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Rb-Sr GEOCHRONOLOGICAL, PETROLOGICAL AND STRUCTURAL STUDY OF THE KAVALA PLUTONIC COMPLEX (N. GREECE)

K. KYRIAKOPOULOS, A. PEZZINO, A. DEL MORO

ABSTRACT

Petrological and petrochemical studies that carried out on samples from Kavala plutonic body shown that it is mainly consisted of granitic-granodioritic composition. The mylonite granodiorites are the most widespread rock types that occur in the entire area of the plutone.
Major and trace element data indicate that these magmatic products displaying a typical calcalcaline chemical character.
The Rb-Sr ages obtained on whole rock dating indicate a later post-recrystallization closure of the Rb-Sr system. The isotope re-equilibration of Sr that apparently was reached locally has dated the mylonitization event that took place around 18 Ma. The mica ages (14-16 Ma) are slightly lower than the isochron ages and follow closely the deformative event.
The structural, micro-structural and paragenetic characteristics of the study rocks suggest that they were deformed, after their crystallization in border conditions between a quasi-plastic and elasto-frizional environment. As a result, we suppose that this shear phase is strictly connected with the overthrust of the Serbo-Macedonian massif onto the lower group of the Rhodope massif during Miocene.

ΣΥΝΟΨΗ

Η πετρολογική και πετροχημική μελέτη που έγινε σε δείγματα από το πλουτώνιο σώμα της Καβάλας έδειξε ότι αποτελείται κυρίως από πετρώματα γρανιτικής και γρανοδιοριτικής σύστασης. Οι γρανοδιοριτικοί βλαστομυλονίτες αποτελούν το πιό εκτεταμένο πέτρωμα που απαντάται σε όλη την περιοχή του πλουτωνίτη.
Τα κύρια χημικά στοιχεία και ιχνοστοιχεία έδειξαν ότι αυτά τα μαγματικά προϊόντα παρουσιάζουν ασβεστοαλκαλικό χαρακτήρα.
Οι ηλικίες που προέκυψαν με τη μέθοδο γεωχρονολόγησης Rb-Sr στο ολικό πέτρωμα αντιπαλλούν το τελευταίο υστερο-μαγματικό κλείσιμο του συστήματος Rb-Sr.

KYRIAKOPOULOS, K.*, PEZZINO, A.**and DEL MORO A.***—Rb-Sr ΓΕΩΧΡΟΝΟΛΟΓΙΚΗ, ΠΕΤΡΟΛΟΓΙΚΗ ΚΑΙ ΤΕΚΤΟΝΙΚΗ ΜΕΛΕΤΗ ΤΟΥ ΠΛΟΥΤΩΝΙΟΥ ΣΥΜΠΛΕΓΜΑΤΟΣ ΤΗΣ ΚΑΒΑΛΑΣ (Β. ΕΛΛΑΔΑ).

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Ο χρόνος της ισοτοπικής εξισορρόπισης του Sr, που όπως αποδεικνύεται επηρέασε τοπικά τον πλουτωνίτη, αναφέρεται στο τεκτονικό γεγονός που προκάλεσε τη μυλονιτίωση, πριν από 18 περίπου εκατομμύρια χρόνια. Οι ηλικίες των μαρμαρυγιών Rb και K εκατ. χρόνια είναι ελαφρώς μικρότερες από τις ηλικίες που ελήφθησαν με την εφαρμογή της μεθόδου της ισόχρονης ευθείας και αντανακλούν το χρόνο μετά το παραμορφωτικό γεγονός.
Τα ιστολογικά, μικρο-δομικά και παραγενετικά χαρακτηριστικά των πετρωμάτων που μελετούνται φανερώνουν ότι υπέστησαν μεταμορφικές διεργασίες μετά την κρυστάλλωσή τους, σε σχεδόν οριακές συνθήκες μεταξύ ημι-πλαστικής μέχρι ελαστικής κατάστασης, σε θερμοκρασίες χαμηλού βα μεταμόρφωσης.
Τέλος, μπορούμε να υποθέσουμε ότι αυτές οι διατμητικές φάσεις που επηρέασαν τον πλουτωνίτη συνδέονται άμεσα με τις επωθητικές κινήσεις της Σερβο-Μακεδονικής μάζας προς το κατώτερο τμήμα της μάζας της Ροδόπης που έλαβαν χώρα κατά τη διάρκεια του Ολιγοκαίνου - Μειοκαίνου.

1. INTRODUCTION

This paper summarises the new geochronological, petrochemical and structural data on the tectono-magmatic evolution of the Kavala plutonic complex.

The plutonite intrusion of Kavala is located on the south-western margin of the Rhodope massif and forms the core of an anticline structure. It is a SW-NE elongated granitoid body about 45 Km long and 5-12 Km wide (fig. 1) (KOKKINAKIS, 1977).

The Rhodope massif is made up of a sequence of crystalline rocks of medium-high metamorphic grade of pre-Paleozoic and Paleozoic age (BITSIOS et al. 1981). The rocks of the crystalline basement are subdivided into two main units: i) the lower gneiss-amfibolite and ii) the upper carbonate (PAPANICOLAOU AND PANAGOPOULOS 1981, DIMADIS AND ZACHOS 1987).

The plutonite of Kavala intruded the lower unit of the crystalline basement of the Rhodope massif. The North-Northeast boundaries come to contact with the high grade metamorphic rocks, mainly composed of gneisses, amphibolites, gneiss-schists, micaschists and marbles. The plutonic and metamorphic rocks are both mylonitic (KOKKINAKIS, 1980, DERCOURT et al. 1980).

