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K/Ar DATING OF NEOGENE CALC-ALKALINE VOLCANIC ROCKS FROM TRANSCARPATHIAN UKRAINE

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Abstract: The Neogene Carpathian arc is a complex magmatic arc, extending from Slovakia into Romania. The Transcarpathian region in SW Ukraine comprises the central part of this arc and was active in the Middle-Late Miocene. The volcanic structures of the Transcarpathian region can be divided into three major areas: a—Outer Arc; b—Intermediate zone; c—Inner Arc. This division reflects the basic tectonic features of the Ukrainian Carpathians, but differs from other parts of the Carpathian arc. The Outer Arc consists of a number of overlapping stratovolcanic structures, generally composed of lava flows, domes, dykes/sills, volcanic necks and lahars of basaltic andesite, andesite and dacite composition. In the Inner Arc, tuffs, ignimbrites and ash deposits of dacite, rhyodacite and rhyolite are abundant. Lava flows of andesitic and basaltic-andesitic composition are present, together with domes of dacite and rhyolite. The Intermediate zone is composed of lava domes and small andesitic shield volcanoes. New K/Ar data obtained from 57 volcanic rock samples has yielded K/Ar ages of 13.4–9.1 Ma. This time interval (~4.5 million years) is similar to that of the neighbouring Carpathian volcanic regions to the west (Tokaj Mts., Hungary) and to the east (Călimani, Romania). Badenian rhyolitic tuffs buried within the Transcarpathian area represented the earlier phases of magmatism, but they have been dated only by biostratigraphic methods. Thus, there is no evidence in this area for any along-arc migration of volcanism, unlike in the Eastern Carpathians of Romania. Formation of volcanic structures started simultaneously in both Outer Arc and Inner Arc volcanic areas (13.4 Ma). Different peaks of volcanic activity were observed: (a) between 13.0–11.5 in the Inner Arc, interpreted as the major period of generation of a complex of resurgent domes related to formation of a caldera, probably situated toward the central part of the Transcarpathian depression, and (b) between 11.2–10.5 Ma in the Outer Arc, representing the main period of volcano generation. The end of the volcanic activity (9.5–9.1 Ma) was scattered and less voluminous.

Key words: SW Ukraine, Transcarpathia, Neogene volcanic activity, calc-alkaline volcanic rocks, K/Ar dating, volcanology.

Introduction

Neogene calc-alkaline volcanic rocks from the south-western part of the Ukraine (Transcarpathia) form part of the Carpathian magmatic arc, which extends from Slovakia into Romania, via Hungary and the Ukraine. The Transcarpathian volcanic area is an integral part of a continuous ~120 km long chain which starts in Slovakia (Vihorlat Mts.) and continues to Romania (Oaş volcanic area).

Previous investigations reviewed by Lyashkevich (1995) recognized two Neogene magmatic formations in Transcarpathia: (1) Rhyodacitic; and (2) Andesitic. The former is located close to and inside the Transcarpathian depression, whereas the latter consists of a volcanic chain closer to the Flysch area. Further west, in Slovakia three types of volcanism were distinguished by Lexa et al. (1993) and Kaličiak & Žec (1995): 1. Rhyolite-rhyodacite areal volcanism (Eggenburgian–Badenian); 2. Andesite areal volcanism (Middle Badenian–Sarmatian); 3. Volcanic arc andesite volcanism (Sarmatian–Pannonian). The first two types correspond roughly to the Rhyodacitic magmatic formation, and the third one is equivalent to the Andesitic magmatic formation of Lyashkevich (1995). Previous K/Ar data suggested an age of 12.6 Ma for the Rhyodacitic formation and 12.3–10.6 Ma for the Andesitic formation (Danilovich 1976 fide Lyashkevich 1995; Bagdasaryan & Danilovich 1968). K/Ar dating was performed on alunite related to hydrothermal activity in the Beregovo region of Transcarpathia (Rakovits et al. 1981) in which two different events were distinguished: 15.21±0.84 Ma and 12.65±0.56 Ma.

In our study new K/Ar ages were measured for 57 samples, covering most of the Transcarpathian volcanic centers. We sampled massive, non-vesicular rocks from both outcrops and boreholes drilled by the Transcarpathian Geological Exploration Company (Beregovo). Although we have not undertaken detailed geological mapping of the eruptive succession, our new data will considerably improve the understanding of the space-time evolution of the volcanic activity in the Transcarpathian region of the Carpathian arc.

Experimental methods

K/Ar age determinations were done at the Institute of Nuclear Research of the Hungarian Academy of Sciences in Debrecen, Hungary. The freshness of specimens was evaluated by microscopic investigation of thin sections and strongly altered specimens were eliminated. Conventional experimental methods were used in the determination of the argon content. K/Ar dating was carried out on whole rock samples, except for one dacitic rock (UA-3), from which biotite was dated.

Argon was extracted from 0.1–0.3 mm sized whole rock samples by RF fusion in Mo crucibles, in previously backed glass and stainless steel vacuum system. ^{38}Ar spike was added from pipette system, 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 magnetic sector type mass-spectrometer built in Debrecen. Recording and evaluation of argon spectrum was controlled by a microcomputer. Details of the instruments, the applied methods and results of calibration have been described elsewhere (Balogh 1985; Odin 1982).

