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^{40}AR/^{39}AR DATING AND COOLING HISTORY OF THE PANGEON GRANITOIDS, RHOPOPE MASSIF (EASTERN MACEDONIA, GREECE)

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ABSTRACT

The Pangeon granitoids are distinguished into two petrographic types with sharp contacts: (a) heterogranular, medium- to coarse-grained, hornblende+biotite- bearing **p**orphyritic **t**onalites and **g**ranodiorites (PTG), and, (b) equigranular, **m**edium-grained, biotite±muscovite-bearing **g**ranodiorites and **g**ranites (MGG). Dark-coloured, medium-grained monzodioritic enclaves occur in PTG rocks.

Hornblende $^{40}Ar/^{39}Ar$ spectra from the PTG rocks yielded cooling ages of 21.7±0.5 Ma to 18.8±0.6 Ma. With the exception one sample, the corresponding hornblende ages from enclaves coincide well with the above ages. The age of 21.7±0.5 Ma is considered as the lower limit for the PTG rocks emplacement. Muscovite-plateau ages of c. 15.7±0.5 Ma and total gas biotite ages of 15.2±0.4 Ma to 13.8±0.5 Ma from the studied rocks, constrain the cooling history of the Pangeon granitoids (with some local variations) in the range 430 - 300΄I C.

KEY WORDS: Rhodope massif, Pangeon granitoids, $^{40}Ar/^{39}Ar$ dating, cooling history.

1.INTRODUCTION

The Pangeon granitoids belong to the Rhodope crystalline belt and are located in the Pangeon Mountains, west of Kavala city, in eastern Macedonia, Greece (Fig. 1). On the basis of geological and petrological criteria, their age was previously considered as Tertiary to pre-Tertiary. Erdmannsdoerffer (1920), for example, supposed that the Mesolakkia granitoids were consolidated almost contemporaneously with the post-Jurassic to pre-Middle-Eocene regional alpine metamorphism. Latter, Osswald (1938) suggested an Eocene age on the basis of petrographic similarities of the Pangeon granitoids with other Macedonian granitoids. Schenck (1970) accepted an Eocene to Lower Oligocene age on the basis of structural relationships of the Pangeon granitoids with the surrounding rocks. K/Ar dates of 15.0 ± 0.3 Ma and 13.8 ± 0.2 Ma (Harre et al., 1968) from the Pangeon granitoids (Mesolakkia) were interpreted by these authors as well as by Meyer (1968) as rejuvenation ages. Dinter and Royden (1993) and Dinter et al. (1995) reinterpreted these dates as cooling ages relating to the exhumation of the Rhodope metamorphic core complex.

The aim of this paper is to constrain the emplacement and cooling history of the Pangeon granitoids using the $^{40}Ar/^{39}Ar$ technique on hornblende, biotite and muscovite separates. Knowledge of the emplacement age of the Pangeon granitoids is critical for understanding the tectonometamorphic evolution of the western part of the **H**ellenic **R**hodope **C**rystalline **C**omplex (HRCC).

2. GEOLOGY

The Rhodope Crystalline Complex occupies an intermediate position between the Carpathian-Balkan branch in the NE and the Dinarides-Hellenides branch of the Alpine orogen in the SW, covering large areas of northeastern Greece and southern Bulgaria.

The Pangeon granitoids intrude the **L**ower **T**ectonic **U**nit (LTU) or Pangeon Unit (Papanikolaou and Panagopoulos, 1981) of the HRCC, which, in the studied area, consists mainly of (a) a lower more or less uniform sequence of schists and gneisses; (b) a middle sequence of strongly alternating marbles, gneisses and amphibolites and (c) an upper thick marble zone (Schenk, 1970). The studied granitoids form small isolated bodies that are exposed in several erosion windows (Fig. 2). From southwest to northeast, the most important bodies are those of Mesolakkia (ME), Podochori (PO), Mesoropi (MR) and Nikisiani (NI). These bodies obviously belong to the same pluton that forms the core of a large (>25 km), SW-NE striking anticline that runs parallel to the neighbouring Kavala Pluton (cf. Figs 1 and 2). Emplacement of the Pangeon Pluton was accommodated by late tectonic activity that formed the Pangeon anticline (Schenck, 1970).

