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Buried Neogene volcanic structures in Hungary

Tibor Zelenka
Hungarian Geological Survey, Budapest

Endre Balázs
MOL, Hungarian Oil Company, Budapest

Kadosa Balogh
Institute of Nuclear Research,
Hungarian Academy of Sciences, Debrecen

János Kiss
Eötvös Loránd Geophysical Institute, Budapest

Miklós Kozák
University of Debrecen, Debrecen

László Nemesi
ELGOSCAR Ltd, Budapest

Zoltán Pécskay
Institute of Nuclear Research,
Hungarian Academy of Sciences, Debrecen

Zoltán Püspöki
University of Debrecen, Debrecen

†Csaba Ravasz
Geological Institute of Hungary, Budapest

Vilma Széky-Fux
University of Debrecen, Debrecen

Antal Újfalussy
MOL, Hungarian Oil Company, Budapest

Surface Neogene volcanics in Hungary are abundantly documented in the literature, but buried volcanic structures are little known. Early burial of the volcanic centers beneath latest Miocene to Pliocene sediments preserved much of their original relief, permitting their classification into genetic types.

More than two-thirds of Hungary is covered by thick Neogene and Quaternary sediments, below which buried volcanic eruptive centers and the extent of their products may only be recognized by complex geologic-geophysical methods. Our study is based on the data of several thousand wells, more than 60,000 km of seismic sections, as well as airborne and surface geophysical (gravimetric, magnetic, electromagnetic, radiometric) data. Results of chemical, mineralogical studies and K/Ar dating of deep cores were also included.

The data were evaluated in terms of the regional deep structure of the Carpathian-Balkan region, the Miocene evolution of which was determined by the position, movement and welding of individual microplates. Integration of all available data reveals that the Miocene volcanic centers are concentrated near microplate boundaries. In the volcanic centers the lavas and pyroclastic deposits far exceed 50 m in thickness. The data show that the buried volcanic rocks below the Transdanubian region (Little Hungarian Plain and Somogy-Baranya Hills), the Danube–Tisza Interfluve and the Great Hungarian Plain extend over a much larger area than do the outcropping volcanoes in Northern Hungary (from the Visegrád to the Tokaj Mts).

Addresses: T. Zelenka: H-1143 Budapest, Stefánia út 14, Hungary, e-mail: zelenka@mgsz.hu
E. Balázs, A. Újfalussy: H-1039 Budapest, Batthyányi u. 25, Hungary
K. Balogh, Z. Pécskay: H-4026 Debrecen, Bem tér 18/c, Hungary
J. Kiss: H-1145 Budapest, Kolumbusz u. 17–23, Hungary
M. Kozák, Z. Püspöki, V. Széky-Fux: H-4010 Debrecen, P.O. Box 4, Hungary
L. Nemesi: H-1145 Budapest, Kolumbusz u. 17–23, Hungary
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In the southern part of Transdanubia (W. Hungary) a major calcalkaline, rhyolitic, ignimbritic event took place early, in Eggenburgian and Ottnangian (Early Miocene) times. The centers and tuff sheets of this volcanic event can be traced from the Mecsek Mts to the Salgótarján Basin, the southwestern Bükk Basin and the central part of the Great Hungarian Plain. This event was followed by andesitic volcanism. The rhyolite and dacite volcanic centers of Karpatian age are predominantly situated in Transdanubia, whereas the Badenian (Mid-Miocene) andesite and dacite series of large stratovolcanoes are buried below southern Transdanubia, the Danube–Tisza Interfluve and the Great Hungarian Plain. In Sarmatian and early Pannonian (Late Miocene) times, pyroclastic sheets several thousand meters thick and lava domes were formed; they are predominantly rhyolitic, subordinately andesitic and dacitic, and are situated in the eastern part of the Great Hungarian Plain (Nyírség).

With the end of microplate motion, as the plate consolidated in the late Miocene, thick but areally restricted alkali-trachite (Little Hungarian Plain) and alkali-basalt lava domes and tuff craters formed in the Little Hungarian Plain, Transdanubia and the Danube–Tisza Interfluve.

Key words: Miocene volcanism, Hungary, basin interpretation, tectonic-magnetic evolution, eruptive centers, volcanic forms, ignimbritic flows, seismic sections, development history

Introduction

In basinal areas of Hungary several thousand deep wells penetrated Miocene or Pliocene volcanic rocks. Their thickness varied from a few centimeters to about 1,000 m. We limited our focus to those occurrences where the combined thickness of pyroclastic and lava layers exceeded 50 m, indicating proximity to ancient volcanic centers.

Hungarian authors recognized as early as about 1960 that in basinal areas there are well-recognizable pyroclastic horizons, and that some tuff horizons are regionally traceable (Pantó 1965). Comparison with typical outcropping pyroclasts, radiometric dating and the paleontological data of contacting sediments enabled a reliable dating of such horizons (Hámor et al. 1979). Balla et al. (1977) summarized our knowledge of the Inner Carpathian Miocene volcanism, including buried volcanics. Ravasz (1982, 1984) compiled a database of all volcanic masses encountered by boreholes.

Beside their drilling activity the oil industry (OKGT) and the Geophysical Institute (MÁELGI) helped to recognize buried structures by means of complex methods. Based on geophysical surveys the buried volcanic rocks of Nyírség (NE Hungary) were evaluated in detail (fig. 5; Polcz 1972, 1973; Nemesi et al. 1990). Széky-Fux and Kozák (1984), Széky-Fux (1985), Széky-Fux et al. (1985, 1987a, b), Széky-Fux and Pécskay (1991) analyzed the petrography and volcanology of the buried volcanic material in this region. Buried volcanoes in other parts of the country were dealt with by Pap (1986; Hajdúság, Danube–Tisza Interfluve). Széky-Fux and Pécskay (1991) described the buried volcanoes at the southern foreland of the Northern Hungarian Range. Balázs and Nusszer (1982) dealt with the Lower Pannonian (Upper Miocene) volcanics while Balázs et al. (1970) summarized our knowledge of Tertiary volcanoes. The tectonic map of Hungary (1986) depicts the extent of Miocene volcanic build-ups. All these publications clearly demonstrated that the area of buried volcanics is far greater than that of the outcropping ones. Geophysical surveys suggested the existence of structural alignments within the extent of volcanic rocks, as well as in the position of eruptive centers.

IGCP project No. 356 aimed at the connection of plate tectonics and metallogeny of the Carpathian–Balkanic region. The 7th Working Group of the Project dealt with the reconstruction of Neogene volcanism in the region. The results will be plotted on a map at 1:50,000 scale depicting the Neogene volcanic structures of Hungary. This mapping work was supported by Hungarian Science Fund (OTKA) project T-030133. For the purposes of this study the draft of "The Miocene volcanism of the basins in Hungary" by Csaba Ravasz (manuscript, 1979, 1981) was used.

Geologic setting

The Pannonian Basin is located in the southern foreland of the Western Carpathians and the western foreland of the Eastern Carpathians. The basin is filled by 1,000–5,000 m-thick Quaternary and Miocene sediments, according to borehole and geophysical data.

Structurally, the pre-Tertiary basement is divided into two units by the ENE–WSW-trending so-called Mid-Hungarian (or Zagreb–Zemplin) Lineament (Fig. 1). The northern one, the ALCAPA Mega-unit (Csontos et al. 1992), includes the Austroalpine, Penninic, Tatro-Veporid, and Pelso Units. Among them, the

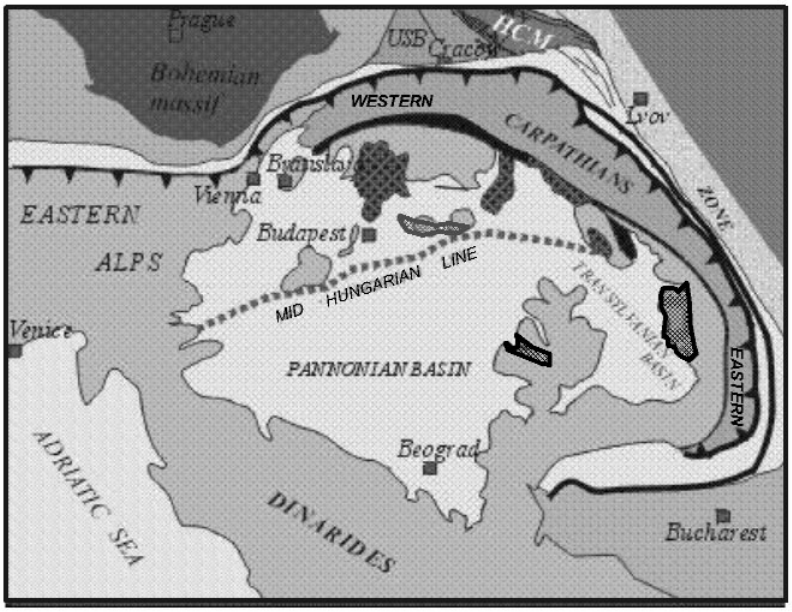


Fig. 1
Study area of buried Miocene volcanics in the Carpathian Mountains

Kőszeg-Sopron Mts, composed of metamorphites, as well as the Bükk, the Aggtelek and Szendrő Mts and the Transdanubian Range, consisting of Upper Paleozoic and Mesozoic sediments, emerge above the present-day basin surface. The southern part is the Tisza Mega-unit, divided into the Slavonia-Drava, Kunság and Békés Units, within which the Mecsek and Villány Mts, built up by heterogeneous Upper Paleozoic and Mesozoic formations, emerge to the surface (Haas et al. 2001).

In the southwestern foreland of the Eastern Carpathians, the basement is assigned to the Dacides, consisting of Early Paleozoic metamorphites and Mesozoic sediments.

In the northern part of the Pannonian Basin, in the Paleogene Basin, thick, shallow and deep-marine sediments are encountered, while in the south, within the Tisza Mega-unit in the Szolnok–Maramures Belt, Cretaceous–Paleogene flysch sediments can be found (Haas et al. 2001).

The Neogene is composed of very varied continental and marine sediments of great thickness. In the Lower Miocene, shallow-water sediments of NE–SW-trending sea branches as well as (in the line of the Sajó River in a NW–SE direction) deep-water sediments can be found (Hámor et al. 2001). The central part of the Tisza Mega-unit was dry land to a great extent. The former sea branches were bordered by the former structural zones; in addition acid, then intermediate volcanites of archipelago origin came into being (Hámor et al. 2001; Harangi 2001).

The shallow and deep-water sediments of the Middle Miocene extend in a NW–SE direction over the entire area of the basin; only the area of the Nyírség was dry land at that time. The thick acid and intermediate volcanites are significant mainly in the northern unit. Beside the shallow-water sediments of the Late Miocene, in certain zones (Jászság, Békés Basin) delta sediments can also be found. In the area of the Great Plain, besides the NE–SW- and NW–SE-trending structures, the products of the acid and intermediate volcanism are significant, predominantly in the Nyírség, where they reach several thousand m in thickness (Széky-Fux and Kozák 1984, Széky-Fux et al. 1985).

In the Pontian, in the Little Plain and the Békés Basin, thick offshore sedimentation took place, while on the margins of the elevated mountains lignite seams can be found (Hámor 1995). The Quaternary sediments, mainly in the southern foreland of the mountains, can even attain several hundred m in thickness (Haas et al. 2001). In the consolidated zones, alkaline basalt volcanites can also be found in the buried areas in the Danube–Tisza Interfluve (Balázs and Nusszer 1982), with a NE–SW structural orientation.

Methods

In over two-thirds of Hungary the buried Miocene volcanic structures are covered by Quaternary and Neogene sedimentary sequences. These were studied using all available geologic and geophysical data. Such data include field and airborne geophysical surveys as well as logs and cores of deep boreholes drilled for water and hydrocarbon prospecting, as well as for basic geologic research. Cores were only occasionally recovered from water and hydrocarbon wells (generally at intervals of 50 or 100 m). Although the wells are located 5–30 km from each other, already in the 1930s it was evident that thick Miocene pyroclast and lava bodies occur in deep basinal settings. Ravasz (1982, 1984) was the first to display the probable location of these on volcanological maps. They also were presented on the Structural Geological Map of Hungary (1990).

Field geophysical survey data (gravimetric, magnetometric, electromagnetometric and seismic) were used to emplace prospecting boreholes. Geophysical surveying, based on physical parameters, reveals the spatial localization of volcanic bodies. In the last decades the entire country was mapped magnetometrically (Fig. 2) and gravimetrically (Bouguer anomaly, residual anomaly) (Fig. 3). The Transdanubian part was also surveyed for telluric conductivity. The seismic sections total over 60,000 km. Complex geoelectric surveys performed in some sub-regions (Fig. 6) and airborne geophysical measurements helped our study a great deal. Some boreholes made it possible to examine the chemistry and petrology of buried volcanic rocks, and in some instances also gave information about their internal structure and situation. The locations of eruptive centers were considered determined only if two different methods gave similar results. In a number of instances we could estimate the position of the lava flows and pyroclastic bodies (ignimbritic flows, debris flows and tuff layers). Their size (thickness, extension) and their distance from the presumed eruptive centers could also be estimated. By comparing seismic velocity data with mineralogical, physical and geochemical characteristics of volcanic rock samples from nearby boreholes, it was possible to delimit the spatial distribution of bodies of a given rock type.

In some areas of Hungary there are older, buried volcanic structures under exposed volcanic complexes, from the Börzsöny to the Tokaj Mts, in the Mecsek Mts, the Balaton Highland and around Salgótarján. We excluded these occurrences from the present study.

