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IMPLICATIONS FROM ROCK CHEMICAL ANALYSIS AND ZIRCON CRYSTAL MORPHOLOGY FOR THE ORIGIN OF PELAGONIAN BASEMENT ROCKS IN THE KAMVOUNIA MOUNTAINS, NORTH THESSALY

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ABSTRACT

In the region of the Kamvounia mountains, north Thessaly, granite, gneiss, mylonitic gneiss, amphibolite and various schists constitute the Pelagonian basement which suffered Variscan and Alpine metamorphism. Chemical analyses of major and trace elements allow implications about the origin of these rocks. The mineralogical and chemical compositions of the granitoids (granites s. str. and granodiorites of the Deskati series) indicate a Caledonian I-type character. Using major element discrimination criteria to discern between ortho- and para-gneiss, the gneisses and mylonites show constantly igneous origin.

The trace element patterns (e.g. high Rb/Nb and Rb/Zr ratios) of the granites and granodiorites show characteristics of subduction-collision related intrusives. The occurrence of large volumes of undeformed granites attribute them to a late- to post-collisional setting of the Variscan orogeny. The trace element patterns of the gneisses and mylonites are identical to those of the undeformed granites to which they show transitions in the field. We propose that the granites were the protoliths of the gneisses and mylonites but escaped deformation. Therefore, the deformation of the gneisses and mylonites is likely to be of Alpine age.

The external morphology of zircon crystals from the granites and granodiorites is characteristic for magma of a mantle origin. Cathodoluminescence examination of zircons indicate only one growth phase of the zircon crystals. This points to an uninterrupted crystallization process in the magma.

The Caledonian I-type character, the evolution of the zircons, and the post-deformation emplacement allow to correlate these granitic rocks with post-closure uplift in a late stage of the Variscan orogenic era. Granites in such a geotectonic setting have generally an important mantle component.

Amphibolites and amphibolitic schists, which suffered Variscan medium-grade metamorphism and Alpine low-grade overprint, probably derive from intermediate volcanic rocks and are interpreted to have formed in a subduction-related environment.

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INTRODUCTION

The Pelagonian zone in the Kamvounia region comprises polymetamorphosed rocks associated with granites. The undeformed granitoids (Deskati series) were considered as post-Alpine intrusions into the basement by Davis & Migiros (1979). In contrast radiometric dating of granites with the Ar/Ar and U/Pb (zircon) methods gave crystallization ages around 300 Ma (Yarwood & Aftalion 1976, Schermer et al. 1990). The granites are therefore late-Variscan.

The chemical element patterns and the modal compositions are used to distinguish between granites derived from a mantle or crustal source. Trace element concentrations of granites have been found to be characteristic of their geotectonic environment (Pearce et al. 1984). The classification proposed by Pearce et al. (1984) distinguishes between ocean ridge (ORG), volcanic arc (VAG), within plate (WPG) and collision (COLG) granites. A closer study of granites intruding in the tectonic environment of a collision zone may subdivide them according to the type of collision involved (continent continent, continent arc, or arc arc).

In this study we present chemical analyses of granites, gneisses, and mylonites from the Pelagonian crystalline basement to receive information about the geotectonic setting of the protoliths.

