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SHORT-LIVED QUATERNARY VOLCANISM IN THE PERŞANI MOUNTAINS (ROMANIA) REVEALED BY COMBINED K-Ar AND PALEOMAGNETIC DATA

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Abstract: New K-Ar ages combined with paleomagnetic data demonstrate that the basaltic volcanism in the Perşani Mountains occurred in two relatively short phases. The first one lasted several tens of thousands of years around 1.2 Ma and it seems that the inception of the volcanic activity took place in two isolated places and reached the maximum extent during the Cobb Mountain Normal Polarity Subchron when larger areas were covered. The second phase started just before 600 ka and was restricted to the central area of the volcanic field. One lava flow of this phase recorded a short-lived reversed polarity event inside the Brunhes Normal Chron, probably the 15β reversal excursion. The duration of this phase was less than 200 kyr, which is the best estimate according to the available radiometric data.

Key words: Carpathians, Perşani Mountains, Quaternary volcanism, alkali basalts, K-Ar data, paleomagnetism, magnetic polarity.

Introduction

The alkali basaltic volcanism in the Perşani Mountains, although of modest extension (ca. 22×8 km), represents an important Quaternary alkali basaltic province inside the Carpathians and south-eastern Europe. Previous K-Ar data pointed to a Late Pliocene, Early and Middle Pleistocene volcanic activity (Casta 1980; Ghenea et al. 1981; Mihăilă & Kreuzer 1981; Downes et al. 1995). Paleomagnetic studies (Hambach et al. 1994; Pătraşcu et al. 1994) showed a strong bias towards normal polarity and intermediate directions but only a few reversed polarities. Because this pattern cannot be explained by a long lasting volcanic activity, a new study was initiated to obtain more reliable K-Ar data in order to constrain better the timing of volcanic activity.

Geological settings and sampling

Well-preserved volcanic structures show spectacular topographic features in the Perşani Mountains: more or less eroded conical hills and remnants of scoria cones on top of a "volcanic plateau". Volcanological investigations revealed several successive stages, each one starting with phreatic or phreatomagmatic eruptions followed by a less energetic strombolian or effusive activity (Seghedi & Szakács 1994). Fossil soils (e.g. Bogata Quarry, Bârc Quarry) separate sequences of pyroclastics and lava flows (Seghedi & Szakács 1994), however, without giving exact information about duration of interruptions in volcanic activity.

The initiation of the volcanic activity is represented by thinly-bedded pyroclastic deposits with plan-parallel, undulatory or cross lamination and frequent bomb-sags indicating near vent phreatomagmatic explosion-derived dilute density currents and co-surge fall-out deposition resulting from the interaction of ascending magma with the shallow water table. These deposits are organized as a number of maar or tuff-ring type volcanic structures (Sărata, Racoş, Măguricea, and Bârc). Such structures are overlain by strombolian fall-out deposits, which constructed volcanic cones, and by lava flows of variable thickness. Thicker lavas generally display various platy, columnar or blocky jointings inside the flow-body, brecciations at the base and clinker-like features at the top. Five isolated volcanic structures have been recognized, three in the north (Sărata, Racoş and Mateiaş) and one in the south (Comana) as well as a more complex volcanic area in the central part (between Hoghiz and Bogata Valley).

For the K-Ar measurements we sampled mostly the fresh lava flows, however, in some cases loose fragments have been also sampled (e.g. a fragment at the base of the upper Bârc lava flow and a fragment of strombolian bomb belonging to the Gruiu cone), in order to accurate the judgment of the event succession. Each collected sample had 2 kg wt. and was macroscopically free of xenoliths. The most suitable samples (free of any alteration and xenoliths) were selected on the basis of the examination of thin sections.