Database

We studied the extent and nature of volcanic bodies in given areas, based on available geophysical and drilling data, and investigated the spatial and temporal position of these structures. Core analysis and mineralogical, petrographic and geochemical descriptions in several hundred drilling reports were examined. In addition, complex interpretations of geophysical studies were also used; in several cases models were constructed

The review of geomagnetic and gravitational anomalies showed that their sources are aligned along NE–SW-trending regional structural lines (Figs 2, 3). These anomalies partly reflect basement structures, but the spatial distribution of Neogene volcanic bodies (their horizontal or vertical extension) greatly

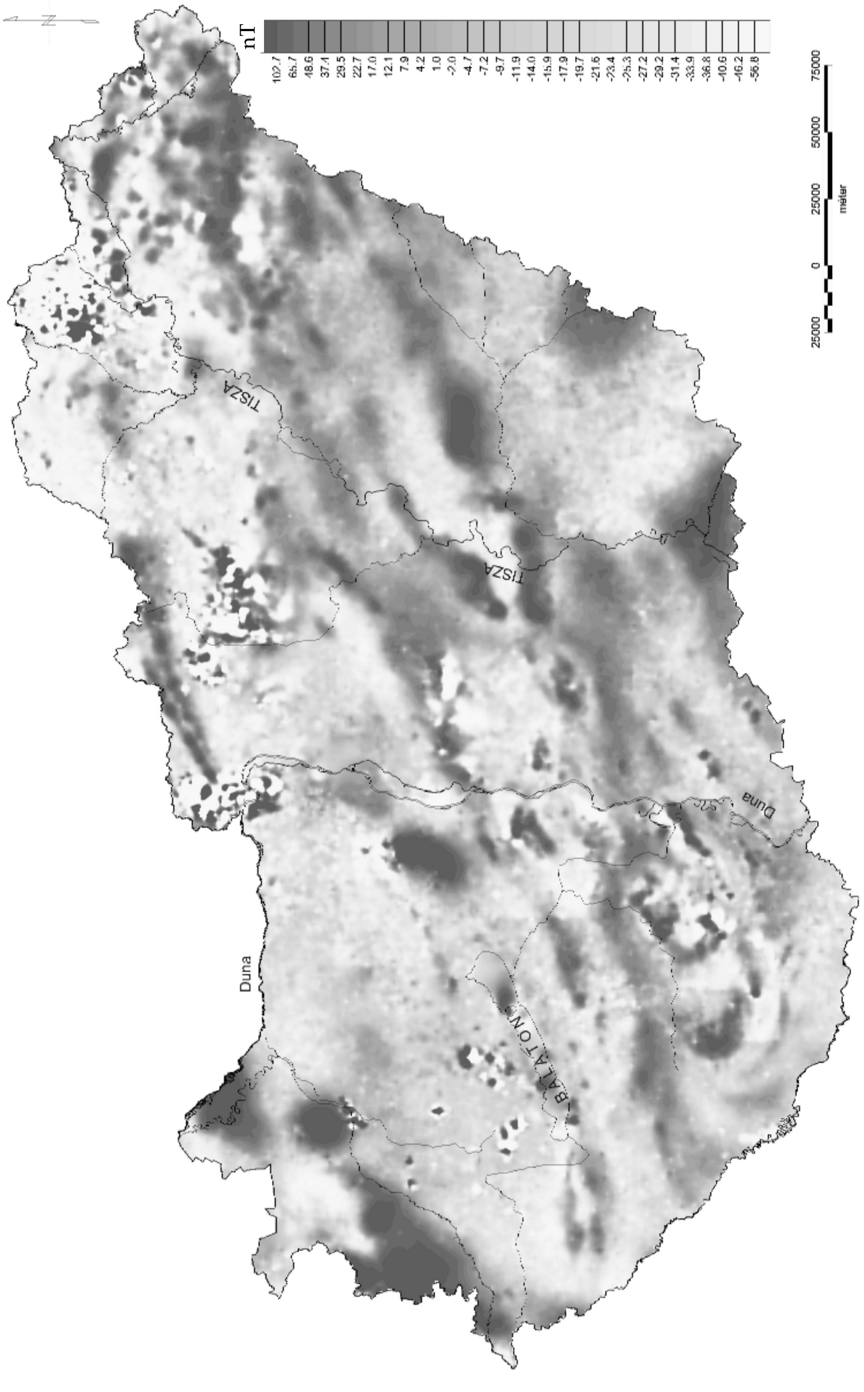


Fig. 2
Geomagnetic ΔZ map of Hungary (constructed by J. Kiss 2003)

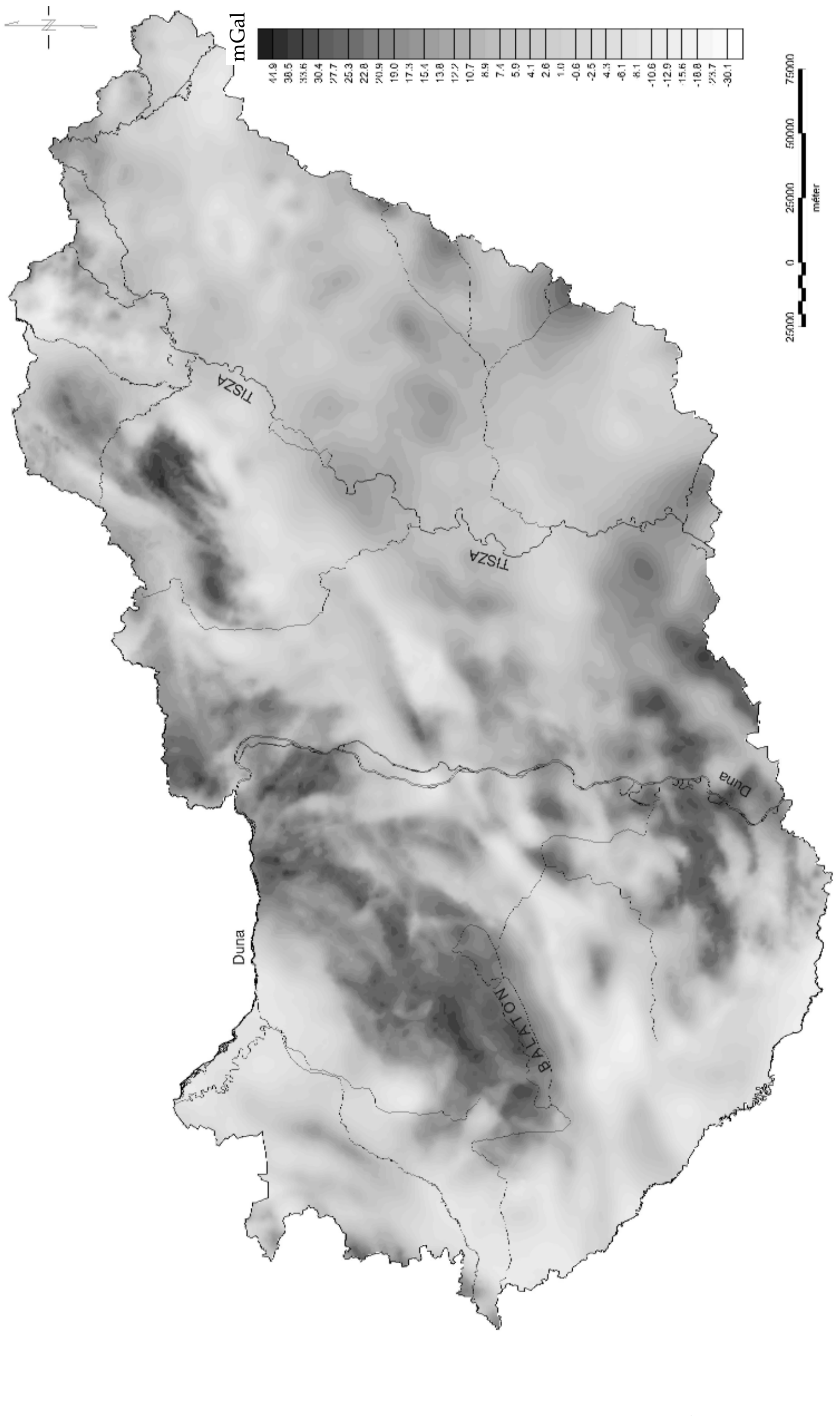


Fig. 3
Bouguer anomaly map of Hungary (constructed by J. Kiss 2003)

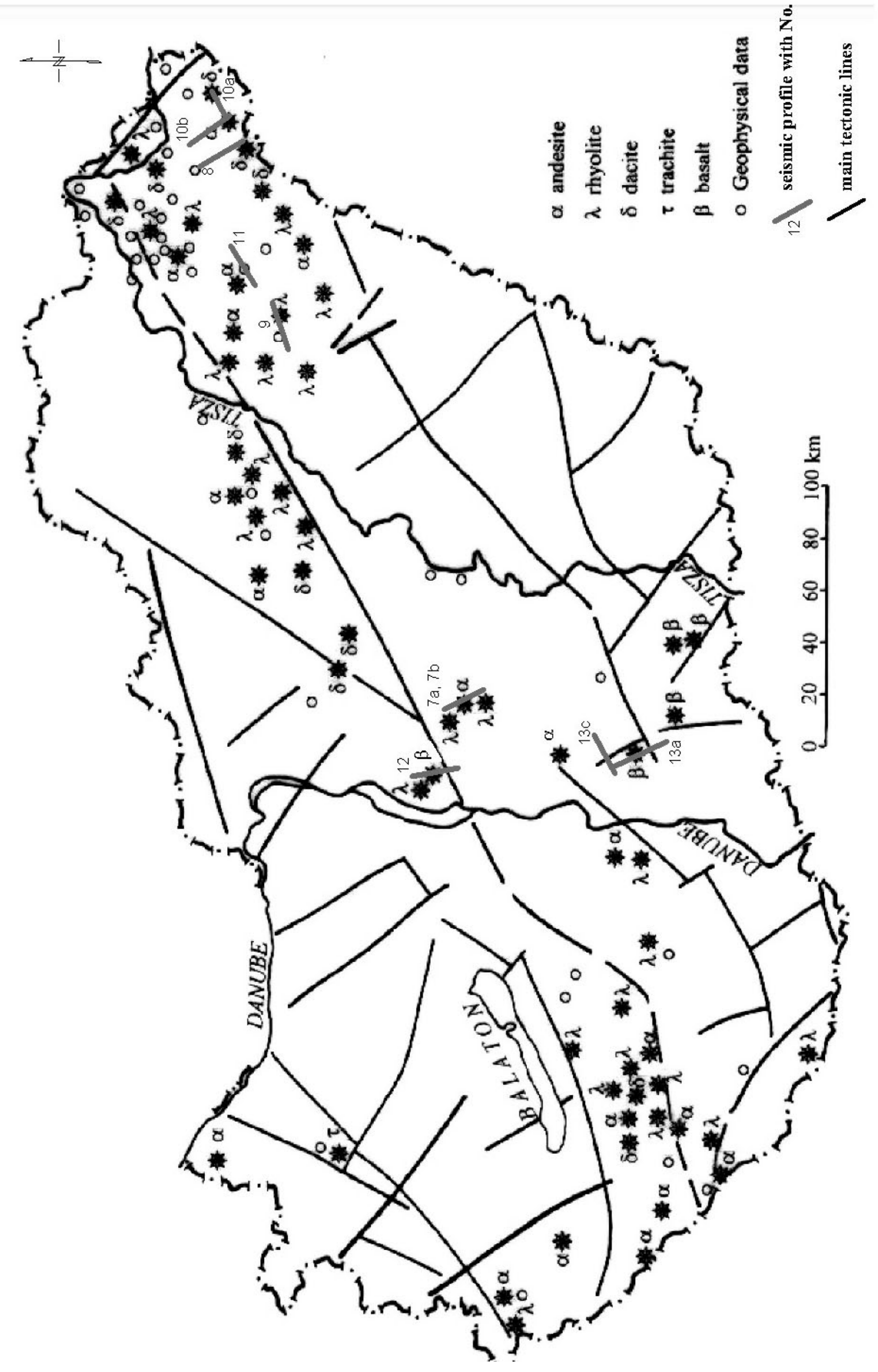


Fig. 4.
Presumed eruptive centers of the buried Miocene volcanoes in Hungary

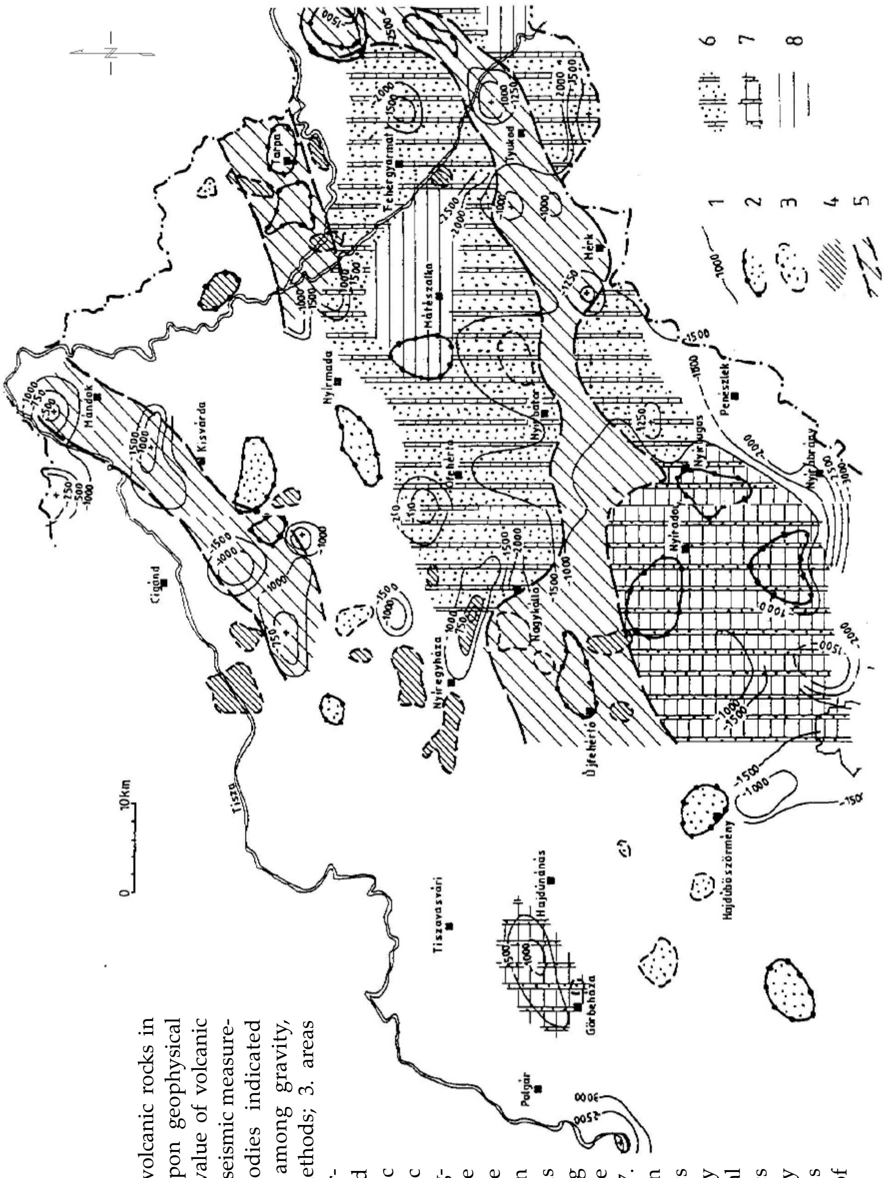


Fig. 5
Summary map of the volcanic rocks in NE Hungary, based upon geophysical survey data. 1. depth value of volcanic bodies from surface by seismic measurements; 2. volcanic bodies indicated almost by two from among gravity, seismic and telluric methods; 3. areas where volcanic formations are deposited only by magnetic anomalies; 4. volcanic body of reversed magnetism; 5. areas where volcanic formations are deposited directly on the basement; 6. areas with thick screening deposits within the sedimentaty series; 7. areas with thin screening deposits within the sedimentary series; 8. interior partial basins without volcanics or only low resistivity tuffs. Blank areas indicate the lack of sufficient data

