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THE A-TYPE KERKINI GRANITIC COMPLEX IN NORTH GREECE: GEOCHRONOLOGY AND GEODYNAMIC IMPLICATIONS

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Abstract

The Kerkini granitic complex (KGC) intrudes the Serbomacedonian massif. KGC comprises the Muries granite (MUR), the Miriofito granite (MIR), and the Kastanusa (KAS) granodiorite. The main rock-type is two-mica granite. Feldspars are represented by albite and perthitic microcline, biotite is iron-rich and white mica is phengite. Fluorite is also present.The rocks are peraluminous, enriched in total alkalis, depleted in MgO and CaO and have high FeOt/MgO ratios. They are enriched in Zr, Nb, Y, Ga and REE, and have strong negative Eu anomaly. They plot in the A-type granite fields of various discriminant diagrams and their chemistry suggests a WPG tectonic environment. Sr initial ratio ranges from 0.7107 to 0.7182. The most probable genetic model is fluid-absent melting of a biotite-rich tonalitic crustal source at 950 - 975 ^{0}C and at considerable depths. Rb-Sr white mica ages and SHRIMP U-Pb zircon ages yielded 246±3 Ma and 247±2Ma, respectively, interpreted as the crystallization age of the KGC. K-Ar ages of 130±3 and 131±3 Ma (biotite) and 133±3 Ma (white mica) can be interpreted by a metamorphic/fluid event at about 133 Ma. Rb-Sr white mica dates at 152±2 Ma probably resulted by incomplete resetting of the Rb-Sr isotopic system and yielded "mixing ages" between crystallization (ca. 247 Ma) possibly related to a Permian – Triassic rift event and metamorphic/fluid event (ca. 133 Ma).

Key words: *A-type granite, SHRIMP, Triassic, rift.*

Περίληψη

Το γρανιτικό σύμπλεγμα της Κερκίνης (KGC) στη Σερβομακεδονική μάζα, συνίσταται από τους γρανίτες Μουριών (MUR) και Μυριόφυτου (MIR), και το γρανοδιορίτη της Καστανούσας (KAS). Επικρατεί ο διμαρμαρυγιακός γρανίτης. Περιέχει αλβίτη και περθιτικό μικροκλινή, πλούσιο σε σίδηρο βιοτίτη, φεγγιτικό λευκό μαρμαρυγία και φθορίτη. Τα πετρώματα είναι υπεραργιλικά, πλούσια σε αλκάλεα, πτωχά σε MgO και CaO και έχουν υψηλό FeOt/MgO. Είναι επίσης εμπλουτισμένα σε Zr, Nb, Y, Ga και

REE και δείχνουν έντονη αρνητική ανωμαλία Eu. Προβάλλονται στο πεδίο των Α-τύπου γρανιτών σε διάφορα διακριτικά διαγράμματα και η γεωχημεία τους υποδηλώνει γρανίτη ενδοπλακικού γεωτεκτονικού περιβάλλοντος (WPG). Η αρχική ισοτοπική αναλογία Sr κυμαίνεται από 0.7107 μέχρι 0.7182. Το πιο πιθανό γενετικό μοντέλο είναι η τήξη, απουσία ρευστού, μιας πλούσιας σε βιοτίτη φλοιϊκής πηγής στους 950 - 975 ^{0}C και σε σημαντικό βάθος. Γεωχρονολογήσεις Rb-Sr σε λευκούς μαρμαρυγίες και SHRIMP U-Pb σε ζιρκόνια έδωσαν ηλικίες 246±3 Ma και 247±2 Ma, αντίστοιχα, που ερμηνεύονται ως ηλικίες κρυστάλλωσης του KGC. Ηλικίες K-Ar 130±3 and 131±3 Ma (βιοτίτης) και 133±3 Ma (λευκός μαρμαρυγίας) μπορούν να εξηγηθούν με ένα μεταμορφικό ή συνδεδεμένο με δράση ρευστών γεγονός στα 133 Ma. Οι ηλικίες Rb-Sr λευκών μαρμαρυγιών στα 152±2 Ma πιθανόν να είναι το αποτέλεσμα μιας ατελούς επανέναρξης του ισοτοπικού συστήματος Rb-Sr, που έδωσαν «μεικτές ηλικίες» μεταξύ της κρυστάλλωσης (ca. 247 Ma), πιθανώς σχετιζόμενης με ένα Περμικό – Τριαδικό άνοιγμα (rift), και του μεταμορφικού ή του συνδεδεμένου με δράση ρευστών γεγονότος (ca. 133 Ma).
Λέξεις κλειδιά: *Α-τύπου γρανίτης, SHRIMP, Τριαδικό, ηπειρωτική διάρρηξη.*