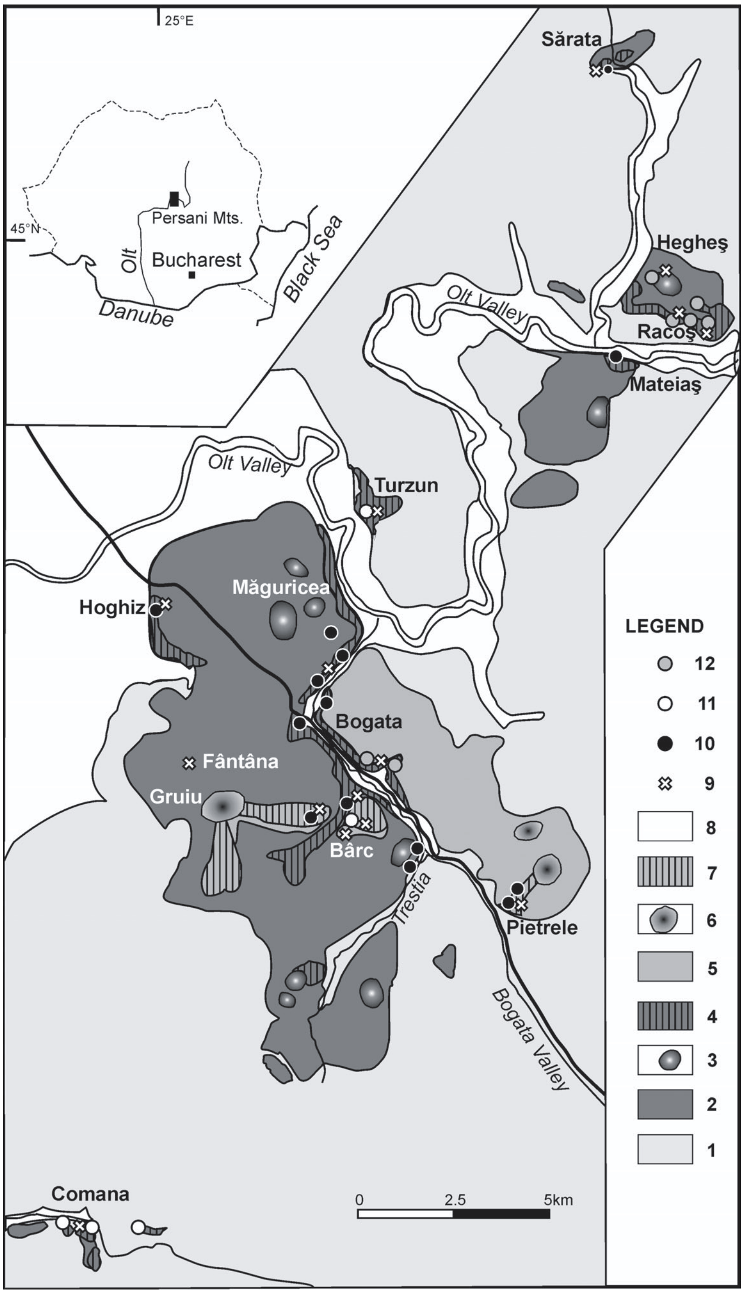

Fig. 1. Volcanological sketch-map of the Perşani Mountains — Quaternary basaltic province. Inset map shows location of the Perşani Mountains in Romania. **1** — Prevolcanic basement (Mesozoic and Cenozoic). ***First phase:*** **2** — Initial pyroclastics (phreatomagmatic deposits); **3** — Scoria cones; **4** — Lava flows. ***Second phase:*** **5** — Pyroclastics (phreatomagmatic deposits); **6** — Scoria cones; **7** — Lava flows; **8** — Holocene alluvia; **9** — Sampling sites for K-Ar. Sampling sites for paleomagnetism: **10** — Normal polarity; **11** — Reversed polarity; **12** — Transitional directions.

Sampling sites for paleomagnetic investigations cover all the volcanic structures, though samples are mainly derived from lava flows. From each site at least 3 block samples or 6 cores have been collected (Table 2). Exogene alterations and lightning areas have been avoided. Fig. 1 shows sample locations on a simplified volcanological map.

