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EVOLUTION OF THE NEOGENE GURGHIU MOUNTAINS VOLCANIC RANGE (EASTERN CARPATHIANS, ROMANIA), BASED ON K-Ar GEOCHRONOLOGY

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Abstract: K-Ar ages of rocks from the Gurghiu Mountains, the middle part of the longest volcanic chain in the Eastern Carpathians (Călimani–Gurghiu–Harghita), indicate an interval of volcanic activity between 9.4–5.4 Ma. Magmatic activity migrated from North to South and built the following volcanic centres: Jirca (J), Fâncel-Lăpuşna (FL), Bacta (B), Seaca-Tătarca (ST), Borzont (BZ), Şumuleu (S) and Ciumani-Fierăstraie (CF). The timing of volcanic activity in each volcanic centre reflects the previously recognized overlapping age progression from North to South along the arc: J = 9.2–7.0 Ma; FL = 9.4–6.0 Ma; B = 7.5–7.0 Ma; ST = 7.3–5.4 Ma; BZ = 6.8 Ma; S = 6.8–6.2 Ma; CF = 7.1–6.3 Ma. Two peripheral small intrusive bodies have also been dated (Ditrău — 7.9 Ma and Corund — 7.4 Ma). The duration of volcanic activity of each centre is ca. 1 Ma, with a larger interval of 2.5 Ma for the Fâncel-Lăpuşna volcano. Volcanic activity in the southernmost volcanic centres (ST; BZ; S; CF) between 7–6 Ma was contemporaneous. Certain volcanological problems are pointed out: (i) the voluminous debris-avalanche deposit assumed to belong to the Călimani Mountains includes blocks of ca. 8 Ma up to the Gurghiu Valley and between 7.5–7.8 Ma south of the Gurghiu Valley (ii) the Fâncel-Lăpuşna caldera was generated around 6.9 Ma and involved a post-caldera uplift and/or erosion of the caldera floor and younger domes; and (iii) the model based on volcanic facies distribution is consistent with the new age-data.

Key words: Eastern Carpathians, Gurghiu Mountains, K-Ar data, volcanology, debris-avalanche.

Introduction

The Călimani–Gurghiu–Harghita (CGH) chain is the southeastern segment of the Neogene/Quaternary magmatic arc adjoining the Carpathians from Slovakia, through Hungary and Ukraine, to Romania. Gurghiu Mountains represent the middle segment of the ~160 km-long CGH volcanic chain located along the inner (western) side of the East Carpathian orogenic zone (Fig. 1). Its geographical boundaries are the Mureş Valley in the north, and the upper reaches of the Târnava Mare Valley in the south, embracing a ~ 60 km-long, 40 km-wide mountain range with its highest elevation at Seaca Peak (1776 m). The Gurghiu Mountains volcanic area is located along the structural boundary between the Inner Eastern Carpathians including the so-called “Crystalline-Mesozoic zone” (Dacides Unit, Săndulescu 1984) of the Eastern Carpathians in the east, and the Neogene sediment-filled Transylvanian Basin in the west. The Quaternary Gheorgheni intra-mountain depression is situated between the volcanic area and the “Crystalline-Mesozoic zone” at the eastern margin of the Gurghiu Mountains.

The CGH volcanic chain, including the Gurghiu Mountains is a typical andesite-dominated calc-alkaline volcanic range, displaying a subduction-type geochemical signature (Rădulescu & Săndulescu 1973; Seghedi et al. 1995; Mason et al. 1996). Compared with other segments of the chain, the volcanic rocks of the Gurghiu Mountains are both petrographically and chemically monotonous. With minor exceptions (basaltic andesites and dacites), andesites are dominant and pyroxene andesite is the most common rock type. Magmas were fractionated with typical mineral assemblages found in calc-alkaline suites and also experienced limited crustal assimilation and mixing processes (Seghedi et al. 1995; Mason et al. 1996).

The volcanism in the Gurghiu Mountains was first dated by Rădulescu et al. (1972) and later by Michailova et al. (1983) and Pécskay et al. (1995). The present geochronological study draws upon these data (36 measurements), as well as on a number of additional K-Ar age determinations (30) performed at the Complutense University of Madrid (Spain) (13) and ATOMKI, Debrecen (Hungary) (14) (Table 1). Collectively, these K-Ar ages allow a more detailed understanding of the evolution of volcanism in the Gurghiu Mountains. The dated samples represent all the volcanic edifices, as well as their peripheral volcaniclastic aprons (Fig. 1). Lava flows, andesite lithic blocks in volcaniclastic rocks, as well as intrusive rocks have been sampled to better constrain the age of different volcanoes and of the principal volcanic events.

Six samples in this study were analysed both in Madrid and Debrecen, enabling us to assess the possible analytical problems that might bear on the reliability and reproducibility of K-Ar dating of Neogene calc-alkaline volcanics.