1. Introduction

Apart from the two fundamental types of granitic rocks defined by Chappell and White (1974) and White and Chappell (1977), known as S-type and I-type granites, White (1979) defined a third granitoid type (M-type) which was considered as deriving directly from the melting of subducted oceanic crust or the overlying mantle. Another distinctive group of granites has since been designated "A-type" by Loiselle and Wones (1979), who used the term to emphasize the anorogenic tectonic setting, and the relatively alkaline composition as well as the supposedly anhydrous character of the magmas. It was emphasized, however, that unlike the S-, I- and M-type, A-type classification does not imply a specific source or mode of origin. Since then various suggestions and proposals have been made concerning source and mode of origin of A-type granites (Clemens *et al.* 1986, Whalen *et al.* 1987, Eby 1990, 1992, Creaser *et al.* 1991, Skjerlie and Johnston 1993, Landenberger and Collins 1996).

The Serbomacedonian massif (SMM) in northern Greece is characterized by numerous felsic plutonic and volcanic rocks of Permian - Triassic to Tertiary age. The presence of granitoids in a complex geotectonic unit such as the SMM is of particular importance since, through their geochemistry, geochronology and tectonics, they can potentially constrain the timing of the main tectonic events. The detailed study of some of the young (Tertiary) granitoids (Christofides *et al.* 1990, De Wet *et al.* 1989) contributed to the reconstruction of the Tertiary geological history in this area.

Among the older intrusions, Arnea granite (de Wet, 1989) and Kerkini granitic complex (KGC) (Christofides *et al.* 1999, 2000, 2006) are the largest ones. Vital (1987, in Frei, 1992) obtained a U-Pb zircon age of 212±7 Ma for the Arnea granite while Kostopoulos *et al.* (2001) gave a Pb-Pb zircon age of 215.0±1.8 Ma. For KGC, Christofides *et al.* (1999) presented K-Ar age data on biotite and white mica (130±3 to 133±3 Ma) and interpreted them as representing a metamorphic event rather than the crystallisation age of the complex. Christofides *et al.* (2006) published new Rb-Sr and U-Pb datings of Permian/Triassic age. In this paper we investigate the Kerkini granitic complex giving emphasis on its geochronology and its geodynamic significance.

2. Geological setting

The SMM in Greece is a complex geotectonic unit which underwent major Permo-Triassic (??) and mid-Mesozoic metamorphic, magmatic and deformational events (Dixon and Dimitriadis 1984, Sakellariou 1989) followed by Eocene and Oligocene/Miocene plutonism (D' Amico *et al.* 1990, Frei 1992). It extends as a long and narrow zone in a SSE direction from near Belgrade in

Serbia to the Chalkidiki peninsula in Greece. Based on lithologies and grade of metamorphism it is divided into two units, namely the Kerdyllia unit, a small area in NE Chalkidiki comprising gneisses, amphibolites and marbles metamorphosed under upper amphibolite facies conditions and the Vertiskos unit to the west, which is in tectonic contact with the upper marble horizon of the Kerdyllia unit and comprises various types of gneisses, and amphibolites, metamorphosed under lower amphibolite facies conditions.

The KGC intrudes the NW Vertiskos unit north of Muries village in Mt. Kerkini straddling the Greece - F.Y.R.O.M. border (Fig. 1). It comprises a large intrusion, namely the Muries granite (MUR), an apophysis of the Muries granite to the south, known as the Miriofito granite (MIR) (Sidiropoulos 1991), which is separated from the main granitic body by the Doirani-Kerkini basin, and the Kastanusa (KAS) granodiorite, a small intrusion to the east (Christofides *et al.* 1999). The country rocks include two-mica and amphibole gneisses, schists and amphibolites. Small outcrops of meta-ultrabasic rocks and marbles are also present. The southern and western contacts of the MUR granite are strongly deformed. Mylonitic fabrics in the granite, especially at the western contact, are well-developed. No contact metamorphism has been observed.