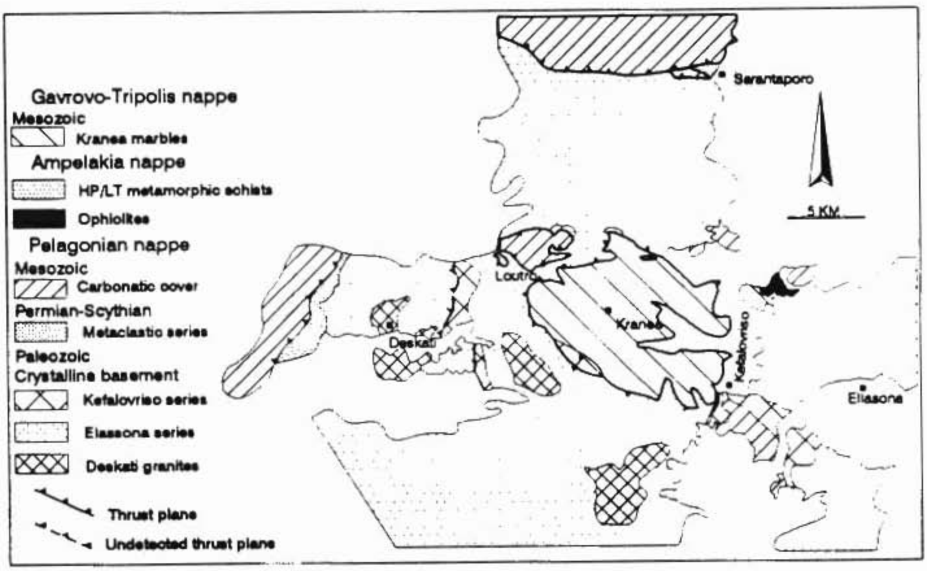

Fig. 1: Simplified geological map of the Kranea region.

GEOLOGY OF THE KAMVOUNIA REGION

Two tectonostratigraphic units compose the Pelagonian zone in the study area (fig.1): (1) The lower tectonic unit is composed of the probably Mesozoic Kranea series, a carbonate sequence with an exposed thickness of about 1500 m. (2) The Variscan crystalline basement and its Permomesozoic cover form the higher tectonic unit. The marble sequence of Kranea appears underneath the Pelagonian crystalline basement in the tectonic window of Kranea (Kilias & Mountrakis 1987, Sfeikos et al. 1991).

The basement occupies the greatest part of the Pelagonian zone in north Thessaly. It consists of metamorphic rocks such as gneiss, augen-gneiss, amphibolite, garnet mica schist, and amphibolitic schist, intruded by undeformed granitoids of the Deskati series. Gneissic and mylonitic rocks in the basement show textural transitions to the granites and granodiorites and are therefore suspected to derive from them. Variscan metamorphism occurred prior to the intrusion of the Late Carboniferous (ca. 300 Ma) granites. K/Ar and Ar/Ar dating (whole rock, amphibole, and mica) revealed metamorphic events in the Early Cretaceous and Paleogene periods (Barton 1976, Yarwood & Aftalion 1976, Schermer et al. 1990).

The weakly metamorphosed Permomesozoic cover consists of a lower clastic and a higher carbonate sequence. The former is similar to a Permoscythian metaclastic sequence described by Mountrakis (1983) along the western margin of the Pelagonian zone. We therefore attribute it to the Late Paleozoic and Early Triassic. The carbonate sequence lithologically correlates with Triassic-Jurassic series elsewhere.

Metaclastic rocks of unkown origin occurring along the thrust of the Pelagonian basement over the Kranea window contain high-pressure minerals (Kilias et al. 1991). They are accompanied by slices of ultramafic rocks.

CHEMICAL CHARACTERISTICS AND TECTONIC SETTING

Samples of granite (EA, EB, EC, MB, KA), gneiss (ED, EH, KH), mylonite (EZ, KZ), and amphibolite (EE, KE, HB) were chemically analyzed by X-ray fluorescence (XRF).

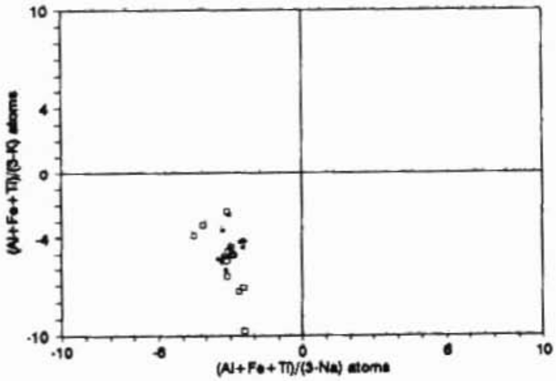

Figure 2 Moine and De la Roche (1968) discrimination diagram for metamorphic rocks. Negative values indicate igneous, positive values sedimentary origin.