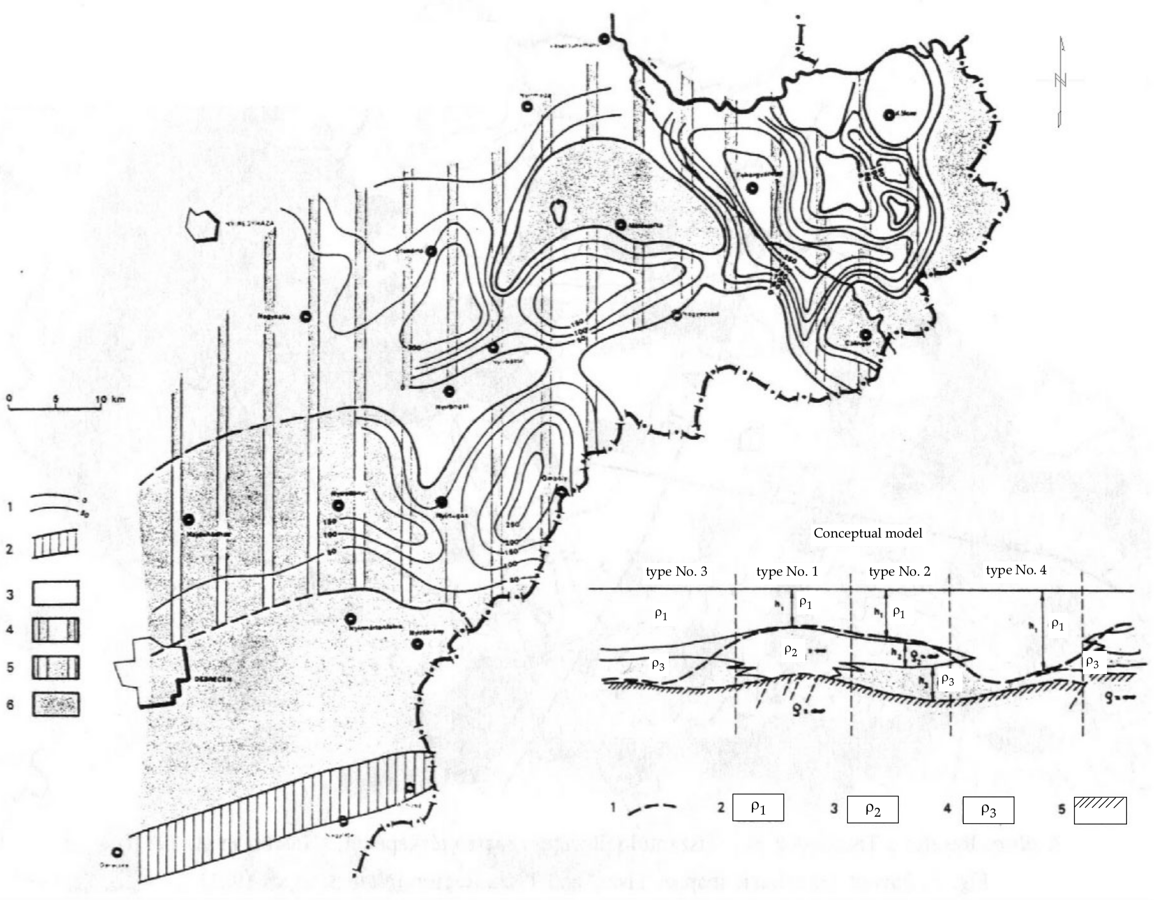


Fig. 6.
Map of geoelectrically typical areas in NE Hungary. Key symbols on the left part: 1. DS isolines characterizing the screened well-conducting formations; 2. distortion zone of the electromagnetic field (tectonic zone determined by seismic); 3. type No. 1 ΔS horizon is the surface of volcanic formations); 4. type No. 2 (thick screening layer within the sedimentary series); 5. type No. 3 (thin screening layer within the sedimentary series); 6. type No. 4 ΔShorizon presumable coincides with the pre-Austrian basement). Key symbols on the right lower part: 1. ρ_∞ horizon of geoelectric measurements as geoelectric basement; 2. conducting upper layer; 3. high resistivity screening (Miocene?) layer; 4. low resistivity sediments below the screening layer; 5. pre-Austrian basement

influences the anomalies. Interpretation of magnetic anomaly field in the case of formations with high magnetic susceptibility is locally problematic since the agent is rather vector than scalar; consequently, the field intensity can decreas with the 3rd power of the distance.

On the presented seismic sections, the locations of the deep wells are indicated (Figs 7a, b, 8, 9, 10, 13). For the volcanologic interpretation of the seismic sections, the mineralogical-petrographic and geochemical investigations of the volcanites encountered in the given deep boreholes served as a starting point. For the different rock types of the deep boreholes we collected the measured resistance and acoustic velocity values for the given depth sections of the well logs. The depth data of the wells were converted to time by means of the well logs; thus, the known formations could be located on the seismic time sections. The extension along the section and morphology of the individual rock types were interpreted on the basis of the shape of the seismic wave image. Where no drilling had occurred along the seismic section the volcanologic forms in the wave image (vents, lava flows, ignimbrite flows) and sedimentation features

Explanation of Fig. 7a, b		
Complex eruptive center type		
Location	Fig. 7a	Fig. 7b
Location of the two seismic sections	N part of the Danube–Tisza Interfluve	
Direction of section	NW–SE	NW–SE
Type of section	migrated time	migrated depth
Morphology		
In the middle part of the seismic section there is a stratovolcanic andesitic eruptive center explored by a borehole. On both sides of this center are rhyolite domes. The volcanites are delimited by a 13 km-wide tectonic graben, which in turn was formed by two transcurrent faults 1500–1700 m deep.		
	andesite volcano	marginal cones
Depth of the summit from surface	300 m	430–550 m
Width of cone at summit	2 km	500–700m
Width at base	6 km	1.5–2.0 km
Height of cone	800–1000m	150–400 m
Below the cones the contour of the basement is indicated by white color.		
Geologic structure		
The grabens between the cones are of tectonic origin. Within the inner cone there is a remnant of a crater. Between 390–620 m, lava and pyroclastic levels alternate seven times. Below that sequence, down to 1010 m, rhyolite lava and tuff alternate down to the top of the metamorphic basement.		
There are no recognizable reflections within the inner part of the volcanic bodies. The highly tectonized upper part does show reflections. The Upper Pannonian sediments pinch out at the slopes of the cones. The tectonic grabens are filled by steeply-dipping Pannonian sediments.		
Petrography	*Seismic properties* (velocity in m/sec)	
Upper Pannonian sediments	1600–1820	
Andesite tuff	2857	
Andesite lava	3333	
Rhyolite tuff	??	
Rhyolite lava	4000	
Basement	4000–5000	

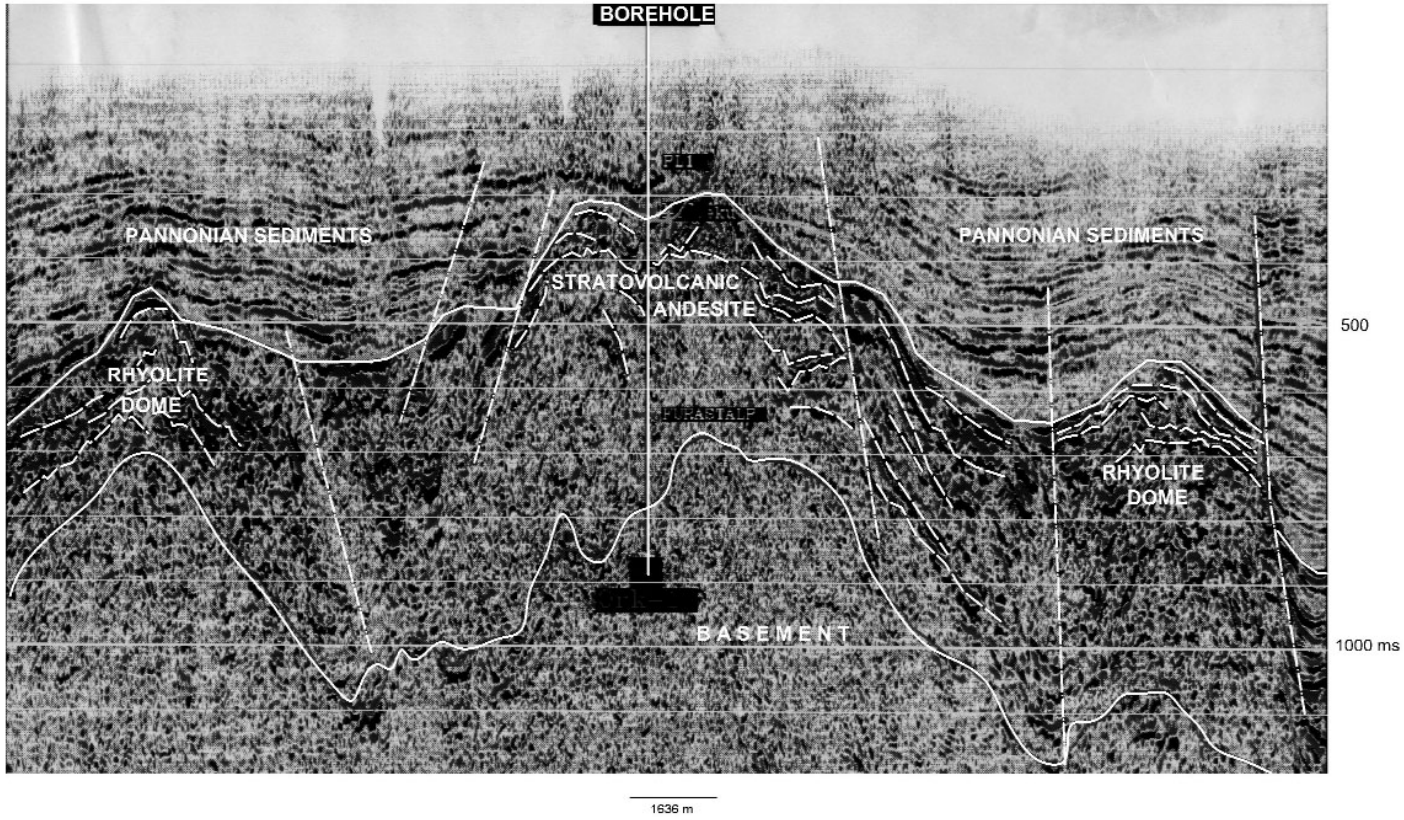


Fig. 7a
NW–SE-oriented seismic section with geologic interpretation of a complex volcanic eruptive type (migrated time section)

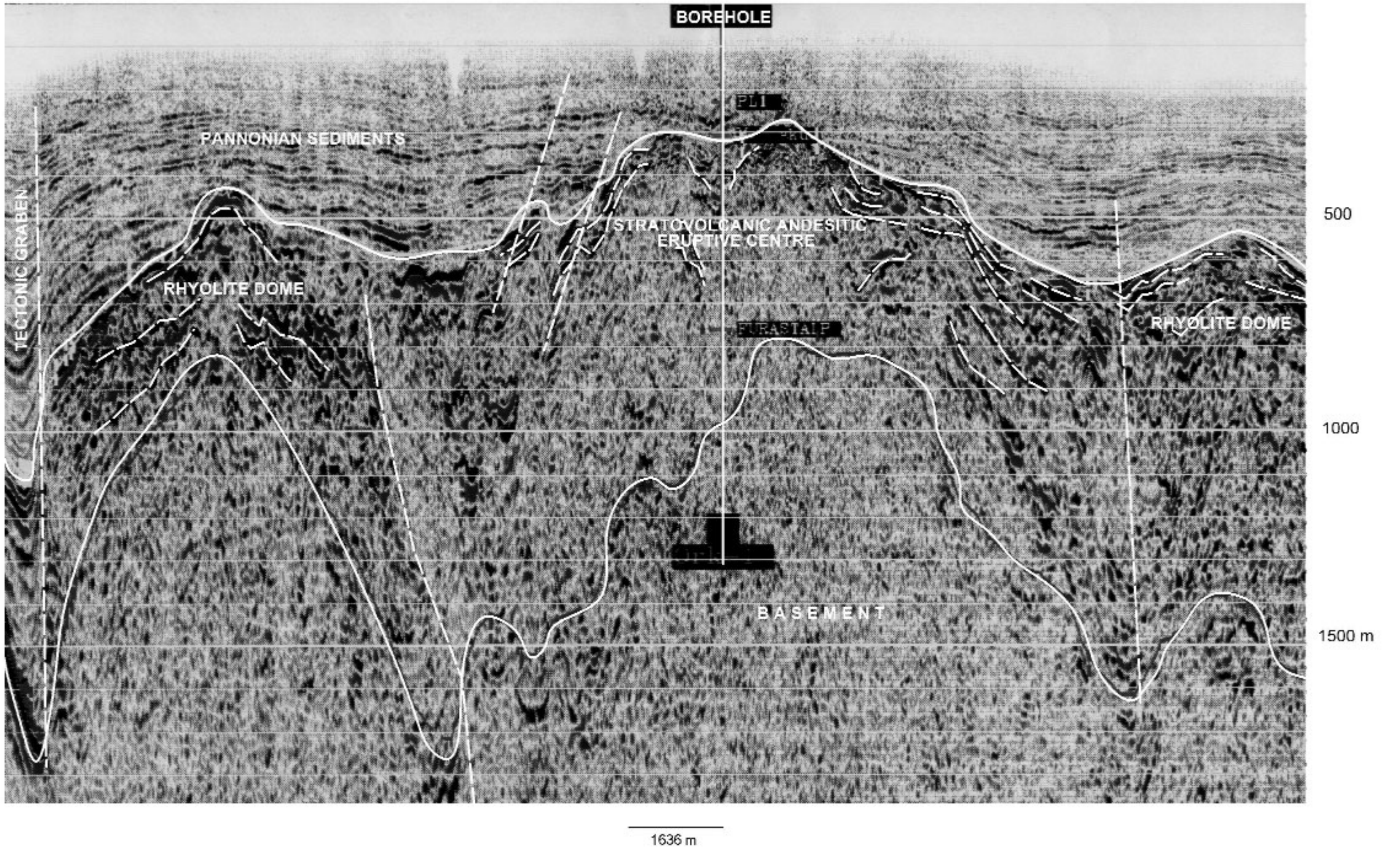


Fig. 7b
NW–SE-oriented seismic section with geologic interpretation of a complex volcanic eruptive type (migrated depth section)

(transgressional cross-bedding, trench filling sedimentation, contact contorted bedding along extrusion, intruding into sediments) were interpreted based on general volcano-morphologic knowledge.

On the basis of the resistance and acoustic velocity of the rocks, the types and basic volcanologic features (pyroclastite, lava flows, ignimbrite flows, strato-volcanic structures) of the intact rocks as well as the rock alteration zones can be distinguished. They can be identified on the basis of the limits of the measurement results.

The errors (diffraction) in the seismic records were filtered. On the basis of all this, the average geophysical measurement parameters for the most important rock types are as follows:

Hard lava rocks have high electric resistivity (60–80 ohm); therefore, these may be distinguished from tuffs (resistivity 5–10 ohm) or from loose covering sediments (2–5 ohm) (Fig. 6).

The velocity values of seismic logs and seismic measurement data do a good job in separating lava bodies (3000–3500 m/sec), welded tuff deposits (2500–3000 m/sec), fallen pyroclastics partly mixed with sediments (2000–2500 m/sec) from overlying young sedimentary layers (1500–2000 m/sec). Basement carbonates (4000–4500 m/sec) and metamorphic rocks (over 5000 m/sec) are characterized by even higher velocities than the volcanic rocks. These values may be doubled in greater depth, partly due to compaction.

Morphology and volcanology of the buried volcanic structures (Morphological types and internal structure of buried volcanoes)

With the help of complex geophysical investigations, probable eruptive centers could be identified in the eastern part (Nyírség) of the Great Hungarian Plain; their morphology, shallow subsurface structure and extent could also be determined. Three to five km-deep tectonic grabens are filled with Miocene volcanic material. Within this infill the depth of the summits of cones as well as the position of their bases can be determined (Nemesi et al. 1990). Drilling data was a great aid in this interpretation. Ten seismic sections are shown illustrating the morphology and internal structure of the major types of buried volcanoes. Using a complex set of geophysical methods, tectonically-delimited graben structures were identified in the Nyírség area (Figs 5 and 6) containing volcanic complexes buried below several hundred or thousand m of overburden. It is evident that there are many more volcanic cones than those encountered by drilling, since these boreholes were specifically prospecting for hydrocarbons and water.

