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PALEOGENE IGNEOUS ROCKS IN THE ZALA BASIN (WESTERN HUNGARY): LINK TO THE PALEOGENE MAGMATIC ACTIVITY ALONG THE PERIADRIATIC LINEAMENT

KÁLMÁN BENEDEK[1], ZOLTÁN PÉCSKAY[2], CSABA SZABÓ[1],
JÓZSEF JÓSVAI[3] and TIBOR NÉMETH[4]

[1]Eötvös University, Department of Petrology and Geochemistry, Lithosphere Fluid Laboratory, Pázmány Péter sétány 1/c, H-1117 Budapest, Hungary; bkalman@ludens.elte.hu; cszabo@iris.geobio.elte.hu
[2]Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Bem tér 18/c, H-4001 Debrecen, Hungary; pecskay@moon.atomki.hu
[3]Hungarian Oil Company (MOL), Batthyány út 45, H-1039 Budapest, Hungary; jjosvai@mol.hu
[4]Laboratory for Geochemical Research, Hungarian Academy of Sciences, Budaörsi út 45, H-1112 Budapest, Hungary; ntibi@sparc.core.hu

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Abstract: Paleogene intrusive (tonalite, diorite) and volcanic (andesite, dacite) rocks have been identified in drilling cores from the Zala Basin, SW-Hungary. The age of these rocks has been considered to be Eocene on the basis of the observation that volcanic rocks are intimately interlayered with sedimentary rocks deposited during Nannoplankton Zone 15/16–18. However, new K/Ar data measured on mineral concentrates (amphibole, biotite, plagioclase) from intrusive and volcanic rocks yielded ages from 28.6±1.8 Ma to 33.9±1.4 Ma and from 26.0±1.2 Ma to 34.9±1.4 Ma, respectively. The Early Oligocene K/Ar age of the andesite and dacite studied contradicts the previous biostratigraphic interpretations. Furthermore, detailed petrographic study of the volcanic rocks and XRD analyses of the Eocene marl deposits are not consistent with simultaneous volcanic activity and sediment deposition. Alternatively, we propose that the volcanic rocks were emplaced as dykes into the Eocene marl during the Early Oligocene. However, an Eocene age of some explosive (mostly tuffaceous) rocks is not debated. The Early Oligocene K/Ar data of the intrusive bodies coincide with the age of other Paleogene tonalitic massives along the Periadriatic Lineament. The geochemical and radiometric age data clearly demonstrate the Alpine connection of the either intrusive or volcanic rocks studied. During the Paleogene the intrusive and volcanic rocks dislocated and as a result of the escape of the ALCAPA (Alpine-Carpathian-Pannonian) block from the Alpine realm they reached their present-day juxtaposed setting in the Early Miocene.

Key words: Paleogene, Periadriatic Lineament, Zala Basin, geochemistry, radiometric age, calc-alkaline.

Introduction

Paleogene calc-alkaline volcanic series as well as small, intrusive bodies have been penetrated by oil-exploring boreholes in the Zala Basin (Fig. 1; Székyné 1957; Kőrössy 1988). On the basis of biostratigraphic data in the northern part of the studied area (Fig. 2), the age of the volcanic rocks has been assumed to be Eocene by observing sedimentary interlayering between the volcanic rocks and the Eocene marl (Lutetian-Early Priabonaian Padrag Marl) deposits. Analogously, the age of the intrusive rocks found only in the southern part of the studied area has been also considered as Eocene, although the Eocene marl deposits are lacking above the intrusive bodies, which are covered by Miocene (Badenian) sediments (Fig. 2; Kőrössy 1988).

As the entire Paleogene succession in the studied area is covered by Badenian sediments (Fig. 2, Kőrössy 1988), it must have undergone intensive erosion between the Paleogene (up to about 30 Ma) and the onset of the Badenian sedimentation. The eroded igneous fragments covered the older formations in the Transdanubian Central Range (Fig. 1). A detailed study of Oligocene-Miocene molasse sediments (Csatka Formation, Fig. 1) in the Transdanubian Central Range indicates that the source region of the igneous clasts must have involved igneous rocks akin to those in the Zala Basin, too (Benedek et al. 2001).

Fission-track (FT) and K/Ar dating of intrusive clasts (tonalite) from the Oligocene-Miocene molasse indicates Early Oligocene age (K/Ar 30–34 Ma) of the source region. Moreover, the FT and K/Ar ages of the volcanic (andesite, dacite) pebbles in the Oligocene-Miocene molasse suggest that these clasts were derived from Oligocene (K/Ar 31–35 Ma) and subordinately from Eocene (~40 Ma) volcanic edifices, which also argues for the presence of Oligocene volcanic activity in the Zala Basin (Benedek et al. 2001).

In this paper we present new K/Ar data of mineral concentrates (amphibole, biotite, plagioclase) from intrusive and volcanic (not explosive) rocks from the Zala Basin and correlate the study area with Alpine analogous regions.

The publication of drilling core names was allowed by the Hungarian Oil Company (MOL) only in coded form.

Geological setting

The Zala Basin (ZB), a part of the ALCAPA (Alpine-Carpathian-Pannonian) megaunit, is located north of the Balaton line, in Western Hungary. The Balaton line is interpreted as the eastern continuation of the Periadriatic Lineament (Kázmér & Kovács 1985; Fodor et al. 1998; Haas et al. 2000). It is believed that the ALCAPA megaunit was displaced horizontally eastward in the Miocene (Majoros 1980; Tari et al.