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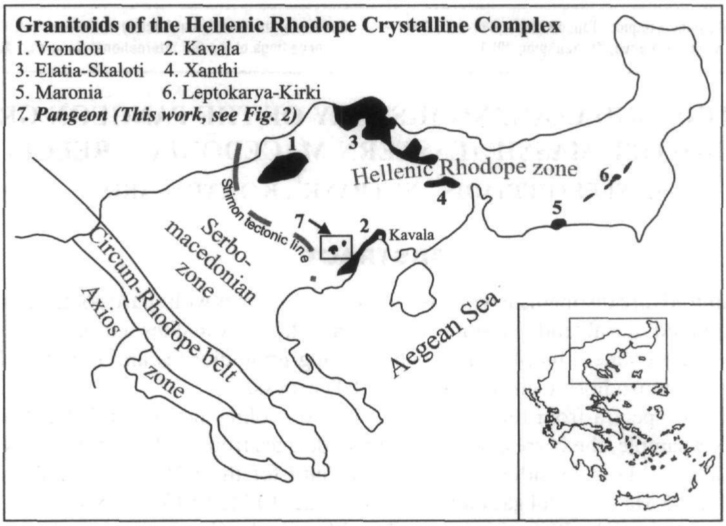

Fig. 1: Simplified geologic map of the Hellenic Rhodope Crystalline Complex showing the distribution and names of the main occurrences of granitoid rocks.

Aplitic up to 1 m thick dykes crosscut the pluton and the surrounding rocks. Dark-coloured, cm-dm sized, rounded to elongated microgranular enclaves occur in some granitoids, most commonly in that of Mesolakkia. Being close to the Strymon detachment zone (Fig. 2), the Mesolakkia granitoids bear also conspicuous dark-coloured veins of pseudotachylites and ultramylonites.

3. PETROGRAPHY

Based on field and petrographical relations, the Pangeon granitoids are divided into two types: An heterogranular, medium- to coarse-grained, porhyritic type (PTG), and an equigranular, fine- to medium-grained, non porphyritic type (MGG). Both rock types are weakly to intensively deformed, in particular, close to the contact with the country rocks. Along with plagioclase, K-feldspar and quartz, PTG rocks contain biotite+hornblende and MGG rocks biotite ± muscovite. The accessory phases in both rock types are apatite, titanite, zircon, allanite, epidote and iron oxides. The contacts between the two rock types are sharp and suggest that the MGG rocks intruded the PTG rocks.

The dark-coloured, microgranular enclaves (ENC) occur only in PTG rocks. They have similar mineralogical composition with their host, but contain more hornblende and biotite.

The SiO_2 content of the Pangeon granitoids varies from 66 to 71 wt% for PTG rocks, and from 68 to 76 wt% for MGG rocks. The ENC are more basic with SiO_2 contents ranging from 59 to 64 wt%. According to the R_1-R_2 classification diagram of de la Roche et al. (1980), PTG rocks are tonalites and granodiorites, and MGG rocks are granodiorites and granites. The ENC turned out to be monzodiorites.

4. ANALYTICAL TECHNIQUES

The analysed samples from the Pangeon granitoids are representative of the three rock types (PTG, MGG, ENC) described earlier. They were collected from all main occurrences (Fig. 2; Tab. 1).

Separates of hornblende, biotite and muscovite were gained by crushing, magnetic separation and subsequent handpicking. This work was curried out at the Department of Mineralogy, Petrology and Economic Geology, University of Thessaloniki and at the Laboratory of Geochronology, University of Vienna. The separates purification was estimated to be >98%. The separates (10 to 20 mg for mica and 50 to 70 mg for hornblende) were put in quartz capsules and irradiated together with standard minerals at the ASTRA reactor of the Austrian Research Centre Seibersdorf.

Hornblende separates were incrementally heated in 6-11 steps. The obtained results are given as age spectra in Fig. 3a,b. Biotites from the same samples were analysed using the total fusion technique. Two muscovite separates (NI8) were analysed by the step heating technique (Fig. 3b).

The K_2O content of hornblende, ranging from 1.1 to 1.7 wt% is considered enough to produce reasonable Ar ages.