Experimental methods

The samples for K-Ar datings were crushed and sieved to 250–100 μm. Sieved fraction was washed with distilled water and dried at 110 °C for 24 h for Ar-analysis. A portion of the fraction was ground using an agate mortar and the resulting powder was analysed for potassium. Due to the mineralogical and petrological character of the rock samples principally the K-Ar age determination was carried out on "whole rock" samples, however, in some cases the analytical work has been made on the "groundmass rich fractions" (iron-oxides and plagioclase phenocrysts were removed using a permanent magnet and an isodynamic separator).

In the ATOMKI, Debrecen, conventional experimental techniques were used for the argon and the potassium analysis. Details of the procedures are those described in Pécskay & Molnár (2002). The results of calibration of the instruments and the applied methods have been described elsewhere (Balogh 1985). All analytical errors given in Table 1 represent one standard deviation (i.e. 68 % analytical confidence level).

In Okayama University the K-Ar dating has been made following the methods described by Nagao et al. (1984) and Itaya et al. (1991). Potassium was analysed by flame photometry using a 2000 ppm Cs buffer. Its analytical error is within 2 % at the 2 sigma confidence level. Argon was analysed by a 15 cm radius sector type mass spectrometer with a single collector system using an isotopic dilution method with a spike of ^{38}Ar. Multiple runs of standard (JG-1 biotite, 91 Ma) indicate that the error of Ar analysis is about 1 % at the 2 sigma confidence level.

Calculations of K-Ar ages were made using the decay constants given by Steiger & Jäger (1977).

K-Ar data from the Perşani Mountains

The new K-Ar ages are presented in Table 1. For the sake of checking reproducibility of Ar analysis duplicate measurements have been made on samples No. 4390 and No. 4389 respectively. These samples have significant importance because they belong to different lava flows. Data show that basaltic volcanism in the Perşani Mountains occurred in two phases: first phase between 1.5–1.2 Ma and the second phase between 0.67–0.52 Ma. Comparing these data with K-Ar ages from Downes et al. (1995) we found a good agreement for the age of Racoş Complex and an important difference for the age of lava flows from Bârc Valley where they reported an age around 1.6 Ma. This discrepancy points out the difficulties to obtain good K-Ar ages for this type of rocks. The assumption that the ^{40}Ar/^{36}Ar ratio of argon trapped in volcanic rocks at eruption is atmospheric (295.5) often gives a large systematic "geological error" in the K-Ar dating of Quaternary basaltic rocks, especially younger than 1 Ma. There are two possible sources of error: a) the existence of excess Ar; b) mass-fractionated initial Ar. The major source of excess Ar is supposed to be the magma itself (Balogh et al. 1994). Frequently the mafic phenocrysts (olivine, pyroxene and amphibole) and crustal quartz xenolith proved to be carriers of excess Ar, too (Fuhrmann & Lippolt 1986). If mass-fractionation of initial Ar occurred this should give a $^{38}Ar/^{36}Ar$ ratio different from the atmospheric ratio, so simply determining the $^{38}Ar/^{36}Ar$ ratio in samples can check this. The error sources other than those mentioned above are uncertainty in the blank correction and instabilities in the sensitivity of mass spectrometer. All these factors produce overlapping of the confidence limits for ages, which make it difficult to distinguish between lava flows.

To avoid any dubious conclusion caused by age disturbing effects, K-Ar ages will be analysed further in combination with paleomagnetic data.

Paleomagnetic data from the Perşani Mountains

The compilation of previous paleomagnetic results (Hambach et al. 1994; Pătraşcu et al. 1994) in conjunction with two new sites is presented in Table 2. All data from Table 2 fulfill the minimum criteria of McElhinny & McFadden (1997) for data quality in secular variation studies from lava flows: (1) there can be no suggestion that the sampling region has been subjected to any tectonic effects; (2) a minimum N = 2 samples per lava flow (site) should have been studied; (3) stability of the magnetization must have been tested by some demagnetization method; (4) the radius of the circle of 95% confidence (α_{95}) for each site must be < 20°.