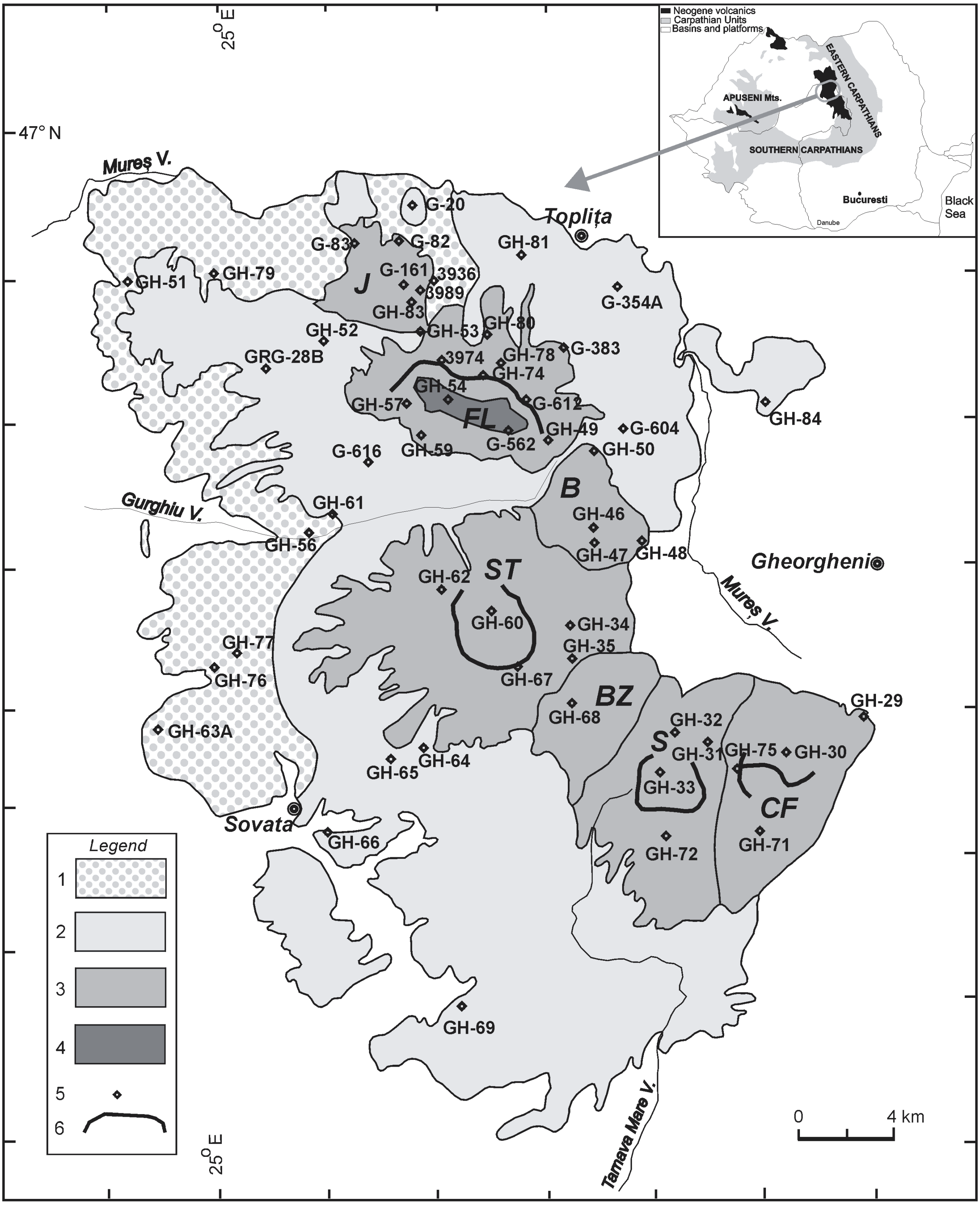

Fig. 1. Geological sketch of the Gurghiu Mountains with K-Ar sample locations: **1** — Volcaniclastic rocks originating from the main source area in the Călimani Mountains — "Rusca-Tihu Debris Avalanche Deposits" and some of "Rusca-Tihu Volcaniclastic Formation"; **2** — Volcaniclastic rocks originating mainly from Fâncel-Lăpuşna, Seaca-Tătarca, Şumuleu and Ciumani-Fierăstraie volcanoes; **3** — Lava and associated cone facies of central-type volcanoes (abbreviations: **J** = Jirca; **FL** = Fâncel-Lăpuşna; **B** = Bacta; **ST** = Seaca-Tătarca; **BZ** = Borzont; **S** = Şumuleu; **CF** = Ciumani-Fierăstraie); **4** — Intrusive complex inside Fâncel-Lăpuşna caldera; **5** — Sample location; **6** — Craters and calderas. Inserted map give detail on the position of the Gurghiu Mountains in the framework of Neogene volcanism in Romania.

Experimental methods, precision and errors

All the potassium determinations reported herein were made in the Debrecen laboratories. Approximately 0.1 g of finely powdered sample was dissolved in acids and the residue was taken into solution; potassium concentration was determined by flame photometry with a Na buffer and a Li internal standard.

Conventional experimental methods were used in the determination of argon. In both laboratories, argon was extracted from 0.2–0.3 mm fraction of whole-rock samples (initial sample weight = 3–5 kg) by induction heating in Mo crucibles and purified in a previously baked glass and stainless steel vacuum system. Argon 38-spike was added from conventional pipette systems (calibrated against international reference samples Asia 1/65, LP-6, HD-B1, GL-0), and the evolved gases were purified using Ti getters, molecular sieves, hot CuO and liquid nitrogen traps. The purified argon was measured in the static mode using a Micromass 6 mass spectrometer in Madrid and a 15 cm-radius sector instrument built in the Institute of Nuclear Research (Hungarian Academy of Sciences) in Debrecen (Balogh 1985). Both instruments were checked regularly by inter-laboratory reference samples: HDB1, LP-6, G1-O, Asia 1/65, and Bern 4M and 4B. When checking against any particular reference sample, the “influence” of that sample was deleted from the calculation of the spike calibration constants.

