ság-hegy and Somló, were complex with multiple vents producing lava flows and/or sill and dyke complexes later in their eruptive history (Martin and Németh 2004). Apart from these volcanic erosion remnants, pyroclastic rocks of eroded tuff rings form the other locations. In the eruption history of each of the volcanoes, magma-water interaction (phreatomagmatism) played the most important role.

Tuff ring craters commonly function as sedimentary traps. Right along N and E of the village of Gérce, two tuff rings are located (Fig. 23). The Gérce-East tuff ring remnant still reflects the original morphology of the pyroclastic edifice, but it seems that the former crater lake must have breached quickly, and, if there was one, no crater lake sediments are preserved by today. The Gérce-N (Hercseg-hegy) tuff ring, however, has been a depocenter of a thick accumulation of fossiliferous Pliocene sediments, forming alginite (oil shale) in the closed crater lake (Fig. 23). The fossil plants from the Gérce (and Pula from the Bakony-Balaton Highland Volcanic Field on Fig. 23) alginites give a unique insight into the early Pliocene flora and climate of the western Pannonian Basin (Hably and Kvaček 1998).

Figure 23: Oblique view of western Hungary on a Digital Terrain Model. Abbreviations: RF - Rába Fault Zone, Sg - Ság-hegy, Ks - Kissomlyó, S - Somló, BBHVF - Bakony- Balaton Highland Volcanic Field. Black and white aerial photo of the visited region around Gérce village (STHW84 refers to the state highway #84). A, and B are the visited sites.

Chronostratigraphy: Early Pliocene. The Hercseg-hegy basalt (Gérce-N) was dated by K/Ar method as 4.77+/-1.8 Ma (Balogh et al. 1986).

Description of the Gérce-E tuff ring: To the east of the village Gérce, a circular arrangement of exposed pyroclastic rocks forms an erosional remnant of a tuff ring 2 km in diameter (Fig.24). The area consists of 4 distinct hill sides; each of them stands about 40 m above the base level (Figs 23 & 24A). The pyroclastic successions form a very gentle dipping array of pyroclastic rock blocks (Fig. 24B). The most extensive outcrops of pyroclastic rocks are located in the Belső-hegy, in the southern part of the complex (Fig.24C).

Pyroclastic rocks consist of alternating coarse-to-fine grained lapilli tuffs and they are occasionally inter-bedded with lapilli stones (Fig. 24B). Large morphology-dependent depositional structures of the pyroclastic beds as humps are exposed in the quarry of the Belső-hegy (Fig. 24D). These humps form tens of metres wide zones, just a few tens of metres away from the otherwise gentle dipping bedded pyroclastic successions (Fig. 2D). The pyroclastic units are in general, well-cemented by silica-gel as well as calcite (Fig. 25A). The dominant lapilli tuff beds are rich in angular, non-to-weakly vesicular volcanic glass shards (Fig. 25B). Vesicles with elongated, oval shapes, are commonly collapsed and filled with secondary minerals such as calcite. Rare volcanic lithic fragments are slightly crystalline, olivine and/or pyroxene bearing alkali basalt lapilli. The lapilli tuff beds are rich (~ 5 vol %) in fragments of peridotite and/or olivine and pyroxene megacrysts (Fig. 25C).