Part of the South Rhodope massif was not a stable structural block, but was affected by intense tectonic metamorphic and widespread magmatic activity (BONCEV 1970).

A large number of granitoid stocks intruded the entire area of the Rhodore massif, ranging in age from 44-36 Ma in Western Bulgarian territory to 28.6-26.3 Ma for Xanthi, 31.9-31.8 Ma for Leptokaria-Kirki, 29.8-28.9 Ma for Maronia and 18.9-18.5 Ma for Samothraki (BOYADJLEV AND LILOW 1976, ELEFTHERIADIS AND LIPPOLT 1984, DEL MORO et al. in press, KYRIAKOPOULOS 1987).

As reported by LYNBERG 1978, there are three different groups of granitoids in the area of the western Rhodope massif, i) the schistose granitoids: tectonically strongly deformed and characterised by a marked schistosity and lineation, mainly of granodioritic composition, ii) granitoids with migmatites: granitic rocks with a close mixture of granitoids and host rocks of mainly granitic-granodioritic composition and iii) massive granitoids: without parallel structure, and mainly of granodioritic or occasionally gabbroic composition.

The schistose (mylonitic) granitoids, including those of Symvolo and Pangheon, were deformen during the same tectonic phase and in the same manner as the corresponding structures observed in the surrounding metasedimentary rocks, resulting in schistosity and lineation with a characteristic NE-SW trend.

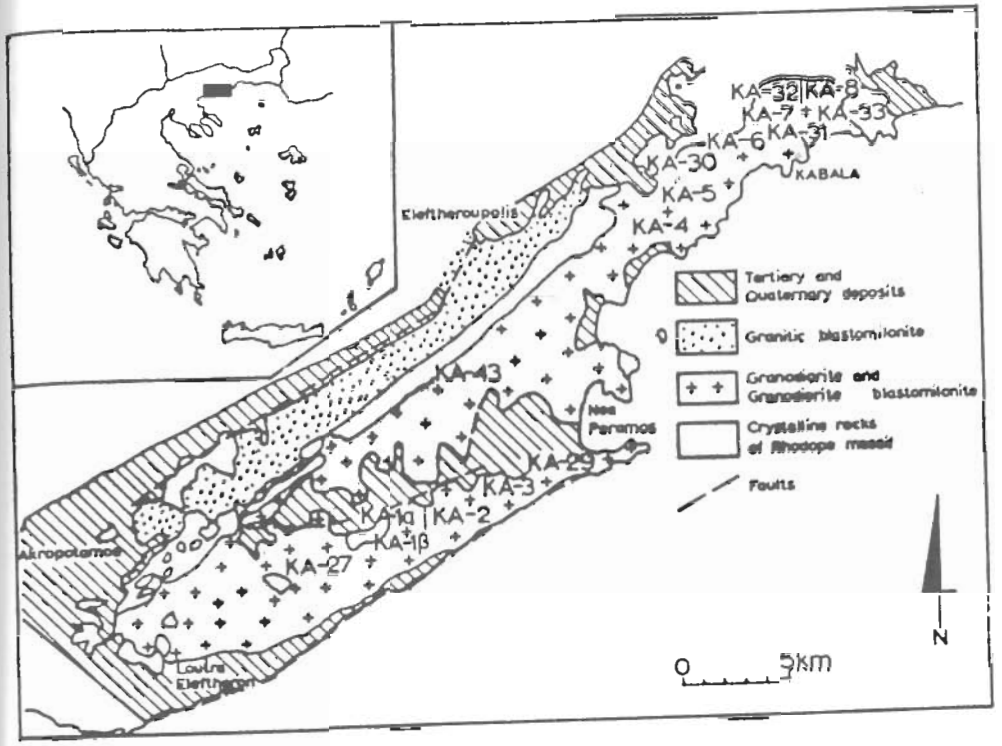


Fig. 1. Geological sketch-map of the Kavala plutonic complex, after Kokkinakis (1977).

Σχ. 1. Γεωλογικός χάρτης του πλουτωνίου συμπλέγματος της Καβάλας κατά Κοκκινάκη (1977).

The contacts with the surrounding rocks are usually sharp and transposed by tectonic shear events. The main petrological types are gneiss granites- granodiorites. The mylonitic granodioritic rocks predominate in the Kavala granitoids. Aplitic veinlets of various sizes are very frequent.

The igneous rocks outcropping in the area of the Rhodope massif are products of the intense magmatic activity during Tertiary age. According to the available geochronological data, the main magmatic events in the Rhodope massif occurred during the last stages of the Alpine orogenic regime (Eocene-Oligocene-Miocene) (FYTIKAS et al. 1984, INNOCENTI et al. 1984).

The granitoids were generated in a geotectonic environment which was determined by the subduction of the oceanic lithospheric slab of Axios (Vardar) zone beneath the Serbomacedonian and the Rhodope massifs (BOCCALETTI et al. 1974, JACOBSHAGEN 1977, YARWOOD 1977).

Within this geodynamic framework, the structural relations between the Serbomacedonian and Rhodope massifs (and especially the lower unit of the Rhodope) are of crucial importance in any reconstruction of the tectono-magmatic events affecting the Kavala plutonic complex. These two massifs come in contact along a line passing east of the Strimonas river (not far south of the study area), (KOCKEL et al, 1971, KOUKOUZAS 1972) with NE verging overthrust frontal zone and NE-SW trending overthrust surfaces dipping 30° -60° south-westwords (DERCOURT et al. 1980).

The age of the overthrust is considered to be Oligocene (KOUKOUZAS 1972, KOCKEL AND KARPELIS 1980) or post-Oligocene (DERCOURT et al. 1980).