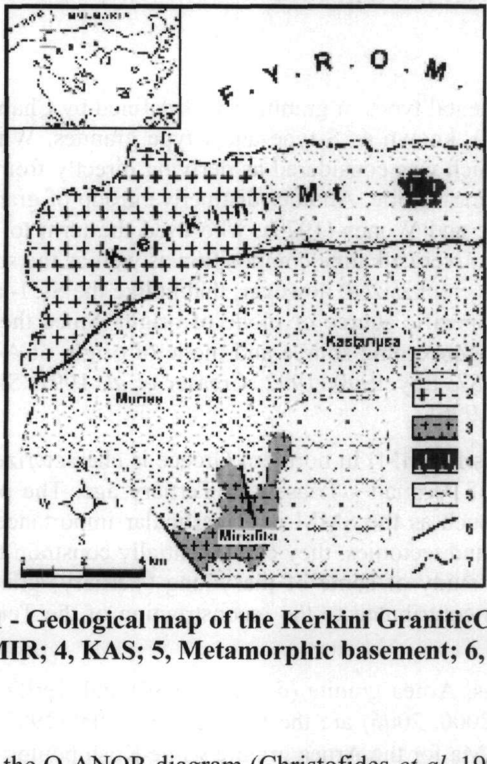

Figure 1 - Geological map of the Kerkini GraniticComplex.
1, Alluvial; 2, MUR; 3, MIR; 4, KAS; 5, Metamorphic basement; 6, Fault; 7, State boundary

3. Petrography

The KGC rocks, based on the Q-ANOR diagram (Christofides *et al.* 1999), are classified as alkali granite to granite (MUR and MIR) and granodiorite (KAS). In most places they are strongly deformed and intensively weathered. MIR is the least deformed granite although hydrothermally altered. The least weathered is the KAS granodiorite which is also the most biotite-rich type. The rocks are medium- to coarse-grained, leucocratic to mesocratic. Fine-grained types with allotriomorphic granular to hypidiomorphic inequigranular textures are also present having subhedral to euhedral perthitic K-feldspar phenocrysts, set in a fine- to medium-grained quartz-feldspathic matrix. The main rock-type is two-mica granite with subordinate biotite and white mica granite (Christofides *et al.* 1999).

The main mineral constituents are quartz, K-feldspar, plagioclase, biotite and white mica. Accessories include opaques (mostly sulfides), zircon, allanite, apatite, fluorite and titanite. Chlorite, epidote and sericite occur as secondary minerals. Quartz is sometimes recrystallized and forms intergrowths with micas. K-feldspar (Or_{94-98}), mostly microcline, occurs as perthitic to micro-perthitic anhedral crystals and as subhedral to euhedral perthitic phenocrysts. Plagioclase is mostly albite and is unzoned (core: Ab_{88-99}, rim: Ab_{87-99}), occurring in subhedral to anhedral crystals. Alteration to sericite is not uncommon. Biotite composition is close to annite end-member (Christofides *et al.* 1999). It is late in the crystallization sequence occurring mostly as interstitial grains between feldspars and quartz. Biotite is frequently altered to chlorite and sometimes to epidote and Fe-Ti oxides. The Si content of the white mica ranges from 6.4 to 6.7 (based on 22 O) and its celadonite component is 22.8-36.8 indicating a phengite-like composition. Microscopically it has features favouring a primary origin (grain size comparable to other primary phases, subhedral form, not enclosed in other minerals). However, such an origin is arguable because of its chemical composition; in terms of Ti, Na and Mg, its analysed grains mostly plot in the secondary muscovite field after Miller *et al.* (1981). Moreover its TiO_2 content is <0.6 % (Zen 1988). It must be stressed here that primary magmatic phengites seem to be very rare. Schleicher and Lippolt (1981) reported a magmatic phengite in felsitic parts of rhyolites from Southwest Germany. Moreover, magmatic phengites were found in a pegmatoid in the area of the Erzgebirge, Saxony (southern Germany) and in a small deformed granitic body in northern Spain (Massonne pers. comm.). The relatively high Si content of the white (magmatic) mica of the Kerkini granite is an indication that crystallization took place at considerable depths.

4. Methods and materials

For Sr isotope analysis, 0.1 g of sample were digested using concentrated HF and HNO3 (4:1) in Teflon crucibles and taken to dryness. Samples were then digested in 6 M HCl and centrifuged at 4500 rpm for 30 minutes to remove traces of insoluble residues. Clear solution was removed and taken to dryness again. Natural strontium was eluted through ca 10 ml quartz columns using Biorad AG50W-X8 200-400 mesh resin with 2.5 M HCl. In all steps, pure acids (Merck Suprapure grade) and 18.3MΩ water was used. Procedural blank was better then 2 ng. Approximately 1 μg of Sr was loaded on Ta filament with 1 M H_3PO_4. Strontium isotopic composition was measured in dynamic multicollector mode (100 ratios) on VG Sector 54E thermal ionization mass spectrometer at 1V of ^{88}Sr signal. The $^{87}Sr/^{86}Sr$ ratio was normalized to $^{86}Sr/^{88}Sr$=0.1194. During period of analyses, SRM-987 yielded a grand mean $^{87}Sr/^{86}Sr$ ratio=0.710236±14 - 0.710262±17 and all $^{87}Sr/^{86}Sr$ ratios in Table 2 were adjusted to value of SRM-987=0.710248.