The available drilling and seismic data reveals that in given areas (Nyírség, Hajdúság, Danube–Tisza Interfluve, Bükk-foreland, Transdanubia and Little Hungarian Plain) there are superimposed Neogene volcanoes of varying ages and petrology. This suggests that in some places the recurrent tectonism induced repeated volcanic activity.

Complex eruptive type volcanoes

A good example of this type was found in the northern part of the Danube–Tisza Interfluve. At the site of a gravity maximum an elevated volcanic structure 13 km in diameter was found, covered by Upper Pannonian sediments. The structure is delimited to the NW and SE by 1500–1700 m-deep tectonic grabens. The seismic section shows a threefold volcanic build-up, in which signs of strike-slip faults can be detected, indicating repeated fault activity (Figs 7/a, 7/b). Drilling activity encountered an Early Badenian rhyolitic phase followed by a massive middle Badenian andesitic stratovolcanic eruption. The two external cones are presumably rhyolitic. They are smaller than the central one; their upper diameter is about 500–700 m, that of the base 1.5 to 2.0 km. Their height is about 150 m. In contrast, the central andesitic cone is 2 km wide at its top, and 6 km at the base; its height is about 1200 m. This tectonic zone may be interpreted as part of the Mid-Hungarian transcurrent tectonic lineament (Csontos 1995).

Dacite dome, rhyolite dome and ignimbrite flow type volcanoes

In the Nyírség (NE Hungary) volcanic structures occur in several stages. In the volcanic center at Nagyecsed the sequence of eruptive rocks is nearly 3,000 m thick, containing a succession of Badenian to latest Sarmatian rhyolitic, andesitic and dacitic lavas and pyroclasts (Széky-Fux et al. 1985). The summit of the cone is situated at a depth of 1,000 m; the cone itself is 4 km wide at its top and 7 km at its base. Its height exceeds 900 m (Fig. 8). Signaling a last intrusion, on the very top of the cone there is a dacite dome 250 m high. The seismic data suggest that the central part of the cone was uplifted in the Pannonian, as the Pannonian layers show disturbed, arched reflections here. The Nagyecsed volcano is in an NW–SE-oriented, 10 km-wide tectonic graben, which includes several independent eruptive centers (Nemesi et al. 1990), documented by the Szamossály-1, Gacsály-1, and Csenger-1 boreholes (Fig. 5). NE of this graben there is a 6–10 km wide basin at Mátészalka filled with a 500–700 m-thick package of ignimbrite flows. The flows may come from both the SW (the Nagyecsed cone) and the NW, where another great cone is located at Mátészalka. The form of the seismic reflectors reveals that the thickness of the individual ignimbrite flows was about 50–75 m. Their length may attain several km, and they flatten in a distal direction.

Similar structures were found in the Hajdúság area (Fig. 9), where relatively small, 600–700 m-high rhyolite cones occur, 1.5–3.0 km wide at the top and 3–4 km at their base. In the depression between the cones there are six overlapping tongues of tuff flows, forming a 500 m-thick package. The deposition was subaqueous judging by the partly zeolitized material observed in cores as well as from the tuffite and tuffitic limestone at the top of the volcanic sequence.

Fig. 8
NW–SE-oriented seismic section with geologic interpretation of a Dacitic dome type (migrated time section)

Explanation of Fig. 8	
Dacitic dome type	
Location	
Location of the section	SE part of Nyírség
Direction	NW–SE
Type of section	migrated time
Morphology	
Two buried volcanic cones are visible at the edges of the section, separated by a basin. At the axis of the southeastern cone a borehole is located. The summit of the southeastern cone is at a depth of 1100 m; its diameter is 4 km. The base of this cone is at a depth of about 2000 m; its diameter 7 km. The height of the cone is 600–800 m.	
Geologic structure	
From the cones thick lava flows started, filling up the internal basin six to ten km wide with a (500–600 m) thick sequence out ward of dipping subaqueous tuff floods. The southeastern cone was later uplifted by almost 500 m lifting the Pannonian cover as well. The internal part of the body did not yield reliable reflections.	
Petrography	*Seismic properties* (velocity in m/sec)
Pannonian covering sediments	1920–2640
Sarmatian dacitic tuff and lava (11.2 Ma)	3320–3600
Andesite lava	4640–4760
Marl	3160–3240
Andesite lava (11.1 Ma)	4840–5058

Explanation of Fig. 9		
Rhyolite dome and ignimbritic lava flow type		
Location		
Location of seismic section	Region of Hajdúság	
Direction of section	WSW–ENE	
Type of section	migrated time	
Morphology		
At the ENE-end of the section there are two rhyolitic eruptive centers penetrated by boreholes. In the center there are similar centers, not confirmed by drilling. A borehole at the WSW-side encountered a deep basin filled with sediments and tuff.		
	Central cone	Cone on the right side
Depth of summit from surface	about 900 m	about 800 m
Diameter	about 1.5 km	about 3.0 km
Diameter of base	about 3.0 km	about 4.0 km
Height of cone	600 m	600–700 m
Geologic structure		
Sheets of ignimbritic rhyolitic lava flows can be followed 3.0–3.5 km from the ENE cone. These were formed in six periods, filling in a graben 500 m deep. On the top of the central cone there is an asymmetrically-placed chimney. WSW of this point there occur tuff flows and tuffaceous limestone; to the ENE out ward-dipping lava flows were detected. The central cone is separated from the ENE one by a graben, presumably of tectonic origin. The young, Pannonian, sedimentary cover dips gently. It is slightly uplifted over the cones, indicating some subsequent tectonic displacement. There is no good reflective surface within the cones. At the foot of the centers the rhyolitic lava and tuff accumulated partly subaqueously, intercalated with tuffaceous limestone and clayey marl.		
Petrography	*Seismic properties* (velocity in m/sec)	
Pannonian sedimentary cover	1890	
Sarmatian rhyolite	3600	
Welded rhyolite tuff	3500	

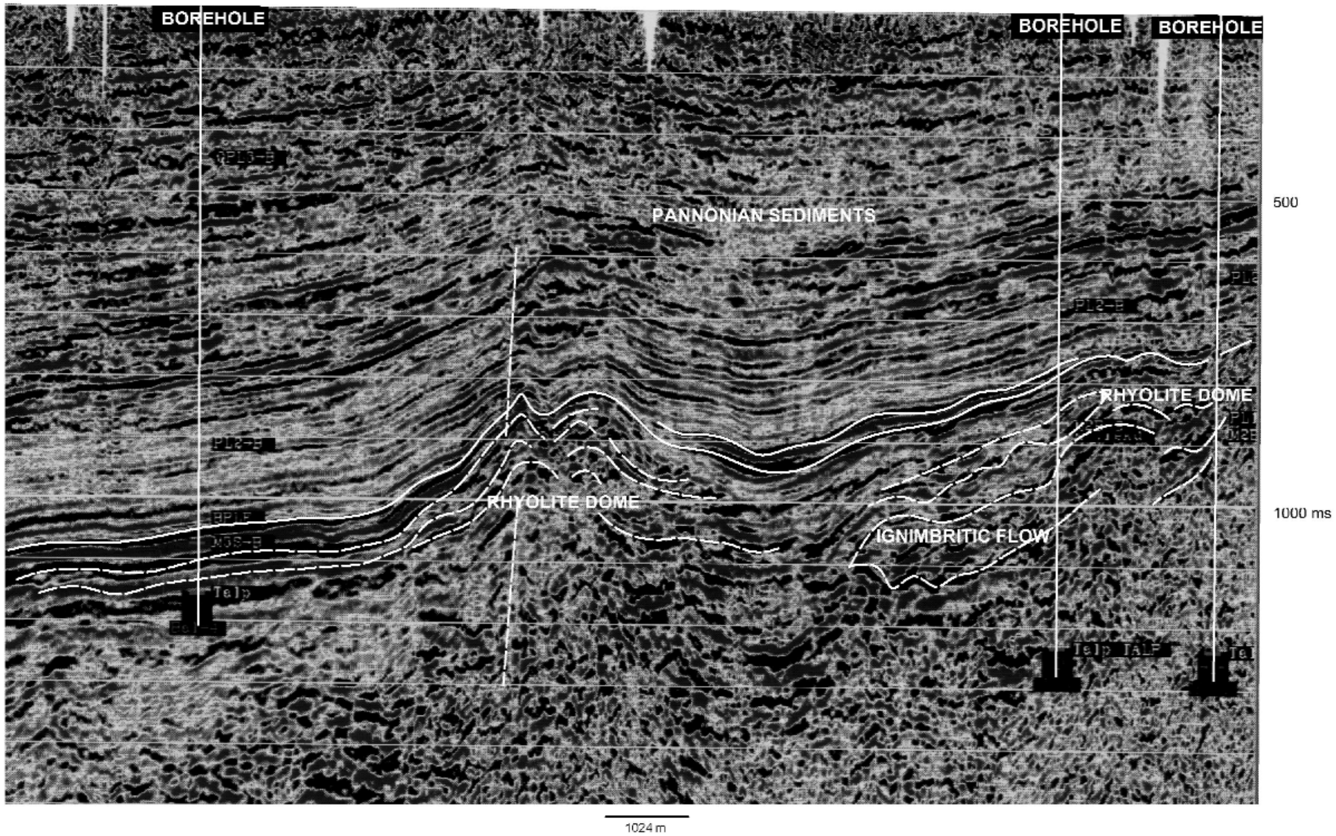


Fig. 9
WSW–ENE-oriented seismic section with geologic interpretation of a rhyolite dome and ignimbritic lava flow type (migrated time section)

Effusive andesite dome and stratovolcanic types

Some seismic sections show repeatedly rejuvenated eruptive craters as well as presumed upward-conducting channels. Figure 11 depicts a section in Nyírség, at Napkor (Nemesi et al. 1990). Here, in a cone of 750 m in diameter, there is a 150 m-wide 50 m-deep crater-like feature. A steep row of reflections, presumably an eruptive channel root structure, can be traced downward for 700 m. On the steep (20–30 degrees) slopes of the cone there are traces of cross-bedded lava flows. At the base, 3.5 km in diameter, we see traces of a 100 m-thick basal cone. The transgressive, almost horizontal Pannonian sediments onlap against the surface of the cone. The volcano is surrounded by a negative magnetic anomaly (Fig. 11).

Presumed eruptive craters on cones similar to the previously described one can be recognized in several sections. At the Szamossály stratovolcano there is a buried andesitic cone 1000 m high and 10 km wide at its top, which is slightly asymmetric. This volcano intruded into the subjacent tuff sequence. Repeated lava intrusions appear as small necks of one km in diameter. According to drilling data (Széky-Fux and Kozák 1984) the seismic section shows repetitions of lava and tuff banks on the slopes (Figs 10a, b).

NE of the cone described above, near the previously-mentioned cone at Gacsály, there are buried rhyolite domes and tuff flows. The slopes of the dome, 2 km in diameter, are steep. NE of the eruption center there are 500 m thick tuff sheets.

Explanation of Fig. 10a, b		
Andesite stratovolcanic type		
Location	Fig. 10a	Fig. 10b
Location of the two seismic sections:	E Nyírség area	
Direction of sections	SW–NE	NW–SE
Type of section	migrated time	migrated time
Morphology		
A borehole is located at the intersection of the two sections. The summit of the central buried cone is at a depth of about 800 m below surface. The diameter at the top is about 10×3 km. The diameter of the cone at its base is about 11×10 km (depth at the base) The height of the cone at its western side is 1000 m, and at its eastern side 600 m. The buildup is asymmetrically step-like toward the NE and SW. On the southwestern side there is a small caldera of 1 km diameter.		
Geologic structure		
Thick outward-dipping lava flows and pyroclastic layers alternate several times. The volcanic body intruded partly into the surrounding sedimentary sequences. The young covering sediments transgress on the flanks of the volcano, which is partly affected by compaction. The contact is intersected by subsequent faults. Connected to the cone, starting from the volcanic crater there is a tuff and lava sequence which was probably deposited subaqueously at the foot of the volcano. The inner part of the volcanic body did not show any reflections worthy of evaluating.		
Petrography	*Seismic properties* (velocity in m/sec)	
Pannonian (U. Miocene) cover	2097	
Sarmatian andesite tuff	3333–3448	
Andesite lava	4347–4761	

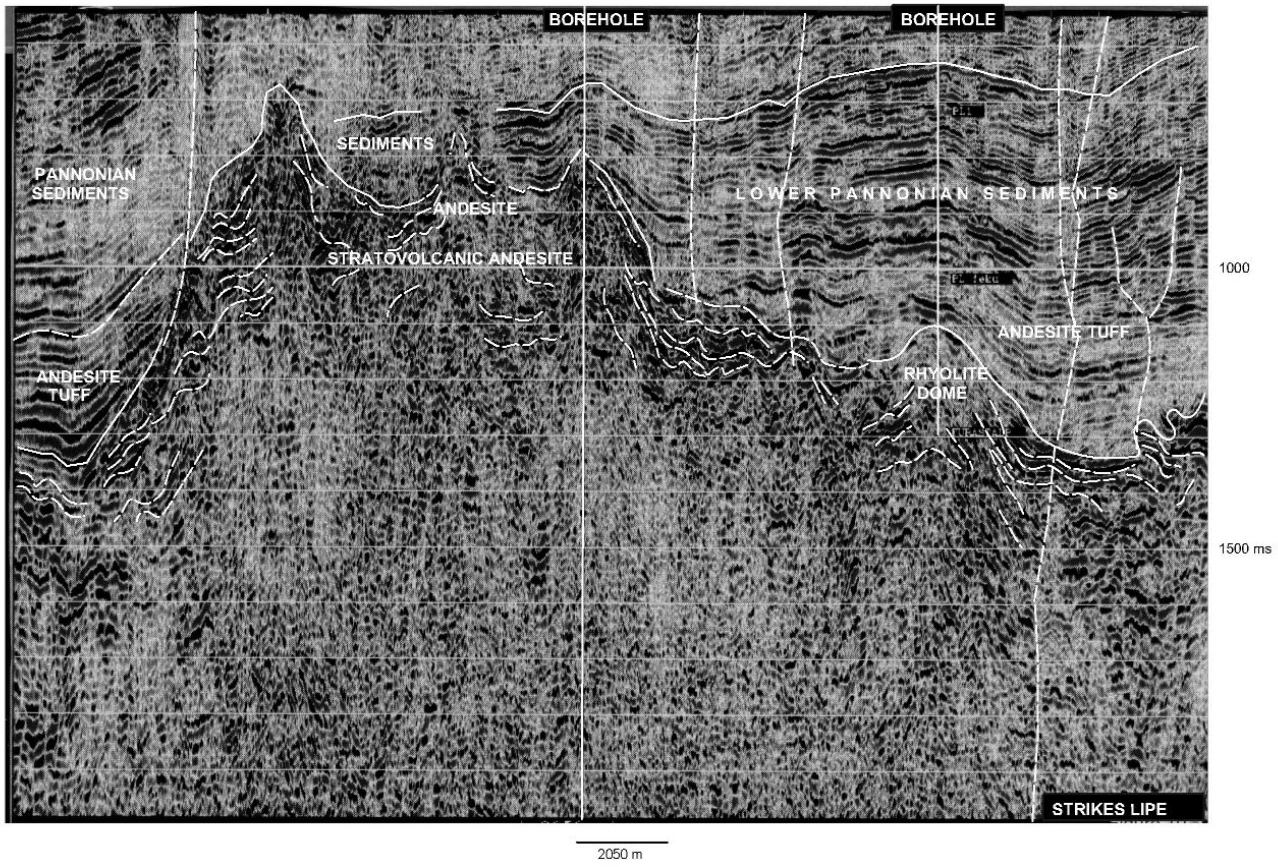


Fig. 10a
SW–NE-oriented seismic section with geologic interpretation of an andesite stratovolcanic type (migrated time section)

