Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, Τομ. XXXIV/3, 939-947, 2001
Πρακτικά 9ου Διεθνούς Συνεδρίου, Αθήνα, Σεπτέμβριος 2001

Bulletin of the Geological Society of Greece, Vol. XXXIV/3, 939-947, 2001
Proceedings of the 9th International Congress, Athens, September 2001

HIGH PRESSURE ALPINE METAMORPHISM OF THE PELAGONIAN ALLOCHTHON IN THE KASTANIA AREA (SOUTHERN VERMION), GREECE

E. MPOSKOS[1] & M. PERRAKI[1]

ABSTRACT

The Pelagonian allochthon in the Kastania area (Southern Vermion) consists of pre-alpine and alpine rocks that underwent two episodes of Alpine HP/LT metamorphism. The first episode, of Lower Cretaceous age, is represented by the mineral assemblages: Quartz-albite-microcline-phengite±garnet-clinozoisite± biotite±rutile-titanite in orthogneisses and the Kastania metagranite and garnet-chloritoid-chlorite±kyanite-white K-mica-paragonite-rutile in high alumina metapelites. Pressures, were estimated at ΄10 kbar at 500 ^{0}C, applying the phengite geobarometry and more than 22 Kbar, calculating the reaction Grt+Rt+Qtz+W®Ttn+Czo, occurred in the Kastania metagranite during decompression. Recrystallization at albite-epidote-amphibolite facies conditions accompanied by penetrative deformation defines the dominant mineral assemblages and textures in orthogneisses, metapelites and metabasites. The second metamorphic episode of a probable Eocene age occurred under blueschist/greenschist facies conditions and produced fine-grained phengite, stilpnomelane, green biotite and blue amphibole in orthogneisses and amphibolites.

KEY WORDS: Pelagonian allochthon, HP/LT alpine metamorphism, Southern Vermion

1. INTRODUCTION

The Pelagonian Zone consists of various tectonic units composed of pre-alpine and alpine protoliths showing different geodynamic evolution. The two lowermost units, the neritic carbonate unit of Olympos-Ossa and Rizomata-Krania, which is exposed as tectonic window and the blueschist unit (Ambelakia Unit), have suffered only one tectonometamorphic event of Tertiary age. On the contrary, the overlying Pelagonian nappe (Kilias & Mountrakis, 1989) is characterized by a more complex tectonometamorphic evolution. It comprises pre-alpine metamorphic and igneous rocks, clastic and volcanic rocks of Permotriassic age, platform carbonates of Triassic-Jurassic age, ophiolites tectonized in the Upper Jurassic-Lower Cretaceous, transgressive limestones of Cretaceous age and flysch of Paleocene age. Shear zones and westward thrusting accompanied the intense tectonism of Lower Cretaceous and Tertiary.

Orthogneisses and metapelites are the dominant pre-alpine rock types. Petrological investigation on metapelites from Vernon Massif (Mposkos et al, this volume) and eastern Orthrys and northern Euboea (Perraki & Mposkos, unpublished data) showed that the Pelagonian prealpine metamorphic rocks had suffered a LP/HT metamorphism (andalusite-sillimanite Series) that led to migmatite formation. The alpine tectonometamorphic events and particularly that of Lower Cretaceous, taken place under epidote-amphibolite facies conditions (Yarwood & Dixon, 1977, Barton, 1976) erased, almost completely, the pre-alpine assemblages and textures. Thus, the discrimination of pre-alpine and alpine protoliths is, extremely, hard, especially in the areas of central Macedonia and eastern Thessaly. In the pre-alpine lithologies of High-Pieria and southern Vermion, Yarwood and Dixon (1977) recognized a greenschistfacies/epidote- amphibolite facies metamorphism of Early Cretaceous age (122 Ma). The deformed Pieria granodiorite, part of which are the orthogneisses and the Kastania metagranite in southern Vermion, has an Upper Carboniferous crystallization age (Yarwood and Aftalion, 1976). It constitutes the upper part of the Pieria allochthon and is tectonically overlain by the carbonate nappe.