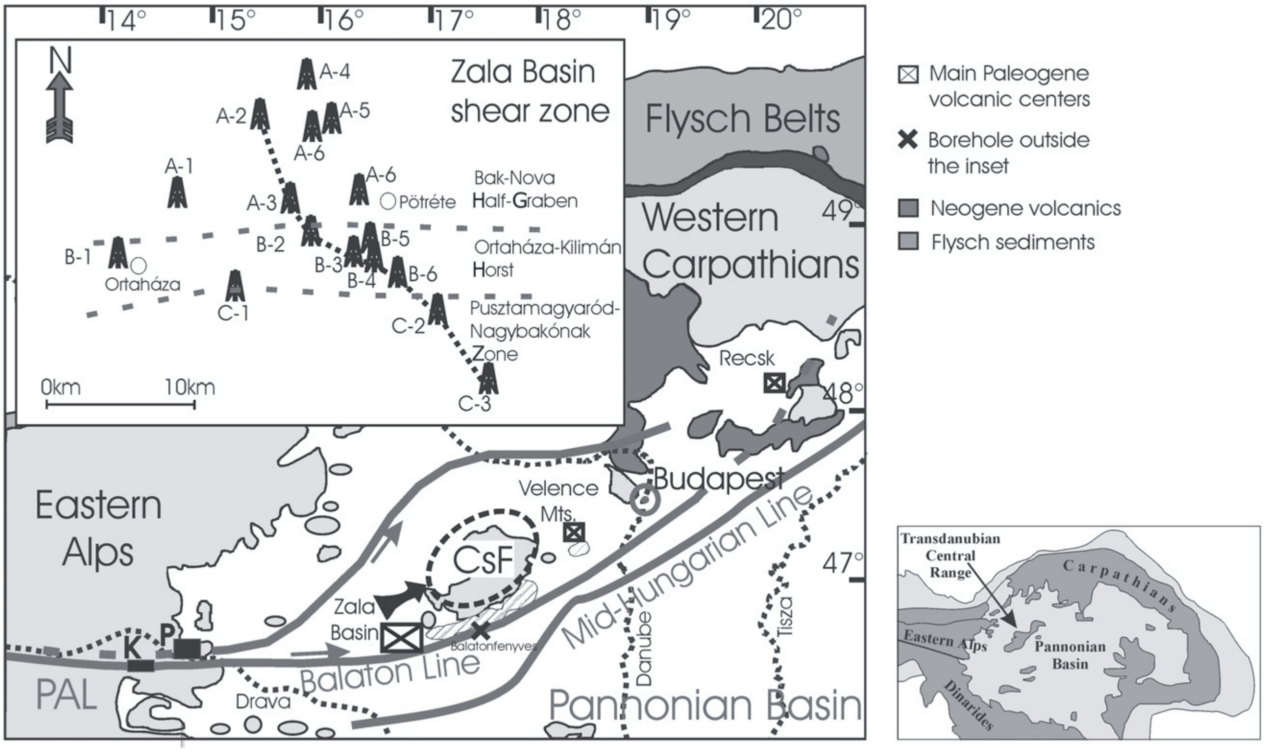

Fig. 1. Sketch-map showing the occurrences of Paleogene magmatic rocks in the Pannonian Basin. *Abbreviations:* **PAL** — Periadriatic Lineament, **CsF** — Csatka Formation, **K** — Karavanke tonalite, **P** — Pohorje tonalite. Black arrow shows paleotransport direction of the Oligocene-Miocene alluvial system (Korpás 1981). Inset shows position of some boreholes studied and the line (dotted line) of the cross-section displayed in Fig. 2. The approximate boundaries (dashed line) of subunits distinguished in the Zala Basin are also shown.

1993; Fodor et al. 1998; Frisch et al. 1998) as a consequence of continental convergence between the Adriatic microplate and stable Europe. However, small movements might have been already initiated during the Eocene (Kázmér & Kovács 1985). The Early Oligocene (30 Ma) position of the ALCAPA megaunit might have been still somewhere between the Eastern and Southern Alps (Kázmér & Kovács 1985; see Fig. 2b in Frisch et al. 1998).

In Hungary three Paleogene igneous magmatic centre can be outlined from SW to NE along the Balaton line and its NE continuation: 1) Zala Basin, 2) the Velence Mts, 3) Recsk (Fig. 1; Benedek 2002).

The study area of this paper, the Zala Basin can be divided into three structural units from south to north (Fig. 1, Fig. 2): 1) the Pusztamagyaród-Nagybakónak Zone; 2) the Ortaháza-Kilimán Horst; and 3) the Bak-Nova Half-Graben. The basement is made up mainly of Triassic formations in the south and east, and Jurassic, Cretaceous ones in the north, which is followed by Eocene sequences in the north and covered by Miocene sediments (Fig. 2; Bérczi-Makk 1980; Kőrössy 1988; Haas 1993).