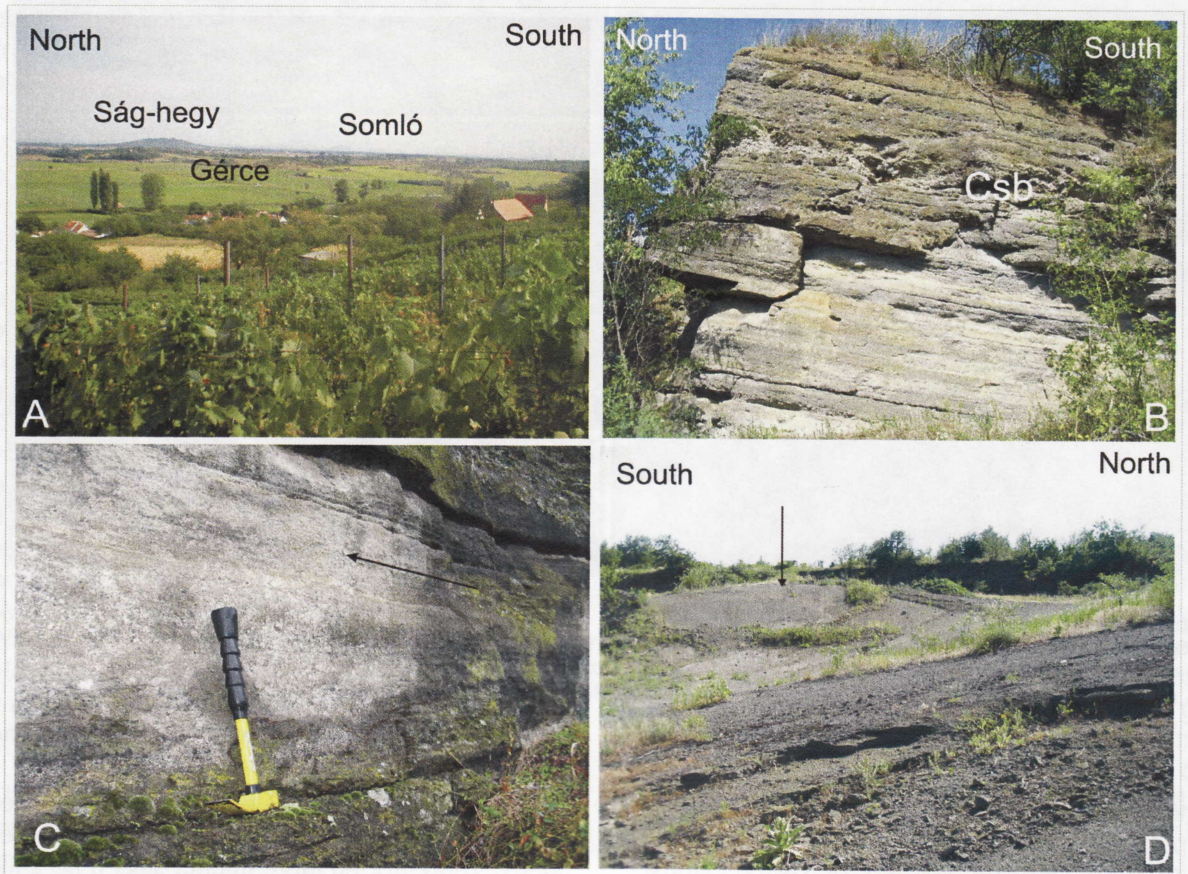

Figure 24
A - overview of the Gérce - E tuff ring erosional remnant.
B - well-bedded lapilli tuff succession from the Gérce - E tuff ring, Csb - coarse grained spatter rich bed
C - parallel bedded lapilli tuff with low angle, low amplitude long wavelength dune (arrow)
D - morphology dependent hump (arrow). Note the otherwise plane parallel bedded tuff ring succession in the distant quarry wall

This "free" crystal content seemingly does not show any systematic distribution pattern neither in vertical nor lateral extent. Larger (cm-scale) peridotites are accumulated in a juvenile lithic fragment rich, 30-40 cm thick horizon in the pyroclastic succession forming the upper exposed section in the largest quarry in the area. Basaltoid lapilli form lava spatters with common twisted form indicating that they were hot upon deposition. The low vesicularity indicates that the melt has been originally low in gas content and/or it has already degassed upon eruption. The pyroclastic beds contain cauliflower lapilli (Fig. 25D) indicating magma - water interaction.