In this paper, petrological data are presented, from the Kastania metagranite and from the metapelites and metabasites of a probable Permotriassic protolith age, that are intercalated between the metagranite and the overlying marbles (of the carbonate nappe), in order to constrain more precisely the alpine metamorphic evolution of the Pelagonian nappe in the southern Vermion area.

1. National Technical University of Athens, Section of Geological Sciences, Heroon Politechniou 9, GR-15780, Zografou, Athens, GREECE, e.mail:mposkos@metal.ntua.gr

2. GEOLOGICAL SETTING

The broader Kastania area, in southern Vermion, consists of: a) the Kastania metagranite (Fig. 1) that, due to more intense deformation in its margins, turns into leucocratic phengitic orthogneisses, mainly augengneisses, b) two-mica gneisses and metamigmatites with intercalations of amphibolites and a marble horizon of 2 m thickness, c) pelitic muscovite gneisses (60-80 m thick), which turn into garnet-chloritoid-mica schists of ´50 m thickness westerly of Panagia Soumela. Amphibolite intercalations with a thickness of some dcm, are, also, present, d) Triassic-Jurassic marbles of the eastern Pelagonian margin, overlying the garnet-mica schists. Along the Veria-Kastania road, the marbles lie through a tectonic contact over the leucocratic orthogneisses, while, to the southwest of Lefkopetra, they lie over mylonitized migmatites. In the Mikri Santa village, the garnet-chloritoid-mica schists are intercalated between the metagranite and the overlying marbles.

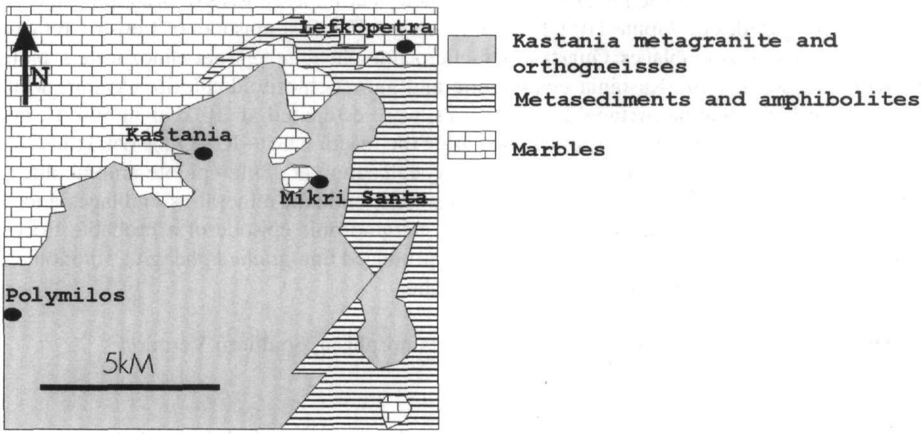

Figure 1: Geological sketch map of the Pelagonian allochthon in the Kastania area, Southern Vermion (after Yarwood & Dixon, 1977).

3. METAPELITES

Petrography and Mineral Chemistry

The metapelites of the Panagia Soumela and Mikri Santa areas are, mainly, high-alumina pelites, characterized by the following mineral assemblages:

A: chloritoid-white K-mica-chlorite-quartz-graphite, B: garnet-chloritoid- white K-mica±kyanite±paragonite-chlorite-quartz-rutile±ilmenite-tourmaline-graphite, C: garnet-white K-mica-chlorite-clinozoisite-rutile-graphite.

They have suffered a polyphase metamorphism and deformation. Two major deformation phases led to the formation of two foliations (S1, S2). The second one (S2) dominates macroscopically. It is imprinted by the parallel growth of muscovite and chlorite flakes (Ms2, fig. 4A) and chloritoid plates. The first schistosity is characterized by muscovite (Ms1) and chlorite flakes having the (001) face in a high angle to S2 (fig. 4A). Garnet appears as porhyroblasts. It contains inclusions of quartz, rutile, clinozoisite as well as chloritoid in the chloritoid-bearing schists (fig. 3B). Inclusions of quartz, rutile and clinozoisite with a sigmoidal orientation signify a syntectonic growth of the garnet. A third deformation phase is characterized by crenulation cleavage, especially in bands rich in micas.