Approximately 0.1 g of finely ground sample was digested in acids and finally dissolved in 0.2 M HCl. Potassium was determined by flame photometry with a Na buffer and Li internal standard. The inter-laboratory standards Asia1/65, LP-6, HD-B1, GL-O and atmospheric Ar were used for checking the measurements. Atomic constants suggested by Steiger & Jäger (1977) were used for calculating the age. All analytical errors represent one standard deviation (68 % analytical confidence level). For stratigraphic classification, the time-scale of Central Paratethys (Vass & Balogh 1989) has been used.

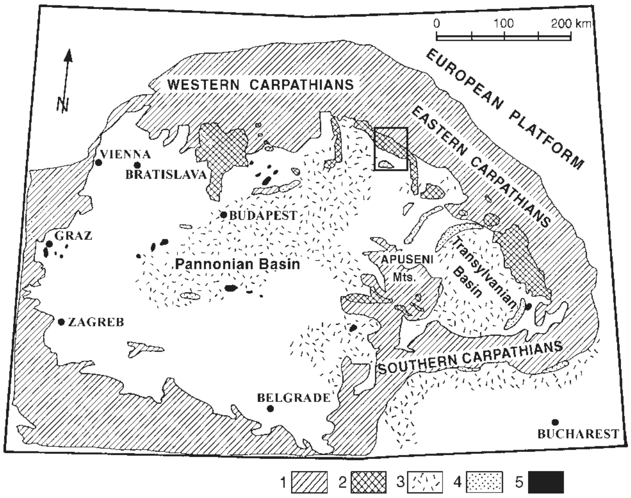

Fig. 1. General map of the Carpathian-Pannonian area showing the study area (quadrangle) in Transcarpathian Ukraine and NE Hungary. 1 — Carpathian Units; 2 — Outcropping intermediate calc-alkaline volcanic rocks; 3 — Buried acidic calc-alkaline volcanic rocks; 4 — Outcropping acidic calc-alkaline volcanic rocks; 5 — Alkali-basaltic volcanic rocks.

Volcanic geology

Geological setting

In the geological context, the Transcarpathian volcanic region is located approximately on the boundary between the Pieniny Klippen Belt and the Carpathian flysch belt in the north, and the Neogene East Slovak and Transcarpathian basin in the south (Fig. 1). The volcanism is in part related to the development of the Transcarpathian depression from Badenian until Pannonian times (Vass et al. 1988; Kaličiak & Pospíšil 1990). A NW–SE longitudinal fault system was significant in the evolution of the Transcarpathian depression, and the faults acted as pathways through which magmas reached the surface. During the Late Miocene to Pliocene, these fault systems were arranged in regional left lateral transtensional corridors, along which several pull-apart basins were formed (Csontos 1995). Conjugate NE-SW faults were active mainly during Sarmatian–Pannonian times, when important extension and sedimentation took place (Kaličiak & Pospíšil 1990).

From the geotectonic point of view, the Transcarpathian volcanics are situated on the northern margin of the Zemplín block, the north-easternmost part of the major ALCAPA* block in the Intracarpathian area, at its contact with the Eurasian plate (Csontos 1995; Haas et al. 1995). There is a significant difference in the crustal structure between the ALCAPA block (~20 km thickness) and the Eurasian plate (~40 km thickness), according to the seismic profile HSS-III, which suggests that the suture zone is situated just below the accretionary flysch belt in the Ukraine. Seismic and magnetotelluric data suggest an asthenospheric upwelling in the central part of Transcarpathian depression, where the asthenosphere-lithosphere boundary is considered to be situated at a depth of ~60 km (Babuska et al. 1986).

Volcanological overview

The volcanic activity in the SW Ukraine is very complex and strongly related to the development of sedimentary basins (mainly the Transcarpathian depression which forms a part of the much larger Pannonian Basin) since Badenian times. A huge volume of volcanic products (mainly volcaniclastics) is buried within the sedimentary pile. Their thickness varies between several tens of meters and several hundred meters. They are buried below the outcropping volcanic areas as a consequence of tectonic movements (Kaličiak & Pospíšil 1990).

From the distribution of the outcropping volcanic rocks in the SW Ukraine, three volcanic areas can be defined. These are oriented ~NW–SE (Fig. 2), strongly suggesting that, their orientation was controlled by major tectonic lines:

1. The Outer Arc volcanic area is composed of a row of eight adjacent and partially overlapping composite andesitic volcanoes (Popriečny, Antalovski, Hotar, Obavski-Kamen, Demianov, Martinski-Kamen & Tolstoi-Tupoi) (Fig. 2). The Tolstoi-Tupoi volcano forms a link towards the SE with the complex shield volcanoes and lava dome structures of the Oaş area (Romania). In the westernmost part Popriečny volcano forms a link with another row (NW–SE oriented) of adjacent overlapping volcanoes belonging to the Vihorlat Mts. All eight volcanoes are similar in size, and evenly spaced (~15 km apart). Much of the following volcanological inter-