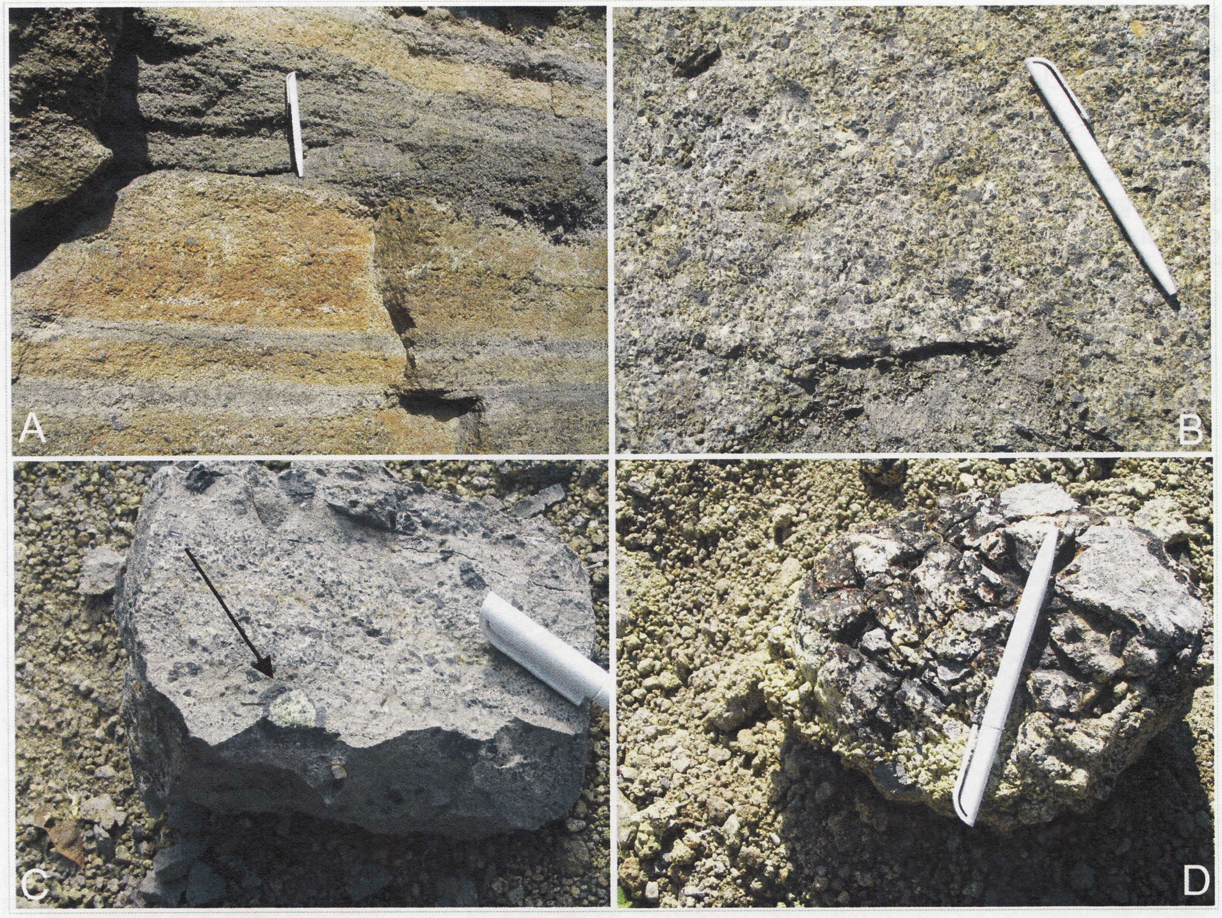

Figure 25
A - close up view of the bedded lapilli tuff succession of the Gérce - E tuff ring
B - unsorted, juvenile lapilli-rich lapilli tuff from the Gérce - E tuff ring
C - unsorted, structureless lapilli tuff from Gérce - E tuff ring. Note the peridotite nodule mantled by chilled lava crust
D - cauliflower bomb from the Gérce - E tuff ring succession