Name	DF Shaw				
EA-1	2,3628	MB-1	2,81131	ED-1	2,15305
EA-2	1,70746	MB-2	0,55396	ED-2	2,68156
EA-3	2,09951	KA1D	0,55948	EH-1	2,20291
EA-4	2,83535	KA1W	0,8132	EZ-1	2,47811
EB-1	3,09793	MD-1	3,08672	EZ-2	2,09772
EB-2	3,22047	KE-2	1,37735	EZ-3	1,86493
EC-1	2,40906	KH-1	1,09978	MK-1	1,73127
EC-2	1,7667	KH-2	2,66034	MK-2	0,37306
EC-3	1,66427	KZ-1	2,89963	MK-3	2,48484
		MZ-1	2,7802	MK-4	7,85949

Table 1. Discrimination values after Shaw (1974)

	Cordielleran I-type	Caledonian I-type	S-type	Deskati granitoids
Na_2O %	>3.2%	>3.2%	<3.2%	>3.2%
normative corundum	<1%	<1%	>1%	<1%
element variation	low	low	high	low
mineral composition	hbl, bi	bi	mu,cord,gt	hbl, bi
Al/(Na+K+0.5Ca)	<1.1	ca 1	>1.1	0.8 - 1.1
Initial $^{87}Sr/^{86}Sr$	<0.706	0.705< <0.709	>0.710	<0.710

Table 2. Characteristics of the Deskati granitoids

The major element concentrations of the gneisses and mylonites indicate an igneous origin for these rocks. They lack excess alumina and do not contain corundum in their normative composition. Potash is more abundant than soda, and the normative quartz content remains below 40 vol-%.

Moine & De La Roche (1968) presented a diagram capable of discriminating between orthogenic and paragenic origin (fig. 2). Paragenic rocks with high alumina contents relative to potassium and sodium have positive values for both parameters. The Pelagonian gneisses and mylonites, however, plot into the field where both parameters are negative (fig. 2) indicating an igneous origin.

Shaw (1972) proposed a discrimination formula (DF) based on major element concentrations of gneisses of known origin:

$$DF = 10.44 - 0.21\,SiO_2 - 0.32\,Fe_2O_3 - 0.98\,MgO + 0.55\,CaO + 1.46\,Na_2O + 0.54\,K_2O$$

The results of the Pelagonian gneiss, augen gneiss, and mylonite samples are presented in table 1. The discrimination value of all samples is positive, ascribing an igneous origin to the rocks.
The granitoids of the Deskati series belong to the "calcic" type according to Peacock's (1931) classification and have a slightly peraluminous character (fig,3). According to the chemical and mineralogical characteristics outlined by Chappell and White (1974) and Pitcher (1982) these granitoids are classified as I-(Caledonian) type granites (table 2). The gneisses and mylonites show the same chemical characteristics.

The multi-element diagrams proposed by Pearce (1984) are used for the discrimination of the granitic, gneissic, and mylonitic rocks in the Pelagonian basement. Again, no differences exist between the granitoids and their deformed derivates. The trace element distribution patterns (fig. 4) show the following characteristics. The large ion lithophile (LIL) elements K, Rb, and Ba are strongly enriched relative to ocean ridge granite (ORG), whereas the high field strength (HFS) elements Nb, Zr, and Y are generally depleted relative to ORG. Strong LIL element enrichment and HFS element depletion characterize volcanic arc and collision granites. Collision granites in general have a high Rb/Ba ratio. In our samples, this ratio is rather low which is in agreement with the I-type character of the rocks.

In several discrimination diagrams (examples in fig.5) the Deskati granitoids and their mylonitic derivates preferable plot into the VAG fields. Since the Cordilleran I types and Caledonian I type granites have siminalar chemical characteristics in many respects a discrimination between these two types is not possible in these diagrams (fig. 5). High concentration in the largely immobile HFS trace elements like Nb and Y (fig. 5b) are probably the result of strong deformation and passive enrichment in these elements due to the migration of major elements (Dostal et al. 1980, Frisch & Raab 1987).

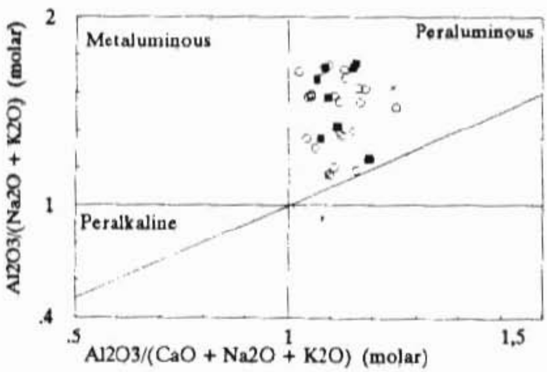

Figure 3 Shand index showing the light peraluminus character of the granitoids.