*Alpine-Carpathian-Pannonian system

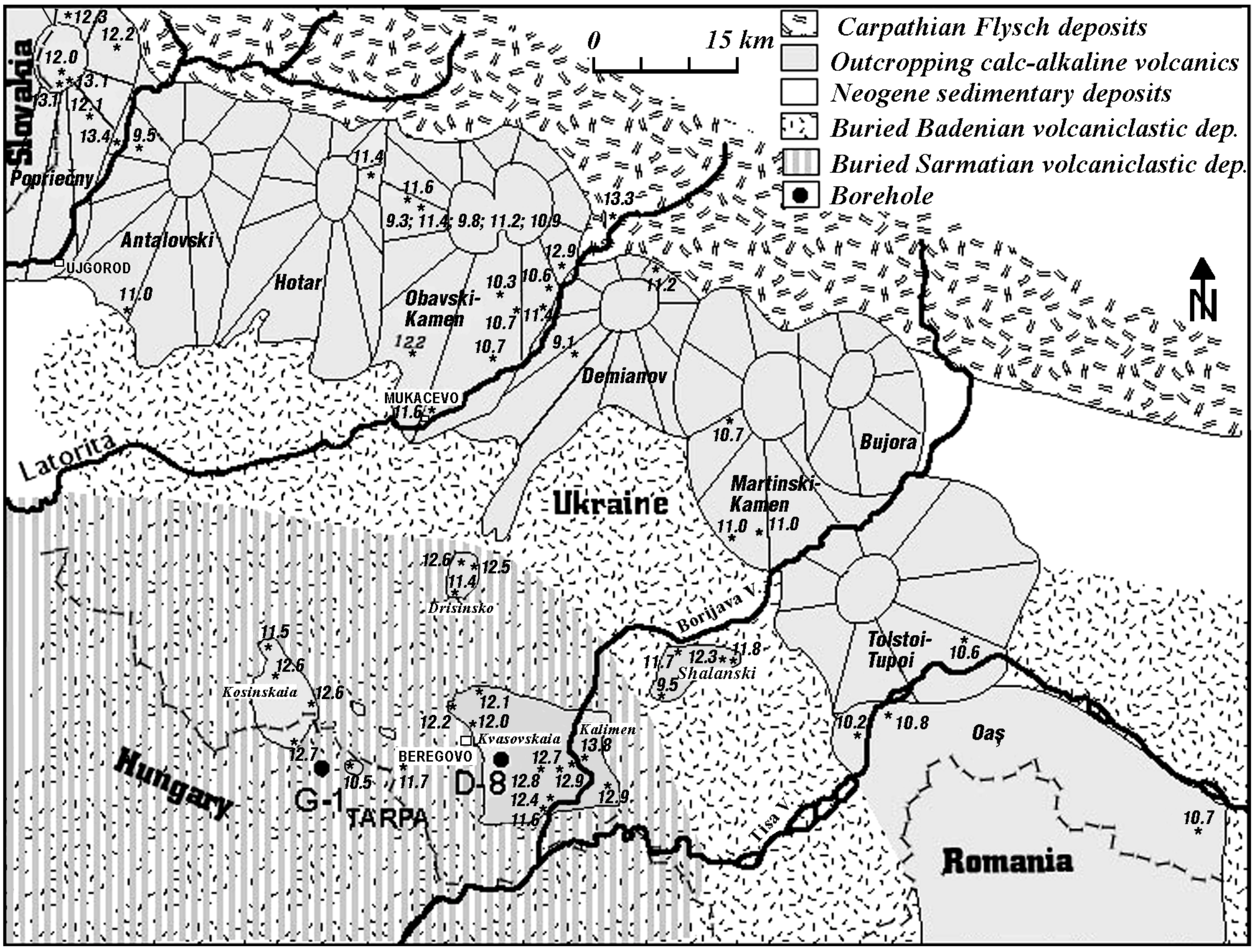

Fig. 2. Volcanological sketch map of the Transcarpathian Neogene volcanics.

pretation of the Outer Arc area is based on the unpublished data of Zobkov & Titov (1977). The volcanic activity was dominantly effusive. The central cone facies is strongly eroded and besides lava flows and lava domes, intrusive dykes or/and necks and different volcanic breccias can be found, sometimes affected by hydrothermal alteration. Numerous porphyritic and aphanitic lava flows were distributed around the source area of each volcano, with their eastern and western slopes buttressed against lavas of the neighbouring volcano. The longest lava flows (~15–20 km) are distributed towards the south, indicating a lower initial topography in this direction. Some lithic-rich debris flows can also be found in distal areas. In the sedimentary basement in the north-eastern part of Obavski-Kamen volcano several sills were also found.

Popriečny volcano seems to be the most complex in the chain, and can be characterized as a stratovolcano. Based on lithofacial observations made mainly in Slovakia, Kaličiak et al. (1995a) pointed out the existence of two proximal "structural levels": the lower one is characterized by the predominance of pyroclastic deposits whereas the upper one is dominated by lava flows. The distal volcanic area, fringing the volcano along its western edge, is characterized by fluvio-lacustrine deposits. The petrography is similar in both "levels", consisting of pyroxene-bearing andesites and/or basaltic andesites. The Popriečny stratovolcano has on its northern periphery a rhyolitic dome, which is not considered to belong to the edifice (Kaličiak et al. 1995b). A dacitic dyke was observed in the central part of the volcano, intruded into pyroxene-bearing andesites.