The majority of the pyroclastic beds are lapilli tuff and lapilli stone beds interbedded with thin, cm-thick veneers of tuff horizons (Fig. 25C). The lapilli tuff and lapilli stone beds are inverse-to-normal or non-graded and unsorted (Fig. 25B). Common are low angle cross-stratification and dune structures (Figs 24C & 25A) in the finer grained matrix supported lapilli tuff beds alongside the general inverse graded lower part of the beds. There are no large impact sags (Figs 24B and 25A), however, small impact features are common in the lower contact of the coarser grained beds. Vesicular tuff beds (Lorenz 1974) form thin beds. Associated with these fine tuff beds mud cracks are common. Mud coated ash and lapilli are common in both fine and coarse grained beds. Palagonitisation (Stroncik and Schmincke 2002) is confined to the thin outer layers of the ash and lapilli, which suggests that palagonitisation may have taken place already during the eruption upon contact of the melt and the moist in the eruption cloud charged with radical gas phases (Dellino et al. 1990; Capaccioni and Coniglio 1995). The blocky shaped volcanic glass shards, their low vesicularity, and edgy delicate shapes indicate that they were deposited from an eruption cloud directly related with the eruption, however, syn-eruptive reworking in a few beds could be supported by the more abraded texture and elevated free crystal content of the beds. In this respect, the Gérce tuff ring sequence is similar to the one described at Kissomlyó volcano (Martin and Németh 2005). However, there is a difference between Kissomlyó and Gérce, which is seen in the pyroclastic units of the later that contains far less non-volcanic fragments such as sand, silt or mineral phases. This implies that the Gérce tuff ring must have operated with a fairly open fissure system, where magma-water interaction took place in near surface environment and the vent must have been relatively clear through most of the eruption. This interpretation is consistent with the fact that the Gérce pyroclastic succession contains a large volume of mantle derived nodules and megacrysts of olivine commonly inferred to be a sign of high magma rise through a relatively open fissure (Spera 1984; Szabó and Bodnar 1996; Klugel et al. 2000). It is also documented in many places that initial phreatomagmatic pyroclastic units are commonly capped by a mantle nodule enriched zone immediately predating the subsequent scoriaceous pyroclastic units (White 1991b; Németh and White 2003; Németh 2004) as a sign of elevated magma discharge, drop of inflow of water to fuel phreatomagmatic interaction and clearer conditions in the vent zone.

The general transportation and deposition mechanism that formed the tephra units around Gérce are inferred to be predominantly horizontally moving pyroclastic density currents (Fig. 25A). The common low angle cross-stratification and dune structures (Figs 24C & 25A) in the finer grained matrix supported lapilli tuff beds along with the general inverse graded lower part of the beds indicate that the deposits were transported by high particle concentration base surges. The long wave length (m-scale) and short amplitude (cm-dm-scale) of dune structures (Figs 24C & 25A), the dominance of coarser grained beds with evidences of traction deposition such as inverse grading and clast trains as well as the general lack of accretionary lapilli in the pyroclastic succession indicate near vent position of the exposed and preserved pyroclastic rock units (Lajoie et al. 1992; Lajoie and Stix 1992; Sohn 1996). Mud coated ash and lapilli indicate that free water-saturated mud was in the eruption cloud.

In summary it can be concluded that Gérce-E is an erosional remnant of a tuff ring volcano. The preserved pyroclastic rock units with low angle dips indicate that a broad tephra ring formed around the active vents predominantly deposited from repeated base surges moved ground-parallel radially from its vent.