Mineral compositions were obtained by electron microprobe analyses using the ARL-SEMQ microprobe analyser at the University of Innsbruck, Austria. *Garnet* is an almandine-rich garnet (Table 1) having the composition $Alm_{63-80}Grs_{5-20}Prp_{5-16}Sps_{1-9}And_{1.5-5.5}$. (Abbreviations after Bucher & Frey, 1994). It, usually, shows a compositional zoning with increase in FeO and MgO and decrease in CaO and MnO from core to the rim. Representative compositional profile of a garnet is shown in figure 2. It is a growth zoning pattern indicating garnet growth during prograde metamorphism.

Chloritoid is iron rich with a Mg/(Mg+Fe) ratio ranging from 0.17 to 0.27. The lowest values are observed in chloritoid inclusions in garnet (Table 1). The composition of the chloritoid included in garnet, changes systematically in relation to that of the host garnet. The Mg/Fe ratio in chloritoid increases with increasing Mg/Fe ratio at the adjacent point of the garnet indicating that the chloritoid inclusions were, always, in chemical equilibrium with the host garnet.

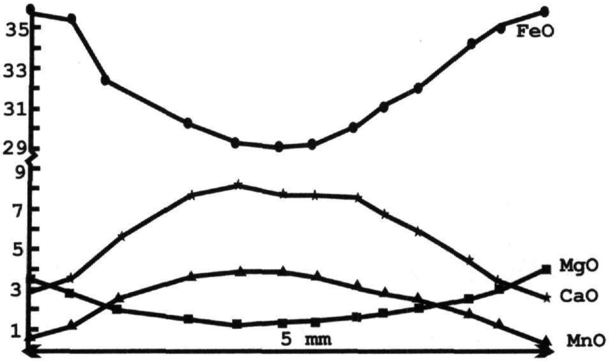

Figure 2: Compositional profile of garnet (wt%) showing growth zoning from a garnet-chloritoid-mica schist

Representative compositions of *white K-micas* are given in Table 1. The relation Altot:Si is given in fig. 5A. Almost, all analyses are plotted below the line that expresses the 2Al=Si+(Fe+Mg) tchermak substitution, indicating that part of the iron is present as Fe^{+3}. The presence of phengitic and non phengitic muscovite, indicated by the wide range of Si values from 6.15 to 6.6 atoms per formula unit (p.f.u.), records the metamorphic evolution of the metapelites, from higher to lower pressure conditions. Phengites document a high-pressure stage, while the less phengitic muscovites have been formed during decompression.

The high-Si phengites have a low Na content. The inverse correlation between paragonite and celadonite component (Fig. 5B) has been, widely, observed in white K-micas (Guidotti, 1984, Evans & Patrick 1987, Mposkos, 1989) and is due to the reluctance of paragonite to accommodate more than 6 atoms p.f.u., limiting the degree of miscibility between phengite and paragonite. Thus, the increase in paragonite content accompanying the change from phengite to less phengitic muscovite, during decompression of the Pelagonian allochthon in the southern Vermion area, is a crystal-chemical effect (see Guidotti, 1984, p.382).

Paragonite is poor in Ca with a margarite component ranging from 1 to 4% and a muscovite component ranging from 7 to 11%.

Chlorite is ferromagnesian with a Mg/(Mg+Fe) ratio ranging from 0.50 to 0.52%.

Phase relations

In figure 3, the phase relations between garnet-chloritoid-chlorite of the metapelites of southern Vermion, are shown. The two-phase assemblage Cld-Grt corresponds to chloritoid inclusions in a garnet core (tie-line 1) and a garnet rim (tie-line 2). The shifting of the tie-line 1 towards more magnesian garnet and chloritoid (tie-line 2) indicates garnet growth at the expense of chloritoid and chlorite during prograde metamorphism, according