The igneous suites in the studied area can be divided into two groups: 1) intrusive rocks occurring in the southern part of the study area (intrusive zone), which continues to the NE through Balatonfenyves (Fig. 1) and 2) zone of volcanic rocks (the volcanic zone) characterizing the northern part. The northern boundary of the intrusive body is outlined by a characteristic dextral strike-slip fault. No evidence for contact metamorphism of the intrusive bodies with the neighbouring

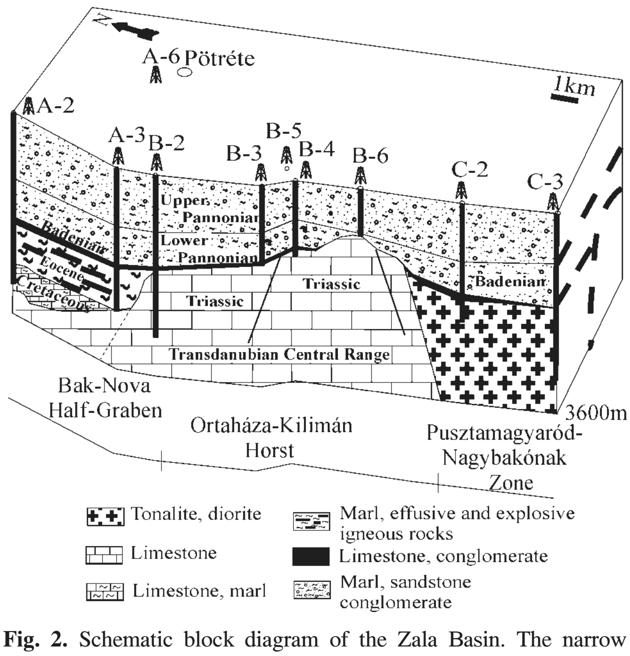

Fig. 2. Schematic block diagram of the Zala Basin. The narrow black field above Eocene in the Bak-Nova Half-Graben, Triassic in the Ortaháza-Kilimán Horst and in the Pusztamagyaród-Nagybakónak Zone represents thin Badenian deposits. The line of the cross-section is shown in the inset of Fig. 1.

Mesozoic carbonates has been observed in the south. In the upper part of the Eocene marl sequence in the Bak-Nova Half-Graben pyroclastic, mainly tuffaceous interlayers occur

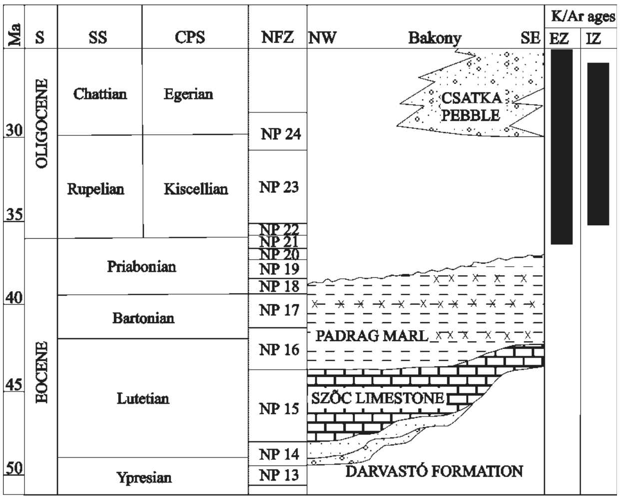

Fig. 3. Simplified Paleogene chronostratigraphy of the Bakony Mts (Zala) modified after Tari et al. (1993). Thick lines represent the K/Ar age interval with errors obtained from the intrusive and volcanic rocks studied. *Abbreviations:* **S** — series, **SS** — standard stages, **CPS** — Central Paratethys stages, **NFZ** — nanno fossil zones, **EZ** — volcanic zone, **IZ** — intrusive zone, **x** in the Padrag Marl — tuff horizons.

(Kőrössy 1988). The marl sequence was deposited between the NP15/16 Zone boundary and NP18 (Fig. 3, about 42–43 and 38 Ma, respectively) and the oldest tuffaceous layers are known from the NP16 Zone (about 42–43 Ma, Nagymarosy, pers. com.). The petrography of the volcanic rocks and igneous clasts hosted by explosive series is basically the same. Skarn at the contact of andesite with Triassic limestone was observed in a few drilling cores. The thickness of the entire Eocene succession can reach almost 1000 m. The oldest cover of the Eocene succession is Badenian sandstone and limestone.

Petrography

Intrusive rocks (tonalite, diorite)

Hypidiomorphic intrusive rocks contain predominant euhedral plagioclase (Fig. 4). Rare potassium feldspar can surround plagioclase. In general, abundant amphiboles and biotites containing plagioclase inclusions are commonly euhedral or subhedral in shape and perfectly fresh. These hydrous minerals appear along lineation and interstitially among feldspars. Rare anhedral or subhedral quartz crystals fill in the available space among the phases crystallized formerly. Rutile, apatite, zircon and oxide minerals are common accessory minerals. Garnet is a rare accessory.

Volcanic rocks (andesite, dacite)

Plagioclase is the dominant phenocryst (Fig. 4). It is a common inclusion in the subsequent mineral phases. Euhedral, subhedral amphibole phenocrysts are fresh or surrounded by oxide mineral rim. Euhedral biotite, sometimes containing sagenitic rutile, is corroded and absent in the majority of samples. Quartz phenocrysts are anhedral due to resorption. Rare clinopyroxene is euhedral and chloritized. Garnet is a rare phenocryst containing small, elongated rutile inclusions. The glassy groundmass is mostly altered to clay minerals (Fig. 4).