Since the radiogenic argon content of these reference samples is about 10 times greater than that of the rock being analysed, systematic errors may be difficult to detect. However, during the course of this investigation, 10 samples were analysed in both laboratories for inter-laboratory comparison. The results, when plotting against each other, generally fall on or close to the line of no significant difference. Some anomalous data are apparent, but we are confident that they result from failure to completely outgas the fused rock samples, rather than systematic instrumental bias.

Replicate analyses made in Madrid on young volcanic samples from the Canary Islands, with an average radiogenic ^{40}Ar content of about 0.12 nl/gm (17 replicates on 7 samples), yielded a pooled standard deviation of ±0.0123 nl (one sigma). The average radiogenic ^{40}Ar content of the samples studied in this investigation is about 0.35 nl/gm, and the aforementioned replicate data would suggest that the precision on the analytical data reported here is likely to be between 5 % and 10 %. Such an estimate agrees well with the errors in the age calculated for each individual analysis by the classical method of partial differentiation of the analytical errors attached to the variables (see for example Baker et al. 1967; Mahood & Drake 1982 and references therein). In calculating the individual age errors, we have assumed errors (one sigma standard deviation) of ±1 % on the measured isotope ratios (^{40}Ar/^{38}Ar and ^{36}Ar/^{38}Ar), ±2 % on the spike calibration and ±3 % on the K determinations. Although we consider that these error estimates are overestimates (probably by a factor of 2), we believe that such conservative assumptions will avoid misleading chronological conclusions that may arise from underestimated errors.

The new data are given in the Table 1. For six samples, argon determinations have been made independently in both Debrecen and Madrid. These samples yield radiogenic argon values that do not differ significantly using the criterion developed by McIntyre (1963). The critical value for the difference between analyses in Debrecen and Madrid should not exceed 2.772 × sigma (0.034 nl), where sigma is taken to be the pooled standard deviation on replicates of ±0.0123 nl, as discussed above. This criterion is developed from the conventional “t-test” and assumes a normal distribution of experimental errors. For these samples, the adopted age is the weighted mean (and weighted standard deviation) of the two determinations.

Volcanic edifices

Although the morphological boundaries are obvious, the Gurghiu Mountains, as a geological entity is more difficult to define, because volcanic rocks (especially volcaniclastic rocks) originating from volcanic edifices located in both the geographically defined Călimani and Gurghiu Mountains, interfinger with each other along the Mureş Valley and its tributaries (Szakács & Seghedi 1996). The “Rusca-Tihu Debris Avalanche Deposit” (a volcanic debris-avalanche deposit) and the “Rusca-Tihu Volcaniclastic Formation”, originating from the Călimani Mountains crop out south of the Mureş Valley, while the “Fâncel-Lăpuşna Volcaniclastic Formation”, derived from the northern Gurghiu (Fâncel-Lăpuşna volcano) occurs north of the Mureş Valley. These formations have been defined by Szakács & Seghedi (1996, 2000) (Fig. 2).

As in the other parts of CGH volcanic chain, the volcanic structure of the Gurghiu Mountains consists of an axial, roughly NW–SE row of adjoining composite volcanic edifices (e.g. Davidson & De Silva 2000) surrounded by extensive merged volcaniclastic aprons (Figs. 1, 2). The peripheral volcaniclastic pile, which was formerly described in terms of a “volcano-sedimentary formation” (Rădulescu et al. 1964a, 1973) consist of a ring-plane-type volcaniclastic association including volcanic debris flow deposits, volcanic debris-avalanche deposits and rarely pyroclastic fall and pyroclastic flow deposits. It represents the medial to distal facies related to the volcanic edifices in the Gurghiu Mts (Szakács & Seghedi 1995).

The types of volcanic edifices in the Gurghiu Mountains include composite volcanoes with or without a caldera, shield volcanoes, and lava dome complexes. Individual or complex intrusive bodies are also present in the centre or at the periphery of the edifices. Adjoining and partially overlapping composite cones are located in the axis of the Gurghiu Mountains. From north to south, there are five larger edifices of this kind, namely: Jirca, Fâncel-Lăpuşna, Seaca-Tătarca, Şumuleu and Ciumani-Fierăstraie (Fig. 1). In addition, there are two lava dome complexes (Borzont and Bacta). Except for the late stage of Fâncel-Lăpuşna, all are essentially lava-dominated volcanoes. The brief characterization of each of these volcanic edifices is summarized from Szakács & Seghedi (1995, 1996).