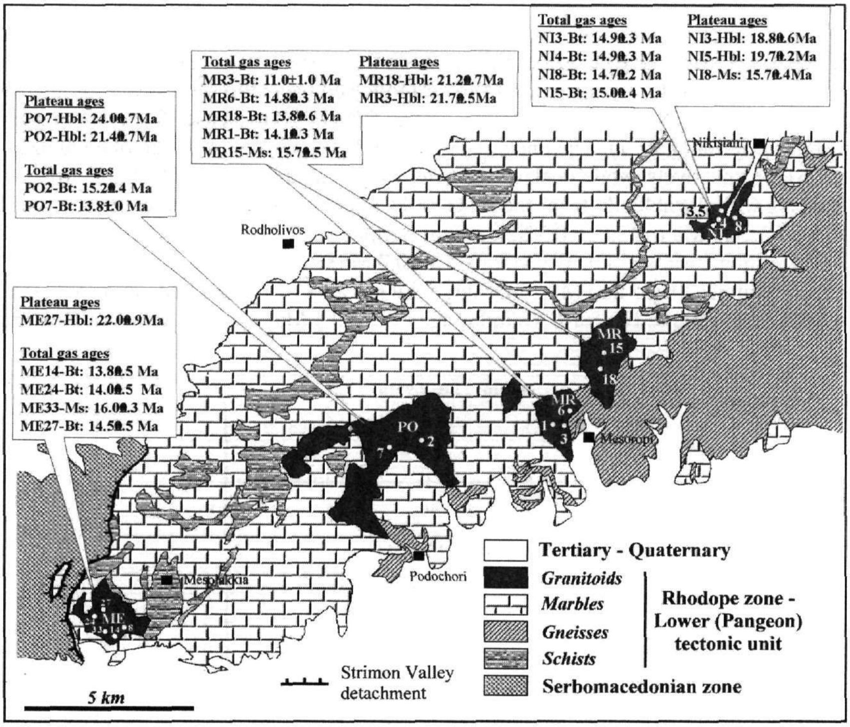

Fig. 2: Simplified geological map (after Schenck, 1970) of the Pangeon granitoids showing the major lithologic types of the sampling area, the sample name and location and the Ar/Ar-ages obtained from Bt (biotite), Hbl (hornblende) and Ms (muscovite) separates.

Table 1. Representative $^{40}Ar/^{39}Ar$ dates from the Pangeon granitoids

Locality (see Fig. 2)	Sample	Rock type	Mineral	Fraction size (mm)	$^{40}Ar/^{39}Ar$	Age (Ma)	STD	Steps
Podochori	PO2	PTG-ton	**Hbl**	0.1-0.25	4.0-5.3	21.4	± 0.7	PL
Mesoropi	MR3	PTG-grd	**Hbl**	0.1-0.25	2.9-5.4	21.7	± 0.5	PL
Mesoropi	MR18	PTG-ton	**Hbl**	0.1-0.25	3.3-5.4	21.2	± 0.7	PL
Nikisiani	NI3	PTG-grd	**Hbl**	0.1-0.25	3.0-5.0	18.8	± 0.6	PL
Mesolakkia	ME27	ENC-mzd	**Hbl**	0.1-0.25	2.7-5.3	22.0	± 0.9	PL
Podochori	PO7(*)	ENC-mzd	**Hbl**	0.1-0.25	2.8-6.0	24.0	± 0.7	PL
Nikisiani	NI5	ENC-mzd	**Hbl**	0.1-0.25	2.2-4.9	19.7	± 0.2	PL
Mesolakkia	ME14	PTG-ton	**Bt**	0.1-0.2	3.42	13.8	± 0.5	TG
Mesolakkia	ME24	PTG-ton	**Bt**	0.1-0.2	3.46	14.0	± 0.5	TG
Podochori	PO2	PTG-ton	**Bt**	>0.2	3.8	15.2	± 0.4	TG
Mesoropi	MR3	PTG-grd	**Bt**	>0.2	2.73	11.0	± 1.0	TG
Mesoropi	MR6	PTG-grd	**Bt**	>0.2	3.65	14.8	± 0.3	TG
Mesoropi	MR18	PTG-ton	**Bt**	>0.2	3.42	13.8	± 0.6	TG
Nikisiani	NI3	PTG-grd	**Bt**	0.1-0.2	3.7	14.9	± 0.3	TG
Mesolakkia	ME8	ENC-mzd	**Bt**	>0.2	3.5	14.1	± 0.7	TG
Mesolakkia	ME27	ENC-mzd	**Bt**	>0.2	3.58	14.5	± 0.5	TG
Podochori	PO7	ENC-mzd	**Bt**	>0.2	3.4	13.8	± 1.0	TG
Nikisiani	NI5	ENC-mzd	**Bt**	0.1-0.2	3.72	15.0	± 0.4	TG
Mesoropi	MR1	MGG-grd	**Bt**	0.1-0.2	3.49	14.1	± 0.3	TG
Nikisiani	NI4	MGG-gr	**Bt**	0.1-0.2	3.67	14.9	± 0.3	TG
Nikisiani	NI8	MGG-gr	**Bt**	0.1-0	3.63	14.7	± 0.2	TG
Mesolakkia	ME33	MGG-gr	**Ms**	0.1-0.2	3.94	16.0	± 0.3	TG
Mesoropi	MR15	MGG-gr	**Ms**	>0.2	3.88	15.7	± 0.5	TG
Nikisiani	NI8	MGG-gr	**Ms**	0.1-0.2	3.9	15.7	± 0.4	PL

(*) PO7: Block of a coarse-grained enclave not found in place.