Analytical techniques

Mineral separation was carried out using standard techniques (i.e. heavy liquids, magnetic separator). The samples were handpicked and cleaned in alcohol with an ultrasonic cleaner. Conventional analytical methods were used in the determination of argon. Argon was extracted from 0.125–0.250 mm sized whole rock and mineral concentrates by radio frequency fusion in Mo crucibles in previously baked stainless steel vacuum systems. ^{38}Ar spike was added from a conventional pipette system (calibrated against international reference samples) and the evolved gases were purified using Ti- and SAES getters and liquid nitrogen traps. The purified argon was measured in the static mode using a 15 cm radius sector mass spectrometer. Approximately 0.1 mg of finely ground sample was dissolved in acids. The residue was taken into solution and K determined by flame photometry with a Na buffer and Li internal standard. K and Ar determinations were checked regularly by interlaboratory standards (HD-B1, LP-6, GL-0, Asia 1/65). All ages (Table 1, Fig. 3) have been calculated by using the constants recommended by Steiger & Jäger (1977). Analytical errors are given in one standard deviation. Details of the instruments, the applied methods and result of the calibration have been described elsewhere (Balogh 1985).

The electron microprobe analysis of the main rock forming minerals was carried out at the Department of Earth Sciences, University of Florence, by JEOL Superprobe JXA-8600 WDS. The accelerating voltage was 15 kV, with 10 nA sample current. We used Bence & Albe's (1968) correction calculation (Table 2). Natural standards were employed.

A Philips PW-1730 diffractometer was used to analyse the clay fractions of the Eocene marl deposits interfingering with volcanic rocks in the Bak-Nova Half-Graben. Graphite monochromator using Cu-Kα radiation at 45 kV and 35 mA with 1° divergence slit and 1° receiving slit was applied. The scanning rate was 0.05° 2Θ per minute from 3° to 70°. Clay minerals were identified on ethylene-glycol solvated and heated (350 °C and 550 °C) samples from the clay fraction (less than 2 μm) using the method of Thorez (1976).

Results

The very low K content of biotite concentrates (sample C-3 tonalite, C-1 tonalite — Table 1) indicate that they are contaminated with low-K phases, for instance amphibole and plagioclase. Electron microprobe analyses of biotite (Table 2) suggests that K_2O wt. % should vary between 7.92–9.40. On the basis of microscopic investigations of mineral concentrates, the presence of plagioclase inclusions in biotite and intergrowing of amphibole with biotite can cause the observed low K content in biotite concentrates. The same problem of preparation can be responsible for the relatively high K con-