Jirca is the northernmost edifice, whose erosional remnants, displaying steep-sided topography, are covered by younger products of the neighboring Fâncel-Lăpuşna volcano and the Călimani Mountains volcanic area. A deeply eroded

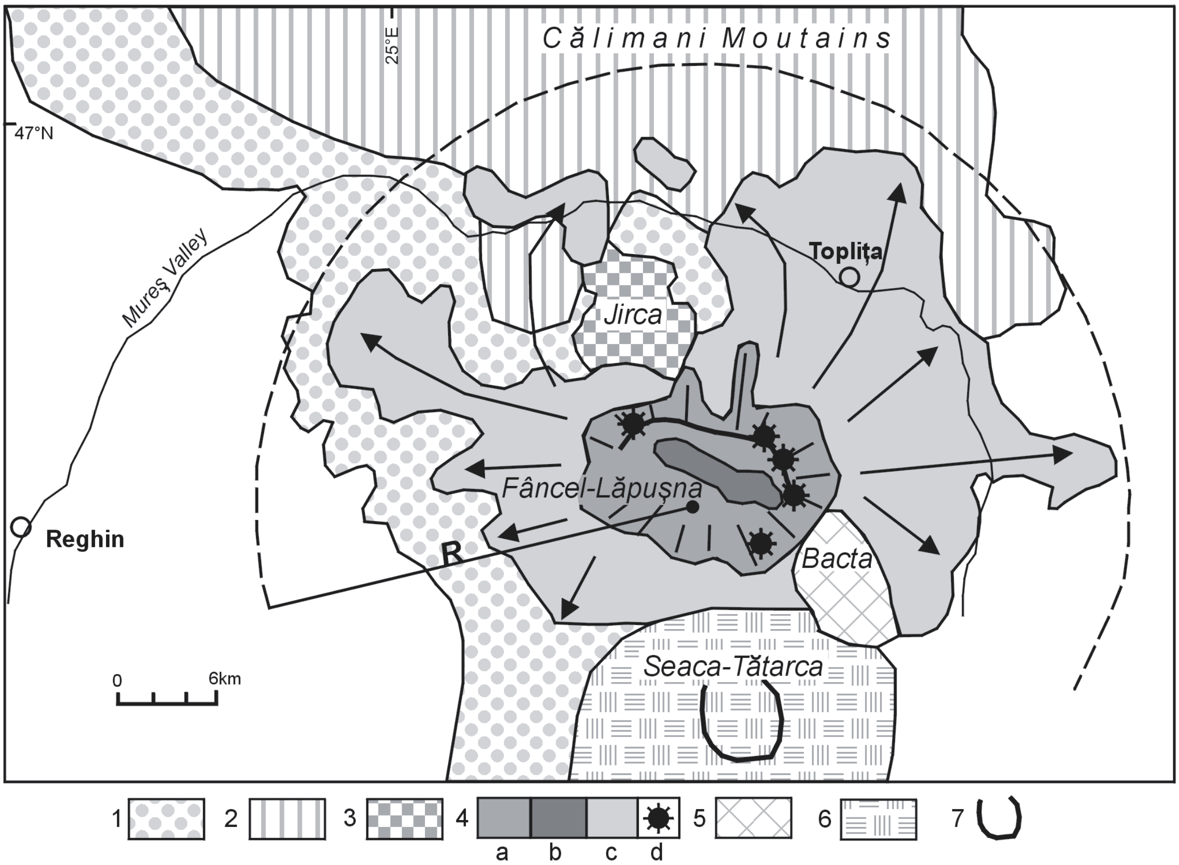

Fig. 2. Sketch map of volcanic events belonging to the Călimani and Gurghiu volcanic areas along the Mureş Valley, emphasizing Fâncel-Lăpuşna caldera generation (modified after Szakács & Seghedi 1996): **1** — Rusca-Tihu Debris Avalanche Deposit; **2** — Rusca-Tihu Volcaniclastic Formation; **3** — Jirca volcanic edifice; **4** — Fâncel-Lăpuşna volcano: **a.** Volcanic edifice, **b.** Central intrusive complex, **c.** Fâncel-Lăpuşna Volcaniclastic Formation (R: 25 km radius), **d.** Late-stage domes; **5** — Bacta dome-cluster; **6** — Seaca-Tătarca volcanic edifice; **7** — Topographic rim of volcanic edifices.

central intrusive complex at Jirca, largely affected by pervasive hydrothermal alteration, is surrounded by lava flows. The remnants of a Strombolian scoria cone (Zespezele) are also recognized. Peripheral volcaniclastic rocks represented by basaltic andesite and andesite debris flow deposits are present, but are covered by younger volcanic rocks belonging to the adjacent larger volcanic structures, Fâncel-Lăpuşna and Călimani.

The southward-open amphitheatre-shaped **Fâncel-Lăpuşna** caldera, ~10 km across (Rădulescu et al. 1964b), dominates the northern half of the Gurghiu Mountains. Unroofed large complex intrusions (andesites and microdiorites) are found inside the caldera. Along and near the topographically-defined caldera-rim, older lava flows and younger lava domes, ranging from basaltic andesites to amphibole andesites, are clustered. The caldera was identified mostly on morphological grounds by Rădulescu et al. (1964b), who suggested the caldera origin of the huge topographic depression 10 km across, but no large-volume eruptive products to account for the missing volume of the presumed pre-caldera volcanic edifice have been recognized by previous researchers. The recent identification of the voluminous pumice-rich Fâncel-Lăpuşna Volcaniclastic Formation (FLVF, Szakács & Seghedi 1996) as the possible candidate for the products of a caldera-forming eruption (e.g. Walker 1984; Lipman 2000) lent more support to this hypothesis. Pumice-rich pyroclastic flow and less frequent pumice fall deposits of amphibole or amphibole-pyroxene andesites composition, have been found on the northern and eastern slopes of the volcanic edifice, including its uppermost parts surrounding the topographic rim of the presumed caldera. Their reworked counterparts (mostly pumice-rich volcanic debris flow deposits) crop out at many locations along the northern and eastern lower slopes of the volcano. FLVF is spread to the north and east of the caldera within a radius of ~25 km; a part of the formation occurs as far as the southern Călimani Mountains (Fig. 2). Its present areal coverage is ~490 km^2, with 10 m-average thickness and an estimated volume of ~4.9 km^3 (Szakács & Seghedi 1996), may at least partially account for the caldera depression. Intrusions consisting of basaltic andesites, andesites and microdiorites have been mapped in the centre of the edifice (Figs. 1, 2). Small amphibole-pyroxene andesite to dacite lava domes (up to 1.5 km in diameter) are located at the margins or in the interior of the caldera edifice. A similar amphibole-pyroxene andesite lava dome cluster, **Bacta** adjoins the caldera at its south-eastern side (Fig. 1).