*Abbrreviations: **PTG: coarse-grained porphyritic tonalite or granodiorite; MGG: medium-grained granodiorite or granite; ENC: enclave in PTG rock; mzd: monzodiorite; ton: tonalite; grd: granodiorite gr: granite; Hbl: hornblende; Bt: biotite; Ms: muscovite; PL: plateau; TG: total gas.***

5. RESULTS

Hornblende separates from the PTG granitoids show similar $^{40}Ar/^{39}Ar$ age spectra (Fig. 3a,b; Tab. 1). They are characterized by low ages at low temperatures that are followed by a more or less well-defined plateau after c. 35-45% ^{39}Ar release. Sample NI3 attained its plateau after 57% of ^{39}Ar release. The plateau ages range from 21.7±0.5 Ma to 18.8±0.6 Ma (Tab. 1). The enclaves ME27 and NI5 gave hornblende plateau ages of 22.0±0.9 Ma and 19.7±0.2 Ma, respectively, while enclave PO7 yielded the highest date of 24.0±0.7 Ma.

Biotites coexisting with hornblende from the PTG rocks and ENC gave distinctly lower (total fusion) ages ranging both from 15.2±0.4 Ma to 13.8 ± 0.5 Ma, except sample MR3 that yielded 11.0±1.0 Ma. Biotites from MGG rocks yielded similar results (14.9±0.3 Ma to 14.1±0.7 Ma).

Muscovites from samples ME33 and MR15 yielded total gas ages of 16.0±0.3 Ma and 15.7±0.5 Ma, respectively, and muscovite from sample NI8 gave a similar age (15.7±0.4 Ma) using incremental heating technique.

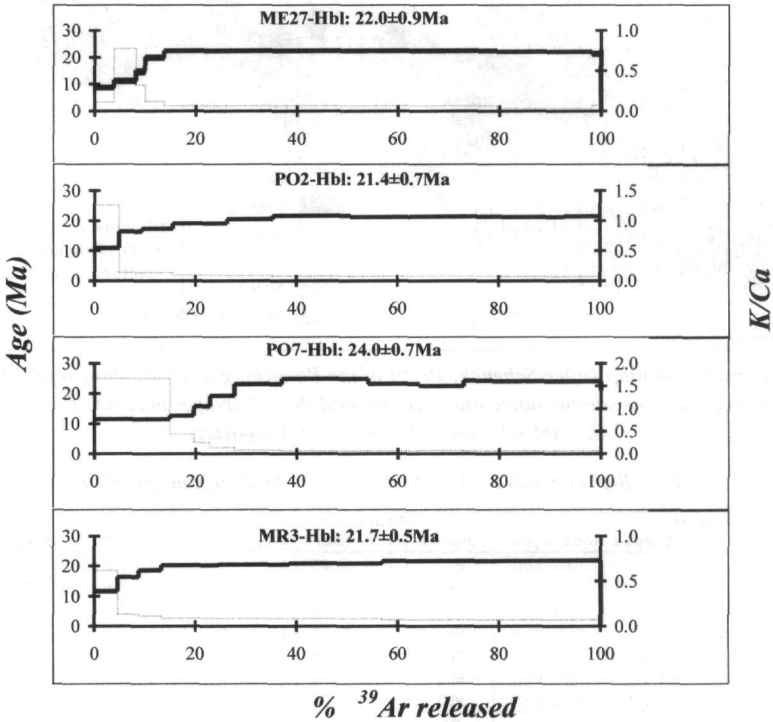

Fig. 3a: Graphical representation of the results obtained by the incremental heating technique of hornblende separates from the Pangeon granitoids (continued)

6. DISCUSSION AND CONCLUSIONS

As shown in Tab. 1, most of the hornblende $^{40}Ar/^{39}Ar$ high temperature plateau ages obtained from PTG rocks of the Pangeon Mountains are almost the same and range mainly from 21.7±0.5 to 21.2±0.7 Ma. This narrow age spread as well as the observed textural, mineralogical and chemical similarities suggest that the PTG rocks from all sampled occurrences are co-magmatic and belong to the same pluton. The younger hornblende plateau age of 18.8 ± 0.6 Ma from sample NI3 is rather due to partial rejuvenation of hornblende than to a younger emplacement age.