Description of the Gérce-N (Hercseg-hegy) tuff ring: North of the village of Gérce and west of the village of Sitke, cliffs of pyroclastic rocks form the outer limit of the Hercseg-hegy/Sitke tuff ring volcanic succession (Figs 23 & 24A). Outcrops of volcanic rocks form a cliff that is about 50 metres above the base level. The contact of pre-volcanic and volcanic succession is not exposed. The underlying rock formations belong to the Neogene fluvio-lacustrine siliciclastic sediments that are largely still sand and silt. The exposed pyroclastic units show sub-horizontal or gentle inward dip directions that point toward the interior of the Hercseg-hegy. The pyroclastic rocks are predominantly lapilli tuff beds, forming dm thick beds, however, massive fine enriched lapilli tuff beds (Fig. 26A) are also present. The matrix of the lapilli tuff is composed of volcanic glass, volcanic lithic clasts and smaller proportion of muscovite, quartz, or clay mineral aggregates (Fig. 26B). Lapilli-sized fragments are predominantly volcanic glass and volcanic lithic fragments (Fig. 26B). Occasionally quartz and/or metamorphic gravel as well as irregular-shaped clay lapilli can be identified. Sandstone fragments up to dm-size are rare but present. Juvenile clasts commonly form ribbon-like bombs with elongated vesicle trains, as well as spindleshaped deformational features. Entrapped, thermally altered clay and silt are common. Occasionally peridotite nodules and/or olivine megacrysts can be identified. No apparent stratigraphical variation has been identified yet in regard of juvenile to non-juvenile fragments ratio and/or characteristic bedding style changes. A few bomb sags show inconclusive transportation direction.