Seaca-Tătarca is the next volcanic edifice to the south. This large, lava-dominated volcano, with a basal diameter of ~16 km, displays a shield-like topography with gentle outer slopes and a surprisingly regular, almost circular, central topographic depression (5 km in diameter), whose rim shows a relatively uniform elevation, breached to the north. Its structure seems simple, consisting of a pile of lava flows, mostly pyroxene andesite. Karátson (1999) and Karátson et al. (1999) describes this depression as an erosion caldera on purely morphological grounds, however, later, Karátson & Thouret (2001) accept that a "true" caldera and an erosion caldera can coexist, as refers to a primary volcanic depression transformed later by erosion.

Since no obvious large-volume pyroclastic deposits are associated with this edifice, nor voluminous effusive products to be allocated to one particular eruptive event, Seaca-Tătarca central depression is rather a remnant of an eroded crater, then a caldera (e.g. Szakács & Ort 2001). The southernmost part of the Gurghiu Mountains consists of a closely-spaced cluster of smaller edifices which, together with the northernmost North Harghita volcanoes, are controlled by WNW–ESE-striking tectonic alignments (Fig. 1). **Borzont** is a small amphibole andesite volcano with a central intrusive core unroofed partially by erosion.

Şumuleu is a composite volcanic edifice, with a basal diameter of ~ 12 km and ~ 4 km in diameter central depression with a well-developed shallow intrusive core-complex. Both the intrusions domes (amphibole and pyroxene andesites and microdiorites) and host lava flows are highly altered. Lava flows (pyroxene andesites), extending beyond the crater show gentle-dipping slopes and are topped by crater-rim lava domes (amphibole and pyroxene andesites). A prominent flank vent that erupted pyroxene andesite lava is present on the lower southern side of the volcano.

Ciumani-Fierăstraie is a double-crater composite edifice with pyroxene andesite lavas dominating its lower slopes that are buttressed westwards against lavas of the neighbouring Şumuleu volcano (Fig. 1). The Ciumani crater is breached to the south and Fierăstraie crater to the north. Lava domes occupy the topographic crest between the two craters on the western part of the summit area. Both craters have been erosion-modified (enlarged) and host intrusive core complexes with related hydrothermal alteration zones.

Volcaniclastic deposits, mostly consisting of volcanic debris flow deposits, cover a widespread area to west and southwest of the Seaca-Tătarca, Şumuleu and Ciumani-Fierăstraie volcanoes. It consists of merged volcaniclastic aprons of the individual volcanoes, which cannot be mapped individually because of the similar composition of their respective source volcanoes (Szakács & Seghedi 1995).

Discussion of K-Ar ages and eruptive history

The location of the thirty new K-Ar whole-rock determinations (Table 1) together with 36 previously published K-Ar determinations (Pécskay et al. 1995), are shown in Fig. 1. The timing of volcanic structures is summarized in Fig. 3.

Recent observations (Szakács & Seghedi 1996) led to a reevaluation of 6 age determinations (Pécskay et al. 1995) on samples of block-sized lithic clasts collected from the western periphery of the Gurghiu Mountains from volcaniclastic deposits. These deposits have been mapped as a volcanic debris-avalanche deposit having their origin in the Călimani Mountains (Figs. 1, 2). These deposits although extremely chaotic and heterogeneous contain mainly basaltic andesites, with large clinopyroxene phenocrysts as a distinctive feature. These rocks show an age interval between 8.0–8.1 Ma north of the Gurghiu Valley (GH-51, GH-56, GH-59). Three samples collected from similar deposits and of similar petrography south of the Gurghiu Valley show slightly younger ages (7.5–7.8 Ma), but with partially overlapping error-bars (Fig. 3). The ages measured on volcanic lithic clasts in the volcanic debris-avalanche deposit indicate ca. 7.5–8.1 Ma as the period of pre-avalanche volcanic activity at the source volcano (Figs. 1, 2), which is consistent with the K-Ar ages of lithologically similar rocks in the Călimani volcanic area (7.4–8.7 Ma) (Seghedi et al. in print). However, the origin of some debris-avalanche clasts (in outcrops located at the south of the Gurghiu Valley) from the early Fâncel-Lapuşna volcano, cannot be ruled out. In the Călimani area, as constrained by K-Ar determinations, 8.0 ± 0.5 Ma is the assumed age for the edifice failure and related debris-avalanche event (Rusca-Tihu Debris Avalanche Deposit) (Szakács & Seghedi 1996; Seghedi et al. in print).