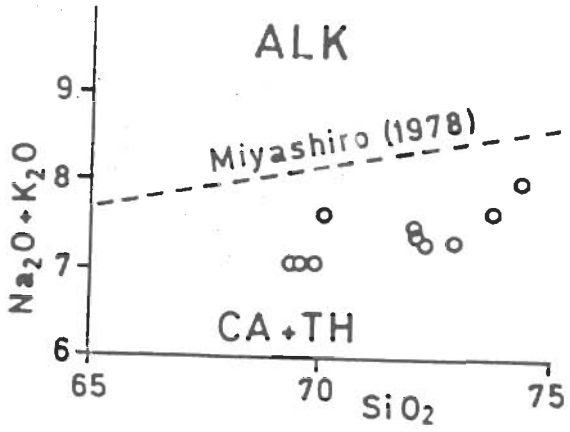


Fig. 2. Plot of the studied samples in the SiO_2 vs (Na_2O+K_2O) diagram after Miyashiro (1978).

Σχ. 2. Προβολή των δειγμάτων που μελετήθηκαν στο διάγραμμα SiO_2—(Na_2O+K_2O) κατά Miyashiro (1978).

2. CHEMICAL CHARACTERISTICS

Ten representative samples were analysed for major elements by XRF, except for MgO (by AA spectrometry), FeO (by tritation) and LOI.

Some trace elements were analysed in the same speciments by XRF; accuracy was evaluated by comparison with the results obtained on some rock-standards (not quoted here);U and Th were determined by gamma spectrometry

Major and trace element contents of the rocks analysed are reported in Table 1. The samples show a very small variation in SiO_2 (69-74%), low TiO_2 (< 0.3%), total FeO (≤ 2.3%) and MgO (< 0.9%);their composition is moderately peraluminous and (A/KCN ratio range between 1 and 1.7).

On the whole, they have a calcalcaline affinity in terms of (Na_2O+K_2O) vs SiO_2 (fig. 2), FeO_t/MgO vs SiO_2 and FeO_t/MgO vs FeO_t plots (fig. 3a,b); the Na_2O/K_2O ratio is always 1.

The k/Rb ratio is constant (200-300) with values typical of granitic rocks. Small but significant variations occur for trace elements of the speciments KA-1a, Ka-1b and Ka-2. These have the lowest contents of Th, U, Zr, Ba, Sr, La and Ce and come from the central southern and most deformed part of the pluton. The Th/U ratio in these samples is higher than 4.5, whereas in the other samples this ratio is lower than 3.3. These chemical differences could be the result of a fluid circulation along a preferential direction in the plutonic complex (HICKMAN AND GLASSLEY, 1984). The ferromagnesian trace elements are generally, in very low concentrations.

According to the multication classification of De La ROCHE et al. (1980), the samples can mainly be assigned to the granodiorite field (fig. 4).

3. Rb-Sr RESULTS

Fourteen samples have been analused for Sr isotopic composition, together with their Sr and Rb elemental contents (Table 2). In a classic Sr isotope

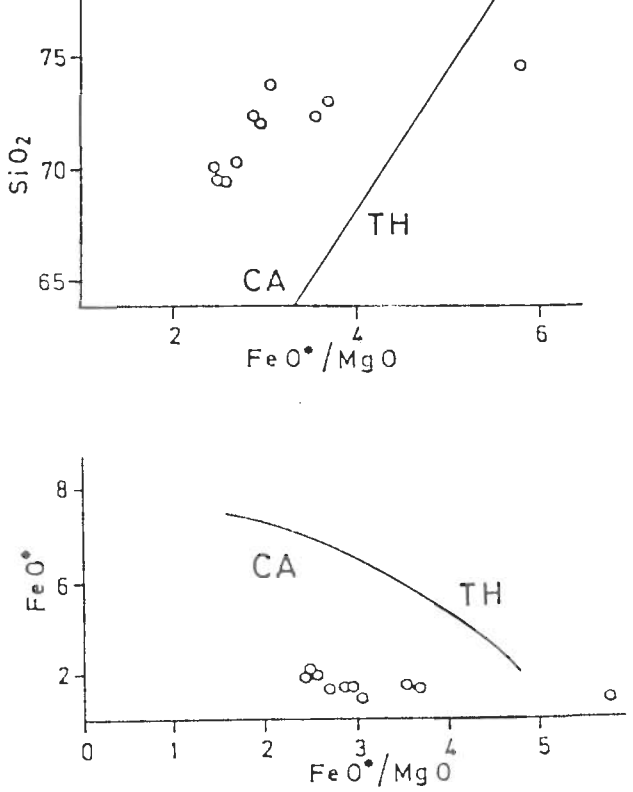


Fig. 3. Plot of the studied samples in the diagrams: a) SiO_2 vs FeO_t/MgO, b) FeO_t vs FeO_t/MgO.