Presented data set includes 26 sites. The age of each site was established by direct K-Ar dating or by a direct geological relation to a dated lava flow: 19 sites belong to phase 1 and 4 sites belong to phase 2. Last four sites in Table 2 (marked with "?") still lack well established ages so they were excluded from further analysis. Data were divided in sites with normal polarity, reversed polarity and transitional directions according to the virtual geomagnetic pole (VGP) latitude for each site (latitude > 45° N for normal polarity, latitude > 45° S for reversed polarity, latitude = 45° N or S for transitional directions) (Fig. 2).

Normal polarity (7 sites, probably from 4–5 independent flows) and transitional directions (8 sites from 4 flows in the Racoş Complex and 1 flow in Bogata Quarry) dominate sites from phase 1. Only four sites (from 2–3 lava flows: Turzun and Comana) have reversed polarity. From phase 2, one site has a reversed polarity and the other two flows (3 sites) have normal polarity.

Correlation of magnetic polarity data and K-Ar ages

To correlate the observed magnetic polarities with the polarity time scale, several histograms of K-Ar ages were computed using the method of Vandamme et al. (1991). Each datum from Table 1 is given unit weight and represented by a Gaussian distribution with standard deviation equal to age uncertainty. This flattens the large uncertainty data and emphasizes the most precise results. The smooth histogram represents the sum of all individual Gaussian distributions. The precise location of the peak and duration of the tails do not reflect the timing of volcanic activity, but parameters linked to argon-loss or argon-excess process. This would account for the asymmetric nature of the histogram with its sharp rise, actually the most

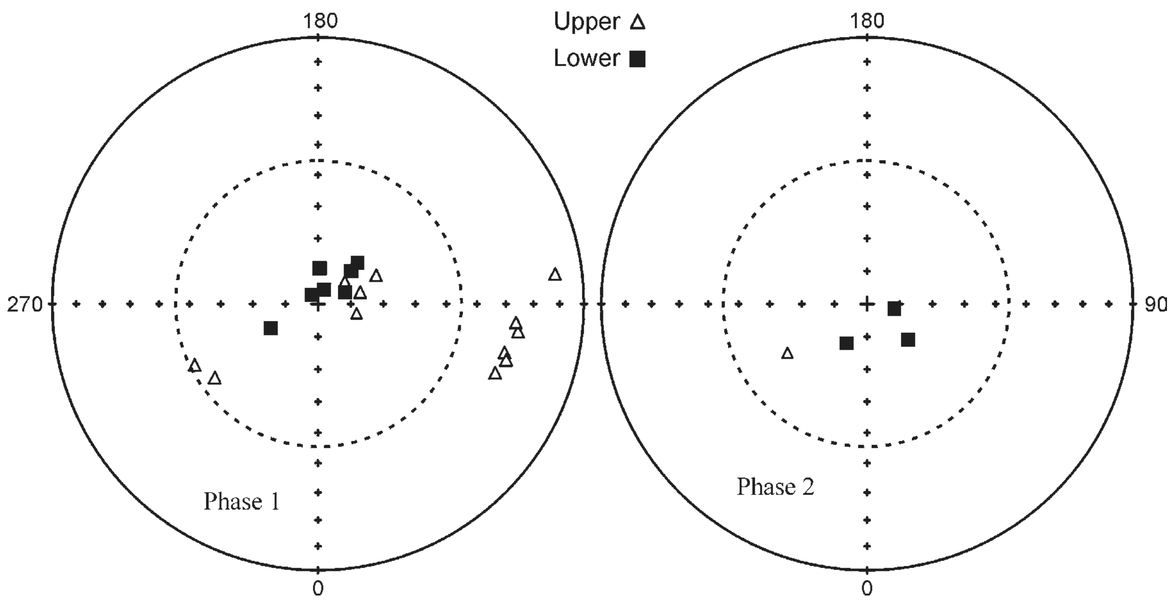

Fig. 2. Equal-area projection of VGPs from the Perşani Mountains: full square — lower hemisphere; open triangle — upper hemisphere. Dotted circle — limit of secular variation (45° north or south).