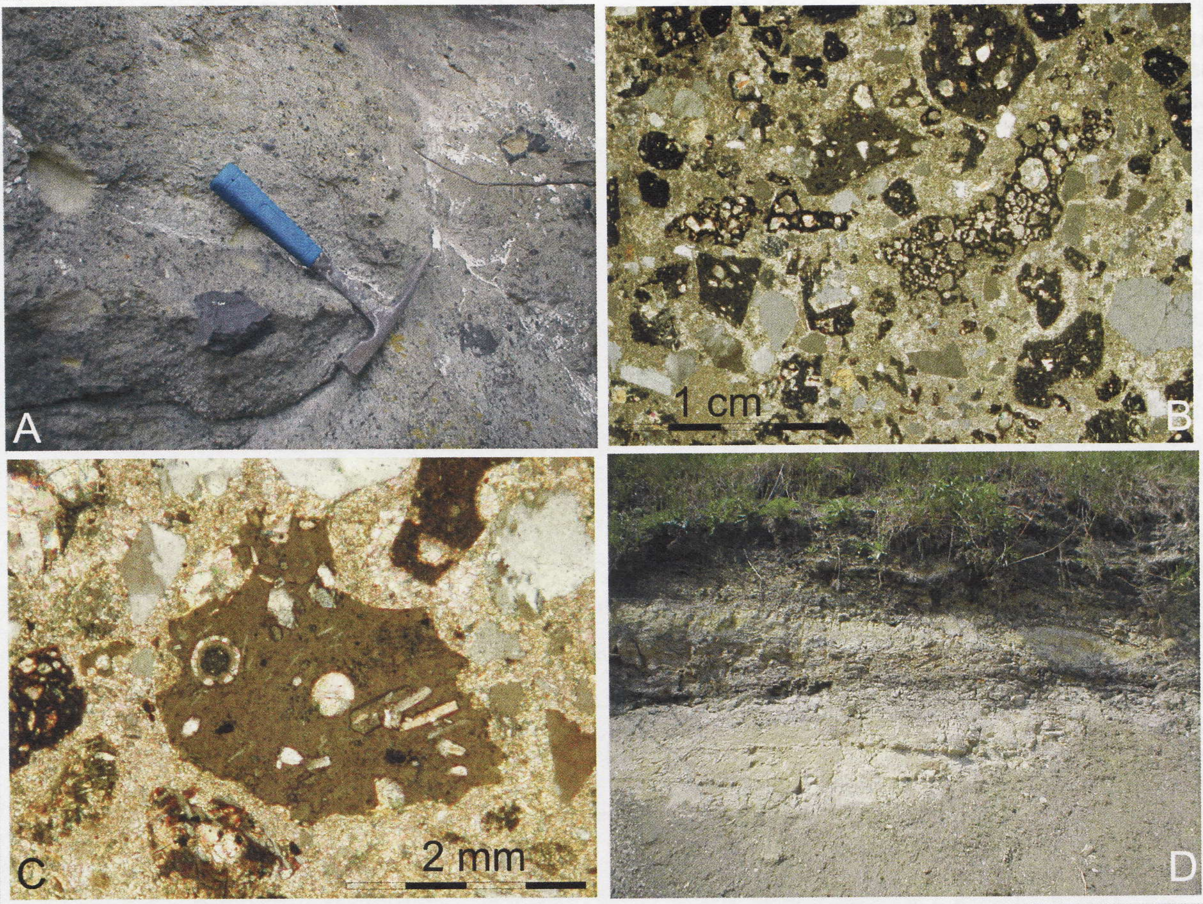

Figure 26
A - matrix supported, unsorted, structureless and weakly bedded lapilli tuff from the Gérce - N (Hercseg-hegy) tuff ring remnant
B - photomicrograph of a lapilli tuff from Gérce - N (Hercseg-hegy) tuff ring. Note the variable vesicularity on the glass shards (black clasts) and the angular quartz grains derived from pre-volcanic siliclastic beds
C - photomicrograph of an angular, non-vesicular, moderately microlite-bearing sideromelan glass shard from a lapilli tuff of the Gérce - N tuff ring
D - overview of an exposed wall of the post-tuff ring crater lake deposits (alginite) from the Gérce - N (Hercseg-hegy) tuff ring

The presence of a large volume (~70 vol %) of angular, non-vesicular to moderately vesicular volcanic glass shards (Fig. 26C) in form of fine ash to fine lapilli indicates interaction between rising magma and external water (Heiken and Wohletz 1986). The siliclastic origin of accidental lithic fragments as well as mineral phases that are characteristic of siliciclastic source deposits/rock indicate that the magma-water interaction occurred in such rock units. The abundance of volcanic glass in the deposits, however, indicates that the eruptive vents were relatively clear through the eruption (White 1991b; White 1991a). Larger lava spatter and ribbon bomb in the otherwise volcanic glass-dominated lapilli tuff beds indicates that successive magma droplets may have reached the surface with no magma-water interaction similarly to the model proposed by laboratory experiments (Mastin et al. 2004). Field observation of subaerial maar-forming eruptions such as

Ukinrek in Alaska showed that successive hot melt passed through base surge deposits formed by phreatomagmatic explosions (Self et al. 1980; Ort et al. 2000). The lack of deep-seated accidental lithic fragments (e.g. Lower Miocene sandstone or crystalline basement) in the pyroclastic rocks indicates that the explosion locus stayed near surface in the course of the eruption, however, lateral vent migrations (Sohn and Park 2005) along a few hundreds of metres wide zone likely occurred, leading to the development of a wide tuff ring with relatively low crater rim, similar to those in Eastern Oregon (Heiken 1971).

Crater lake deposits of the Gérce-N (Hercseg-hegy) tuff ring: The pyroclastic succession of the Hercseg-hegy tuff ring remnant is overlain by thick (70 m) post-tuff-ring crater lake deposits rich in fossils (Fig. 4D). Special circumstances of sedimentary deposition evolved in the crater lake. All clastic material came from the inner walls of the crater. *Botryococcus braunii*, an alga that produces and accumulates oily hydrocarbons, occurred in the eutrophic crater lake in unusual abundance (Nagy 1997). Diatoms were also represented. These planktic algae flourished in the lake during the warm season. Inorganic components, siliceous, calcareous and argillaceous material played a major role in sedimentation in the warm season, whereas organic matter was deposited in greater amount during the cold season (Ravasz and Solti 1987). Accumulation took place in 5-10 m deep water, under anaerobic conditions (Kvaček et al. 1994). 0.1 to 5 mm thick laminae, alternately rich and poor in organic matter, formed a varved sedimentary sequence of annual rhytmicity. The average thickness of a lamina couplet is 0.5 mm, thus the approximate time represented by the Gérce sequence is 140,000 years (Jámbor and Solti 1976). The sedimentation was disturbed by earthquakes and slumps in the steep crater wall. During lithification, laminae rich in organic matter were altered into alginite, calcareous alginite, or diatomaceous alginite by the process of diagenesis (Solti 1987; Ravasz and Solti 1987).