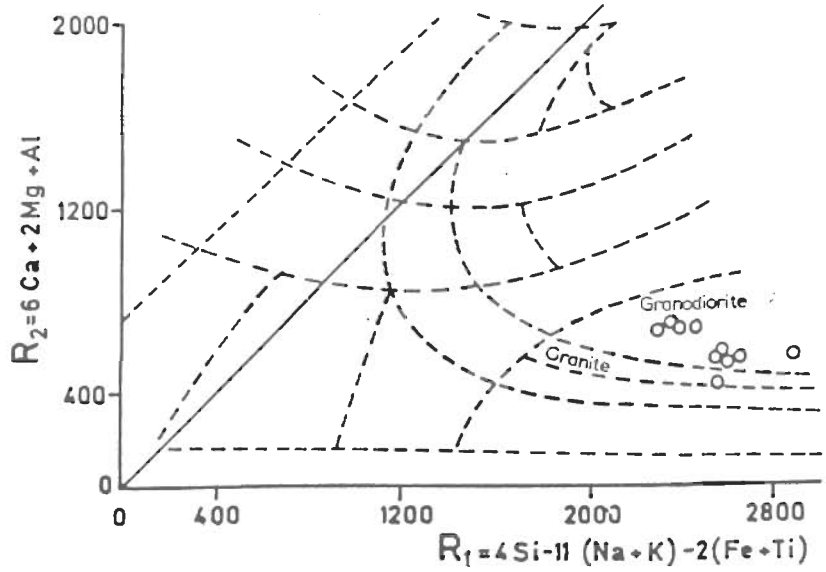


Fig. 4. Plot of the analyzed samples in the DE LA ROCHE et al. (1980) classification diagram R_1—R_2.

Σχ. 4. Προβολή των δειγμάτων που αναλύθηκαν στο διάγραμμα ταξινόμησης R_1-R_2 κατά DE LA ROCHE et al. (1980).

Table 1. Representative chemical analyses of the Kavala plutoni body. Major elements % and trace elements ppm abundances.

Sample	KA-1a	KA-1b	KA-2	KA-3	KA-4	KA-5	KA-6	KA-7
SiO_2	72.10	72.34	73.74	70.30	72.29	72.99	69.98	69.39
TiO_2	0.20	0.20	0.13	0.17	0.18	0.16	0.26	0.26
Al_2O_3	15.29	15.09	14.78	16.39	15.03	14.79	15.72	15.76
Fe_2O_3	1.00	0.96	0.61	0.92	0.88	0.85	1.09	1.15
MnO	0.05	0.05	0.05	0.05	0.05	0.08	0.05	0.03
MgO	0.53	0.54	0.33	0.54	0.42	0.36	0.83	0.82
CaO	2.16	2.12	2.04	2.98	2.44	2.24	3.08	3.27
Na_2O	4.25	4.21	4.02	4.82	3.91	3.78	4.12	4.26
K_2O	3.19	3.12	3.65	2.75	3.46	3.53	2.94	3.01
P_2O_5	0.08	0.08	0.05	0.04	0.07	0.05	0.10	0.12
LOI	0.51	0.60	0.40	0.42	0.58	0.60	0.75	0.90
A/CNK	1.06	1.07	1.04	1.00	1.03	1.05	1.01	0.95
Ni	2.00	3.00	2.00	3.00	2.00	2.00	4.00	3.00
Cr	4.00	3.00	2.00	5.00	3.00	2.00	3.00	5.00
V	19.00	20.00	12.00	27.00	14.00	14.00	34.00	36.00
Rb	127.00	126.00	139.00	73.00	125.00	144.00	114.00	122.00
Sr	465.00	466.00	306.00	706.00	545.00	460.00	676.00	576.00
Ba	572.00	564.00	358.00	701.00	778.00	643.00	701.00	580.00
Zr	117.00	116.00	91.00	138.00	171.00	146.00	151.00	150.00
Nb	11.60	10.80	10.30	9.80	11.90	16.80	10.60	11.90
Y	15.90	16.10	15.80	14.00	18.90	37.10	16.70	18.20
Ce	37.00	45.00	28.00	44.00	75.00	66.00	60.00	61.00
La	20.00	23.00	14.00	22.00	34.00	28.00	30.00	30.00
Th	14.80	14.40	15.80	17.90	22.90	28.00	20.50	27.30
U	2.90	3.20	3.40	6.30	7.90	11.20	9.70	17.00
Th/U	5.10	4.50	4.60	2.80	2.90	2.50	2.10	1.60

Table 2. Rb, Sr contents (ppm) and Sr isotope data from granitoids of the Kavala plutonic complex.

Sample	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$
KA-1	126	466	0.78	0.70798 ± 8
KA-2	139	306	1.31	0.70817 ± 4
KA-3	73	706	0.30	0.70703 ± 9
KA-4	125	545	0.67	0.70750 ± 8
KA-5	144	460	0.91	0.70761 ±11
KA-6	114	676	0.49	0.70688 ± 9
KA-7	122	576	0.61	0.70692 ± 8
KA-8	162	163	2.87	0.70802 ± 4
KA-27	179	366	1.42	0.70741 ± 5
KA-29	145	653	0.64	0.70732 ± 4
KA-30	199	70	8.27	0.71008 ± 4
KA-31	168	106	4.56	0.70782 ± 8
KA-32	293	174	4.88	0.70845 ± 6
KA-33	136	57	6.89	0.70882 ± 9

Corrected by 0.7080 (Eimer and Amend $SrCO_3$ standard)

Table 3. Rb-Sr mineral isotopic data from the Kavala plutonic complex.

Sample	Mineral	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$	Age Ma
KA-2	Biotite	1000	31.4	92.23	0.72630 ± 20	14.0 ± 0.4
KA-5	Biotite	973	36.5	77.48	0.72422 ± 28	15.3 ± 0.5
"	Muscovite	966	37.3	74.98	0.72342 ± 24	15.0 ± 0.5
KA-7	Biotite	986	5.4	534.39	0.82770 ± 12	
"	K-feldsp.	319	708.0	1.30	0.70728 ± 6	16.0 ± 0.5
"	Plagioclase	21.5	503.0	0.12	0.70695 ± 9	

Rb-Sr mica ages are calculated using mica-whole rock isochron. Whole-rock analyses are shown in Table 2.

evolution diagram of the whole rock samples show a good linear array but scatter along a 21 Ma reference line (I.R. = 0.70721-2) obtained data using main frame computer system. This suggests either secondary disturbances of the whole rock Rb-Sr system or an initial isotopic heterogeneity or both.