Table 1: K-Ar ages (Ma) from basaltic lavas of the Perşani Mountains.

Locality	Lab. Nr.	Dated fraction	K %	^{40}Ar rad %	^{40}Ar rad cc STP/gr	K-Ar age Debrecen	K-Ar age Okayama	Magnetic polarity
Phase 1								
Turzun	5162	wr	0.94	9.1	5.295×10^{-8}	1.44 ± 0.22		Reversed
Comana Quarry	5163	wr	0.87	11.0	5.286×10^{-8}	1.53 ± 0.23		Reversed
Sărata	4799	wr	1.26	10.0	6.609×10^{-8}	1.34 ± 0.18		Normal
Hoghiz	4391	wr	1.06	16.9	5.552×10^{-8}	1.35 ± 0.11		Normal
Bogata Valley	5164	wr	1.29	15.6	7.239×10^{-8}	1.44 ± 0.13		Normal
Bârc Valley	4390	wr	1.42	15.1	7.542×10^{-8}	1.36 ± 0.14		Normal
Bârc Valley	4390	wr	1.42	15.7	7.757×10^{-8}	1.39 ± 0.13		Normal
Bârc lithic	4382	wr	1.31	34.3	6.384×10^{-8}	1.25 ± 0.06		-
Bogata Quarry	4386	wr	1.53	8.9	7.583×10^{-8}	1.27 ± 0.20		Transitional
Racoş low	4387	wr	0.67	15.4	3.180×10^{-8}		1.21 ± 0.12	Transitional
Racoş middle	3517	wr	1.24	29.9	6.022×10^{-8}	1.24 ± 0.06		Transitional
Racoş upper (Hegheş)	4388	pm	1.33	7.9	6.744×10^{-8}	1.39 ± 0.24		Transitional
Racoş upper (Hegheş)	4388	wr	1.22	24.3	6.040×10^{-8}		1.27 ± 0.07	Transitional
Phase 2								
Pietrele Valley	5682	wr	1.59	11.3	4.130×10^{-8}	0.668 ± 0.08		Normal
Old Bârc Quarry	5683	wr	1.76	15.9	4.645×10^{-8}	0.679 ± 0.06		Normal
Bârc Quarry	4389	wr	1.55	6.9	3.477×10^{-8}	0.578 ± 0.12		Reversed
Bârc Quarry	4389	wr	1.55	11.1	3.682×10^{-8}	0.612 ± 0.08		Reversed
Bârc Quarry	4389	wr	1.55	16.8	3.810×10^{-8}		0.631 ± 0.05	Reversed
Gruiu (Fîntâna)	5421	wr	1.79	5.9	3.647×10^{-8}	0.524 ± 0.02		

significant feature with respect to true age. The width of the histogram peak at half amplitude is probably the best estimate of the geological age. We computed several histograms (Fig. 3) grouping the data from Table 1 according to their magnetic polarity and volcanic phase. The histogram for transitional directions was constructed using both data from Table 1 and the age (1.19 ± 0.05 Ma) reported for the Racoş volcano by Downes et al. (1995).