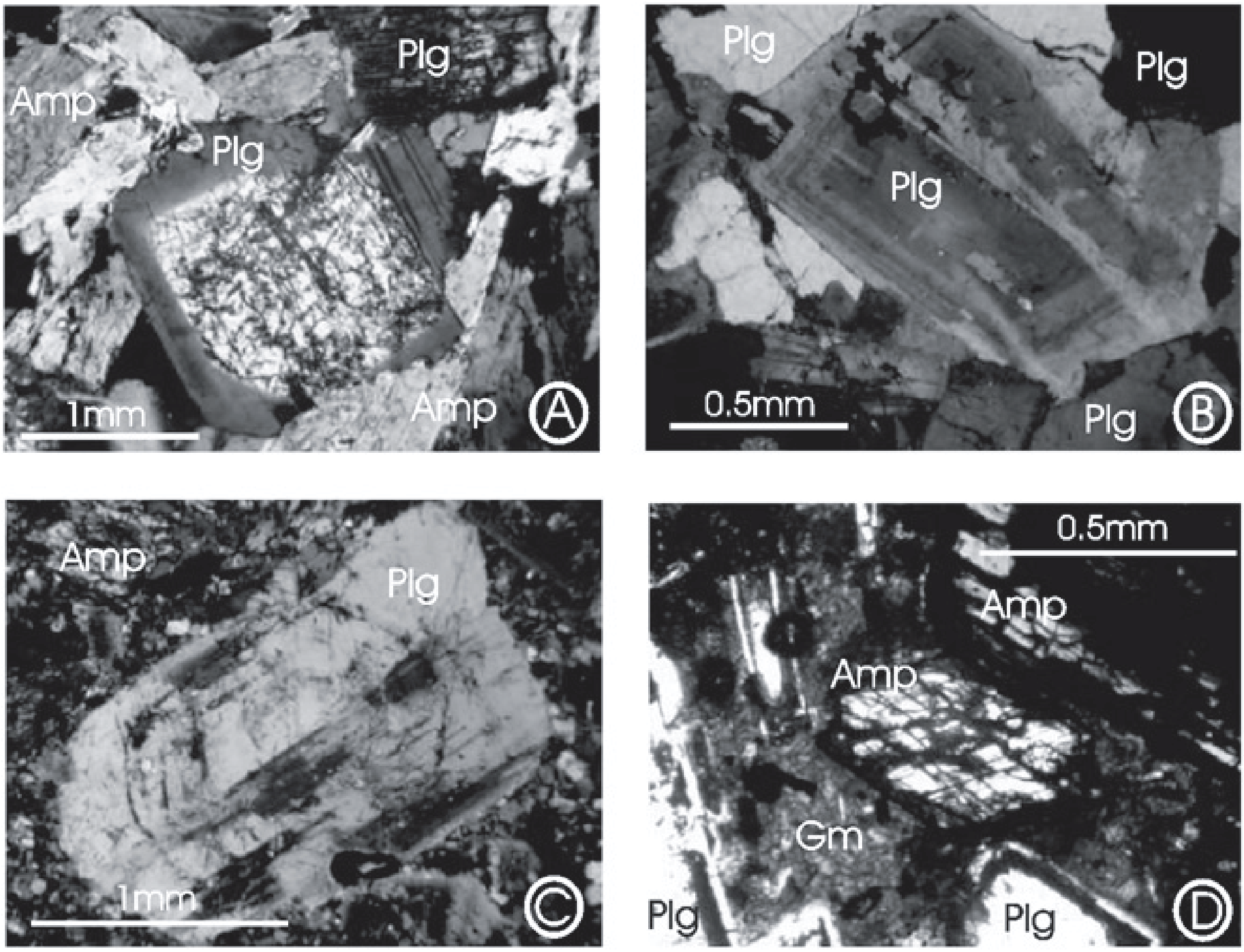

Fig. 4. Photomicrographs of representative igneous rocks studied. **A** — Zoned plagioclase surrounded by amphiboles in hypidiomorphic tonalite. N+, sample C-3. **B** — Strongly zoned plagioclase in hypidiomorphic tonalite. N+, sample C-1. **C** — Zoned plagioclase and amphibole phenocrysts in porphyritic andesite. The groundmass contains plagioclase, rare amphibole and glass. N+, sample B-1. **4** — Amphibole and plagioclase phenocrysts in dacite. The amphibole phenocrysts are rimmed by oxide minerals. The groundmass is altered to clay minerals. N+, sample A-3.

tent of some plagioclase concentrates (C-1 tonalite, B-1 andesite, A-2 andesite, Table 1), as, apart from the alteration of the groundmass in samples A-1 andesite, A-2 andesite and A-3 dacite (Fig. 1), there is no evidence for secondary alteration of the samples dated. In samples A-2 and A-3, the plagioclase ages (27.1±1.4 and 31.6±1.3, respectively) are younger than the amphibole ones (32.5±1.4 and 34.9±1.4, respectively, Table 1) and do not fall within the range of analytical error. This phenomenon is due to the preparation technique, since after using heavy liquids the magnetic separator was not able to separate plagioclase completely from altered groundmass, wich resulted in younger K/Ar age.

Mineral concentrates (amphibole, biotite, plagioclase) from the intrusives yielded K/Ar ages ranging from 28.6±1.8 to 33.9±1.4 Ma, while concentrates of amphibole and plagioclase from volcanic rocks give K/Ar ages between 26.0±1.2 and 34.9±1.4 Ma (Table 1). It is noteworthy that Balogh et al. (1983) reported Oligocene K/Ar age (30.7±1.0 Ma) of a small tonalite body NE to the Zala Basin, near to the Balaton line (Balatonfenyves, Fig. 1).

Discussion

The K/Ar ages of the tonalite samples (C-3 and C-1, Table 1) overlap with those of the igneous plutons (Bergell, Adamello, Riesenferner, Karawanke, etc.) aligned along the Periadriatic Lineament (about 30 Ma, e.g. von Blanckenburg & Davies 1995). Thus, the studied intrusive bodies can represent fragments deriving from the Periadriatic tonalite belt in accordance with the palinspastic restoration of Kázmér & Kovács (1985). The present-day position of the intrusive zone studied was a result of large-scale lateral displacement during the Miocene (Majoros 1980; Ratschbacher et al. 1991; Tari et al. 1993; Fodor et al. 1998; Frisch et al. 1998). Therefore, the intrusive bodies studied may have been located far west in the Alpine realm at about 30 Ma.

The interpretation of the age data from the volcanic zone is more complex. Our data (considering analytical error) indicate Late Eocene-Oligocene (latest Priabonaian-Chattian) volcanic activity, which contradicts the former concept of a Middle to Late Eocene age of the volcanism (Fig. 3; Kőrössy 1988). Nev-

Table 1: K/Ar data and main petrographic features of igneous rocks from the Zala Basin, Hungary. For the sake of completeness, we presented also some unpublished K/Ar data of the Hungarian Oil Company (MOL). These data are bolded.

Sample No. Rock type Depth	Petrographic description	Dated fraction	K (%)	$^{40}Ar_{rad}$ (%)	$^{40}Ar_{rad}$ (ccSTP/g)* 10^{-6}	K/Ar age (Ma)
C-3 Tonalite 1867–1870 m	Hypidiomorphic tonalite consisting of plagioclase (50–60), amphibole (20–25), biotite (10–15), quartz (10–15). Apatite, zircon and opaque minerals are accessory phases.	Biotite	3.25	63.4	4.328	33.9±1.4
		Amphibole	1.28	42.8	1.664	33.0±1.5
		Plagioclase	0.49	34.7	0.585	30.4±1.5
C-1 Tonalite 1795.5–1798 m	Hypidiomorphic tonalite consisting of plagioclase (55–65), amphibole (5–10), biotite (10–15), quartz (15–20). Apatite, zircon and opaque minerals are accessory phases.	Biotite	3.91	23.7	4.377	28.6±1.8
		Plagioclase	1.23	40.6	1.344	27.9±1.3
A-3 Dacite 2302–2306.5 m	Porphyritic dacite with phenocrysts of plagioclase (25–35), amphibole (20–25), accessory apatite, zircon. The glassy groundmass (40–50) is altered into clay minerals.	Amphibole	0.58	54.2	0.794	34.9±1.4
		Plagioclase	0.95	58.4	1.173	31.6±1.3
A-1 Andesite 2812–2813.5 m	Porphyritic andesite with phenocrysts of plagioclase (30–40), amphibole (15–25), biotite (0–5), quartz (0–5), accessory apatite, zircon. The groundmass is altered into clay minerals.	Amphibole	0.29	15.6	3.581	31.1±2.8
B-1 Andesite 2338–2342 m	Porphyritic andesite with phenocrysts of plagioclase (45–55), amphibole (15–20), biotite (0–5), quartz (0–5) in microcrystalline groundmass composed of plagioclase and opaque minerals.	Amphibole	1.22	45.4	1.247	26.0±1.2
		Plagioclase	1.49	66.2	1.650	27.9±1.1
A-6 Andesite 1878.5–1880 m	Porphyritic andesite with phenocrysts of plagioclase (30–40), clinopyroxene (10–20), accessory garnet, apatite and zircon. The groundmass is microcrystalline.	Whole rock	2.6	59.4	2.483	**29.3±1.2**
		Heavy frac.	2.1	62.4	2.601	**31.6±1.3**
		Light frac.	2.41	72.6	3.203	**33.9±1.3**
A-2 Andesite 2304.5–2305.5 m	Porphyritic andesite with phenocrysts of plagioclase (50–60), amphibole (5–10), accessory apatite, zircon. The groundmass is altered into clay minerals.	Whole rock	1.98	57.3	2.117	**27.3±1.1**
		Amphibole	1.91	51.7	2.430	**32.5±1.4**
		Plagioclase	1.10	34.0	1.173	**27.1±1.4**