The basement amphibolites derive from andesitic to dacitic protoliths, according to the Zr/Ti and Nb/Y ratios (Winchester and Floyd 1977) (fig 6). The trace element pattern of the amphibolites show strong enrichment of incompatible LIL elements relative to mid-ocean ridge basalt (MORB). The high Rb/Nb and Ba/Nb ratios are indicative of a subduction related environment. High P and Zr contents

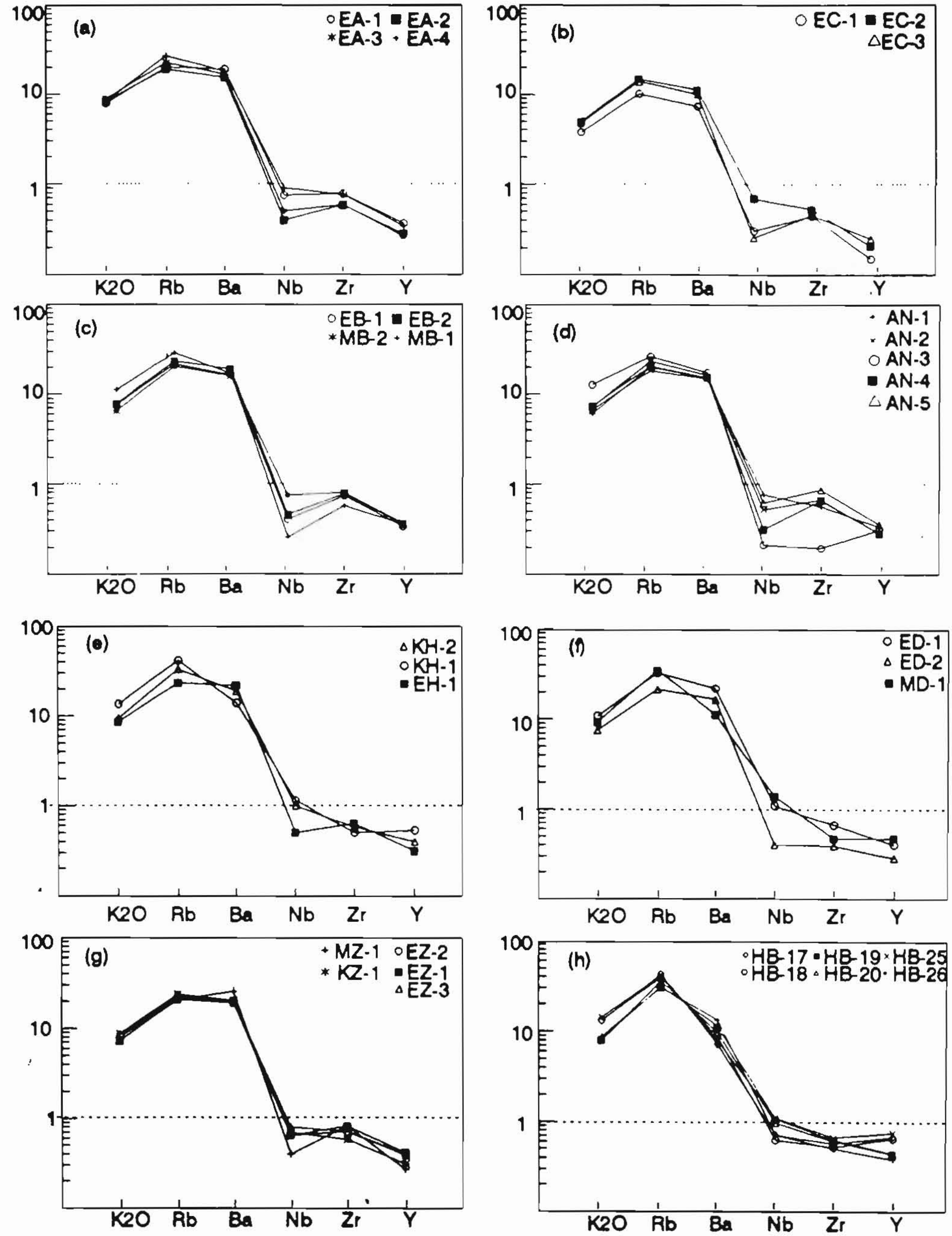

Figure 4 ORG normalized minor and trace element patterns of Pelagonian granitoids.