Looking at the position of the histogram peaks for phase 1 on the polarity time scale, it is obvious that expected magnetic polarities should be dominated by reversed polarity. On contrary, paleomagnetic polarities measured in lava flows belonging to this volcanic phase are dominantly normal and transitional. This aspect reduces dramatically the duration of eruptions and suggests that most of volcanic activity was during Cobb Mountain Normal Polarity Subchron (CMNS). In order to check if our K-Ar ages are in agreement with this interpretation, we computed a new histogram combining all sites with normal and transitional directions. The width of histogram peak at half amplitude suggests an age between 1.15 Ma and 1.4 Ma. This time interval includes the age accepted for CMNS between 1.17 and 1.24 Ma (Table 3). The combined histogram is asymmetric with a tail toward older ages. The asymmetry was produced by K-Ar ages obtained from sites with normal polarity, most of them achieved from the Bogata area and reflecting excess argon in samples. For this reason, the symmetrical histogram for transitional directions gives a better estimation for the age of the first phase: 1.24 ± 0.09 Ma. This age confirms the suggestion of Hambach et al. (1994) that transitional directions from the lava flows of the Racoş Complex recorded the CMNS. The new K-Ar data show that not only the transitional directions of CMNS were recorded, but also the normal polarity associated with this subchron. The duration of CMNS based on paleomagnetic studies on sediments is around 88 kyr (Clement & Martinson 1992), with normal polarity around 30 kyr (Clement & Martinson 1992) or 23 kyr (Yang et al. 2001) or even 10 kyr (Horng et al. 2002).

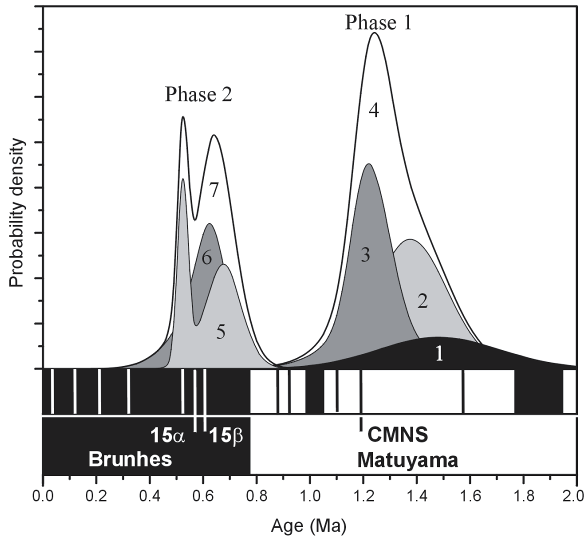

Fig. 3. Histograms of K-Ar ages from the Perşani Mountains: **1** — phase 1 reversed polarity; **2** — phase 1 normal polarity; **3** — phase 1 transitional directions; **4** — phase 1 combined normal and transitional directions; **5** — phase 2 normal polarity; **6** — phase 2 reversed polarity; **7** — phase 2 combined normal and reversed polarity. Main Geomagnetic polarity time scale after Cande & Kent (1995): black = normal polarity; white = reversed polarity. Full white bands are short-lived global polarity events inside the Brunhes Normal Chron after Langereis et al. (1997) and Quidelleur et al. (1999), 15α = Big Lost; 15β = La Palma. Position of reversal and events during the late Matuyama Reversed Chron are after Singer et al. (1999). CMNS = Cobb Mountain Normal Polarity Subchron.

Table 2: Site mean paleomagnetic data from basaltic volcanism in the Perşani Mountains.