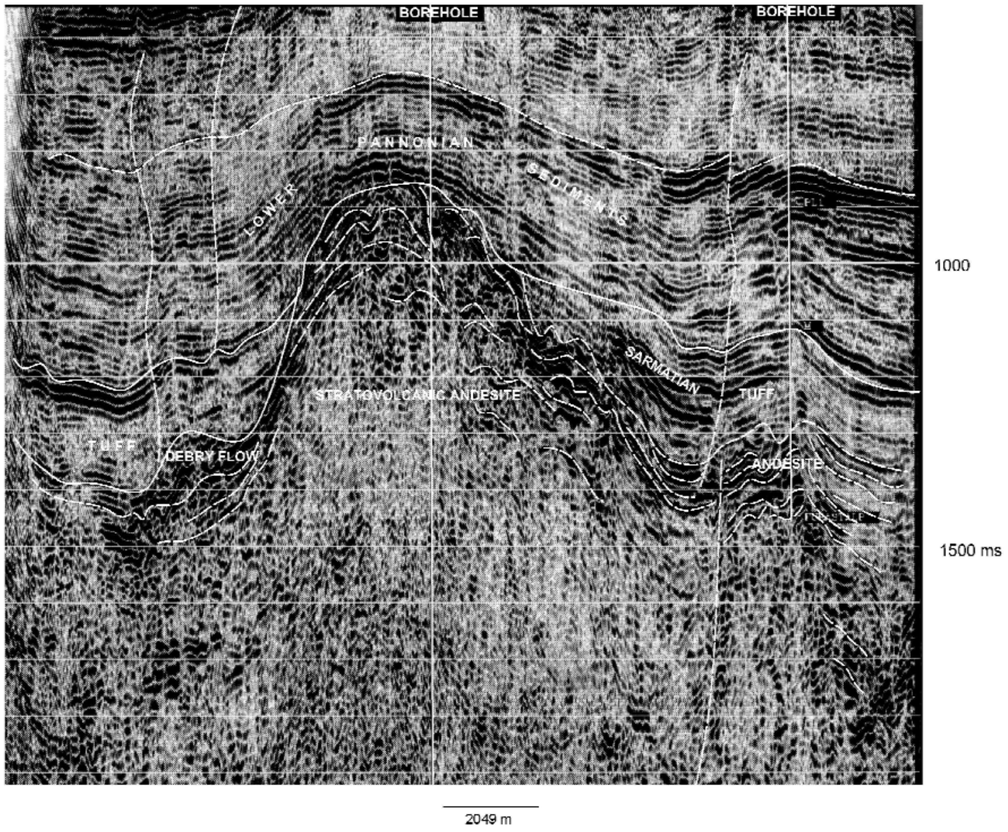


Fig. 10b
NW–SE-oriented seismic section with geologic interpretation of an andesite stratovolcanic type (migrated time section)

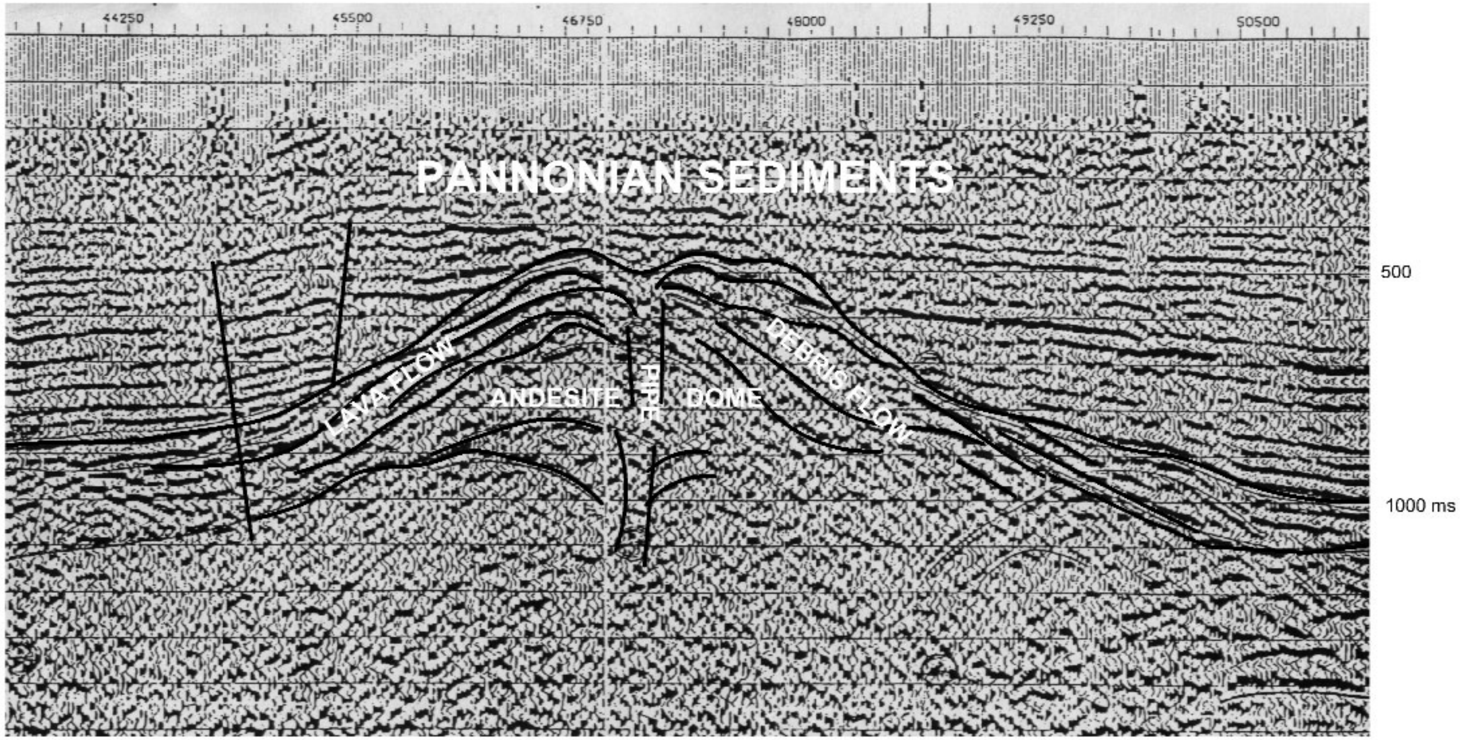


Fig. 11
WSW–ENE-oriented seismic section with geologic interpretation of an andesite dome type (time section)

Explanation of Fig. 11	
Andesite dome type	
Location	
Position of the seismic section: Napkor in Nyírség	
Direction of section: SWW–NEE	
Type of section: time	
Morphology	
There was no drilling along the seismic and magnetotelluric lines. The section crosses an inverse magnetic anomaly zone.	
Depth of summit below surface	500 m
Diameter of summit of the dome	750 m
Diameter at base	3.5 km
Height of dome	500 m
At the center of the dome there is a 150 m-wide depression. An upward-conducting funnel can be supposed below the depression down to a depth of 700 m. The internal structure of the dome is threefold; the units are delimited by 150–200 m-wide arched surfaces.	
Geologic structure	
At the upper part of the dome intersecting lava flows are visible. On the ENE-side there are traces of a 100 m-thick (debris) cone, which may be the result of a debris flow. The sedimentary cover consists of layers pinching out and contacting the cone at acute angles.	
Petrography	
Without drilling data, only the significant negative magnetic anomaly allows us to speculate about the andesitic nature of the dome.	

Basalt extrusive and shield volcano types

In the northwestern part of the Danube–Tisza Interfluve, west of the complex eruption center described above and shown in Fig. 12, there is a presumably basaltic extrusion, a 12 km-wide, tectonically uplifted zone. This body, 300 m high, was intruded into the Pannonian sediments. The marly and clayey sediments are folded at the top and around the structure (Fig. 12). No drilling penetrated the area; therefore seismic sections were used for determining the position of the Miocene volcanites and the basement rocks beneath the extrusive body.

In the southern part of the Danube–Tisza Interfluve ("Kecel-Kiskunhalas West" hydrocarbon prospecting area) there are basaltic shield volcanoes below a 1000 m-thick Pannonian sedimentary cover. These are situated in front of a tectonically uplifted metamorphic (amphibole magmatite) horst (Balázs and Nusszer 1982; Pap 1986). The boreholes (Fig. 13b) and seismic sections (Figs 13a, 13c) reveal an alternating sequence of subaquatic lava flows, hyaloclastic breccia, tuff and intercalated Pannonian marl with a total thickness of 700 m. The presumed central funnel of the shield can also be recognized on the seismic section (Fig. 13c). The compacted Pannonian sediments cover the tectonically-bounded shield volcanoes.

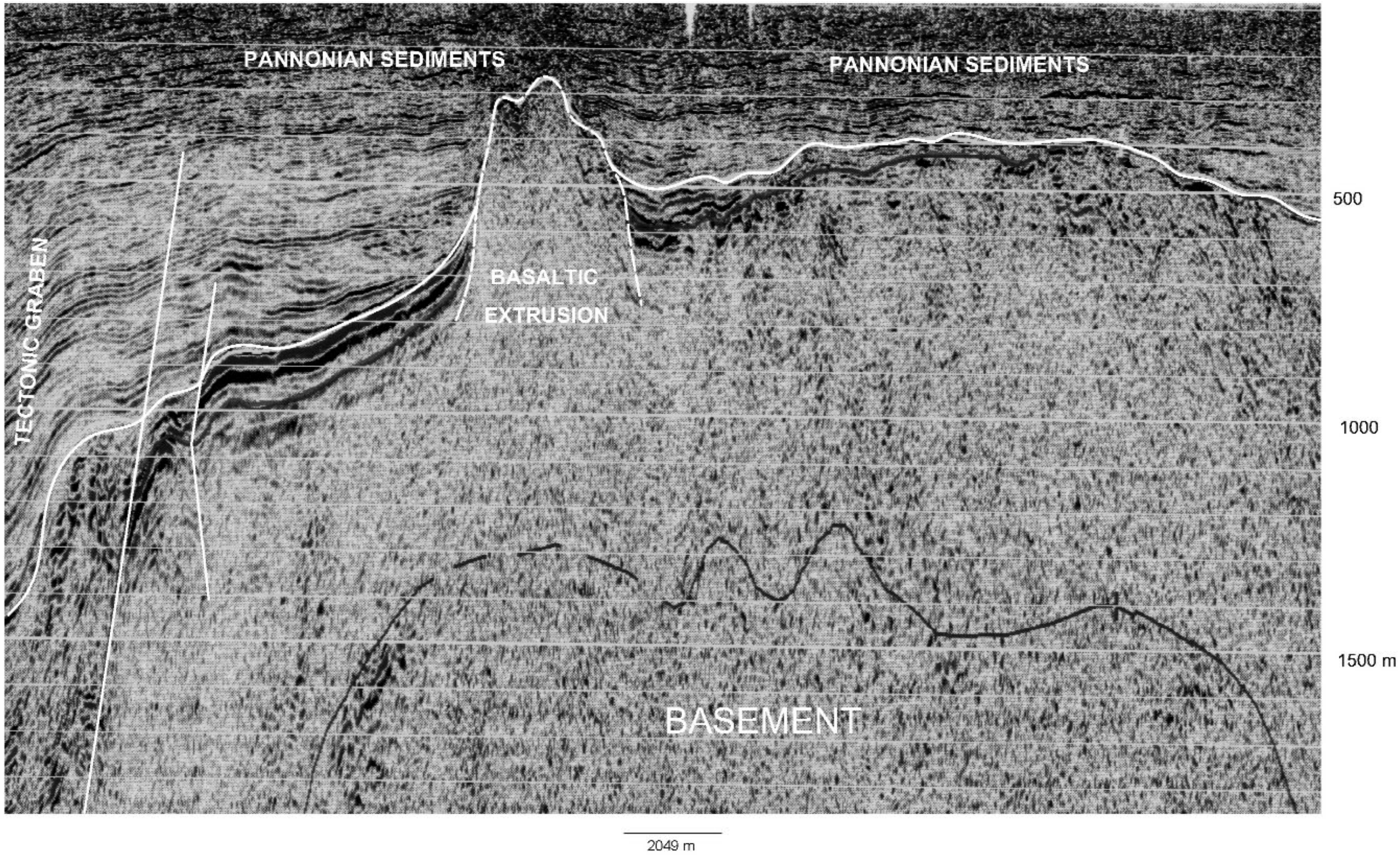


Fig. 12
NW–SE-oriented seismic section with geologic interpretation of an extrusive (basalt?) intrusion type (depth section)

Space-time distribution of Neogene buried volcanics

Spatial and temporal evolution of the buried Neogene (Miocene–Pliocene) volcanism

The spatial and temporal evolution of the outcropping Miocene of the Carpathian-Pannonian Region volcanoes has been described several times previously (Szabó et al. 1992; Pécskay et al. 1995; Seghedi and Konecny 1998; Lexa and Konecny 1999; Hámor et al. 2001; Harangi 2001). As for the buried part, the general trends were already outlined for the Great Hungarian Plain (Alföld) region (Széky-Fux 1985). Several authors dealt with an overview of Neogene volcanism and the genetic interpretation of the Carpathian-Pannonian region. The volcanites of the Western Carpathians and the Pannonian Basin were divided into two main groups by Lexa and Konecny (1999). They distinguished repeated flows of areal-type andesitic volcanites (rich in silicon) and calc-alkaline ones, as well as calc-alkaline basaltic andesite dykes and arc-type andesites. Seghedi et al. (1998) distinguished four units in space and time. In the Western Carpathians and the Pannonian Basin, above the subsiding flank of the subduction, they report repeated acid and intermediate volcanism from the Lower Miocene. They characterize the northern flank of the Eastern Carpathians, from the Tokaj-Slanec to the northern Calimani Mts, as well as the southern