The U-Pb zircon data were obtained on SHRIMP II at the Geological Survey of Canada, Ottawa. The spot size was ca. 20 μm in diameter. For data collection, seven scans through the critical mass range were made. U/Pb ratios were calibrated relative to standard BR266. For details on the SHRIMP technique see Stern (1997) or Williams (1998). Data were corrected for common Pb using the ^{207}Pb correction method (see Williams 1998). Cathodoluminescence (CL) images of the zircons revealed that the ca. 200 μm long euhedral crystals are composed largely of a single domain with oscillatory zoning (Fig. 2).

5. Geochemistry

Major and trace element analyses of 18 selected samples from all rock-types were determined by XRF. Six of them were analysed for REE and some trace elements by INAA. Chemical data of the analysed samples as well as major, trace and rare earth element compositional variations are presented by Christofides *et al.* (1999). Here, only some critical geochemical characteristics will be reported. The SiO_2 content of the KGC ranges between 69 and 76 wt%. Total alkalis are high, ranging from 8.2 to 9.5 wt% while CaO is <1.5 wt% and in most samples <0.7 wt%. Although $(Na_2O+K_2O)/Al_2O_3$ is high, none of the rocks is peralkaline. FeO_t/MgO ratio ranges from 6.2 to 19.1. The rocks are in general enriched in Zr, Nb, Ga, Rb, Y, Th and U. The Y/Nb ratio in the KGC ranges from 2.4 to 4.3 and it remains constant with SiO_2 increase. The REE patterns of all samples are similar and quite enriched relative to chondrite (La_{CN}=150-220) but with slight LREE enrichement [$(La/Lu)_{CN}$=3-6]. ΣREE ranges from 214 to 315 ppm. The REE patterns show a large negative Eu anomaly (Eu/Eu*=0.06-0.30) which increases with increasing Sr content.

Compared with the MUR granite the KAS granodiorite shows a few differences. The most notable ones are the higher Al_2O_3 and Na_2O contents and the significantly lower K_2O content in the granodiorite. Its trace elements are also different particularly, V, Nb, Zr, Y, Rb, Ba and Sr. The KAS REE pattern is similar to those of MUR in respect to LREE enrichement [$(La/Lu)_{CN}$=3.5] but shows smaller Eu anomaly (Eu/Eu*=0.62) and is less enriched relative to chondrite (La_{CN}=100). Moreover its ΣREE is significantly lower (150 ppm). Probably the KAS granodiorite represents a different intrusion and thus it is not considered further.

The MIR granite follows in general the MUR oxide trends. However, it is distinguishable in terms of Al_2O_3, CaO, Nb, Zr and Y. Its REE patterns is similar to those of MUR granite with small slope [$(La/Lu)_{CN}$=3.3] and strong negative Eu anomaly (Eu/Eu*=0.15). MIR, however, is significantly poorer in REE compared to MUR at the same SiO_2 content (La_{CN}=132, ΣREE=197 ppm). The rocks analysed are peraluminous in terms of A/CNK molar ratio which ranges between 1.0 and 1.3. Only one sample has A/CNK=0.8.

Sr initial ratio is relatively high ranging from 0.7107 to 0.7182 based on 247 Ma (see below).

6. Geochronology

Various geochronological methods (K-Ar, Rb-Sr on micas, whole-rock Rb-Sr, SHRIMP zircon U-Pb) have been applied to accurately define the crystallization age of KGC and any post-crystallization metamorphic/fluid event. Christofides *et al.* (1999) reported K-Ar ages on biotite of 130±3 and 131±3 Ma and on white mica of 133±3 Ma. U-Pb SHRIMP radiometric data on zircon and Rb-Sr whole-rock and micas data are given in Tables 1 and 2 respectively.