The oldest and northernmost volcanic structure belonging to the Gurghiu Mountains is **Jirca** (9.2–8.4 Ma). An isolated intrusion, situated close to Jirca volcano toward north, which consist of pyroxene-bearing aphyric andesite (G-20), was dated at 7.0 Ma, however it is not clear if this event can be attributed to the Jirca volcano. At its periphery, the Jirca volcano is partially covered by younger volcaniclastic products belonging to both the North Călimani and the Fâncel-Lăpuşna volcanoes.

The **Fâncel-Lăpuşna** volcano has been the major focus of K-Ar studies, since it is the largest volcanic structure of the Gurghiu Mountains. The oldest volcanic activity is mostly effusive and represented mainly by basaltic andesites and pyroxene and amphibole andesites, which corresponds to the 8.7–7.5 Ma interval (GH-53, GH-80, GH-79, GH-78, 3974). Fragments of the same petrography belonging to the volcaniclastic apron around the volcano show an age interval between 7.7–7.5 Ma suggesting their generation contemporaneous with the effusive edifice (GH-49, GH-81, GH-61). This interval can be considered as the pre-caldera stage. Amphibole, pyroxene-bearing andesites and dacites, found as volcaniclastic deposits attributed to FLVF show 7.1–6.91 Ma and have been generated during the caldera stage (Fig. 3). Younger ages have been obtained for the amphibole (pyroxene) andesite domes at the border of the caldera (5.99–6.23 Ma), which belong to the post-caldera stage according to morphological observations. Three different bodies, belonging to an intrusive complex in the caldera interior, showing various petrography (microdiorite with pyroxene, andesites with pyroxene and amphibole, basaltic andesites) have been dated. Results (9.44 Ma, 8.5 Ma and 8.13 Ma) show a wide range. The small-sized **Bacta** structure, located southeast of the Fâncel-Lăpuşna volcano, homogeneous from petrographic point of view (amphibole, pyroxene-bearing andesites), evolved between 6.97–7.52 Ma. It is indicating a relatively short time interval of extrusion. Similar rock types belonging

Table 1: K-Ar ages for rocks from Gurghiu Mountains volcanic area. The samples follow the order of volcanoes from north to south as they are shown in Fig. 1. Abbreviation: for volcanoes as in Fig. 1, additional: **PI** — peripheric intrusions, **DA** — clasts in debris-avalanche. For rock types: **AB** — basaltic andesite, **A** — andesite, **D** — dacite, **Md** — microdiorite, **px** — pyroxene, **am** — amphibole. Laboratory: **M** — Madrid, **D** — Debrecen.

Nr. crt	Sample	Locality	Volcano	Rock type	K%	vol.rg 40 Ar nl/gm	% atm.	Age (Ma)	Adopted age	Lab.	References
1	GH-84	Ditrau V.	PI	Apxam	1.88	0.6490	57.63	7.86 ± 0.37		D	
2	GH-76	Nirajul Mare	DA	Apx	0.64	0.3300	19.29	7.74 ± 0.40		D	
3	GH-77	Nirajul Mare	DA	Apx	0.92	0.4560	29.23	7.50 ± 0.33		D	
4	GH-83	Magura de sus V.	J	Aam	0.90	0.3280	31.24	8.90 ± 0.46		D	
5	GH-83	Magura de sus V.	J	Aam	0.81	0.2523	77.90	9.12 ± 0.52		M	
6	GH-82	Gudea V.	J	Apx	1.07	0.3497	53.21	8.38 ± 0.31		M	
7	GH-49	Eszenyo V.	FL	Aam	1.85	0.5538	59.70	5.99 ± 0.31		D	
8	G-612	Cilnic Ridge	FL	Aam	1.48	0.1830	35.88	6.23 ± 0.50		D	
9	G-616	Fancel Ridge	FL	Aampx	1.62	0.3300	43.59	6.91 ± 0.34		D	
10	GRG-28B	Coasta Mare Ridge	FL	Dam	1.57	0.4292	42.10	7.01± 0.32		D	
11	G-354A	Galautas V.	FL	Aam	1.39	0.4088	31.50	7.54 ± 0.30		D	
12	G-383	Musca Brook	FL	Apx	1.46	0.4300	31.70	7.59 ± 0.30		D	
13	GH-78	Batrana Ridge	FL	Apxam	1.85	0.5468	37.20	7.59 ± 0.30		M	
14	GH-81	Mariselu V.	FL	Aam	1.83	0.7440	54.85	7.69 ± 0.29		D	
15	GH-79	Viclean Ridge	FL	Apx	0.81	0.2752	79.45	7.74 ± 0.56		M	
16	GH-54	Zambroi Summit	FL	AB	0.82	0.3070	25.83	8.13 ± 0.43		D	
17	GH-80	Piatra Ridge	FL	Apxam	1.62	0.5474	41.50	8.68 ± 0.35		M	
18	G-562	Fancel V.	FL	Mdpx	1.54	0.1760	56.65	9.44 ± 0.77		D	
19	G-604	Fagul Ascutit	B	Aampx	1.29	0.3210	33.08	6.58 ± 0.34		D	
20	GH-50	Sineu Quarry	B	Aam	1.46	0.4141	50.10	7.29 ± 0.31	6.97 ± 0.25*	M	
20	"	"	"			0.3938	66.10	6.60 ± 0.33		D	Pécskay et al. 1995
21	GH-46	Bacta V.	B	Aampx	1.42	0.4027	15.50	7.29 ± 0.28		M	
22	GH-47	Bacta V.	B	Aampx	1.32	0.3903	54.20	7.53 ± 0.33	7.46 ± 0.31*	M	
22	"	"	"			0.3608	89.00	7.00 ± 0.88		D	Pécskay et al. 1995
23	GH-48	Bacta V.	B	Aam	1.33	0.3909	44.10	7.55 ± 0.31	7.52 ± 0.21*	M	
23	"	"	"			0.3895	29.50	7.50 ± 0.29		D	Pécskay et al. 1995
24	GH-34	Tarvez Summit	ST	Apx	0.97	0.2414	45.10	6.39 ± 0.27	6.39 ± 0.21*	M	
24	"	"	"			0.2429	67.40	6.40 ± 0.33		D	Pécskay et al. 1995
25	GH-35	Bucin Pass	ST	Apx	1.11	0.3124	34.70	7.29 ± 0.29	7.25 ± 0.21*	M	
25	"	"	"			0.3095	42.00	7.20 ± 0.30		D	Pécskay et al. 1995
26	GH-33	Sumuleul Mare V.	S	ABpxam	0.99	0.2407	58.30	6.20 ± 0.28		D	Pécskay et al. 1995
27	GH-31	Sumuleul Mic V	S	Apx	1.11	0.2928	51.20	6.70 ± 0.29		D	Pécskay et al. 1995
28	GH-32	Sumuleu Mare V.	S	Apxam	1.11	0.3023	43.10	7.00 ± 0.29	6.80 ± 0.21*	M	
28	"	"	"			0.2852	54.30	6.60 ± 0.29		D	Pécskay et al. 1995
29	GH-29	Chilieni Quarry	CF	Apx	0.98	0.2669	34.80	7.00 ± 0.28		M	
30	GH-30	Drumul lui Gavrila V.	CF	Aam	1.18	0.3243	37.10	7.10 ± 0.28		D	Pécskay et al. 1995