Fossils: Because of the style of sedimentation, the preservation of the fossils in the finely laminated, fine-grained deposits is generally good. Plant fossils occur as carbonized compressions or impressions with some organic matter, usually as undamaged leaves (rarely leafy shoots) widely scattered throughout the fossiliferous sequence. Seed and fruit compressions are rare (Hably and Kvaček 1998). The following taxa have been identified among the plant megafossils from Gérce (selcted from Hably and Kvaček 1997):

Gymnosperms

Cupressaceae gen. et sp.
Ginkgo adiantoides (Unger) Heer
Juniperus sp.
Pinus sp.
Torreya sp.
Tsuga sp.

Angiosperms

Acer integerrimum (Viviani) Massalongo
Acer cf. *subcampestre* Goeppert
Acer pseudomonspessulanum Unger
Acer sp.
Ampelopsis cf. *malvaeformis* (Schlotheim) Mai
Betula sp.
Buxus pliocenica Saporta et Marion
Carpinus grandis Unger
Carpinus betulus L. *fossilis*
Carpinus neilreichii Kováts
Carpolites sp.
Carya sp.
Carya serraefolia (Goeppert) Kräusel
Celtis trachytica Ettingshausen
cf. *Cotinus* sp.
?*Crataegus* sp.
Cyperaceae gen. et sp.
Dicotylophyllum sp. div.
?"*Diospyros*" *brachysepala* Heer
Engelhardia orsbergensis (Wessel et Weber)
Ericaceae gen. et sp.
Eucommia sp.
cf. *Gleditsia* sp.
Juglandaceae gen. et sp.
Leguminosites sp. div.
cf. *Magnolia* sp.
cf. *Malus* sp.
Monocotyledonae gen. et sp.
„*Parrotia*" *pristina* (Ettingshausen) Štúr
Populus populina (Brongniart) Knobloch
Populus sp.
Pterocarya paradisiaca (Unger) Iljinskaja
Pterocarya sp.
Quercus kubinyii (Kováts ex Ettingshausen) Czeczott
Quercus pseudorobur Kováts
Quercus sp. div.
Ribes sp.
?*Rosa* sp.
Salix sp.
Sassafras ferretianum Massalongo et Scarabelli

Ulmus braunii Heer
Ulmus sp. div.
Zelkova zelkovifolia (Unger) Buzek et Kotlaba

Although plant fossils predominate, large number of insect wings can be found and it is possible to find entire insects. The majority of the species and specimens belongs to a lacustrine fauna, the most abundant being water bugs (Corixidae), dragonflies' larvae and plumed gnats (Chironomidae) in all stages (larvae, pupae, adults) (Krzeminski et al. 1997).

***Paleoenvironment, paleoclimate*:** The pyroclastic sequences of the volcanoes indicate water availability in the shallow sub-surface aquifers and potentially from surface water masses, such as swamps, shallow lakes or braided shallow river systems. The presence of *Salix* and *Populus*, whose occurence is related to the moist soils rather than to the climate, corroborates surface water availablity (Hably and Kvaček 1998).
The alginite preserved the remains of a mesophytic arboreal coenosis. The predominant *Quercus kubinyii* displays xeromorphic features, such as teeth terminating in long bristles and hypodermal tissue. In general, the alginite assemblage was composed of small-leaved species. The other dominant species at Gérce is *Ulmus braunii*, which has quite small leaves. Similarly the presence of *Buxus* and *Juniperus*, as well as the occurrence of *Crataegus*, *Cotinus* and Leguminosae, indicates a partly dry climate (Hably and Kvaček 1997; Hably and Kvaček 1998).
Considering its demands on the temperature, the vegetation can be regarded as warm temperate. The presence of deciduous Lauraceae (*Sassafras ferretianum*), Magnoliaceae (cf. *Magnolia* sp. seeds and pollen), and the occurrence of *Engelhardia orsbergensis*, a remnant of the Eocene flora, indicates that the temperature regime must have been favourable even for quite thermophilous species. Most of the dominant and accessory elements of the mesophytic forest are more or less thermophilous (Hably and Kvaček 1998).
A mean annual temperature of 10-13°C and a mean annual precipitation of 1000 mm or less with some dry periods during the year can be inferred for the Pliocene deciduous oak mixed forests in Hungary (Hably and Kvaček 1998).