<table>
<tr><td colspan="2">Explanation of Fig. 12</td></tr>
<tr><td colspan="2"><i>Intruded (Basalt?) intrusion type</i></td></tr>
<tr><td colspan="2"><i>Location</i></td></tr>
<tr><td colspan="2">Location of the seismic section: N part of the Danube–Tisza Interfluve</td></tr>
<tr><td colspan="2">Direction of section: NW–SE</td></tr>
<tr><td colspan="2">Type of section: depth</td></tr>
<tr><td colspan="2"><i>Morphology</i></td></tr>
<tr><td colspan="2">There is no drilling data along the seismic section. At the northwestern end of the section there is a 1700–1800 m deep graben, with signs of transcurrent faults. The section intersects this graben as well as a tectonically uplifted 12 km-wide zone situated southeastward of the graben. At the northwestern part of the uplifted area there is a neck-like structure within a covering sedimentary sequence. This structure is probably made of basaltic material.</td></tr>
<tr><td>Depth of summit below surface</td><td>270 m</td></tr>
<tr><td>Width of upper part of extrusive structure</td><td>1.5 km</td></tr>
<tr><td>Width at base</td><td>about 4 km</td></tr>
<tr><td>Height of structure</td><td>about 300 m</td></tr>
<tr><td colspan="2">Beneath the basaltic neck structure the structure of the basement is imaged seismically. The upper part of the neck is asymmetric. No reflections are visible from the inner part of the volcano. The sides of the lower part of the body widen downward as is common in the case of necks.</td></tr>
<tr><td colspan="2"><i>Geologic structure</i></td></tr>
<tr><td colspan="2">The intrusion took place after the deposition of the sedimentary cover, uplifting the lower layers along the outline of the neck. At the top of the neck the sediments are about 50 to 70 m thick.
In the absence of drilling data we assume that the presumed basement is covered by older Miocene sediments, 1,000 m thick, which are delimited by repeatedly rejuvenated faults. The young, Pannonian sequence, 500–1,500 m thick, is deposited over an eroded surface and the tectonic graben. This structure was disturbed by the intrusive event.</td></tr>
</table>

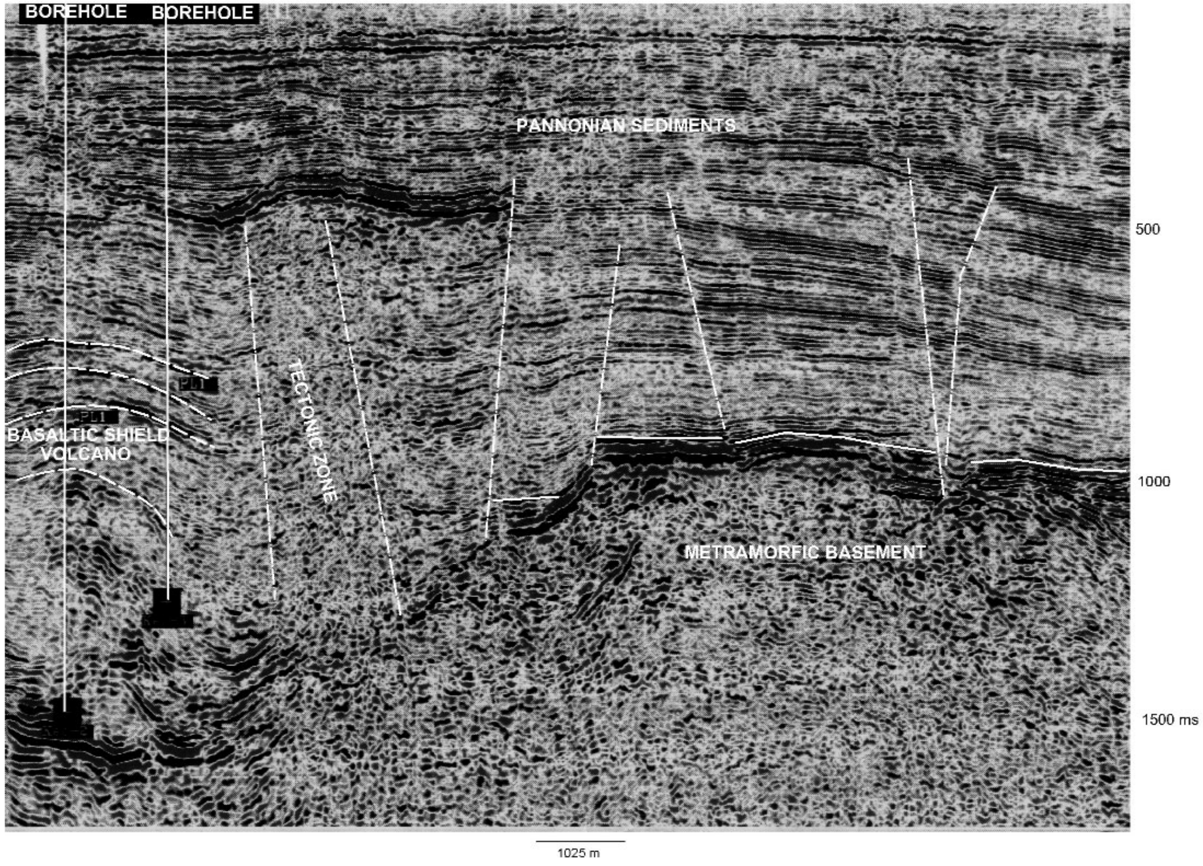
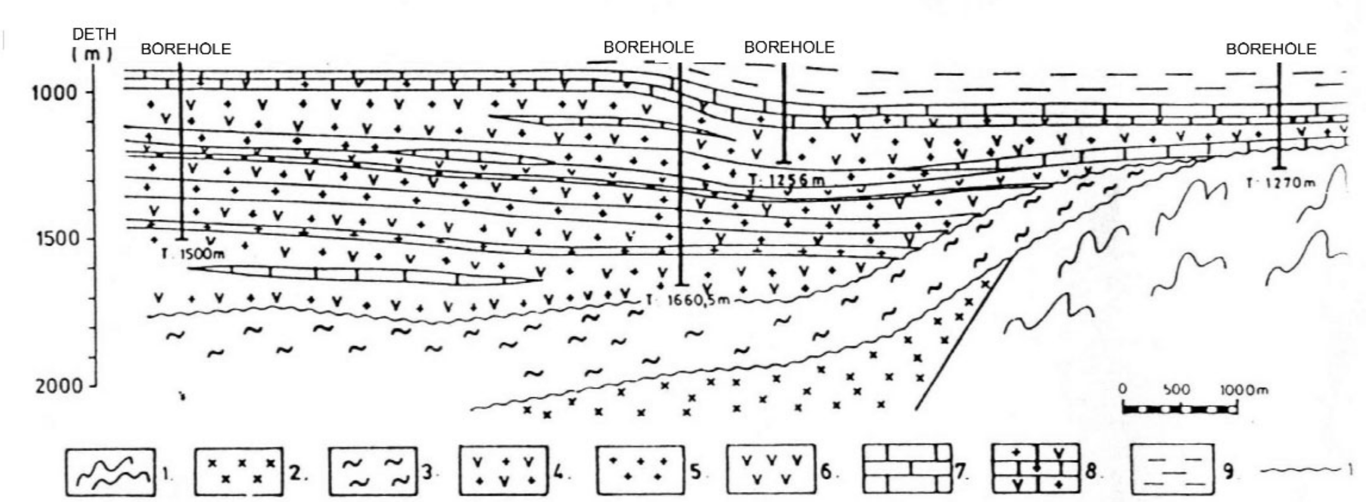


Fig. 13a
NW–SE-oriented seismic section with geologic interpretation of a basalt shield volcano type (migrated time section)



1. Precambrian-Early Paleozoic amphibolite and migmatite
2. Permian quartz porphyrite and sandstone microbreccia
3. Badenian marl, calcareous marl
   4.–8. Lower Pannonian formations
4. basalt agglomerata and tuff
5. basalt
6. basalt tuff
7. marl, calcareous marl
8. marl, calcareous marl with reworked basalt tuff and blocks
9. clay marl and aleurolite
10. unconformity

Fig. 13b
NW–SE-oriented seismic section with geologic interpretation of a basalt shield volcano type (after Pap 1986)

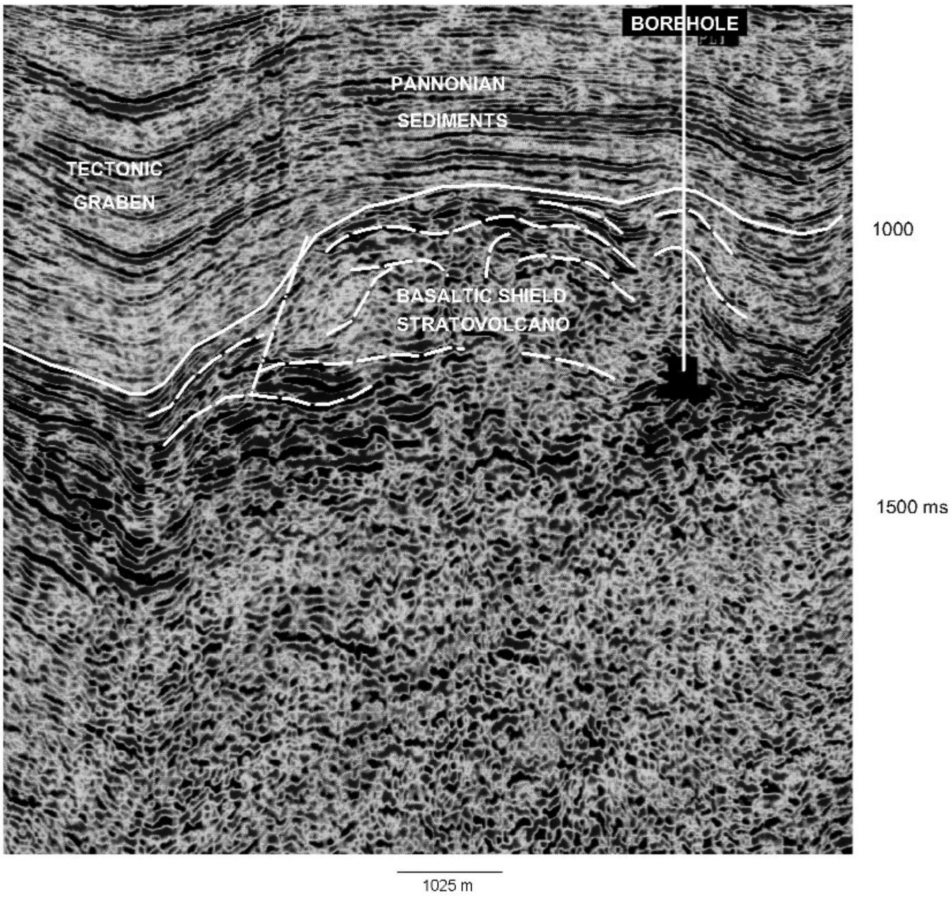


Fig. 13c
SW–NE oriented seismic section with geological interpretation of a Basalt shield volcano type (migrated time section)

Calimani and Harghita Mts, by calc-alkaline volcanism developed through lateral rotation of subduction. They regard the calc-alkaline magmatism of the Apuseni Mts as a result of the rotation and translation of the Tisza-Getic Block, and consider the alkaline basalt, shoshonite, ultraalkaline volcanism as sporadic.

Harangi (2001) distinguished four main volcanite groups within the Carpathian–Pannonian region in the Neogene. According to him, the volcanites rich in silicon in the synrift phase occur repeatedly from the Early Miocene on, in 3 explosive phases with block rotation and lateral movement. He connects the alkaline and ultraalkaline volcanism, occurring locally from the Miocene to the Pliocene, with the general extension of the Pannonian Basin. He explains the development of the calc-alkaline volcanism in the northern Pannonian Basin and its southern part, from the Miocene to the Quaternary, by lithosphere attenuation as well as partial melting and contamination. Beside the Eastern Carpathians, according to him the calc-alkaline volcanites are in connection with the subduction arc. The extension of the basin is followed by the appearance of alkaline volcanism of mantle origin.

Hámor et al. (2001) assume a four-phase volcanism. In their opinion, in the Early Miocene NW–SE-trending synrift, crust-origin, areal acid volcanism was prevalent, followed in the Middle Miocene by NE–SW-trending mantle-origin areal andesite volcanism. In the Late Miocene, thermal dome formation occurred.

In the Pliocene and Quaternary, in the Transdanubian region and the Danube–Tisza Interfluve, the emergence of the terrain is accompanied by alkaline basalt volcanism, while the Danube, Drava and Tisza Basins were continuously sinking.

According to the investigations, the following facts characterize the buried volcanoes:

– The majority of the volcanites is situated in regions with negative Bouguer anomaly (Fig. 3) from the eastern foothills of the Alps, through southern Transdanubia and the Danube–Tisza Interfluve, to the eastern part of the Great Hungarian Plain (Nyírség). These gravity anomalies are bordered by major structural lineaments (e.g. Mid-Hungarian Line, Balaton–Darnó Line). Presumed eruption centers, deduced by geophysical methods (seismic, magnetic,

Explanation of Figs 13a, b, c		
Basalt shield volcano type		
Location	Fig. 13a	Fig. 13c
Location of the two seismic sections: S part of the Danube–Tisza Interfluve		
Direction of section	NW–SE	SW–NE
Type of section	migrated time	migrated time
Morphology		
At the northwestern part of the section, Fig. 13a shows two boreholes penetrating the basaltic volcanoes. At the southeastern side the metamorphic basement forms an elevated plateau, delimited by a tectonic zone. The shape of the basalt shield stratovolcano is clearly discernible on the other section (Fig. 13b).		
Depth of summit from surface	about 900 m	
Upper diameter	min. 2.0 km	(3 km)
Basal diameter	min. 2.5 km	(5.0 km)
Height	700 m	
Petrography	*Seismic properties* (velocity in m/sec)	
Pannonian clayey sedimentary cover	2200	
Pannonian marls	2400	
Lower Pannonian basalt, basaltic breccia	2800	
Basalt tuff	2680	
Basalt lava	3200	
Geologic structure		
Subaqueous lava upwelling. In the shield volcano there are intercalations of thick lava flows and basalt tuff, and hyaloclastite breccia tuff levels. There is a 1.5 km-wide tectonic zone between the basalt eruption and the metamorphic plateau. This tectonism disturbed the lower Pannonian sedimentary layers as well. Within the basalt sequence and above it are intercalating Pannonian marls. The upper Pannonian in the higher parts of the section remained undisturbed.		

geoelectric) were supported by drilling data in more than sixty cases. The data suggest that most volcanic centers are aligned along repeatedly reactivated structural lineaments, within a band about 50 km wide (Fig. 4).

– Volcanic activity becomes increasingly younger from SW to NE as major structural lineaments were repeatedly rejuvenated, resulting in continuously subsiding volcano-tectonic grabens. These graben-like structures are filled by 1 km, sometimes even 3 km-thick volcanic material (lava, ignimbrite, hyaloclasts, tuffite), as a result of multiple eruptions (e.g. Nagyecsed, Baktalórántháza, Mernye, Mezőcsokonya, Verpelét, etc.) (Figs 7 and 10). The bulk of the eruptive centers shift northeastward through time.

– The mineralogy of the volcanic rocks shows differentiation similar to that observed over subducting slabs (Fig. 14). This process was repeated at least three times, as also observed in outcropping volcanic structures (Hámor et al. 1978 1979, Hámor 1995):

1. Eggenburgian to Ottnangian rhyolite tuff, "lower rhyolite tuff level", (Gyulakeszi Rhyolite Tuff Formation), pyroxene andesite.
2. Karpathian to Badenian dacitic tuff, "middle rhyolite tuff level" (Tar Dacite Tuff Formation), amphibole-andesite-dacite.
3. Sarmatian to Lower Pannonian rhyolite tuff, "upper rhyolite tuff level", (Galgavölgy Rhyolite Tuff Formation), andesite (Table 1).

By the end of the calc-alkaline volcanism, from the Early Pannonian on, alkali-rich rocks (shoshonite-trachite) appear along tectonic lineaments perpendicular to those mentioned above, i.e. trending NW–SE. The localities with alkaline basalts are characterized by thick crust.