*Calcuted mean age

to the Fâncel-Lăpuşna volcano are almost coeval (7.5–6.0 Ma). An isolated small dome on the eastern periphery of Bacta shows 6.6 Ma.

The bulk of the **Seaca-Tătarca** volcano evolved between 7.2–6.3 Ma. A younger age was detected for a lava flow inside the edifice (5.4 Ma) suggesting a last eruption (Pécskay et al. 1995). There is an excellent agreement between the duplicate measurements performed on pyroxene andesite samples (GH-34, GH-35) from this volcano. Moreover, the sample collected by Michailova et al. (1983), from the same outcrop (GH-35), gave the same K-Ar age within error (7.4 Ma) as the new age (7.25 ± 0.21 Ma).

The only sample dated from the **Borzont** lava volcano (6.8 Ma) (Pécskay et al. 1995), brings an age in the same range as that of the neighbouring volcanic structures (Fig. 3).

Age data for the **Şumuleu** volcano (6.8–6.2 Ma) and for the **Ciumani-Fierăstraie** edifice (7.1–6.3 Ma) show a roughly similar age interval.

The small pyroxene amphibole-bearing andesite bodies (several meters in diameter), mapped as intrusions, which cut volcaniclastic deposits at the south-western periphery of the Gurghiu Mountains, give 7.4 Ma (GH-69) (Pécskay et al. 1995). Similar rocks on the north-eastern margin of the Gurghiu volcanic (Ditrău) show 7.9 Ma (GH-84).

Conclusions

The age determinations show an interval of volcanic activity between 9.4–5.4 Ma. The distribution of K-Ar data (Fig. 3) confirms the previously recognized age progression along the Călimani–Gurghiu–Harghita arc (Rădulescu et al. 1973; Pécskay et al. 1995). The duration of the main volcanic activity corresponding to each volcanic center is considered to be about 1 Ma, with a longer interval for the most complex Fâncel-Lăpuşna volcano (2.5 Ma), which was active mainly during Pannonian times.

Simultaneous activity of all the volcanoes (Seaca Tătarca, Borzont, Şumuleu and Ciumani-Fierăstraie), took place in the southern part of the Gurghiu Mountains between 7–6 Ma.