Table 2: Representative composition of mineral fractions dated. *Abbreviations:* c — core, r — rim, b.d.l. — below detection limit.

plagioclase	C-3 c	C-3 r	C-1 c	C-1 r	A-3 c	A-3 r	B-1 c	B-1 r
SiO_2	44.80	55.90	60.92	51.88	47.26	55.67	45.24	59.73
Al_2O_3	35.40	27.10	24.99	30.84	33.22	28.66	36.03	25.57
FeO	0.15	0.00	0.17	0.02	0.35	0.32	0.13	0.11
CaO	19.70	9.80	6.69	13.25	16.74	10.71	19.04	7.22
Na_2O	0.99	6.35	8.57	3.69	2.07	5.57	0.66	7.71
K_2O	b.d.l	0.11	0.36	0.08	0.09	0.33	b.d.l	0.38
Sum	101.0	99.2	101.7	99.8	99.7	101.2	101.1	100.7

amphibole	C-3 c	C-3 r	A-3 c	A-3 r	B-1 c	B-1 r
SiO_2	42.49	49.78	42.99	42.43	43.40	45.08
TiO_2	2.05	0.42	2.30	2.31	0.90	1.64
Al_2O_3	13.62	7.25	13.32	13.32	12.57	8.95
FeO	16.95	14.31	9.16	9.08	15.04	15.33
MnO	0.23	0.25	0.13	0.09	0.58	0.32
MgO	9.84	13.50	15.40	15.33	11.40	13.20
CaO	10.53	11.04	11.60	11.69	10.36	10.82
Na_2O	0.97	0.60	2.35	2.24	2.30	1.58
K_2O	0.99	0.15	0.60	0.64	0.47	0.59
Sum	97.73	97.44	98.16	97.31	97.12	97.67

biotite	C-3 c	C-3 r	C-1 c	C-1 r
SiO_2	36.65	36.28	35.40	35.80
TiO_2	2.00	1.84	4.99	2.91
Al_2O_3	16.21	15.84	13.50	13.70
FeO	18.17	17.78	22.10	22.00
MnO	0.12	0.13	0.13	0.49
MgO	13.20	13.04	9.31	9.54
K_2O	7.92	8.43	9.40	9.28
Sum	94.77	93.90	95.34	94.52

ertheless, some explosive (mostly tuffaceous) layers do interfinger with paleontologically well-dated deposits of the Eocene marl (Kőrössy 1988, Nagymarosy, pers. com.). Further study of explosive layers is outside the scope of this paper.

Modification of K/Ar systems due to postmagmatic processes

The formation age of the volcanic rocks could have been modified by: (1) metamorphism, (2) hydrothermal alteration, (3) superficial or subsurface weathering, (4) thermal effect (due to volcanism).

Index minerals of any metamorphic overprint have not been observed in the samples studied (Fig. 4). The pre-Late Carboniferous rocks of the Transdanubian Central Range underwent low grade, regional pre-Westfalian metamorphism (Árkai & Lelkes-Felvári 1987), but they were overprinted by subsequent Alpine metamorphism (Lelkes-Felvári et al. 1996).

In order to determine the maximum temperature reached after the deposition of the Eocene marl, XRD analyses on clay mineral fractions separated from the marl were carried out (Kőrössy 1988). The shift of 1.4 nm peak to 1.7 nm in ethylene glycol treated samples indicated the presence of smectite (stability max. 70 °C, Glasmann et al. 1989) in the marl. This suggested that post-magmatic (or post-Eocene) thermal modification of the volcanic rocks due to metamorphism or the neighbouring Miocene volcanic activity (Kőrössy 1988) is not a viable scenario to account for the discrepancy between radiometric and stratigraphic data.

The Velence Mts and Recsk (other Paleogene igneous complexes in Hungary, Fig. 1) demonstrate many features of hydrothermal alteration (Molnár 1996), however detailed petrographic study on the volcanic rocks suggested that hydrothermal alteration did not modify the samples dated (Fig. 4). Petrographic observations and electron microprobe analyses of dated mineral phases also exclude superficial or subsurface alteration of the samples studied. Only alteration of the groundmass was observed in samples A-1, A-2, and A-3.