The widespread effects of the pervasive strain of the samples suggest that the first hypothesis is more reliable, indicating an open-system behaviour of the rocks, which, to different extents, lost their Rb and Sr during the deformative event without aschieving a general Sr isotopic rehomogenization.

According to recent studies on deformational and metamorphic processes (DIETRICH et al. 1969, ABBOT 1972, GRIFFITH et al. 1977, ETHERIDGE AND cooper 1981, O'HARA AND GROMET 1983, HICKMAN AND GLASSELEY 1984) a total-rock Rb-Sr isochron on a shear zone generally dates the time of the last strain episode.

In the Kavala plutonic complex the total lack of unsheared zones prevents any determination of its intrusion age by radiometric techniques.

However, in the 87Sr/86Sr vs 87Rb/86Sr plot in Fig. 5 four linear arrays give a similar age but different initial Sr isotopic ratio, which could be interpreted as the result of a process loading to Sr isotopic equilibrium on a few Km-scale. So these regression lines could indicate the age of the shear event.

Even though the specimens are, on the whole, chemically homogeneous, the Sr isotope families described earlier have some distinctive features. Samples KA-1 and KA-2 (KA-30 was not analyzed chemically), which have highest Sr isotope value, have Ba, Zr, La, Ce, U, Th and, to a minor extent Sr and CaO, contents that distinguish them from all the other samples.

The isotopic groups are subdivided areally and distributed along SW-NE parallel bands in the map (Fig. 6). The two leucocratic dyke samples (KA-8 and KA-30) however fall outside the main groups.

The Rb-Sr mica ages that are reported in Table 3, range between 14 and 16 Ma, are slightly lower than the isochron ages and follow closely on the deformative event KOKKINAKIS (1980), ELEFTHERIADIS AND LIPOLT (1984) reported similar biotite ages on the same pluton by K-Ar radiometric method. The first author (op. cit.) also obtained significantly older discordant U-Pb zircon ages.

The slight discrepancy between the Rb-Sr mineral ages (14-16Ma) and Rb-Sr whole rock dating (18-19 Ma), indicates a later post-recrystallization closure of the Rb-Sr mica system and a similar behaviour of the biotite and muscovite clocks in this case.

The variable Rb-Sr mineral ages seem to be related with the intensity of tectonization, decreasing from the SW sector to the NE. The less deformed rocks are in fact located near Kavala, in the north-eastern part of the plutonic body.

4. STRUCTURAL AND PETROLOGICAL EVIDENCE

Structural analysis of a representative sections from the Mirtofiton area revealed that deformational events affected both the plutonic and associated metamorphic rocks.

These are effectively mylonites s.l. (from protomylonites to ultramylonites) with a penetrative foliation (Fm) that in some cases entirely obliterates the originel structures. This foliation is less marked in the mica poor lithotypes with coarse grain (Phot. 1). Stretching lineation (b_2) on this surface trends mainly NW-SE, dipping NE.

The direction of these lineations depents to a great extent on the size

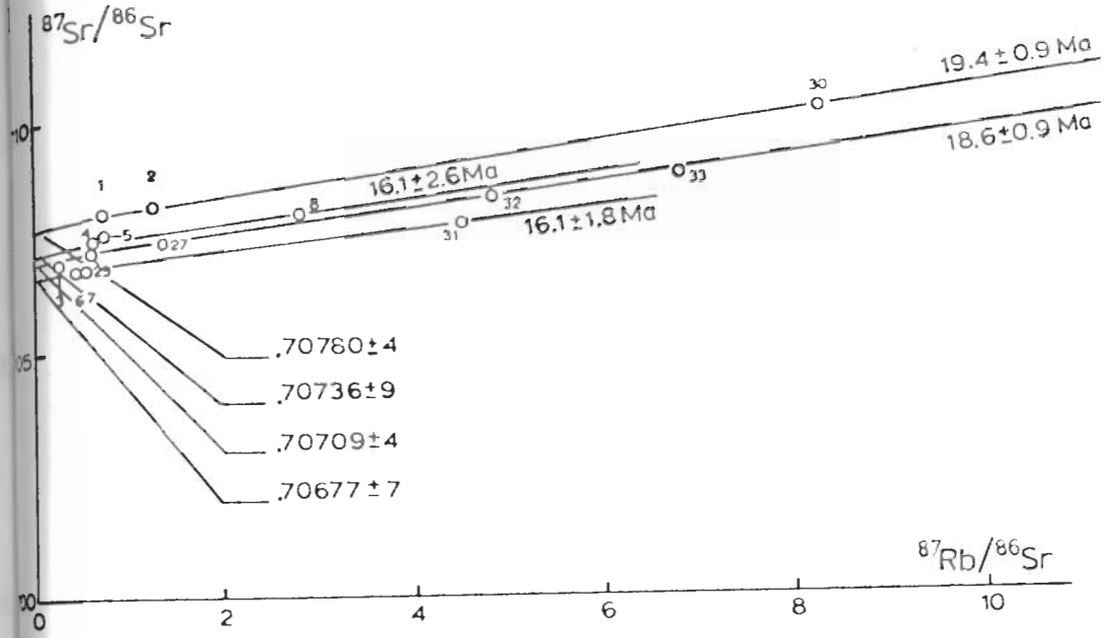


Fig. 5. Whole rock $^{87}Sr/^{86}Sr$—$^{87}Rb/^{86}Sr$ isochron diagram of the Kavala plutonic complex.