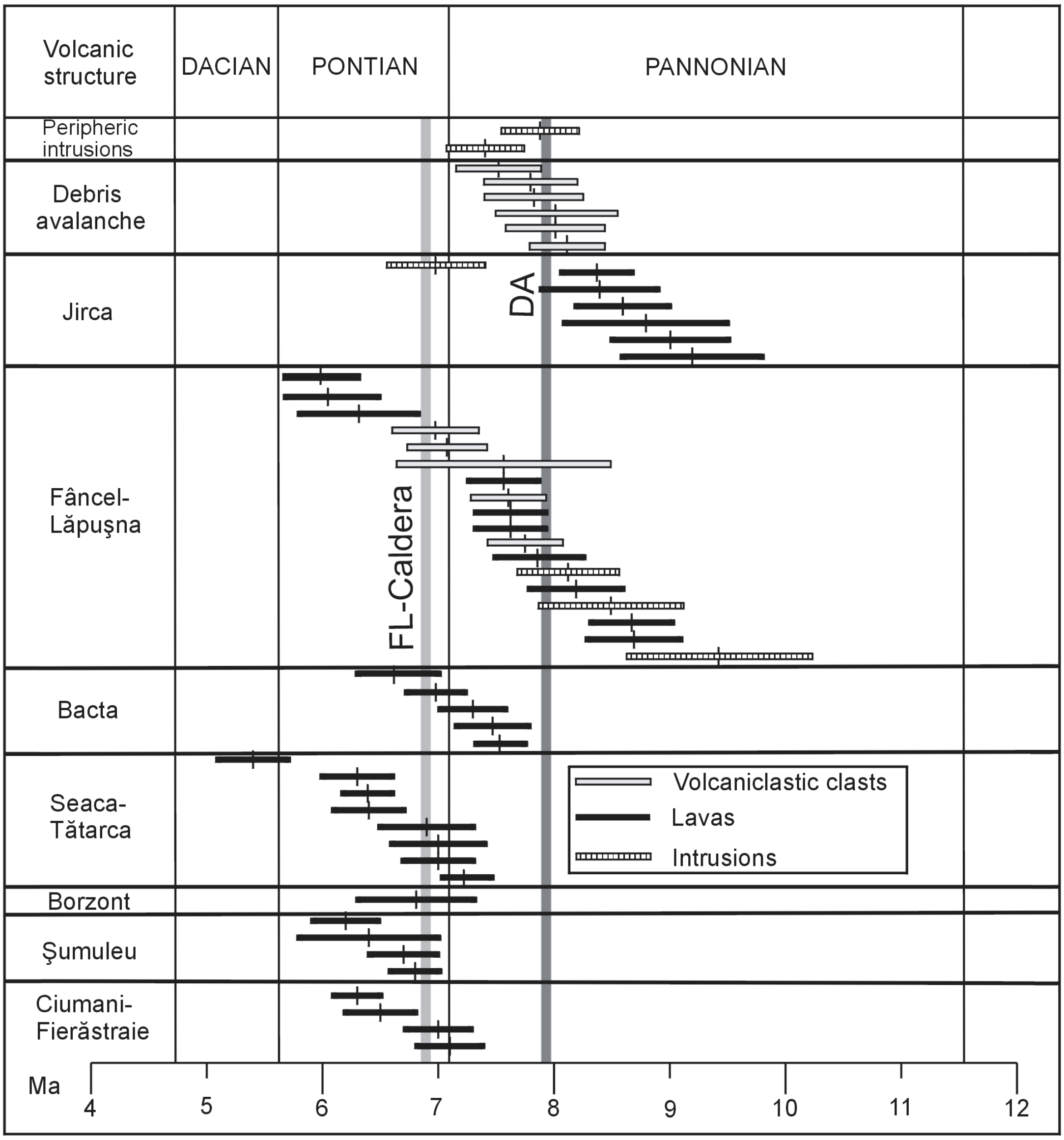

Fig. 3. Timing of Neogene volcanic events in the Gurghiu Mountains (Călimani–Gurghiu–Harghita chain, Romania). Major volcanic events: **FL-Caldera** — Fâncel-Lăpuşna caldera-forming event; **DA** — Debris-avalanche event.

This suggest that andesitic magma reached the surface during the ca. 1 Ma time interval, which is a typical duration for individual East Carpathian volcanoes (Szakács et al. 1997).

The K-Ar data sustain volcanological observations that the volcanic units belonging to neighbouring edifices interfinger at their peripheries during the inferred interval of volcanic activity. Such space-time relationships have been observed between the Călimani and Fâncel-Lăpuşna (Fig. 2) and especially between Seaca-Tătarca, Şumuleu and Ciumani-Fierăstraie volcanoes. However, the pile of peripheral volcaniclastic deposit in the south-western part of the Gurghiu cannot be assigned to the different volcanic source-areas since they show similar ages, as well as similar petrography.

K-Ar ages considerably refined other volcanological interpretations, as well. The ages obtained on clasts in volcaniclastic deposits derived from the Călimani Mountains constrain the timing of edifice failure of the source volcano (Rusca-Tihu) around 8 Ma (Figs. 1, 2) (Szakács & Seghedi 2000). We also may estimate the time of caldera formation at the Fâncel-Lăpuşna volcano (around 6.9 Ma), on the basis of the age of the youngest dated clast in the FLVF. Additionally, the andesite domes at the border of the caldera (5.99–6.23 Ma) suggests the timing of post-caldera volcanic activity. The intrusive complex of various age and petrography inside the Fâncel-Lăpuşna caldera may suggest either uplifting during a resurgence event, following the caldera generation, or an erosional exposure after the caldera generation. Most of the large intrusive bodies inside the central edifice have ages between 8.5–8.13 Ma, in the same range with lavas that constructed the initial volcanic edifice (8.7–7.5 Ma), which may represent the core-complex roots of the pre-caldera edifice. However, the oldest dated intrusion (9.4 Ma) shows similar petrography and age as of the pre-volcanic intrusions below the Călimani volcanic area (Seghedi et al. in print) and it can be attributed to this event. The ages of the most distal lava flows and volcaniclastic deposits (e.g. in the Fâncel-Lăpuşna and Seaca-Tătarca volcanoes) are similar to those of corresponding central edifices, each of which display a central (proximal) facies and peripheral (distal) facies, as has previously been reported (Szakács & Seghedi 1995).

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