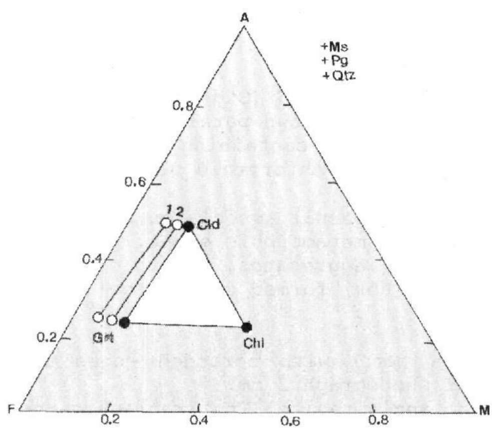

Figure 3: AFM projection of coexisting Grt-Cld-Chl in the high-alumina metapelites. Lines 1 and 2 tie Grt and Cld included in Grt core and Grt rim respectively.

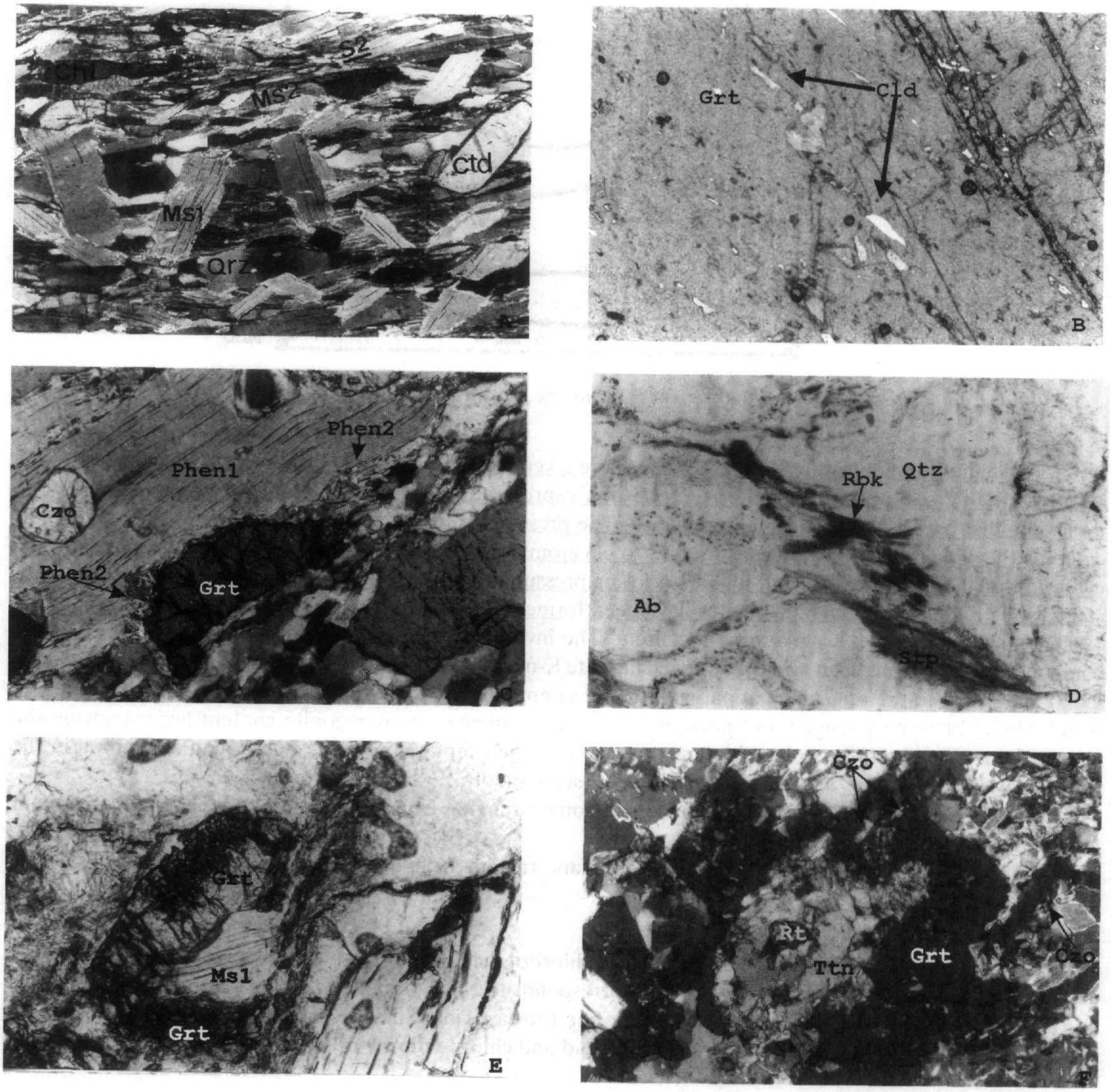

Figure 4:

A,B: Garnet-chloritoid-mica schist

A: Muscovite1 (Ms1) and chloritoid (Ctd) are cut to a high angle by the second schistosity S2. Muscovite2 (Ms2) is grown parallel to S2. (Length of photograph 2 mm)

B: Garnet porphyroblast (Grt) containing oriented chloritoid inclusions (Cld). Note the corroded edges of the chloritoid plates. Length of photograph 2 mm.

C,D: Orthogneisses

C: Phengite porphyroclast (phen1) associated to garnet (Grt) and clinozoisite (Czo) deformed during the second metamorphic event. At the rims it is recrystallized to fine-grained phengite (phen2) aggregates. Length of photograph 2 mm.

D: Bundle of riebeckite (Rbk) formed during the second metamorphic event. Length of photograph 2 mm.

E,F: Metagranite

E: Magmatic muscovite (Ms1) with corroded edges is replaced by garnet aggregates (Grt). Length of photograph 2 mm.

F: Clinozoisite (Czo) and titanite (Ttn) replace garnet (Grt) and rutile (Rt). Note the relics of rutile, rimmed by titanite aggregates. Length of photograph 2 mm.

to the reaction Cld+Chl+ Qtz®Grt+W. The phase assemblage Grt-Cld-Chl in the matrix shows even higher Mg/(Mg+Fe) ratio, indicating a still higher grade of metamorphism.

4. METAGRANITE AND ORTHOGNEISSES

In the Kastania area, leucocratic orthogneisses dominate. Depending on the grade of deformation, they occur either as plate gneisses or as augengneisses.

They are, mainly, composed of phengite, albite, microcline, quartz, and clinozoisite. Biotite, garnet and amphibole are present in small amounts. Two major tectonometamorphic events are recognized in orthogneisses. The first one is characterized by the growth of large phengite flakes and large grains of microcline, albite, clinozoisite, biotite and garnet. Phengites, formed during the first tectonometamorphic event, behaved, during the second one, as porphyroclasts. They show typical mica-fish textures (fig. 4C). In their rims, they are recrystallized to fine-grained phengite aggregates and biotite.

In some gneisses, bundles of blue amphibole (riebeckite) (fig. 4D), green biotite and stilpnomelane have been formed. Biotite and stilpnomelane replace garnet. They document the effect of a second, lower temperature, retrograde metamorphism.

The Kastania metagranite is exposed as tectonic megaboudin in the orthogneisses. It represents a part of the Pieria metagranodiorite, much less deformed compared to the surrounding orthogneisses. Due to weak deformation, the magmatic assemblage Kfs-Plg-Qtz-Ms-Bi and the magmatic textures are still preserved. Perthitized K-feldspar is microcline. It contains inclusions of magmatic plagioclases (often with corroded edges) that, as the matrix plagioclases, have been replaced by Phen+Czo+Ab±Grt. Magmatic muscovite flakes are replaced by garnet aggregates (Fig. 4E). Garnet contains inclusions of phengite, titanite, rutile and quartz. Garnet and matrix rutile are replaced by titanite and clinozoisite (Fig. 4F), indicating that the reaction Grt+Rt+Qtz+W®Ttn+Czo took place, probably, during decompression.