Σχ. 5. Διάγραμμα $^{87}Sr/^{86}Sr$—$^{87}Rb/^{86}Sr$ ισόχρονης ευθείας ολικού πετρώματος για τον πλουτωνίτη της Καβάλας.

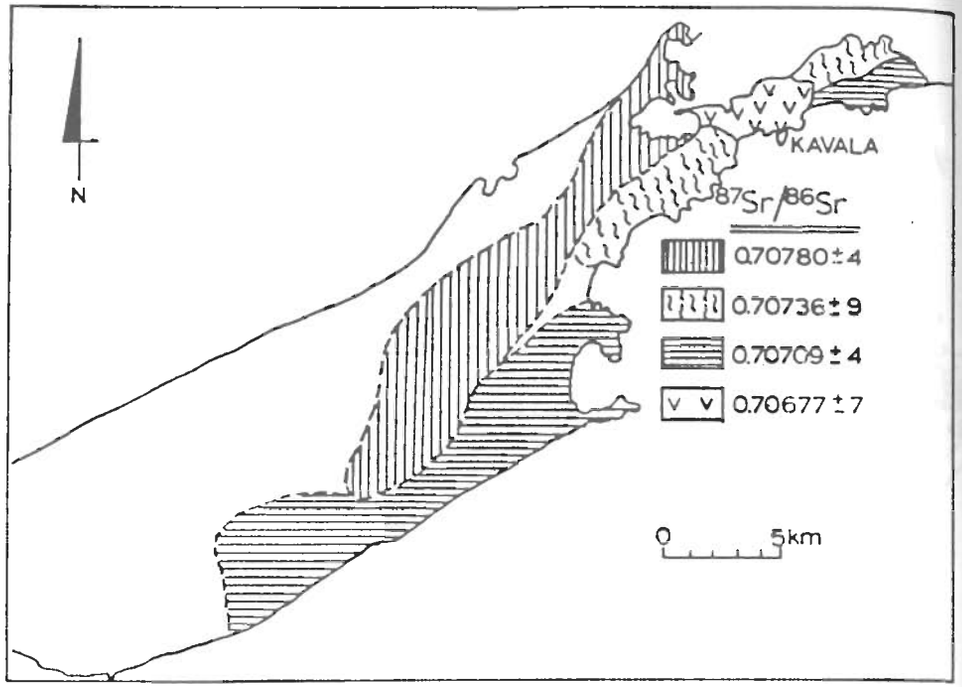
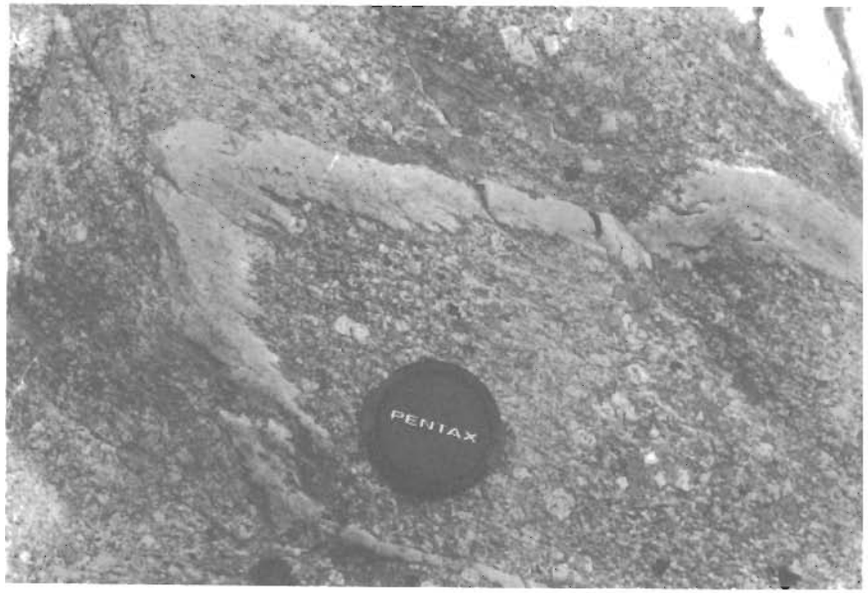


Fig. 6. Distribution of the initial strontium isotopic ratio $(^{87}Sr/^{86}Sr)_o$ values in the area of the Kavala plutonic complex.

Σχ. 6. Κατανομή της τιμής του αρχικού ισοτοπικού λόγου του στροντίου $(^{87}Sr/^{86}Sr)_o$ στην περιοχή του πλουτωνίτη της Καβάλας.



Phot.1. Axial plane shistosity of aplitic veins in the granodioritic rocks. Fm foliation is less marked in the mica poor lithotypes with coarse grain.

Φωτ. 1. Ανάπτυξη σχιστότητας κατ'αξονικό επίπεδο απλιτικής φλέβας στα γρανοδιορητικά πετρώματα. Η φύλλωση (Fm) είναι λιγότερο εμφανής στους πτωχούς

of the porphyroclasts;the lineations are more marked and irregular where there is a predominance of granites with large feldspathic augens.

In areas in which the deformative events accured at shallower depths, pseudo-tachylites of a few millimeters in size have developed parallel to the cataclastic surfaces.

Analysis of the mesostructural features indicates that this deformative episode definitely occurred after the emplacement of the plutonic complex since the contacts between the later and the host metamorphites were adopted and reoriented in Fm by the dynamic event. This foliation in the metamorphites followed, and in some cases mobilized, an axial plane schistosity of isoclinal folds.

The structural features of this foliation show no change throughout the section analysed, except a variation in intensity.