Table 1 - U, Th, Pb SHRIMP data for magmatic zircon domains from KGC

Sample	U	Th	Th/U	Pb*	$f_{206}Pb$	$^{207}Pb/^{206}Pb$±error (uncorrected)	$^{238}U/^{206}Pb$±error (uncorrected)	Age ± error (Ma)
MP501-7.1	1050	1014	0.998	49	0.001	0.0520±0.0005	25.13±0.27	251.3±2.7
MP501-19.1	223	157	0.727	9	0.007	0.0565±0.0012	25.44±0.32	247.0±3.0
MP501-28.1	118	60	0.521	5	0.019	0.0663±0.0016	25.70±0.36	241.5±3.4
MP501-30.1	490	335	0.705	21	0.005	0.0549±0.0007	25.52±0.28	246.6±2.7
MP501-26.1	220	119	0.558	9	0.007	0.0569±0.0010	25.55±0.33	245.7±3.1
MP501-22.1	535	160	0.308	20	0.004	0.0545±0.0010	25.44±0.28	247.5±2.7
Notes: 1. Pb* is radiogenic Pb; **2.** $f_{206}Pb$ denotes the percentage of ^{206}Pb that is common Pb; **3.** WM: weighted mean (error on the WM is at the 95% c.l.); **4.** ±error is at 1 sigma level.							**WM: 247.0 ± 2.3 Ma**	

Cathodoluminescence (CL) images of the zircons revealed that the ca. 200 μm long euhedral crystals are composed largely of a single domain with oscillatory zoning (Fig. 2), indicating that they precipitated from a melt. The fact that the zircon crystals consist of a single (magmatic) domain argues against an S-type origin for the Kerkini granite, since zircons from S-type granites have, in their majority, inherited cores. Most zircon crystals separated from the Kerkini granite show in CL thin bright (U-poor) domains either at the outermost margins of the crystals or on either side of fractures (Fig. 2).

These CL bright domains are probably the result of post-crystallization action of fluids, related to a metamorphic/deformational event. The development of such thin metamorphic rims on zircon indicates low grade of metamorphism (usually below ca. 600 °C) and/or low amounts of fluids. The data are graphically presented on a Tera-Wasserburg diagram (Tera and Wasserburg 1972), uncorrected for common Pb. Six data points on six different zircon crystals plot on a mixing line with common Pb and calibrated total $^{238}U/^{206}Pb$ as end members (Fig. 3). The weighted mean age of these analyses is 247.0±2.3 Ma (MSWD=1.1; error on the 95 % c.l.). This age is interpreted to reflect the crystallisation time of the KGC. It was not possible to get U-Pb data for the post-crystallization, metamorphic/deformational event affecting this granite due to the small thickness of the metamorphic domains of the zircons (Fig. 2), in combination with their very low U content.

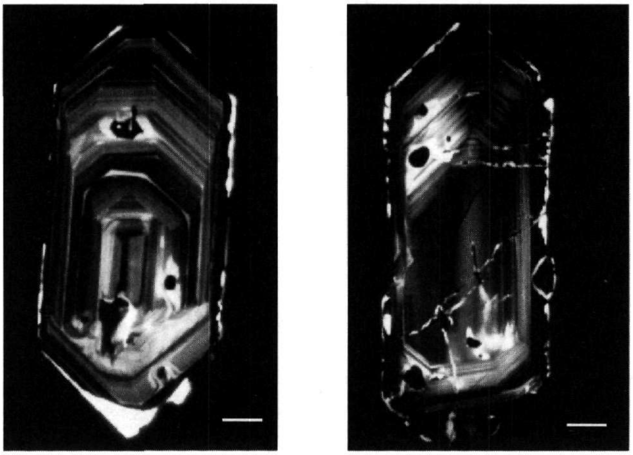

Figure 2 - Cathodoluminescence images of representative zircon crystals from the KGC showing oscillatory zoning, typical for co-magmatic zircons. Note the bright thin rims (broadest at the bottom of the left-side crystal) and fractures (right-side crystal) indicative of post-crystallization interaction with fluids (see text). White bars are 20 microns

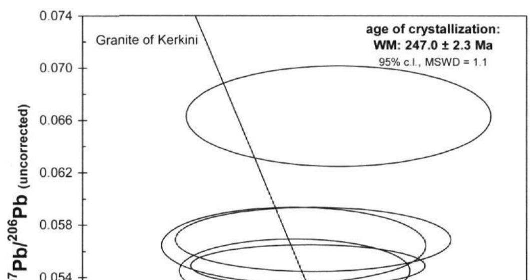

Figure 3 - Tera-Wasserburg plot with data from the KGC

Six representative whole-rock samples were analyzed for Sr isotopes. Using all data an age of 259±12 can be obtained with an MSWD value equal to 18 (Fig. 4a). Due to this high MSWD value the regression line can be interpreted as errorchorn rather than isochron. Using five of the six samples (excluding MP-100 although no petrological reason exists) a quite similar age of 259.0±7.8 Ma is calculated but with a significantly lower MSWD value of 6.4 (Fig. 4b). Taking into account the number of samples, the latter MSWD value allows us to interpret this line as representing an isochron. The 259±12 Ma or 259.0±7.8 Ma Rb/Sr age is, within uncertainty, in line with the 247.0±2.3 Ma U-Pb SHRIMP age interpreted as the time of crystallisation of the granite. Whole-rock - biotite pair gave 137 Ma while two whole-rock - white mica pairs gave 152 and 246 Ma (Table 2).