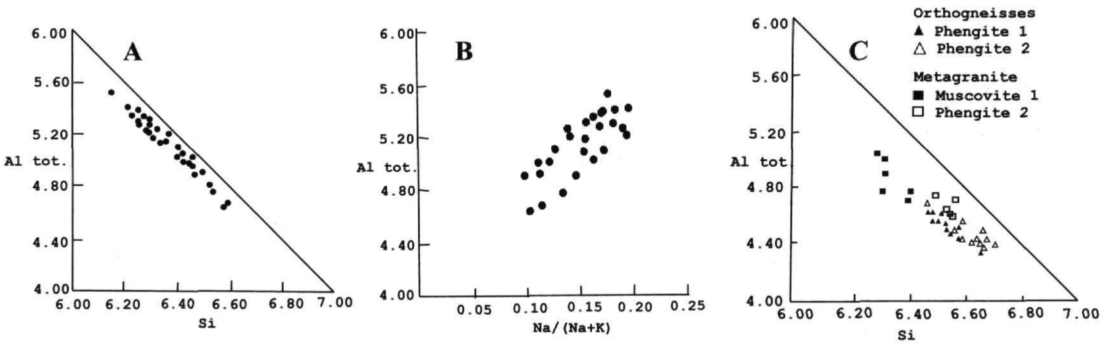

Figure 5: Variation in chemical composition of white K-mica in high-alumina metapelites in term of Altot:Si (A) and Altot:Na/(Na+K) and in orthogneisses and the Kastania metagranite in term of Altot:Si (C).

Representative compositions of *phengites* from orthogneisses and the metagranite are given in Table 2. The relation of Altot:Si is shown in fig. 5C. All the analyses are plotted below the line expressing the relation 2Al Si+(Fe^{+2}+Mg), indicating that appreciable amount of iron in white mica is ferric. The Si content of white K-mica ranges from 6.40 to 6.73 atoms p.f.u.. In some phengites, chemical zoning was observed with decreasing Si content from the core to the rim. The two phengite generations, distinguished on textural criteria, have no significant difference on their Si content, indicating that both mica generations formed under high pressures. In the Kastania metagranite, the magmatic muscovite is relatively rich in Fe and Mg (Mg=0.42-0.77 atoms p.f.u.). The Mg values are, always, higher than the corresponding Si ones that express the celadonite substitution (Si-6=0.19-0.38 atoms p.f.u.). Moreover, the total sum of the octahedral cations is higher than 4, indicating solid solution between dioctahedral and trioctahedral mica. The metamorphic phengite has a flake size 10-20 times smaller than that of the magmatic muscovite and has higher Si values. The Si content ranges from 6.48 to 6.58 atoms p.f.u.

Garnet is rich in almandine and grossular component. Higher grossular contents are recorded on garnets from the orthogneisses (Table 2). In metagranite, garnet shows a compositional zoning having a core composition $Grs_{37}Alm_{59}Prp_3Sps_1$ and a rim composition Grs46Alm48Prp_5Sps_1 (Table 2). Almandine and grossular rich garnets from Pieria granodiorite are, also, reported by Kotopouli et al (2000). *Clinozoisite* shows small variations in iron content with $Fe^{+3}/(Fe^{+3}/Al)$ ratio ranging from 0.14 to 0.16. Plagioclase from orthogneisses and metagranite is *albite* with an anorthite component of 0-3%.

Table 1: Representative mineral compositions from high-alumina metapelites of the Pelagonian allochthon in the Kastania area, southern Vermion