Site	n	Dec (°)	Inc (°)	k	α_{95} (°)	Lat (°)	Long (°)	Polarity	Phase	Ref.
Turzun	9	168.1	–57.1	140	4.4	–77.9	76.2	R	1	2
Comana Quarry (A)	24	164.8	–65.4	84.7	3.2	–79.4	129.6	R	1	1
Comana Quarry (B)	6	160.6	–64.7	242	4.3	–76.6	105.7	R	1	2
Comana Old Quarry	6	152.5	–61.7	295	4.5	–70.2	116.1	R	1	3
Sărata	14	6.3	55.6	260	2.5	79.1	177.7	N	1	1
Racoş (1)	12	110.8	8.6	21	9.7	–11.1	97.2	T	1	1
Racoş (2)	8	130.6	4.7	82	6.1	–25.0	82.2	T	1	1
Racoş (3A)	14	143.0	10.1	84.5	4.3	–29.3	68.8	T	1	1
Racoş (4B)	10	137.6	8.8	246	3.1	–27.1	74.4	T	1	1
Racoş (5C)	6	138.7	7.9	91	7.1	–27.1	73.5	T	1	2
Racoş (Hegheş)	14	129.6	0.1	107	3.9	–26.2	84.6	T	1	1
Hoghiz	17	13.0	63.9	431	1.7	81.0	113.1	N	1	1
Bogata Valley (1)	5	20.7	57.2	76	8.8	72.6	136.1	N	1	1
Bogata Valley (2)	9	17.6	59.0	943	1.7	75.7	134.8	N	1	1
Bogata Valley (3)	23	359.4	61.6	157.6	2.4	86.7	212.8	N	1	1
Bogata Valley (4)	6	337.4	62.9	528	5.4	73.8	297	N	1	2
Bogata Quarry (A)	19	232.8	–50.6	260	2.1	–47.1	296.2	T	1	1
Bogata Quarry (B)	6	225.4	–47.5	154	6.2	–50.6	305.4	T	1	2
Bârc Valley	15	4.8	61.6	88	4.1	85.3	156.4	N	1	1
Bârc Quarry	15	216.6	–55.9	504	1.7	–61.2	301.4	R	2	1
Bârc Old Quarry	5	342.1	69.3	74	6.8	76.5	332.5	N	2	3
Pietrele (A)	7	10.7	67.5	369	4.0	81.6	79.6	N	2	1
Pietrele (B)	6	13.6	74.2	1585	1.7	73.4	49.1	N	2	2
Mateiaş Quarry	14	3.1	64.3	360	2.1	87.8	110.4	N	1?	1
Măguricea	16	29.6	51.6	226	2.5	63.5	136.0	N	1?	1
Trestia Valley (1)	7	10.7	67.5	369.3	4.0	81.6	79.6	N	1?	1
Trestia Valley (2)	6	348.5	74.3	273	4.4	73.8	74.9	N	1?	2

Site means were computed using Fisher's statistics (1953): n — number of specimens; Dec — paleomagnetic declination; Inc — paleomagnetic inclination; k — precision parameter; α_{95} — 95% confidence circle; Lat — latitude and Long — longitude of paleomagnetic pole; Polarity: N — normal, R — reversed, T — transitional directions; Ref: 1 (Hambach et al. 1994), 2 (Pătraşcu et al. 1994), 3 (this study). Sites labeled with A, B, C were sampled in the same lava flow.

K-Ar ages of reversals recorded in Turzun and Comana are affected by relatively large analytic errors and excess argon, but we supposed that they erupted not much before the start of CMNS. In conclusion, the total duration of the first phase of eruption in the Perşani Mountains was in the order of ten thousand years.

The second phase of eruptions took place between 0.5–0.72 Ma, according to the width of total histogram peak at half amplitude. Several eruptions occurred during this interval, since one of them recorded one short-lived polarity event inside the Brunhes Normal Chron (e.g. Gubbins 1999). One lava flow from Bârc Quarry has a paleomagnetic direction inside the secular variation limits for a full reversal. The age of this reversed polarity event is around 0.63 ± 0.08 Ma considering the symmetrical histogram computed from the K-Ar ages determined from this quarry (Table 1). This interval includes two reversal excursions, reported both in lava flows and sediments. The most detailed record of this sequence of excursions was recovered from Leg 172 sediments (Lund et al. 2001). The older excursion 15β has an astronomical age around 604 ka and strongly negative inclinations and significant declination variability. According to this age estimation, 15β excursion can be correlated with an excursion of the geomagnetic field characterized by strongly abnormal directions

Table 3: Comparison of magnetic reversal ages used in this paper.