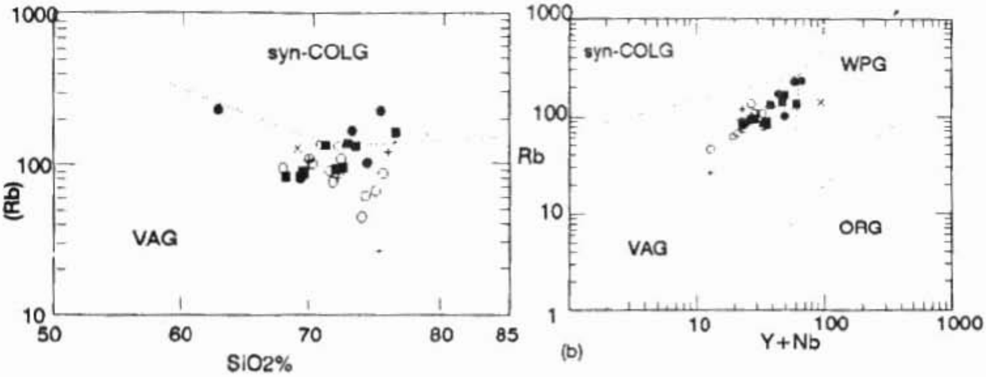

Figure 5 Variation diagrams for the discrimination of granitic rocks after Pearce (1984).

may be indicative of an enriched mantle as it occurs in ensialic subduction-related environments (Pearce 1983). The amphibolites form banded sequences together with more acid rocks which partly probably derive from acid calc-alkaline volcanics. We interpret this sequence as pre-Variscan subduction zone magmatism.

ZIRCON MORPHOLOGY

The external morphology and internal zonation of zircon crystals in granites provide information about the origin and evolution of the rocks. The models of Pupin (1980) and Vavra (1989) outline the principles of zircon crystal growth in relation to changes in the growth parameters.

Zircon populations were separated from three granit amples of the Deskati series. In most crystals, the simple prism (100) and the flat pyramid (101) are the dominating crystal faces. These zircons represent the D-type to which a mantle origin is attributed (Pupin 1980). The internal zoning was studied using cathodoluminescence technique with an electron microscope. The internal structure reveals only one growth phase. The shapes of

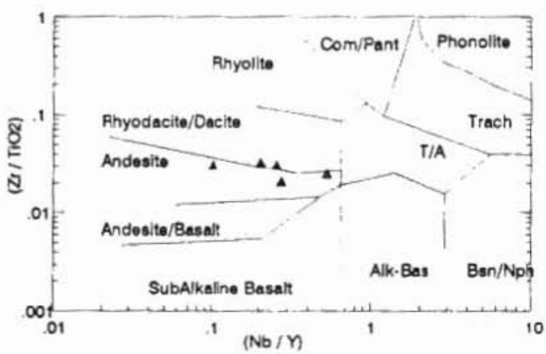

Figure 6 Ocean rock discrimination diagram after Winchester and Floyd (1977).

the single zones are the same as of the finite morphology. This indicates an uninterrupted crystallization process in the magma.

CONCLUSIONS

The Pelagonian crystalline basement comprises various magmatogenic rocks such as granite and granodiorite, granite gneiss, granite mylonite, and amphibolites. The granitoids of the Deskati series and their gneissic and mylonitic derivates have characteristics of a mantle-derived magma as it is typical of I-type granites. More specific, the chemical pattern and the mineralogical composition identify them as Caledonian I-types. Large volumes of undeformed granite, indicate a late- to post-collisional emplacement relative to the Variscan orogeny which is in agreement with the typical post-closure uplift setting of this granite type. The deformation of the granite gneisses and mylonites, which derived from the Deskati granites is considered to be of Alpine age. Caledonian I-type granites are apparently widespread on the Variscan orogen which was recently pointed out by Neubauer (1991) and Frisch et al. (1992).

The andesitic/dacitic amphibolites as part of a calc-alkaline volcanic sequence in the Pelagonian basement may indicate pre-Variscan subduction activity. This would support the assumption of the existence of a subduction-related magmatic complex in the Pelagonian basement as it is widespread in the basement complexes of the Mediterranean Alpine mountain chains.

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