	Ms		Pg	Chl	Grt		Ctd		
	1	2	3	4	5c	6r	7i	8i	9
SiO$_2$	49.12	46.91	46.72	24.19	37.37	36.81	23.81	24.67	24.63
TiO$_2$	0.36	0.40	0.10	0.05	0.06	0.03	-	-	0.05
Al$_2$O$_3$	29.51	33.44	39.20	21.54	20.43	20.98	40.25	40.79	40.03
FeO$_{tot}$	2.30	1.64	0.48	25.70	31.50	34.82	25.36	24.01	23.03
MnO	-	-	-	-	5.45	2.92	-	0.25	0.01
MgO	2.55	1.52	0.14	15.24	1.69	3.55	2.94	3.22	4.69
CaO	-	-	0.20	-	3.50	0.70	0.44	0.03	0.06
Ía$_2$Ï	0.83	1.42	7.07	0.03	-	-	-	-	-
Ê$_2$Ï	10.10	9.85	1.06	-	-	-	-	-	-
Total	94.78	95.20	94.98	86.75	100.00	99.80	92.80	92.98	92.53
Number of cations/O		(22)			(28)			(24)	
Si	6.591	6.260	6.002	5.179	6.021	5.954	3.945	4.039	4.001
Ti	0.037	0.041	0.009	0.008	0.007	0.004	-	-	0.007
Al	4.667	5.260	5.935	5.435	3.900	4.000	7.861	7.870	7.661
Fe	0.258	0.183	0.052	4.602	4.266	4.709	3.514	3.288	3.128
Mn	-	-	-	-	0.747	0.400	-	0.034	0.001
Mg	0.511	0.302	0.027	4.863	0.408	0.855	0.726	0.787	1.135
Ca	-	-	0.028	-	0.607	0.121	0.078	0.005	0.011
Na	0.216	0.367	1.761	0.012	-	-	-	-	-
K	1.729	1.677	0.173	-	-	-	-	-	-
Mg/(Mg+Fe	-	-	-	-	0.09	0.16	0.17	0.19	0.27

Table 2: Representative mineral compositions from othogneisses and the metagranite of the Pelagonian allochthon in the Kastania area, southern Vermion

	Orthogneiss				Metagranite				
	Phen1		Phen2	Grt	Ms1		Phen	Grt	
	1	2	3	4	5	6	7	8r	9c
SiO$_2$	49.46	48.46	49.76	38.10	46.43	47.28	50.73	37.13	37.43
TiO$_2$	0.48	0.55	0.22	-	0.69	0.77	0.65	-	-
Al$_2$O$_3$	25.74	26.16	25.71	21.62	31.01	30.48	28.05	20.85	21.61
FeO$_{tot}$	4.96	4.92	4.75	18.37	2.96	2.59	2.23	26.60	21.80
MnO	-	-	0.51	1.21	-	-	-	0.52	0.57
MgO	3.31	3.33	3.66	-	3.46	2.66	3.47	0.83	1.34
CaO	0.30	-	-	20.55	0.32	0.36	0.23	13.10	16.51
Ía$_2$Ï	-	-	-	-	0.93	-	-	-	-
Ê$_2$Ï	10.98	10.88	11.30	-	11.07	10.73	11.37	-	-
Total	95.25	94.41	95.93	99.87	97.27	94.87	96.73	99.03	99.26
Number of cations/O (24)		(22)			(24)		(22)		
Si	6.709	6.632	6.731	5.983	6.227	6.383	6.700	5.977	5.931
Al	4.115	4.220	4.098	4.002	4.859	4.849	4.360	-	-
Ti	0.049	0.057	0.023	-	0.069	0.078	0.064	-	-
Fe	0.562	0.563	0.537	2.412	0.329	0.292	0.246	3.581	2.889
Mn	-	-	0.058	0.161	-	-	-	0.071	0.076
Mg	0.670	0.679	0.737	-	0.685	0.535	0.683	0.199	0.316
Ca	0.044	-	-	3.458	0.045	0.052	0.032	2.259	2.803
Na	-	-	-	-	0.239	-	-	-	-
K	1.900	1.900	1.950	-	1.877	1.848	1.916	-	-

5. AMPHIBOLITES

The amphibolites of the Kastania area, are common amphibolites with the mineral assemblage Hbl-Ab-Chl-Czo-Qtz-Rt and garnet-amphibolites with the mineral assemblage Grt-Hbl-Ab-Czo-Qtz-Ilm-Rt-Ttn. Garnet forms small isometric grains, often with rutile and clinozoisite inclusions. Hornblende is a magnesio- hornblende or edenitic hornblende with an Al_2O_3 content ranging from 9.51 to 12.36%, a Na_2O content ranging from 2.58 to 3.42% and a TiO_2 content ranging from 0.34 to 0.47%. The amphiboles of a metagabbro from Sfikia area, exposed 100m below the Triassic marbles (Mposkos, 1987) have a similar composition. Hornblende is, rarely, replaced by blue amphibole. Albite (An 1-1.5%) forms equigranular grains containing clinozoisite and quartz inclusions. Rutile is replaced by ilmenite. Chlorite is magnesium rich with a Mg/(Mg+Fe) ratio in the range of 0.69-0.73.