7. Tectonic setting

The major element geochemistry of the KGC rocks is consistent with late-orogenic and anorogenic granitoids as defined by Batchelor and Bowden (1985) (Christofides *et al.* 1999). Moreover KGC rocks plot in the within-plate granites (WPG) field of Pearce *et al.* (1984) diagrams, showing that their genesis is very probably related to a WPG tectonic setting. However, the characteristic geochemical features of KGC could also be related to its source material rather to a specific tectonic setting.

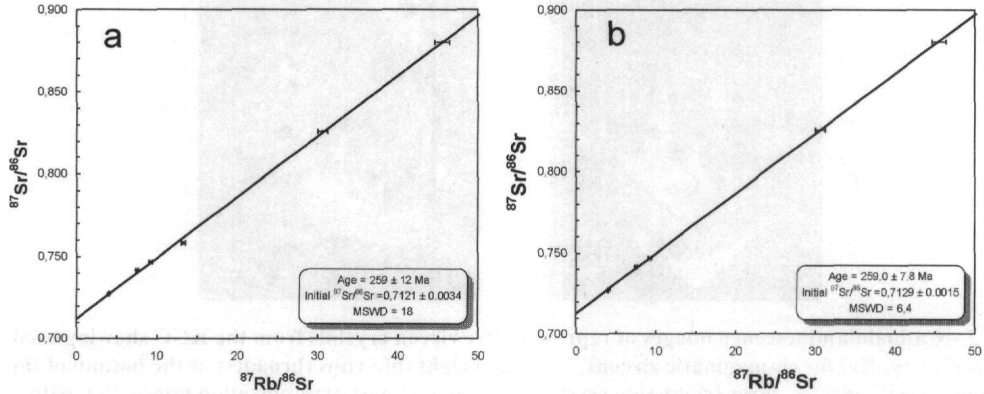

Figure 4 – Rb-Sr whole-rock 6-point errorchron (a) and 5-point isochron for the KGC

Table 2 - Whole-rock and micas Rb-Sr isotopic data for the KGC

Sample		Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	2σ abs	$(^{87}Sr/^{86}Sr)_0$	±	Age (Ma)
MP-100	wr	178.3	38.9	13.3267	0.758068	38	0.7107	9	
MP-100	bt	902.2	8.8	316.0	1.34618	2			136.7±1.4
MP-103	wr	46.0	33	4.0407	0.727195	36	0.7128	3	
MP-103	wm	173.0	8.0	65.35	0.94140	7			245.6±2.6
MP-104	wr	112.5	43.3	7.5420	0.741513	37	0.7147	5	
MP-104	wm	424.1	6.7	190.3	1.13712	3			152.2±1.6
MP-114	wr	124	39	9.2343	0.746810	37	0.7140	7	
MP-105	wr	220	21	30.6608	0.825900	41	0.7169	22	
MP-23	wr	201	13	45.4883	0.880010	44	0.7182	32	

Error on $^{87}Rb/^{86}Sr$ is 1%; wr, whole-rock; bt, biotite; wm, white mica.

8. Origin

The plot of the KGC in the WPG field of Pearce *et al.* (1984) discriminant diagram (see Christofides *et al.* 1999) is an indication that it is related with A-type granite magmatism (Pearce *et al.* 1984, Whalen *et al.* 1987, Eby 1990). In fact the Kerkini granitic complex has features characteristic for A-type granites as these have been described by many authors for various suites of such type e.g. Collins *et al.* (1982), Whalen *et al.* (1987), Eby (1990), Landenberger and Collins (1996), Mohamed *et al.* (1999). In particular the rocks investigated: are peraluminous, are depleted in MgO and CaO, enriched in total alkalis and they have high FeOt/MgO ratios, are enriched in Zr, Nb, Y, Ga and REE, they have strong negative Eu anomaly and they contain iron-rich interstitial biotite (annite), and fluorite, indicating dry or almost anhydrous melts with elevated fluorine content.

Moreover the KGC samples fall in the A-type granite field of Whalen *et al.* (1987) discriminant diagrams (see Christofides *et al.* 1999) and of Eby's (1990) discriminant diagrams FeOt/MgO and 10000*Ga/Al vs Zr+Nb+Ce+Y (Figs 5a, b).