The age of the volcanic rocks

Concluding the preceeding sections, secondary modification of the K/Ar system of the volcanic rocks studied cannot be responsible for the discrepancy between radiometric and paleontological age data. Study on abundant planktonic foraminiferal assemblages suggests deposition of the Eocene marl in a water depth of about 800–1200 m (Báldi-Beke & Báldi 1990). As a consequence, if volcanic activity producing volcanic material and marl deposition (Fig. 2) were contemporaneous, the volcanic activity should have shown submarine features. However, the discrete petrographic consequences of submarine volcanic activity (pillow lava, peperite, amygdale, blistered structure and typical chilled, variolitic texture of the groundmass) have not been observed in the volcanic rocks studied. In addition, this process should have been accompanied by intensive chloritization, carbonitization and clay mineralization. None of these diagnostic features were observed in the studied samples (Fig. 4), therefore the data do not support coeval submarine magmatism with the deposition of the Eocene marl.

We assume that K/Ar ages measured on amphibole concentrates of volcanic rocks (Table 1) represent true formation ages and were not modified significantly by subsequent geological-geochemical processes. We suggest that the volcanic rocks studied are dykes crosscutting the Eocene marl succession. This concept is based on the following evidence: 1) the penetrated thickness of the studied volcanic rocks is usually not more than 5 m and 2) seismic sections and stratigraphic considerations do not suggest post-Paleogene tectonism in the explored sections (at least in the appropriate depth interval of the boreholes studied), which excludes tectonic contact of volcanic rocks studied and the Eocene marl. This interpretation resembles the situation in the Velence Mts (Fig. 1), where Józsa (1983) described abundant andesitic dyke magmatism of the same age (radiometric ages concentrate between 29–35 Ma) penetrating Variscan granitoid.

The younger K/Ar age of the plagioclase concentrates of samples A-3 and A-2 (Table 1) is due to the presence of altered groundmass in the separated material, which refers to immediate alteration of the groundmass just after magmatic activity.

Paleogene position of the studied igneous rocks

The schematic block diagram of the Zala Basin (Fig. 2) demonstrates the tectonic connection of the intrusive zone and the volcanic zone. Further evidence for non-uniform behaviour of the studied area in the Paleogene can be gained by comparing the southern intrusive and the northern volcanic rocks in the nature of their emplacement. According to geobarometric calculations, the intrusive rocks studied crystallized at depth of 7–15 km (Benedek & Szabó 2000). As the intrusive rocks are covered by Miocene sediments at present (Fig. 2; Kőrössy 1988), they must have undergone intensive erosion prior to the Miocene. Consequently, if the entire area studied had behaved uniformly during the Paleogene, the Eocene marl sequences should have been eroded completly. However, this is not the case in the north (Fig. 2).

Fodor et al. (1998) suggested that superficial occurrences of Paleozoic granite in the Velence Mts and subsurface lenses south of Lake Balaton in Hungary can be correlated with the Eisenkappel granite (see Fig. 1 in Fodor et al. 1998). Accordingly, the Hungarian granite occurrences can be interpreted as the eastern continuation of strike-slip duplexes described in the Central Karavanke Zone due to Miocene dextral displacement along the Periadriatic Lineament system (Fodor et al. 1998). Following this concept, we suggest that the intrusive zone studied can be the eastern equivalent of the Periadriatic tonalite belt (von Blanckenburg & Davies 1995) and their separation took place contemporaneously with that of the Paleozoic granites (Fodor et al. 1998). Accordingly, the intrusive zone studied can represent a strike-slip duplex. The close genetic relationship of the Karavanke tonalite (Fig. 1, ~30 Ma, Scharbert 1975) and the intrusive zone studied has been successfully demonstrated by using chondrite and MORB normalized trace element distribution diagram (Fig. 5A,B). In contrast, the Pohorje tonalite (Fig. 1, 15.5–17 Ma) is enriched in LILE (large ion lithophile elements) and La, Ce relative to those of the intrusive rocks studied and the Karavanke intrusives (Fig. 5A,B). The close correspondence of the age data and the geochemistry of the Karavanke intrusive rocks and the studied ones support a genetic relationship between these plutons.

The tectonic interpretation of the studied area means that the Paleogene position of the volcanic zone (Fig. 1, Fig. 2) was west of the 30 Ma position of the intrusive zone and volcanic rocks were juxtaposed as a result of the escape of the ALCAPA block from the Alpine realm in the Miocene. Frisch et al. (1998) placed the northern part of the studied area southeast of the hidden Tauern Window and west of the present-day setting of the Karavanke tonalite in their palinspastic reconstruction at 30 Ma. This implies that the Karavanke tonalite is the only possible counterpart for the intrusive zone studied along the Periadriatic intrusive belt. Tari (1994) estimated a dextral slip of 350–550 km along the Periadriatic Lineament.

The suggested non-uniform behaviour of the studied area in the Paleogene can explain why the Eocene marl in the N was not eroded completely: different subunits of the studied area (Fig. 2) could have undergone different Paleogene evolution.

The origin of igneous clasts found in the Csatka Formation

Benedek et al. (2001) described clasts of tonalite (30–34 Ma), andesite and dacite (31–35 Ma) in the Oligocene-Miocene molasse deposits (Csatka Formation, Western Hungary, Fig. 1). By comparing the trace element composition of the intrusive and volcanic rocks studied and that of igneous clasts found in the molasse, a perfect compositional (Fig. 5C,D) and age fit can be observed. This suggests that the drainage area of the former alluvial system must have included the Oligocene magmatic suites now located in the Zala Basin. Sedimentary features (direction of gravel imbrication) of the alluvial deposits (Korpás 1981) also support this interpretation.