Under microscope the mesoscopic structural evidence in the granitoid rocks is confirmed;the microstructural characteristics differ according to the grain and % of mica. The predominant lithotypes are protomylonites (SIBSON, 1977, 1983) with 10-20 % of recrystallized matrix. Their S planes (corrisponding to the mesoscopic Fm) are well-defined and the C planes less so. There are numerous protomylonites with 40-50 % matrix and mylonites with more than 50 % of recrystallized matrix. The latter have SC I and SC II type structures (BURG and LAURENT 1978, BERTHE et al. 1979, LISTER and SNOKE 1984, VAUCHEZ 1987) that are very well-defined (Phot.2). Less frequent are the protomylonites with more than 90 % of matrix.

Rotational structures in the porphyroclasts occur frequently in the lithotypes with an average or high percentage of matrix, whereas SC II type structures can be noted in the mica-rich lithotypes (LISTER and SNOKE 1984).

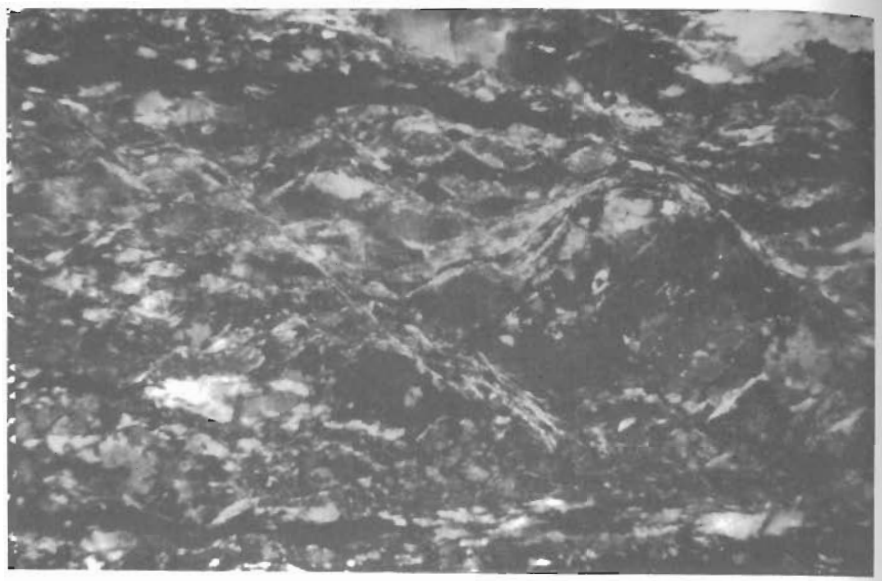
Mylonitization not only reduced the grain size and increased the C and C'planes, but also reduced the α angle between the S and C planes (Fig. 7). The lowest value found in the most deformed lithotypes was 20^o .

As regards mineralogical composition, the main asemblage is that produced by: K-feldspars in porphyroclasts, even of large size (4-5 cm), with rotational structures, C and C'conjugated shear systems, with extension fractures perpendicular to stretching (Phot. 3, Fig. 8); Quartz rarely in phenoclasts, usually recrystallized in the graoundmass in continous S-oriented bands (=Fm) and in microgranoblastic aggregates around the phenoclasts; Muscovite both in microcrystalline eggregates grouped in thin films along S, C and C'or, in the samples richest in mica, in isolated fish-type lamellae with planes (001) set at an angle of 0-35^o with respect to S; Biotite in crystallized microlamellar aggregates along S or in "fish" laminae, of a pretectonic nature, lying along S (=Fm); Plagioclase oligoclastic, usually in the groundmass and sometimes in fairly large porphyroclasts. Also garnet, zircon, epidote and sphene, usually in the groundmass.

The quartzose dyke manifestations cutting the Fm belong to a post-mylonitic event. A late folding phase affected both the Fm and the quartzose dykes.

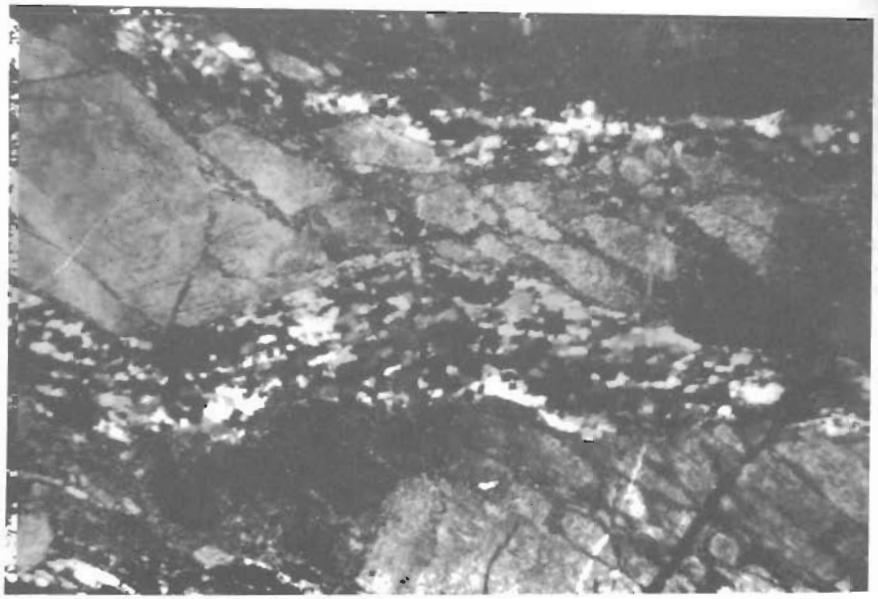
5. CONCLUSION REMARKS

The Rb-Sr isotope method applied to the strongly deformed granitoids of Kavala plutonic complex was unable to provide the age emplacement and of crystallization of the magmatic body, because of chemical and isotopic variations. In similar situations these processes have been shown to occur during dynamic recrystallization in the shear (mylonitic) zone.