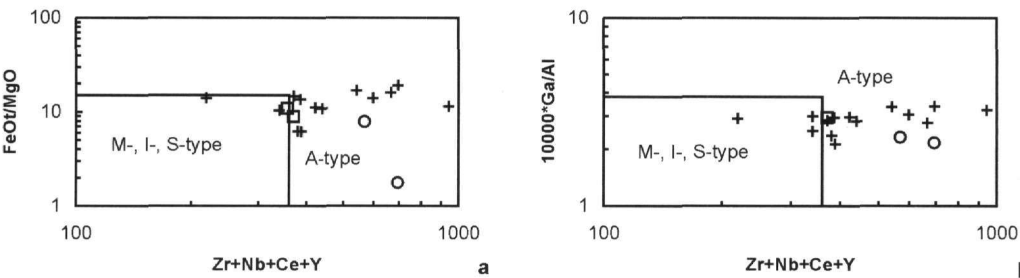

Figure 5 – Plot of the KGC samples on the Eby's (1990) discrimination diagrams. Cross, MUR; circle, KAS; rectangle, MIR

Several mechanisms have been considered for the genesis of A-type magmas. The most credible genetic model involves high temperature partial melting of melt-depleted I-type source rocks (a granulitic residue) in the lower continental crust (Collins *et al.* 1982, Clemens *et al.* 1986, Whalen *et al.* 1987). In such a model, melting would probably involve fluid-absent breakdown of residual, halogen-enriched micas and amphiboles and the melts would be relatively water poor. The genesis of A-type granites has also been explained by partial melting of non-restitic crustal igneous rocks of tonalitic to granodioritic composition at mid-crustal pressures (Creaser et *al.* 1991, Skjerlie and Johnston 1993). An alternative model for the origin of A-type granites involves partial melting of a lower-crustal source that was dehydrated, but not geochemically depleted (Landenberger and Collins 1996).

Fluid-absent melting experiments on a biotite (20 wt%) and hornblende (2 wt%) bearing tonalitic gneiss (sample AGC150) were conducted by Skjerlie and Johnston (1993) at 6 kbar (900-975 ^{0}C), 10 kbar (875-1075 ^{0}C) and 14 kbar (950-975 ^{0}C) to study melt productivity from weakly peraluminous quartz-feldspathic metamorphic rocks. These experiments showed that the dehydration-melting of F-enriched biotite source produces F-rich granitic liquids with compositions within the range of A-type granites leaving behind a granulitic residue dominated by orthopyroxene, quartz and plagioclase. Initiation of dehydration melting is caused by intrusion of hot, mantle-derived magmas into the lower crust.

A crustal origin for the KGC is supported by its relatively high Sr initial ratio (0.7107-0.7182 based on 247 Ma) and its Y/Nb ratio (2.4 to 4.3) which falls within the range 1.2-7 for which Eby (1990) considered a crustal involvement in magma genesis. The majority of the KGC samples which plot on the A – B diagram of Debon and Le Fort (1983) fall in the field defined by the experimental liquids of Skjerlie and Johnston (1993) in particular where the liquids were produced at

6 - 10 kbar and 950 - 975 ^{0}C (see Christofides *et al.* 1999). Note the dispersion of the KAS granodiorite in the above field. Therefore, a similar source and a similar mechanism would give the Kerkini granites. It is worth mentioning that the internal structure of the zircons (lack of inherited cores; a single magmatic oscillatory zoning domain) strongly argues against a possible metasedimentary source for the genesis of this granite. The presence of plagioclase in the residue could explain both their strongly negative Eu anomaly and their low Sr content. Hence, the most probable genetic model for the origin of the KGC is fluid-absent melting of a biotite-rich tonalitic source at 950 - 975 ^{0}C and, due to the high Si content of white mica, at considerable depths, leaving a granulitic residue dominated by orthopyroxene, quartz and plagioclase (Christofides *et al.* 1999).

9. Discussion - conclusions

The 247.0±2.3 Ma age obtained by SHIRMP on zircon crystals, supported also by the Rb-Sr whole rock age (259±12 Ma or 259.0±7.8 Ma), is considered as the crystallisation age of the granite and places its genesis in the Late Permian/Early Triassic boundary. The identical 246±3 Ma Rb-Sr age on white mica of KGC, is also interpreted as the crystallisation age (Fig. 6). It seems that white mica has at least partly kept its magmatic signature implying that the metamorphism affecting the granite was of relatively low grade allowing white mica to escape total recrystallisation and total resetting of the Rb-Sr system. This is in accordance with the development of very thin metamorphic domains of the zircons, as well as with petrological observations.