Conclusion

Paleogene igneous rocks buried by sedimentary formations in the Zala Basin were identified as Eocene on the basis of biostratigraphical criteria. In this paper we present new K/Ar data, which contradict this interpretation. The major conclusions of this paper include:

1) K/Ar ages of amphibole, biotite and plagioclase concentrates from intrusive (28.6±1.8–33.9±1.4 Ma) and volcanic (26±1.2–34.9±1.4 Ma) rocks studied constrain to classify these formations to the latest Priabonian–Chattian. However Eocene onset of Paleogene magmatism is apparent on the basis of biostratigraphical data.

2) Post-magmatic processes could not modify K/Ar geochronometers.

3) Volcanic rocks, as dykes, crosscut sediments of the Eocene marl.

4) The intrusive zone encountered along the Balaton line is a fragment of the magmatic belt along the Periadriatic Lineament.

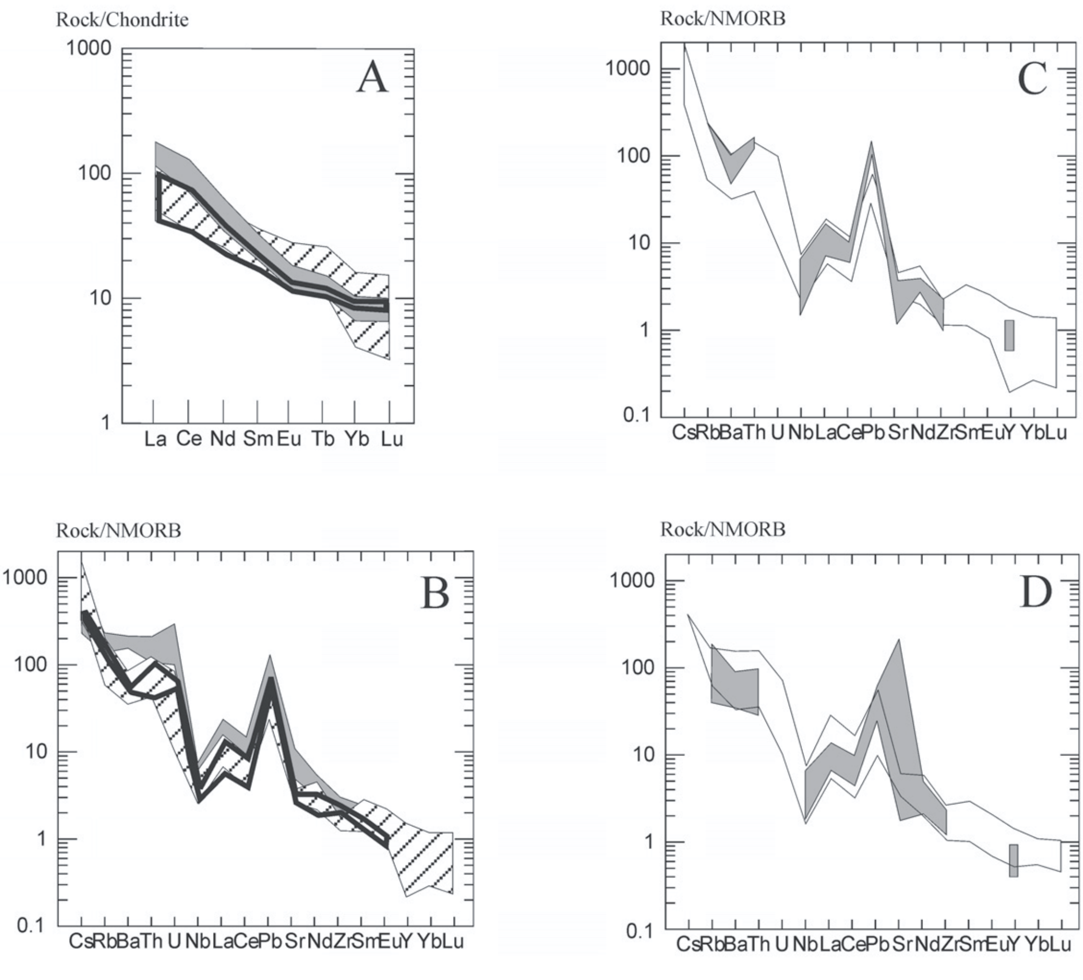

Fig. 5. Chondrite-normalized REE **(A)** and MORB-normalized trace element **(B)** pattern of the intrusive zone studied (hatched field), Karawanke (thick solid line), and Pohorje Mts (grey field). Trace element data of Karawanke and Pohorje Mts were taken from Altherr et al. (1995) and Pamić & Palinkaš (2000). MORB-normalized trace element pattern of the intrusive **(C)** and volcanic **(D)** rocks studied (solid line) and pebbles from the Oligocene-Miocene molasse (grey field). Data of igneous pebbles from the molasse were taken from Benedek et al. (2001). Composition of the igneous rocks studied is taken from Benedek et al. (unpublished data). Normalizing constants of MORB are from Sun & McDonough (1989) and that of chondrite from Nakamura (1974).

5) The Zala Basin did not function uniformly during the Paleogene. The intrusive zone was situated east relative to the volcanic zone 30 Ma, very close to the Karavanke tonalite. The intrusive zone most likely represents a strike-slip duplex that was formed by dextral displacement along the Periadriatic Lineament system in the Miocene. Thus volcanic and intrusive suites in the studied area were juxtaposed as a result of the escape of the ALCAPA block.

6) Igneous rocks in the present-day Zala Basin survived an important erosion event between ca. 30 Ma and the Badenian and a great amount of the eroded material accumulated in the lower part of the Oligocene-Miocene molasse deposits.

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