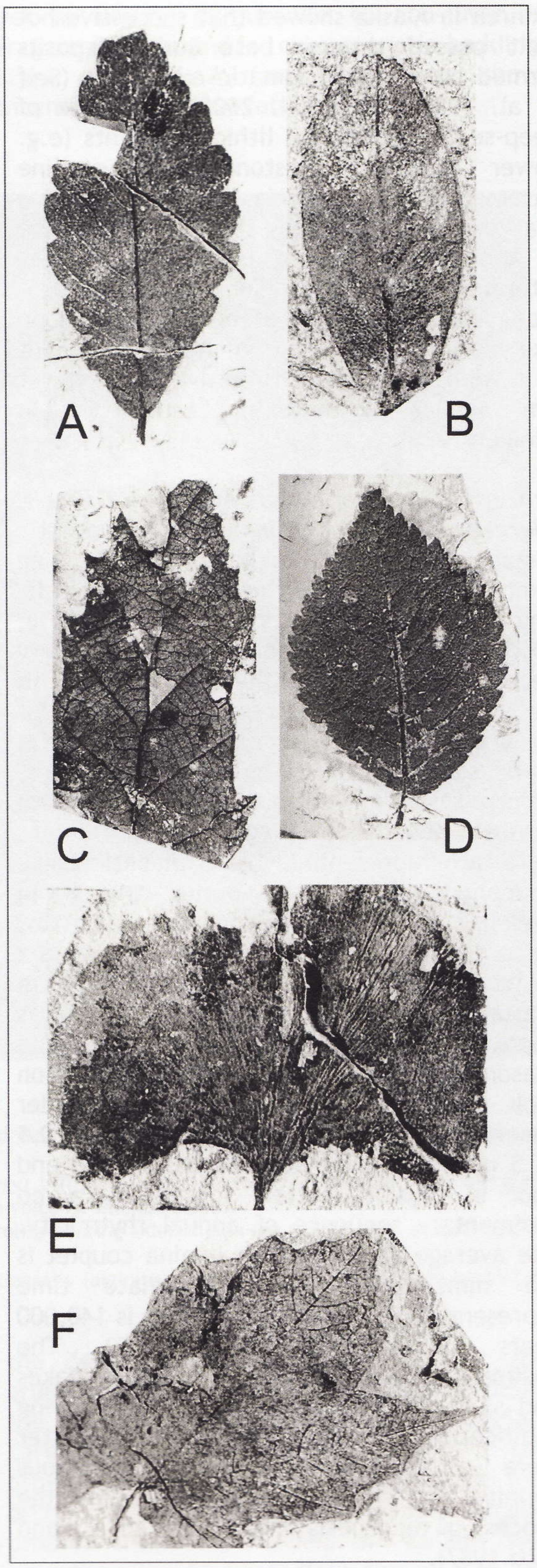

Figure 27: Selected plantfossils (from Hably and Kvaček 1998). A: *Zelkova zelovifolia*, B: *Buxux pliocenica*, C: *Quercus kubinyii*, D: *Ulmus braunii*, E: *Ginkgo aldiantoides*, F: *Acer* cf. *subcampestre*