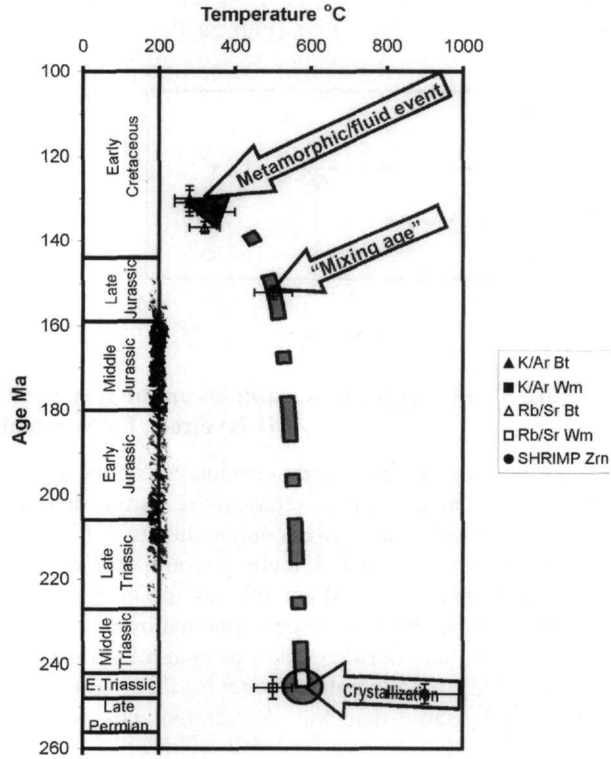

Figure 6 – Plot of mineral age vs. blocking temperature fot the KGC rocks

The K-Ar ages on micas and the Rb-Sr age on biotite can be interpreted by a metamorphic/fluid event at about 133 Ma. K-Ar and Rb-Sr mica ages of 102 to 131 Ma obtained from Vertiscos rocks were interpreted (Papadopoulos and Kilias 1985) to reflect a retrograde and deformation event or a lower Cretaceous rejuvenation (Frei 1992). The last event was considered by Sakellariou (1989) equal to the regional lower amphibolite facies metamorphic event responsible for the main structural overprint in the SMM rocks. The 152±2 Rb-Sr white mica date could be considered as a "mixing age" between the crystallization age of the granite (ca. 247 Ma) and the metamorphic/fluid event (ca. 133 Ma). This "mixing age" very probably reflects partial resetting of the Rb-Sr white mica isotopic system. The same is true for the 137 Ma Rb-Sr biotite age (Fig. 6).

The Late Permian/Eearly Triassic KGC is a WPG with A-type granite characteristics. Its Sr initial ratio, ranging between 0.7107 and 7182 (based on 247 Ma) reflects the high contribution of crustal material for the magma genesis. The most probable genetic model for the origin of KGC is fluid-absent melting of a biotite-rich tonalitic source at 6 - 10 kbar and 950 - 975 ^{0}C, leaving behind a granulitic residue dominated by orthopyroxene, quartz and plagioclase (Christofides *et al.* 1999).

The A-type characteristics of KGC and its WPG tectonic setting is in favour of a rift-related genesis although its A-type characteristics could also be related to its source material, having a peculiar composition or even to a post-collisional tectonic setting (cf. Eby 1992, Wu *et al.* 2002, Zhou 2006) although a clear distinction between rift-related and post-collisional A-type granites is not well documented. A rift responsible for several magmatic events in the broader area has been suggested by many researchers (cf. Pe-Piper and Piper 2002 and references therein). De Wet (1989) suggested a rift event to which he ascribed the magmatism that gave the Arnea granite. A rift event is also considered responsible, by Kostopoulos *et al.* (2001), for the Arnea granite, which although younger (215.0±1.8 Ma) than KGC shows many geochemical similarities (Christofides *et al.* 2000). Moreover, Dimitriadis and Asvesta (1993) considered most of the "volcano-sedimentary" series as related to a Permian - Triassic rift. Hence, it is concluded that the genesis of KGC is very probably related to the Permian – Triassic event that affected the broader area. It is noted that in W. and E. Rhodope, eclogites of Upper Permian protolith ages, indicating a rift-related setting are also reported (Liati and Fanning 2005). Finally, poly-episodic Permo-Triassic rifting, indicated by different thermal pulses of mainly felsic but also mafic magmas in this time period, is also a general feature commonly identified in Western Europe.

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