For a blocking temperature of hornblende at c. 500΄I C (Harrison, 1981), the measured hornblende plateau age of 21.7±0.5 Ma is considered as the lower time limit for PTG-magma emplacement. This suggestion is supported also by titanite U/Pb ages (21.1±0.8 to 19.1±0.2 Ma) and $^{40}Ar/^{39}Ar$ hornblende ages (21.7±0.4 to 20.1±0.3 Ma) constraining the intrusion of the structurally and petrologically similar Kavala granodiorite (Dinter et al., 1995). The oldest age of 24.0 ±0.7 Ma, obtained from enclave PO7, is not considered significant, because

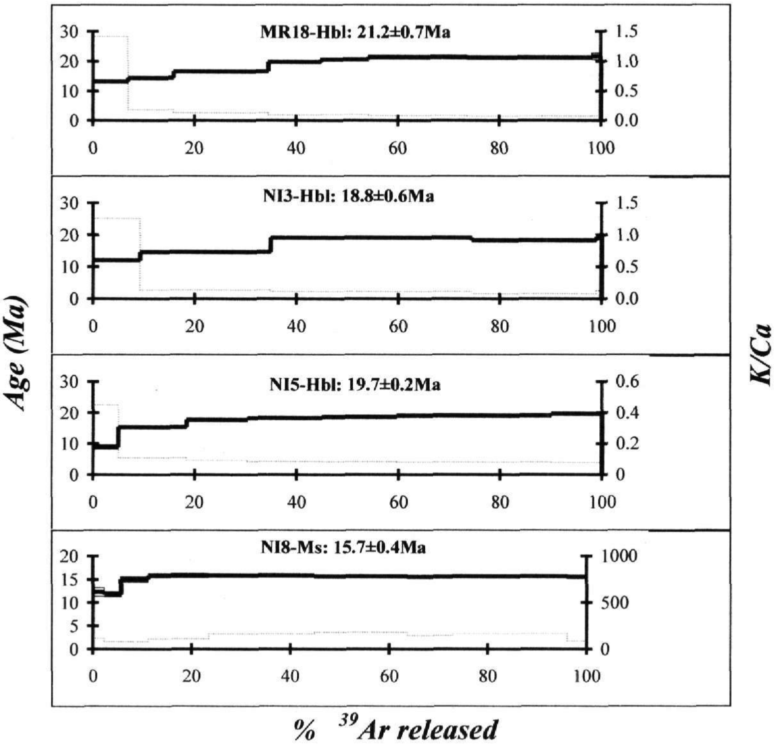

Fig. 3b: Graphical representation of the results obtained by the incremental heating technique of hornblende and muscovite separates from the Pangeon granitoids.

(a) it deviates considerably from most other ages and (b) the PO7 relation to the other plutonic rocks is not clear (see caption in Tab. 1).

Muscovite ages of 16.0±0.3 to 15.7±0.4 Ma and the lower total gas ages of biotites (15.2±0.4 to 13.8±0.5 Ma) from all the studied rocks (PTG, MGG, ENC), constrain the cooling history of the Pangeon granitoids at lower temperatures. It should be mentioned here that the K/Ar biotite ages of 15.2±0.3 to 13.8±0.2 Ma from the Mesolakkia plutonic body given by Harre et al. (1968) were interpreted as "rejuvenation ages" and "cooling ages" by Meyer (1968) and Dinter et al. (1995), respectively. The Ar/Ar mica ages reported here are close to and partly overlap with apatite fission track ages from the same area (Hejl et al., 1998; Kyriakopoulos et al., 1997).

In summary, the results of this study as well as literature data suggest that the cooling history of the Pangeon granitoids is characterized by a two-stage evolution. The first stage (a) is constrained by the hornblende and muscovite Ar/Ar-cooling ages between c. 22 and 16 Ma, respectively; (b) was characterized by a rather "normal" cooling rate over 8 Ma from c. 500 to c. 450°C; (c) took place during declining deformation that is documented by the late syn-tectonic textural features of the rocks. The second stage is characterized by temperatures <450°C and started at c. 16-14 Ma. It is constrained by the partial overlap of the Ar/Ar-cooling ages from muscovites and biotites of this study with the fission track ages mentioned above. This overlap suggests a rapid cooling that was most probably induced by rapid tectonic exhumation and erosion. As suggested by the several occurrences of pseudotachylites within the granitic rocks of Mesolakkia, this stage continued below the ductile-to-brittle transition of the Pangeon granitoids.

A difference in emplacement age for the PTG and MGG rock types cannot be established by the presented data. Unfortunately no hornblendes are present in the MGG rocks. However, although there are field observations that the MGG type rocks intrude the PTG rocks, the absolute age difference between the emplacement ages of both rock types may be within the uncertainty of the analyses.

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