Phot.2. Thin sections of a sheared granodiorite with S, C and C'surfaces. See text for details (Phot. 100 X).

Φωτ. 2. Λεπτές τομές από γρανοδιορύτη με διατμητικές επιφάνειες S, C και C'.



Phot. 3. Feldspatic clast oriented in the S-foliation surface. Whereas C-shear surfaces are evident, C'-shear surfaces are not. Quartz crystallized in continues S oriented bands and in micro-granoblastic aggregates around the phenoclasts, (phot. 25 X).

Φωτ. 3. Θραύσμα κόκκου αστρίων έχει προσανατολισμένες S επιφάνειες φύλλωσης. Όπου παρουσιάζονται οι C διατμητικές επιφάνειες, ενώ οι C' δεν φαίνονται. Ο χαλαζίας κρυσταλλώθηκε σε συνεχείς ταινίες παράλληλα στην επιφάνεια S και σε μικροβλαστικά συσσωματώματα γύρω από τους φαινοκρυστάλλους.

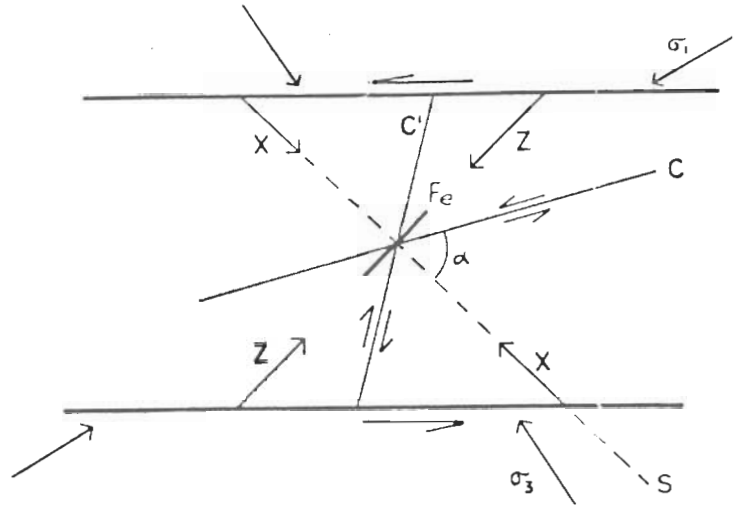


Fig. 7. Relationships between S-foliation surface, C and C'- shear surfaces and extentional fracture (Fm). X and Z are the long and short axis of the Strain ellipsoid respectively. See text for details.

Σχ. 7. Σχέση μεταξύ S-επιφανειών φύλλωσης, C και C' διατμητικών επιφανειών και εφελκυστικών ρωγμών (Fm). X και Z είναι ο μεγαλύτερος και ο μικρότερος άξονας του ελλειψοειδούς των τάσεων αντίστοιχα.

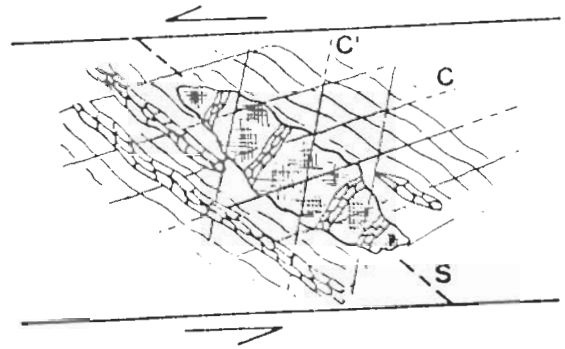


Fig. 8. Feldspatic clast oriented in the S-foliation surface. C—C' -shear surfaces and extentional fractures welded with quartz in filling are shown as well.

Σχ. 8. Θραύσμα κόκκου αστρίων έχει προσανατολιστεί κατά τις επιφάνειες φύλλωσης S. C και C' διατμητικές επιφάνειες και εφελκυστικές ρωγμές πληρωμένες με χαλαζία.

The overall open-system behaviour of the rocks also excludes any possible petrogenetic conclusions based on calculations of the initial Sr isotope ratio.

Viceversa, the isotope re-equilibration of Sr that apparently was reached locally has dated the mylonitization at around 18 Ma.

This age was confirmed by the mica analyses, which indicate that the shear process developed in the midle Miocene, decreasing in intensity from the south-western sector north-eastwards towards the plutonic complex.

At the same time, different proportions of some trace elements could have been removed by the fluid circulation during the same event but along different paths within the plutonic body.

The textural, microstructural and paragenetic characteristics of the plutonic rock samples suggest that they were deformed, after their crystallization, in border conditions between a quasi-plastic and elasto-frizional environment, at temperatures of lower grade metamorphism (SIBSON 1977).

The shear phase responsible for the formation of the SC 1 and SCC' 1 mylonitic structures in the granitoids and for the displacement of the intrusive contacts with the host metamorphites is likely associated with the complex tectonic phases involved in the convergence and interaction between the African and European plates and, in particular, with system of shears connected with the overthrust of the Serbo-Macedonian massif onto the lower group of the Rhodope massif. The contact surface between these two complexes runs just south of the study area with a NE vergence dipping 30-60°.

For high values of shear strain, the lineations in the mylonitic foliation also indicate the direction of transport across the shear zone (RAMSAY and GRAHAM 1970, SIMPSON and SCHIMD 1983). The lineations dippind NE wards in the Kavala plutonic complex indicate an overall movement southwestwards along NW-SE trending planes.

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