2. An Intermediate zone is represented by lava domes and small shield volcanoes (mostly andesitic) in two isolated areas (Drisinsko and Shalanski) (Fig. 2). The whole intermediate area also contains abundant buried acid volcaniclastic deposits of Badenian and Sarmatian age.

3. The Inner Arc, around Beregovo town, is a cluster of dacite and rhyolite domes. According to borehole data, the compositional spectrum of the rocks is wider, including basalts, basaltic andesites and andesites, along with the predominant dacites and rhyolites. Furthermore, boreholes drilled in Hungary, close to the Ukrainian border (e.g. Gelénes-1) and near Beregovo (Derekaszeg-8) (Fig. 3) revealed, in addition to older sedimentary and volcanic deposits (Lower to Upper Badenian), a thick buried pile (>600 m) of rhyodacitic volcaniclastic deposits (mainly ignimbrites), Sarmatian in age (Kulcsár 1968). The cluster of domes around Beregovo could be interpreted as a resurgent dome-complex related to caldera formation (Pantó 1966). The centre of the caldera was probably situated near the central part of the Transcarpathian depression.

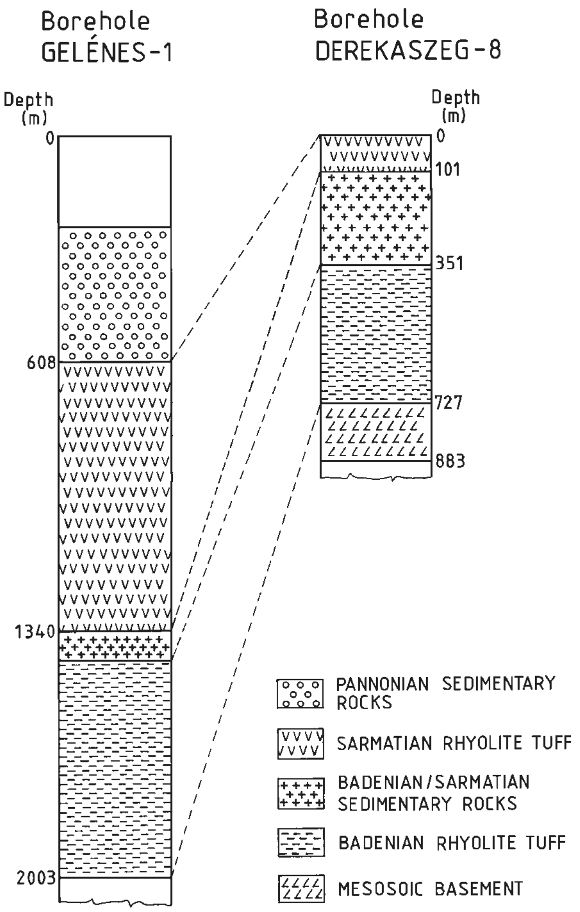

Fig. 3. Borehole stratigraphy in the Transcarpathian depression (location: Gelénes and Derekaszeg) showing the relationships between Badenian and Sarmatian tuff layers.

The analyzed Transcarpathian volcanic rocks consist of plagiophyric pyroxene basaltic andesites, andesites and dacites, and relatively plagioclase phenocryst-poor to aphanitic andesites, dacites and rhyolites. The volume of aphanitic rocks is larger in the eastern part of the Outer Arc (Tolstoi-Tupoi volcanic cone, Oaş) and also for the rhyolites from the Inner Arc. Andesites are the dominant volcanic products of the Outer Arc, but some rare dacites and rhyolites can be found. In contrast, in the Inner Arc, rhyolites and dacites are dominant, but basalts, basaltic andesites and andesites can also be found.

Eruptive history based on K/Ar data

Although numerous age determinations have been carried out in our study (Table 1), the data are insufficient to reconstruct the evolution of each individual volcanic edifice.

According to our data the oldest volcanic edifice is Popriečny (13.4 Ma), the western volcano in the Outer Arc. A long time interval (13.4–10.2 Ma) has been determined for the Popriečny volcano. Based on the borehole data (C11 reached the Mesozoic metamorphic basement at 590 m) and geophysical data, this volcano is tilted southward (Kaličiak et al. 1995b). Consequently the oldest volcanic rocks (Lower Sarmatian) are exposed only in the northern part of the volcanic edifice. Much younger volcanic rocks were taken from the southern slopes of the Popriečny (Lower Pannonian), (Kaličiak et al. 1995a). A similar age (13.3 Ma) was measured on a sill (UA-13) intruded into the flysch deposits north of the Obavski-Kamen volcano but the geological meaning of this radiometric age is questionable due to the large analytical error (>1 Ma).