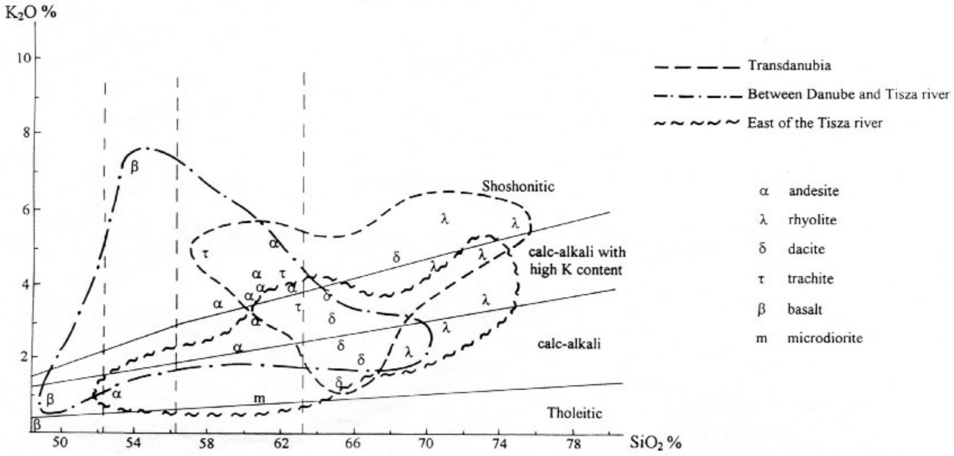


Fig. 14
TAS (SiO_2–K_2O) diagram of the buried Miocene and Pliocene volcanic rocks of Hungary

Table 1
Summary lithological section of the buried volcanoes in Hungary

Age	Regional units		
	Transdanubia	Danube–Tisza Interfluve Region	Great Hungarian Plain
Lower Pannonian	Trachyte (8.6 Ma) Trachyte tuff (Pásztori, Bősárkány)	Basalt (8.1 – 10.4 Ma) Basaltic tuff, tuffite (Kecel, Üllés, Ruzsa)	Pyroxene dacite (Tarpa, 10.5 Ma)
Sarmatian	Rhyolite tuffite (Mezőcsokonya)	Rhyolite tuff, tuffite (13.1 Ma) (Verpelét) Pyroxene andesite, tuff (Verpelét, Örkény)	Amphibole dacite, tuff (11.5 Ma) (Nagyecsed, Komoró) Pyroxene andesite (11.1 – 12.1 Ma) (Nagyecsed, Komoró, Szamossály) Rhyolite, rhyolite tuff, tuffite (13.5 Ma) (Nyíregyháza, Baktalórántháza)
Badenian	Rhyolite tuff (13.9 Ma) (Vése, Mezőcsokonya) Biotite andesite Andesite tuff Andesite agglomerate (Nagyszakácsi, Csákány, Mezőcsokonya)	Rhyolite, rhyolite tuff (14.7 Ma) (Verpelét-5, Albertirsa) Amphibole-, biotite-andesite (Kaskantyú) Andesite tuff Hyaloclastite breccia (Verpelét, Kerecsend, Mezőkövesd)	Rhyolite, rhyolite tuff (welded) (15.2 Ma) (Nyírmártonfalva, Penészlek, Hajdúhadház, Kisújszállás-1) Andesite tuff Pyroxene andesite (15.8 Ma) (Balmazújváros-5, Kisújszállás-20)
Karpatian	Rhyolite, rhyodacite (Mesztegnyő, Mezőcsokonya, Tengelic) Rhyolite (dacite) tuff (17.5 Ma) (Kadarkút, Kaposfő-2)	Rhyolite/dacite tuff (16.7 Ma) (Görbeháza)	Rhyo/dacite tuff, Rhyolite (16.5 Ma) (Józsa 2) Andesite Andesite tuff (17.1 Ma) (Nyírmártonfalva–Kunhegyes)
Ottnangian Eggenburg.	Biotite amphibole andesite Pyroxene andesite (19 Ma) (Letenye, Berzence, Szenta) Rhyolite, rhyolite tuff (19.5 Ma) (Igal, Nagyszokoly, Tengelic)	Rhyolite tuff (18.5–19.1 Ma) (Lajosmizse, Egerlövő, Mezőkövesd, Mezőkeresztes)	Rhyolite tuff (18–19.1 Ma) (Kisújszállás-13, Kunmadaras)

These rocks occur near to high positive gravity anomaly zones in buried positions as well (Transdanubia, southern Danube–Tisza Interfluve, on the eastern flank of the Battonya-Pusztaföldvár Ridge).

The oldest (Eggenburgian, L. Miocene) volcanic centers (Fig. 15) are situated near the southwestern border of Hungary, at Letenye, Berzence and Szenta. They are thick (200–750 m) stratovolcanic structures. The Eggenburgian and Ottnangian rhyolite tuff levels occur NW of these centers, along the Mid-Hungarian Line. They are about 100 to 600 m thick south of Lake Balaton and at the southern foreland of the Bükk Mts. Having erupted in several phases, these are mainly subaqueous deposits of welded rhyolite flood tuff and zeolitized tuff masses along the Nagyszakácsi-Mesztegnyő and Mezőkeresztes–Emőd–Hídvégardó lines.

South of the above-mentioned region, the "Lower Rhyolite Tuff" occurs in patches; it is about 100–300 m thick and is clearly related to tectonic lineaments (Tengelic, Kaba), underlining the role played by transcurrent faults in the earliest Miocene volcanism. Along such tectonic lines there are volcanites above the Paleozoic metamorphics and the Szolnok-Máramaros Cretaceous–Paleogene Flysch Zone in Transdanubia, the Danube–Tisza Interfluve and eastern Hungary.

By the late Karpatian (Early Miocene) the dacitic lava and tuff supply was restricted mainly to southern Transdanubian centers. Along the above-mentioned tectonic lineaments several hundred meters of welded dacite tuff, tuffite and tuffitic sediment pockets were formed, from Kadarkút through Verpelét to Hídvégardó, and E of the Tisza River to Nyírmártonfalva.

The central mass of the Badenian (Middle Miocene) andesite volcanism formed thick (300 to 1200 m) stratovolcanic centers (Fig. 15) at Mezőcsokonya, Mernye and Bolhás. In the Danube–Tisza Interfluve Badenian andesites occur only sporadically (at Örkény and Soltvadkert). The mass center of the volcanism was partly in the southern foreland of the Mátra and Bükk Mts, partly, in patches, in areas E of the Tisza River, in the Hajdúság and the southern part of the Nyírség (Nagyecsed). In the upper part of the Badenian stage thick (100 to 600 m) rhyolitic and dacitic volcanics occur in Transdanubia and the Hajdúság, predominantly as great tuff flows and subaqueous volcanoclastic depositions.

The Sarmatian (uppermost Middle and lowermost Upper Miocene) buried volcanics occur predominantly in the Danube–Tisza Interfluve and the Nyírség (Fig. 16). They belong to the so called "Upper Rhyolite Tuff", which may be as thick as 150–1000 m. The lava and tuff flows are partly rhyodacitic, partly rhyolitic, and are deposited in three, WSW–ENE-oriented, 10 to 15 km-wide grabens of volcano-tectonic origin (Fig. 9; Nyírbátor–Nagyecsed–Szamossály, Vásárosnamény–Mátészalka–Gelénes and Kisvárda–Komoró). Geophysical surveys and the sporadic boreholes point to a continuous uplift, resp., subsidence of these volcano-tectonic grabens of the Nyírség area. In the intergraben areas the thickness of the subaqueous tuff flows, tuffite and tuffitic sediments may reach several hundred meters. The volcanism lasted to the beginning of the Early

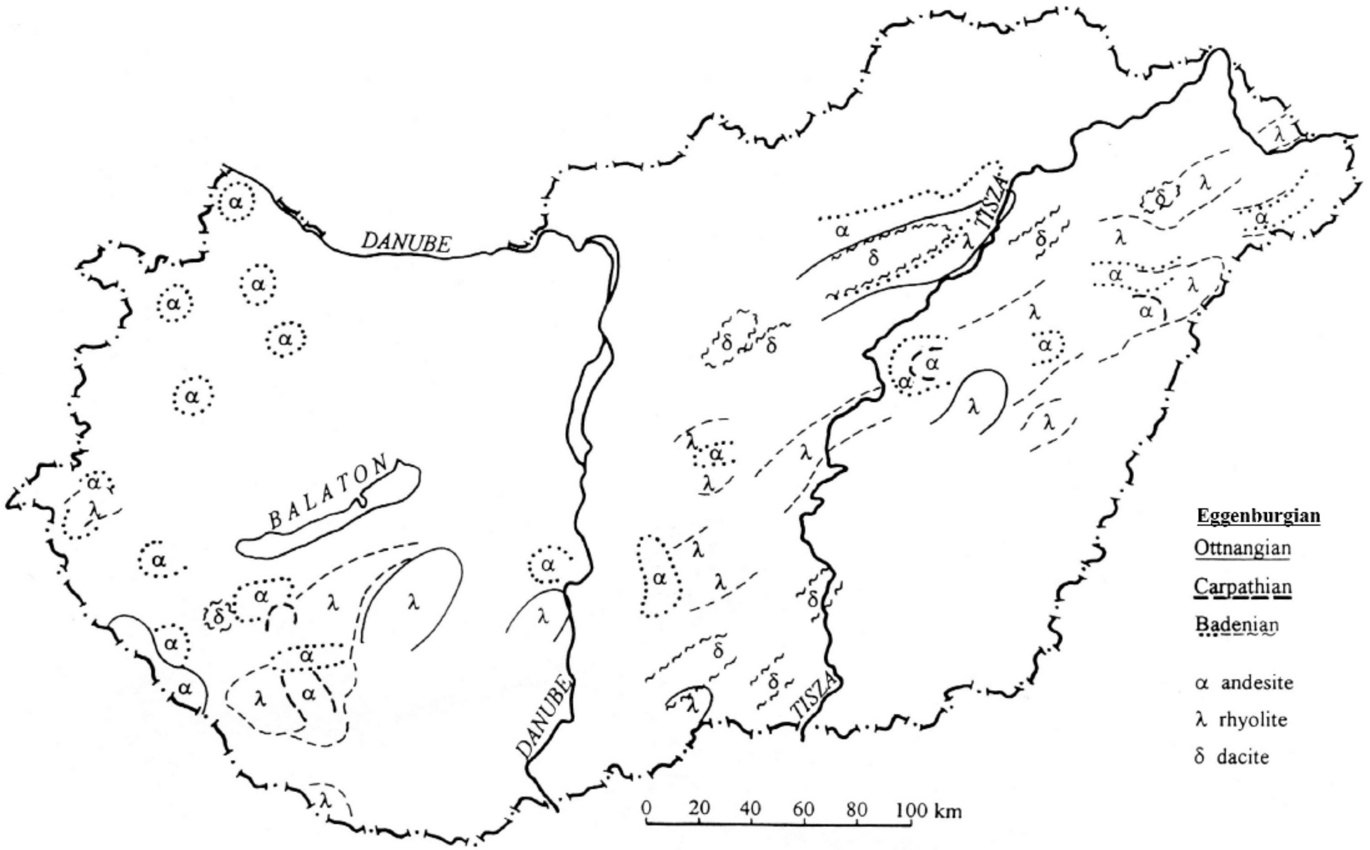


Fig. 15.
Range map of the buried Badenian and older Miocene volcanic rocks in Hungary

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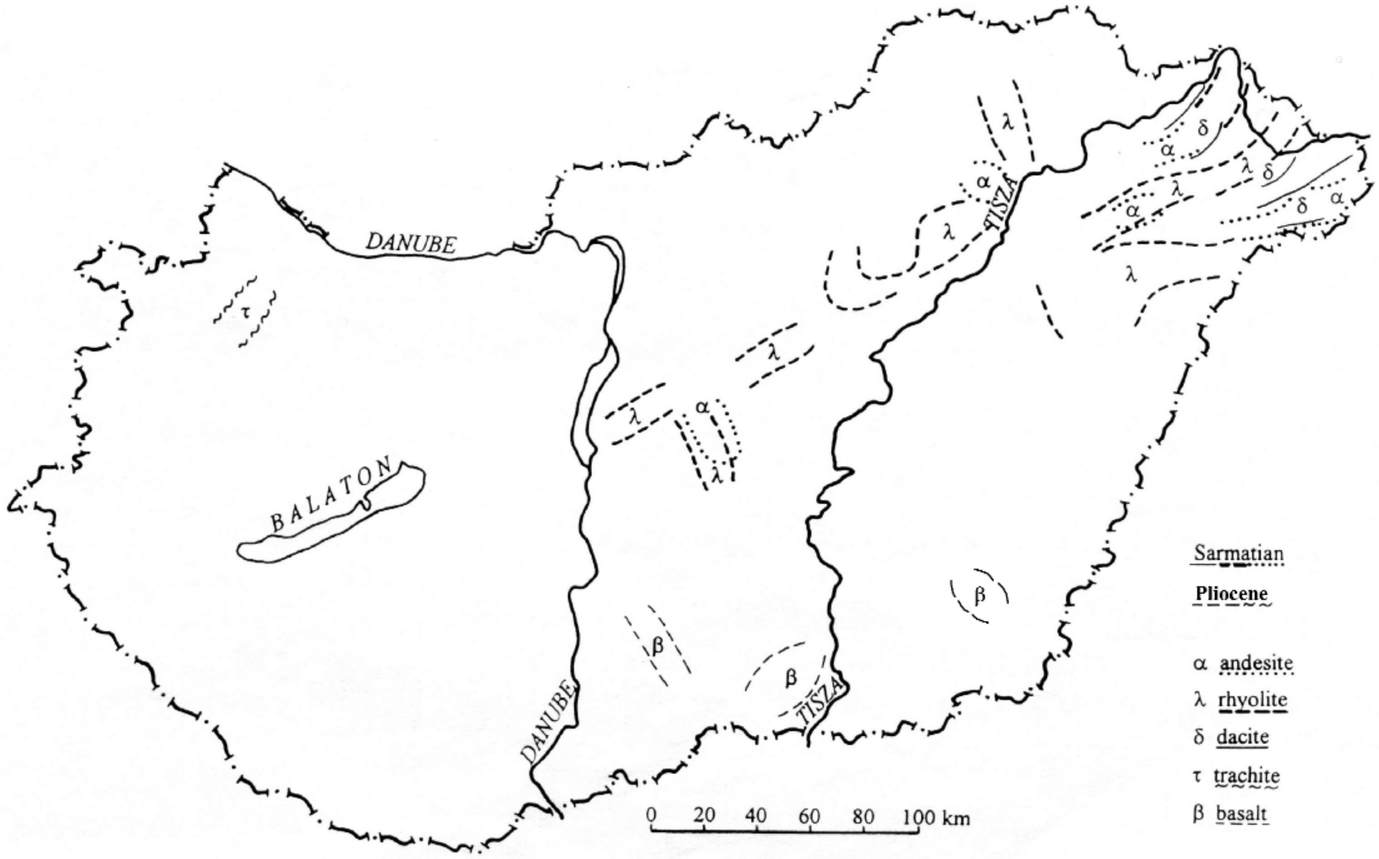

Fig. 16
Range map of the buried Sarmatian and Pliocene volcanic rocks in Hungary

Pannonian, according to radiometric and paleontological data. In the Little Hungarian Plain, with its predominantly metamorphic basement, and in the geologically complicated southern Danube–Tisza Interfluve area, the alkaline volcanism produced stratovolcanoes (trachite at Pásztori, basalt at Kecel) and solitary eruptive cones (Fig. 16, Table 2).