Magnetic Reversal	Astronomical age (Ma)		Combined	Radiometric ages (Ma)		
				$^{40}Ar/^{39}Ar$	K-Ar	
Cobb Mountain Normal Subchron						
Cobb Mt.	1.173±0.004 (top) [1] 1.185±0.005 (base)	1.190 [2]	1.21–1.24 [2]	1.181±0.007 [2]		
Racoş					1.19±0.05 [3]	1.24±0.09 [7]
Excursions in Brunhes Chron						
Big Lost	0.573±0.03 [4]				0.565±0.014 [4]	
La Palma				0.602±0.012 [5]		
15α	0.573 [6]					
15β	0.604 [6]					
Bârc Quarry						0.63±0.08 [7]

[1]Horng et al. (2002); [2]Singer et al. (1999) and references therein; [3]Downes et al. (1995); [4]Langereis et al. (1997) and references therein; [5]Quidelleur et al. (1999); [6]Lund et al. (2001); [7]this study.

associated with a field intensity as low as 7 μT identified in a lava flow sequence from La Palma, Canary Islands (602 ± 12 ka obtained by K/Ar dating, using the Cassignol technique, Quidelleur et al. 1999). This age is concordant with a minimum observed in the global SINT800 composite record, derived from worldwide deep-sea records of relative paleointensity (Guyodo & Valet 1999). Taking into account this directional behaviour, 15β can be defined as a short duration of the altered polarity according to the definition of Gubbins (1999) or a reversal excursion (e.g. Langereis et al. 1997). The younger excursion, 15α, has an age of 573 ka and less directional variability with minimum inclinations reaching only 0°. It can be classified as a large secular variation event. Both the age and the directional behaviour of 15α are similar to the event CR3 found in an eastern Mediterranean piston core (Langereis et al. 1997). Langereis and co-workers correlated it with the Big Lost Event. Since the direction recorded in the Bârc Quarry look like a full reversal, we supposed that the best correlation is with 15β which is also a full reversal and not with Big Lost.

Conclusions

The new K-Ar data combined with paleomagnetic data demonstrate that the basaltic volcanism in Perşani Mountains took place in two relatively short phases. The first one lasted about ten thousand years around 1.2 Ma, however, not as continuous activity but showing in this interval several short term volcanic pulses. At the actual level of knowledge, it seems that the volcanic activity started in two isolated places (Turzun and Comana) and reached the maximum extension and volume during CMNS. The duration of volcanic activity in different parts of the Perşani Mountains can be estimated on the basis of the length of CNMS from marine sediments: **1.** Racoş volcano, with transitional directions, consists of several eruptions, suggesting its generation in less than 5 kyr; **2.** The lava flow from Bogata Quarry, with a different transitional direction than the Racoş directions, was not erupted simultaneously with the Racoş lavas; **3.** The lavas with full normal polarity (Sărata, Hoghiz, Bogata Valley, Bârc Valley) were emplaced in less than 10–20 kyr.

The second phase started just before 600 ka and was restricted to both sides of the Bogata Valley. The duration of this phase was less than 200 kyr, which is the best estimate according to the available radiometric data. Paleomagnetic data and K-Ar ages give evidence for three independent lava flows belonging to this second phase. Additional evidence for the long lasting gap between the two eruption phases is given by a paleosol complex between the lavas from the Bârc Valley (phase 1) and Bârc Quarry (phase 2). This fossil soil developed on a wind blown volcanogenic detrital sediment and not directly on the lava flows. Such successions indicate at least one glacial/interglacial cycle between the volcanic phases.

Our analyses demonstrate that by combining paleomagnetic and K-Ar data with magnetic polarity time scale, it was possible to obtain more detailed and accurate information about the age of volcanic activity in the Perşani Mountains. This approach overcame analytical difficulties in using K-Ar dating methods on young basaltic rocks and it helped to remove the effect of a perturbing factor, such as excess argon. Moreover, these results not only contributed with additional constraints and information to the knowledge about the volcanological evolution of the Perşani Mountains in the last 1.2 Ma, but also demonstrated the potential for studying the behaviour of the past geomagnetic field. More analytical (paleomagnetic and more precise Ar-Ar dating) and volcanological work in this area to benefit from this unique feature of the basaltic lava flows from the Perşani Mountains to record both the Cobb Mountain Normal Subchron and reversal excursions inside the Brunhes Chron.

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