In the Outer Arc the most detailed analytical work has been made in the Obavski-Kamen volcano (15 samples). The samples were collected not only from outcrops, but also from several massive rocks pierced by borehole C-30T, located on the western slope of the volcano, from borehole 260, on the southern slope and borehole 7T in the eastern part of the volcano (Table 1). After drilling more than 1100 m of volcanic deposits borehole C-30T reached the sedimentary basement at 1150 m. In a continuous drilling interval (553–1167 m) the volcanic structure was shown to be typical of a stratovolcano, with intervals of thick massive lava flows and thin intercalations of volcaniclastic deposits (mainly tuffs). However, some intrusions (dykes or sills) are also present. In the eastern and southern slopes of the volcano the boreholes (265, 7T) reached the oldest volcanic rocks (12.9–12.2 Ma). The ages obtained in the C-30T borehole in the depth interval 819–1148 m are slightly younger (11.6–11.3 Ma). The outcropping lava flows, close to the vent area, yield ages of 10.7–10.3 Ma. The youngest ages were determined on the core samples taken from C-30T borehole (9.8–9.3 Ma) from two intervals at different levels: 660 m and 910 m. These younger ages are probably related to an intrusive origin. This database makes it possible to consider the 3.6 million years interval of volcanic activity of the Obavski-Kamen volcano as being representative for the entire Outer Arc volcanic area.

The rest of the samples from the other volcanoes of the Outer Arc (Popriečny, Antalovski, Hotar, Demianov, Martinski-Kamen, Tolstoi-Tupoi, Oaş) were collected mostly from outcrops, or shallow drillholes. In Popriečny, where the whole succession was dated, the interval of volcanic activity is very similar to Obavski-Kamen (13.4–10.0 Ma) (Kaličiak et al. 1995a and this work). For the rest of the volcanic structures in the Outer Arc, where mostly the upper lava flows were sampled, the ages correspond to the younger activity of Obavski-Kamen (11.2–9.1 Ma). In this interval we have a higher volume of erupted products between 11.2 and 10.5 Ma (Fig. 4 and Fig. 5). We would expect a similar eruptive volume for each volcano during this interval of activity, as the volcanoes have almost identical dimensions and show obvious lateral symmetry (Fig. 2).

In the Intermediate volcanic area andesitic rocks are dominant on the surface. There are only a few outcrops in this area and, with one exception (UA-31), all the samples were taken from different boreholes. The age of the andesitic rocks ranges between 12.6 and 11.6 Ma, with one exception (UA-23, K/Ar age: 9.5 Ma). A pyroxene-bearing dacite from Drisinsko area has a similar petrography to the Tarpa dacite (T-96, K/Ar age:10.5 Ma) from the Inner Arc, but yielded a different age (UA-37, K/Ar age:11.4 Ma).

On the basis of borehole data (Fig. 3), it has been established that in the Inner Arc, significant acid volcanic activity took place during Badenian and Sarmatian times (Maleev

Table 1: Analytical data of the Neogene volcanic rock of Transcarpathian region, SW Ukraine and NE Hungary. Abbreviation: **Apx** (pyroxene andesite), **Bapx** (pyroxene basaltic andesite), **Dpx** (pyroxene dacite), **R** (rhyolite), **D** (dacite), **Dam,bi** (amphibole biotite dacite).