Conclusion

In the Hungarian basinal areas major tectonic activity (stretching and subsequent compression) occurred repeatedly, at least three times (Posgay et al. 2000). This activity took place along the major structural lineaments (which coincide with negative Bouguer anomalies), resulting in the eruption of differentiated, dacitic and rhyolitic, later predominantly andesitic, material. By the time of subsidence of the Pannonian Basin alkaline volcanism of deep crustal and astenospheric origin took place in more consolidated areas (Little Hungarian Plain, Danube–Tisza Interfluve), an indication of repeated rejuvenation of plate tectonic activity during the Neogene. Strike-slip displacements resulted in continuously subsiding volcanotectonic graben structures in Hungary, accounting for the widespread occurrence of the buried Neogene volcanic structures over an area of about 25,000 km^2. These structures coincide with NE–SW-oriented mobile zones, about 450 km long. In the area of the Nyírség, this direction is crossed by an Upper Miocene, NW–SE-trending structure toward the Tokaj Mts, in harmony with the arc of the Eastern Carpathians (Seghedi et al. 1998).

The calc-alkaline buried volcanism began about 19.5 Ma (Eggenburgian) and lasted until 10.5 Ma (Pannonian). This activity was followed by alkaline basaltic volcanism (»9-2.5 Ma?) (Table 2).

The buried volcanites of the Pannonian Basin are in close relationship to the Neogene–Quaternary volcanites of the Western and Eastern Carpathians (Pécskay et al. 1995; Seghedi et al. 1998; Lexa and Konecny 1999; Harangi 2001; Hámor et al. 2001), as regards their conditions of formation, composition and age. Further investigations of the buried volcanites could allow a more detailed volcanologic interpretation of the still unclear geophysical anomalies.

Acknowledgements

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Table 2. Rock type and radiometric age of the buried volcanic structures

No of drilling	Depth interval (m)	Thickness (m)	Rock type	Depth (m)	Measured mineral	K/Ar age (Ma)	Geologic age
GREAT HUNGARIAN PLAIN							
Gelénes-1	608–1341	733	Rhyolite pyroclastic flow	631	biotite	11.0	Upper Sarmatian
			Rhyolite pyroclastic	1265	whole rock	14.3	Upper Badenian
	1341–2003	>662	Rhyolite ignimbrite	1639	biotite	14.7	Upper Badenian
Barabás (outcrop)		>78	Rhyolite pyroclastic flow and rhyolite lava	outcrop	whole rock	11.2–12.8	Middle Sarmatian
Tarpa (outcrop)		>50	Pyroxene dacite	outcrop	whole rock	10.5	Lower Pannonian
Komoró-1	1328–1678	350	Rhyolite tuff and rhyolite tuffite				Middle Sarmatian
	1678–1871	193	Andesite tuff, andesite				Middle Sarmatian
	1833,7		Andesite	1833.7	whole rock	12.1	Middle Sarmatian
	1871–2506	635	Dacite, dacite, tuff, dacite tuffite	2355	whole rock	12.1	
	2395–2438		Dacitogenic propilite	2438	whole rock	11.2	
	2506-2859	353	Dacite tuffite				Upper Sarmatian
			Reached the Mesozoic basement				
Kisvárda (Fürdőkút)	1000		Pannonian sediment (clay, sand)				
	1040–1065		Andesite and tuff				
	1065–1180	115	Rhyolite and Rhyolite tuff	1150–1152	whole rock	11.0	Upper Sarmatian
Nagyecsed	1074–1712	638	Amfibol dacite and prop. andesite	1109–1110.5		11.2–11.5	Upper Sarmatian
	1712–2101	389	Propilitic andesite, tuff, tuffite	2209			
	2101–2554	453	Andesite (pyroxene)		whole rock	11.1	Upper Sarmatian
	2554–2843	289	Pirite, siliceous rhyolite	3017			
	2843–3233	390	Propolitic andesite (dyke)		whole rock	10.2?	Pannonian?
	3233–3766	533	Rhyolite				
	3766–4001	234	Epidot quartz diorite		whole rock	14.5	Badenian
Tiszaberek	1292–1500	208	Dacite tuff and tuffite				
Csenger-1	1375–2150	775	Rhyolite tuff, at the base andesite	2147	whole rock	11.0	Upper Sarmatian
Szamossály-1	905–1050	145	Andesite	932.8	feldspar	12.0	Sarmatian
		805	Andesite tuff	1045–1050	whole rock	13.4	Lower Sarmatian
Gacsály-1	1310–1850	540	Rhyolite tuff				
Baktalórándháza-1	1560–2210	550	Ignimbritic rhyolite tuff with	2004.5–	feldspar	13.0	Lower Sarmatian
	2210–2295	185	Pyroxene lithoclast	2004.7	biotite	13.5	Lower Sarmatian
	2295-2800	505	Rhyolite tuff and rhyolite tuffite	2214.3–	feldspar	13.5	Lower Sarmatian
	2800-4000	1200	Dacite, dacite tuff	2214.4	feldspar	15.0	Middle Badenian
			Rhyolite tuffite	2823.0–			
				2823.2			

Table 2 (cont.)

Nyírábrány-1	1315–1473	158	Rhyolite tuff, dacite tuff and rhyolite tuffite	1435–1440	biotite	15.0	Badenian
	1323–3205		Rhyolite tuff and sediment				
Nyíregyháza-1	979–1150	181	Rhyolite tuffite				
	1150–1310	160	Andesite, andesite tuff				
	1310–1820	510	Rhyolite, rhyolite tuff				
	1820–1887	67	Dacite tuff				
	1887–2198	311	Rhyolite tuff, rhyolite (welded)	2000	whole rock	10.8	rejuvenated age
	2198–2428	230	Dacite, dacite tuff	2162	feldspar	10.8	rejuvenated age
	2428–2447	19	Trachite				
	2447–2496	49	Tuff, tuffite				
	2495–2575	79	Rhyolite	2543	feldspar	13.5	Lower Sarmatian
Hajdúnánás-1	1215–1315	100					
		435	Rhyolite tuff				
	– 1977	250	Rhyolite	1997	whole rock	11.4	Upper Sarmatian
Hajdúnánás-2	1545		Pyroxene-andesite	1545	whole rock	13.0	Sarmatian
Penészlek-3			Rhyolite tuff (welded)	1255.0–1272.5	biotite	15.0	Badenian
Penészlek-15			Rhyolite tuff	1303	feldspar	13.8	Badenian
Penészlek-17	1183–1750	567	Amphibole dacite tuff	1745	whole rock	12.6	Sarmatian Upper Badenian
Nyírmártonfalva-1	693–1137		Rhyolite tuff, rhyolite	716–721		15.2	Badenian
	1120–1218		Rhyolite		biotite	15.8	Badenian
	1218–1312	94	Andesite, andesite tuff	932	biotite	17.1?	Karpathian?
	2183		Rhyolite intrusion	2183	whole rock	16.0	Lower Badenian
Hajdúhadház-1			Rhyolite tuff	735.0–739.0	biotite	15.3	Badenian
Hajdúböszörmény-1	933–1083	150	Rhyolite tuff	1000–1001.7	biotite	11.8	Sarmatian
	1083–1542	459	Rhyolite tuff				
Hajdúböszörmény-2	994–998,2	4.2	Clayer tuff				
	998.2–1005		Agglomerate				
	1055–1060	349.5	coarse tuff				
	1060–1409.5	498	Andesite tuff and lava				
	1409.5–1427.3		Andesite				
	1427.3–1477.1		Andesite tuff				
	1477–1547.3		Andesite	1526.5	whole rock	15.1	Badenian
Józsa-2	1238–1264	26	Tuffite				
	1264–1280		Tuffitic limestone				Sarmatian
	1280–1720	560	Rhyolite, dacite and rhyolite tuff ("middle")	1633–1637	biotite	16.5	Lower Badenian

Table 2 (cont.)

Józsa-3	815–1285	470	Tuffaceous limy marl, tuff				
	1285–1331	46	Rhyolite tuff, rhyodacite tuff	1326	biotite	14.6	Upper Badenian
Józsa-5			Ignimbrite (pumiceous)	1098	biotite	14.3	Upper Badenian
					feldspar	14.8	
Balmazújváros-2	1196–1228	39	? Rhyolite				
	1467–1477	10	? Rhyolite				
	1639–1675		? Rhyolite				
Balmazújváros-3	1194–1235	41	Amphibole andesite (propilitic)	1216–1219	whole rock	14.8	Badenian
	1235–1328	93	Andesite tuff				
	1328–1550	222	Rhyolite tuff with claymarl				
Balmazújváros-4	1155–1214	59	Tuffitic limestone		biotite	12.5	
	1214–1323	129	Rhyolite tuff	1227	feldspar	12.1	Sarmatian
	1323–1341	18	Andesite tuff				
	1341–1350	9	Rhyolite tuff				Badenian
Balmazújváros-5	1334–1380	46	Oolitic limestone				Sarmatian
	1380–1460	80	Andesite	1415–1418	whole rock	15.8	Lower Badenian
	1460–1551	89	Rhyolite tuff				
Kaba-É-4	1462–1483	21	Tufitic limestone				Sarmatian
	1483–1538	45	Rhyolite tuff with rhyolite dykes	1520	biotite	15.07	Upper Badenian
Hajdúszoboszló-22			Rhyolite tuff	1448–1450	biotite	13.6	Lower Sarmatian
Hajdúszoboszló-9			Rhyolite tuff	1375–1377	biotite	14.4	Upper Badenian
Nádudvar-2	1725–1730		Rhyolite tuff welded			11.1	Upper Sarmatian
Nádudvar-5			Andesite (propolitic)	1930	whole rock	9.9	Age of secondary activity
Nádudvar-7			Andesite	1875	whole rock	9.2	
Nádudvar-15	1580–1599	19	Andesite				
	1599–1649	50	Andesite tuff				
Kisújszállás-ÉK-1	1662–1772	90	Rhyolite crystalline tuff, rhyolite	1664–1682	biotite and feldspar	18.3	Ottnangian
	1860–1900	40	Rhyolite tuff, rhyolite	1863–1880	biotite and feldspar	18.1	Ottnangian
Kisújszállás-1	1450–1544	94	Tuffaceous limestone				Sarmatian
	1544–1736	192	Rhyolite tuff, limy marl	1614–1618	biotite	14.2	Upper Badenian
	1736–1738	2	Amphibole andesite				
Kisújszállás-13			Rhyolite tuff	1765–1770	biotite	15.7	Badenian
			Andesite dyke	1905–1909	whole rock	13.6	Sarmatian
			Rhyolite tuff, reworked tuff	1961–1964	biotite	19.1	Ottnangian
Kisújszállás-14			Rhyolite tuff?	1725–1731	biotite	19.3	Ottnangian

Table 2 (cont.)

Kisújszállás-17			Andesite	1821.5–1821.6	whole rock	15.3	Badenian
Kisújszállás-20			Pyroxene andesite	1725.9–1727.7	whole rock	15.2	Badenian
Albertírsa			K-Rhyolite	887–900	whole rock	14.7	Upper Badenian
Lajosmizse-1			Rhyolite tuff (welded)	949	biotite	19.0	Ottnangian
Lajosmizse-1			Rhyolite tuff	1027–1032	biotite	19.1	Ottnangian
Görbeháza-1			Rhyolite tuff Dacite	1455–1457 1531–1533	biotite and feldspar biotite and feldspar	15.1 16.7	Badenian Karpathian
Kunmadaras-3	1808–1838	30	Rhyolite tuff		biotite	18.0	Ottnangian
Kunmadaras-1			Rhyolite Rhyolite	1693–1695 1757–1762	feldspar feldspar	16.9 16.8	Karpathian–Badenian Karpathian–Badenian
Kunmadaras-6	1874–1878		Rhyolite tuff	1874	feldspar	16.9	Lower Badenian–Karpathian
Kunmadaras-8			Rhyolite tuff	1800–1805	biotite	16.4	Badenian
Kunhegyes-K-1	2796–2801 2934	105	Dacite tuff Amphibole andesite	2796 2974	feldspar	17.0	Karpathian
DANUBE–TISZA INTERFLUVE							
Mezőkeresztes-K-1			Rhyolite ignimbrite (Lower tuff)	1059	biotite	17.9	Ottnangian
Hejőszalonta	1151–1160		Dacite, ignimbrite	1151	biotite	18.5	Ottnangian
Mezőcsát-1			Rhyolite tuff Dacite Rhyolite tuff	1202–1211 1369–1370 1545–1548	biotite feldspar	14.1 13.6 16.4	Upper Badenian Lower Badenian
Sajóhídvég-2			Rhyolite tuff	1065	feldspar	14.6	Badenian
Farmos-2			Andesite	1497	whole rock	14.7	Badenian
Alatyán-1			Rhyolite tuff	2170	feldspar	10.8	Pannon Sarmatian
Alatyán-1			Carbonandesite Carbonandesite	2541 2926	feldspar whole rock	15.6 15.1	Badenian Badenian
Verpelét-5			Rhyolite tuff Rhyolite tuff	1495 1115	biotite biotite	15.9 13.1	Badenian Sarmatian
Kecel-1			Basalt	1432–1434		8.5	Lower Pannonian
Kecel-2			Basalt	1426–1426.5		8.1	Lower Pannonian
Kecel-Ny-2			Basalt	1502	whole rock	9.4	Lower Pannonian
Kiskunhalas-Ny-4			Basalt	1162–1167		9.4	Lower Pannonian
Ruzsa-4			Basalt	2657–2666		10.4	Lower Pannonian

Table 2 (cont.)

TRANSDANUBIA							
Pötréte-1			Amphibole andesite	1878.5–1880.0	whole rock	29.3	Lower Pannonian
Kutas-2			Biotite amphibole andesite	1723.5–1729.0	whole rock biotite	16.3 20.0	
Szenta-1			Biotite amphibole andesite	2530.0–2530.5	whole rock	19.5	
Kadarkút-2			Rhyolite tuff	917.0–920.0	biotite	19.1	
Vése-4			Biotitic rhyolite tuff	1282.0–1288.0	biotite feldspar	24.5 13.9	Reworked tuff
Kaposfő-2			Rhyolite tuff	1898.0–1902	feldspar	17.5	
Csákány-2			Amphibole andesite	2544.0-255.0	whole rock	7.0?	
Kisbattyán-1			Rhyolite tuff	357.5	biotite	19.7	Ottnangian–Eggenburgian
Kisbattyán-33			Rhyodacite tuff	110.0	biotite	19.7	Ottnangian–Eggenburgian
Hidas-53			Rhyodacite tuff	813.0	biotite	15.0	Badenian
Apátvarasd-5			Rhyodacite tuff	173.1	biotite	15.8	Badenian
Nagydorog			Rhyolite	362.0	biotite	19.9	Ottnangian–Eggenburgian
Nagydorog			Rhyolite	527.0	biotite	19.3	Ottnangian–Eggenburgian
Perbál-6			Rhyolite tuff	179.0	biotite	14.2	Badenian

Remarked: K/Ar age published in: Balogh et al. (1983), Széky-Fux et al. (1987a, b), Széky-Fux et al. (1989)

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