Sample	Locality	Volcanic structure	Rock type		K (%)	$^{40}Ar_{rad}$ (ccSTP/g)	$^{40}Ar_{rad}$ (%)	K-Ar age (Ma)
UA-1	Suroy V.	Popriečny	Apx	lava flow	1.37	$6.402.10^{-7}$	40.8	12.0±0.6
UA-2	Suroy V.	Popriečny	BApx	lava flow	1.29	$6.587.10^{-7}$	39.1	13.1± 0.6
UA-3	Suroy V.	Popriečny	Dam,bi	dyke	5.8	$2.962.10^{-6}$	51.2	13.1± 0.6
UA-4	Suroy V.	Popriečny	Apx	lava flow	1.55	$7.3337.10^{-7}$	51.5	12.1± 0.5
153	Novoselitsa	Popriečny	Apx	lava flow	1.19	$5.724.10^{-7}$	44.2	12.3± 0.5
341	NW Perecin	Popriečny	R	dome	2.59	$1.228.10^{-6}$	50.8	12.2± 0.5
546	Kamianitsa	Popriečny	Diorite	intrusion	1.14	$5.963.10^{-7}$	58.8	13.4± 0.6
361	Veliki Lazi	Antalovski	Apx	lava flow	1.22	$5.225.10^{-7}$	23.2	11.0±0.7
349	Nevitske	Antalovski	Apx	lava flow	1.22	$4.513.10^{-7}$	27.2	9.5±0.6
756	Visnica V.	Hotar	R	dome	4.31	$1.916.10^{-6}$	80.3	11.4±0.4
UA-16	Kolchino Quarry	Obavski Kamen	Apx	intrusion	2.91	$1.166.10^{-6}$	51.8	10.3±0.4
UA-17	Obava Quarry	Obavski Kamen	Apx	lava flow	1.82	$7.594.10^{-7}$	37.4	10.7±0.5
UA-14	Chinadieva	Obavski Kamen	BApx	lava flow	1.24	$5.142.10^{-7}$	41.9	10.6±0.5
UA-15	Chinadieva	Obavski Kamen	BApx	lava flow	1.26	$5.585.10^{-7}$	67.5	11.4±0.4
UA-21	Bh. 7T/396m	Obavski Kamen	Apx	intrusion	1.97	$9.881.10^{-7}$	16.1	12.9±1.1
UA-13	Golubina	Obavski Kamen	BApx	sill	1.24	$6.475.10^{-7}$	12.6	13.3±1.5
75	Zarnina	Obavski Kamen	D	lava flow	1.99	$9.013.10^{-7}$	70.5	11.6±0.5
976	Kolchino	Obavski Kamen	BApx	lava flow	1.32	$5.501.10^{-7}$	61.1	10.7±0.4
265	Lahova, Bh 265/330m	Obavski Kamen	Apx	lava flow	1.47	$5.977.10^{-7}$	34.3	12.2±0.6
30-1	Siniak,Bh C-30T/660m	Obavski Kamen	Apx	intrusion	1.83	$6.621.10^{-7}$	25.6	9.3±0.6
30-2	Siniak,Bh C-30T/819m	Obavski Kamen	BApx	lava flow	1.85	$8.096.10^{-7}$	19.9	11.5±0.8
30-3	Siniak,Bh C-30T/910m	Obavski Kamen	BApx	intrusion	1.49	$5.628.10^{-7}$	20.7	9.8±0.7
30-4	Siniak,Bh C-30T/976m	Obavski Kamen	Apx	lava flow	1.48	$6.482.10^{-7}$	36.9	11.2±0.5
30-5	Siniak,Bh C-30T/1145m	Obavski Kamen	Apx	lava flow	1.68	$7.080.10^{-7}$	41.4	10.8±0.5
UA-33	Siniak,Bh C-30T/1148m	Obavski Kamen	Apx	lava flow	1.76	$7.792.10^{-7}$	34.2	11.6±0.6
476	Olghavica	Demianov	Apx	lava flow	0.88	$3.115.10^{-7}$	10.2	9.1±1.3
886	Soyva	Demianov	Apx	intrusion	1.97	$8.607.10^{-7}$	19.6	11.2±0.8
UA-12	Pidhirne Quarry	Martinski Kamen	BApx	lava flow	1.33	$5.529.10^{-7}$	40.2	10.7±0.5
UA-11	Siltse Quarry	Martinski Kamen	BApx	neck	1.46	$6.285.10^{-7}$	27.4	11.0±0.6
997	Irshava,Bh. 997/51m	Martinski Kamen	BApx	lava flow	1.70	$7.301.10^{-7}$	22.7	11.0±0.7
UA-9	Rokosov Quarry	Tolstoi Tupoi	Dpx	lava flow	2.04	$8.442.10^{-7}$	42.4	10.6±0.5
UA-7	Wereyatsa Quarry	Oaş	Dpx	lava flow	2.49	$1.045.10^{-6}$	45.6	10.8±0.5
UA-8	Ciorni Hill	Oaş	Dpx	lava flow	2.60	$1.036.10^{-6}$	64.8	10.2±0.4
UA-10	Vischova Village	Oaş	Apx	sill	1.50	$6.253.10^{-7}$	26.9	10.7±0.6
UA-5	Koshini Quarry	Beregovo	R	lava flow	2.52	$1.239.10^{-6}$	61.8	12.6±0.5
UA-6	Began Quarry	Beregovo	R	lava flow	2.41	$1.185.10^{-6}$	34.8	12.6±0.6
UA-30	Ardov Quarry	Beregovo	R	lava flow	2.81	$1.341.10^{-6}$	28.3	12.2±0.7
304	Bh.304/243m	Beregovo	R	lava flow	2.75	$1.237.10^{-6}$	43.4	11.5±0.5
435	Bh.435/213m	Beregovo	D	lava flow	2.84	$9.308.10^{-7}$	43.7	11.7±0.5
B-96	Barabas	Beregovo	R	lava flow	2.46	$1.219.10^{-6}$	57.4	12.7±0.5
T-96	Tarpa	Beregovo	Dpx	dome	2.10	$8.690.10^{-7}$	60.0	10.5±0.5
UA-26	Haiesh Quarry	Kalimen	R	dome	2.71	$1.308.10^{-6}$	21.9	12.4±0.8
UA-31	Fogosh Quarry	Kalimen	R	lava flow	4.06	$1.900.10^{-6}$	23.1	12.0±0.8
UA-28	Pelikan Quarry	Kalimen	R-perlite	lava flow	3.08	$1.539.10^{-6}$	50.0	12.8±0.5
UA-22	Borijava Bh.4T/510m	Kalimen	Apx	lava flow	1.33	$6.001.10^{-7}$	9.5	11.6±1.7
UA-20	Chopivko Bh 423/391m	Kalimen	Apx	lava flow	1.77	$8.361.10^{-7}$	25.4	12.1±0.7
UA-41	Bh.320/306m	Kalimen	BApx	lava flow	0.99	$4.967.10^{-7}$	27.2	12.9±0.7
409	Bh.409/151m	Kalimen	BApx	lava flow	0.74	$3.712.10^{-7}$	35.1	12.9±0.6
408	Bh.408/283m	Kalimen	BApx	lava flow	1.05	$5.646.10^{-7}$	15.8	13.8±1.2
295	Bh. 295/154m	Kalimen	Apx	lava flow	1.01	$5.018.10^{-7}$	16.9	12.7±1.1
UA-37	Gat, Bh.407/195m	Drisinsko	Dpx	dome	2.06	$9.171.10^{-7}$	45.3	11.4±0.5
UA-18	Drisino, Bh. 327/587m	Drisinsko	Apx	sill	1.07	$5.218.10^{-7}$	22.6	12.5±0.8
327	Drisino, Bh. 327/588m	Drisinsko	Apx	sill	1.21	$5.929.10^{-7}$	34.2	12.6±0.6
UA-24	Shalanki	Shalanki	Apx	lava flow	1.48	$6.755.10^{-7}$	56.6	11.7±0.5
UA-39	Bh.316/125m	Shalanki	BApx	lava flow	1.28	$6.154.10^{-7}$	52.1	12.3±0.5
UA-40	Bh.316/286m	Shalanki	BApx	lava flow	1.28	$5.882.10^{-7}$	19.8	11.8±0.9
UA-23	Bh.438/228m	Shalanki	Apx	lava flow	1.68	$6.255.10^{-7}$	16.7	9.5±0.8

1964; Kulcsár 1968; Rakovits et al. 1981). The Gelénes borehole (NE Hungary) penetrated about 700 m of Badenian rhyolite ignimbrites (14.7 Ma) and another 700 m of Sarmatian rhyodacitic ignimbrites (13.0–11.0 Ma) (Széky-Fux et al. 1987). Close to Beregovo, the borehole Derekaszeg-8 shows 376 m of rhyolitic Badenian tuffs and 80 m of Sarmatian acid tuffs (Kulcsár 1968). The outcropping volcanic rocks are dominantly acidic in composition (rhyolites and dacites), and pierce the acid volcaniclastic rocks. In addition, basaltic andesites and andesites of 13.8–11.5 Ma were found in boreholes in the eastern part of the Inner Arc area.

On the basis of the radiometric dating the basaltic andesite (408, K/Ar age: 13.8 Ma) is the oldest volcanic product analysed in the Inner Arc, and agrees well with the age of the oldest volcanic product from the Outer Arc (13.4 Ma). However the great analytical error (1.2 Ma) suggests that this ba-

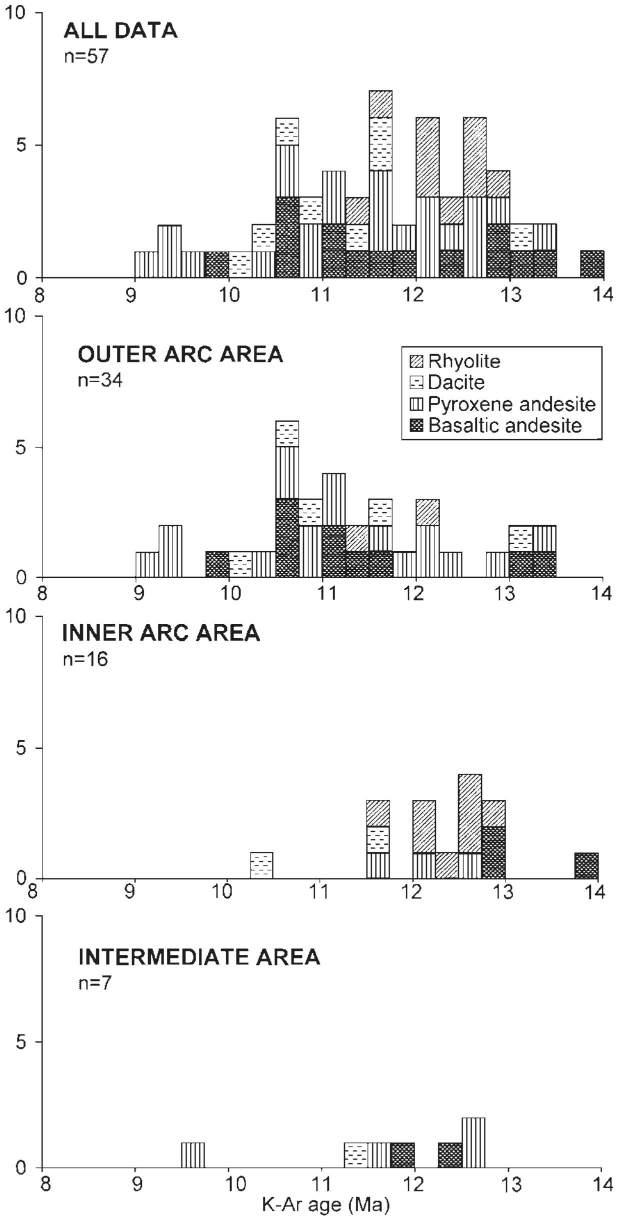

Fig. 4. Histogram of the new K/Ar age data in the Transcarpathian region.

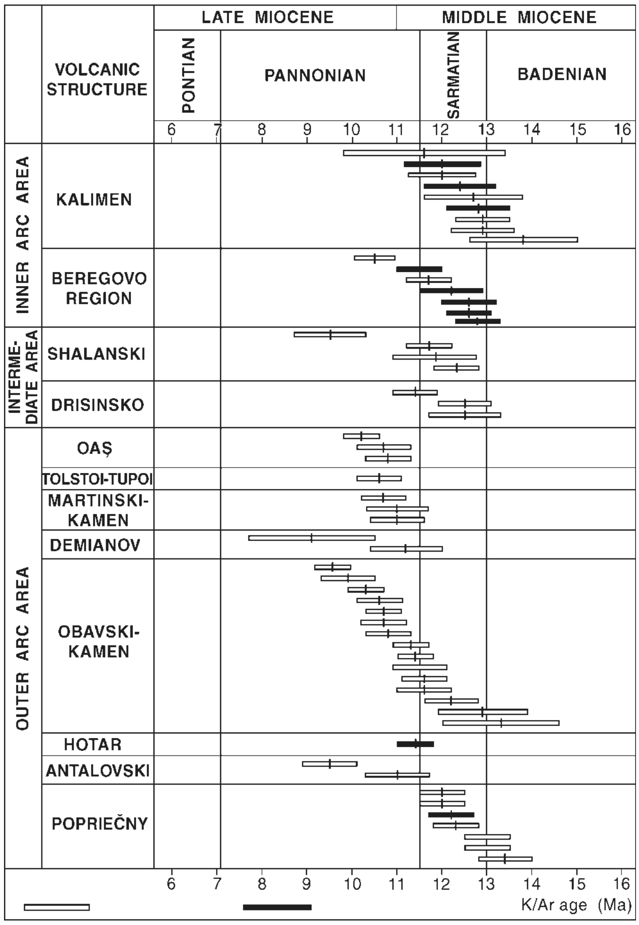

Fig. 5. Individual K/Ar measurements (showing the analytical error bars) for different volcanic structures. Acidic rocks in black, intermediate rocks in white.

saltic andesite was probably affected by secondary alteration. On the other hand, the presence of some excess argon cannot be excluded. Consequently, we may relate the open question of the geological age of the oldest intermediate volcanic rocks to the lack of suitable sample for radiometric dating in the Inner Arc. The acid rocks in the Inner Arc (mainly rhyolites) are slightly younger and show a longer interval of volcanic activity (12.8–11.5 Ma). This latter period corresponds to the climax of volcanic activity in the Inner Arc, and possibly suggests that the end of the volcanic activity was related to a large caldera situated further south. If we consider that the Inner Arc volcanic area was related to caldera formation documented as starting around 13 Ma ago, then the interval of volcanic activity during which the caldera, Outer Arc and Inner Arc were all active was between 13.4–11.5 Ma.

On the basis of radiometric data, the Neogene volcanic activity in E Slovakia, NE Hungary and NW Romania took place in the same time interval (approx. 15.5–9.0 Ma) (Pécskay et al. 1995; Széky-Fux et al. 1987). Volcanic activity constrained by biostratigraphy started with eruption of acidic tuffs in the Badenian. The location of the source of this volcanic activity is unknown. These tuffs contain andesitic lithic fragments which must represent an older phase of eruptive activity. In SE Slovakia, older rhyolite tuffs were also recognized (Eggenburgian) (Orlický et al. 1974). In the Tokaj-Slánske mountains, the peak of intermediate volcanism is slightly older (12.5 Ma) than in the Vihorlat–Gutinsky area (Vass et al. 1978; Kaličiak & Repčok 1987; Pécskay et al. 1986). It is significant that the stratovolcanoes and the extended andesitic lava flows of the Vihorlat–Popriečny–Gutinsky–Oaş–Gutîi range were all formed contemporaneously during Sarmatian and Early Pannonian times (13–9 Ma) (Duriča et al. 1978; Kaličiak et al. 1995a,b; Kovács et al. 1997; Pécskay et al. 1994).

Conclusions

Our present data set has extended our understanding of the evolution of the Neogene calc-alkaline volcanoes of Transcarpathia and adjacent areas. After eruption of the Badenian rhyolite tuffs, voluminous andesitic magmas were erupted mostly in the Outer Arc area. Andesitic volcanic activity started simultaneously in both the Outer Arc and Inner Arc areas in Transcarpathia (13.8 Ma and 13.4 Ma, respectively), but ceased around 11.5 Ma ago in the Inner Arc (except for the Tarpa dacite dome (10.5 Ma) formed within the assumed caldera) and around 9.0 Ma in the Outer Arc. In the Inner Arc, eruption of acidic and intermediate volcanics alternated during the Sarmatian. The most vigorous interval of volcanic activity was 11.2–10.5 Ma in the Outer Arc and 13.0–11.5 Ma in the Inner Arc.

The lifetime of the volcanic activity was between 13.8 and 9.1 Ma, similar in all the range from the Vihorlat (Slovakia) to Călimani (Romania), as pointed out by Pécskay et al. (1995). Taking into account the K/Ar data obtained in the Vihorlat and Oaş-Gutîi volcanic regions, a significant peak can be observed in the histogram which reflects the contemporaneity of the volcanism along the arc from the Vihorlat to the Gutîi.

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