6. PT CONDITIONS

The mineral assemblage Hbl+Ab+Czo±Chl± Grt+Qtz+Rt in amphibolites indicates an albite – epidote - amphibolite facies metamorphism. Moreover, the presence of phengite in the orthogneisses and the metagranite of the Kastania area, with maximum Si=6.75 atoms p.f.u., indicates that the metamorphic event occurred at high pressures.

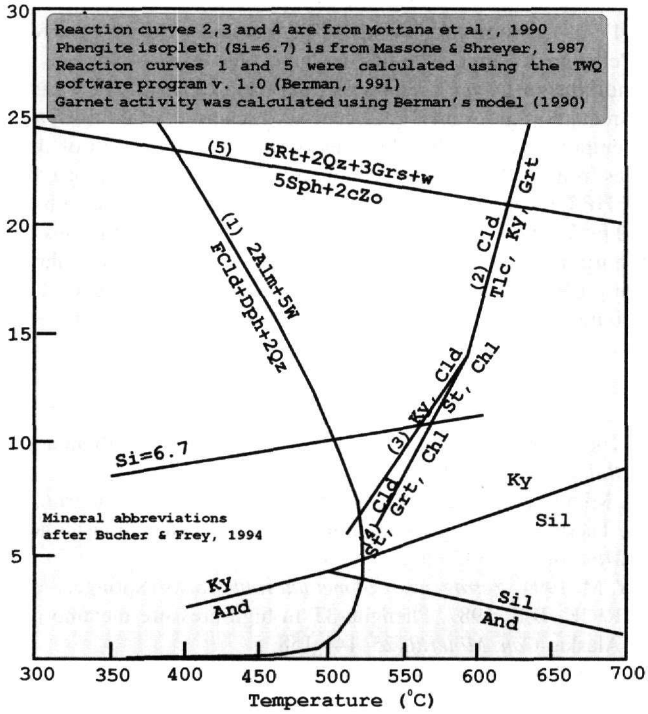

Figure 6: P-T diagram with reaction curves constraining the metamorphic conditions of the Pelagonian allochthon in Southern Vermion.

P-T conditions are estimated, using known reaction curves and applying thermodynamic calculations on the mineral assemblages of the metapelites and the orthogneisses (fig. 6). The mineral paragenesis Grt-Cld-Chl, which is common in the high-alumina metapelites of the Kastania area, limits the metamorphic conditions between the curves 1 and 2 (fig. 6). The presence of kyanite, limits the maximum temperature on the left-hand side of the curve 3. The intersection of curve 1 with the phengite isopleth Si=6.7, constrains the peak P-T conditions at 10 kbar and 500 °C. The calculated reaction Grt+Rt+Qtz+W→Czo+Ttn, which has taken place during the first stages of decompression, indicated by the replacement of associated garnet and rutile by titanite and clinozoisite in the Kastania metagranite (fig. 4F), gives minimum pressure of 22 Kbar for assumed temperature of 500 °C (fig. 6). Due to the absence of experimental data and the effect of the composition of the fluid phase, the calculated pressure has to be taken with caution.

7. CONCLUSIONS

Petrological data from the Kastania metagranite, the orthogneisses, the amphibolites and the garnet-chloritoid schists showed that the Pelagonian nappe, in southern Vermion, suffered a HP/LT metamorphism. In the garnet-chloritoid schists, it is represented by the mineral assemblage Grt-Cld-Chl±Ky-Phen-Pr-Rt. In the Kastania metagranite and orthogneisses, it is represented by the mineral assemblage Qtz-Ab-Kfs-Phen-Grt-Czo-Rt-Ttn and in metabasites by the assemblage Hbl-Ab-Czo-Chl-Grt-Qtz-Rt.

Phengite geobarometry applied on orthogneisses, combined with the reaction Cld+Chl+Qtz→Grt+W, taken place in the associated metapelites, yielded P-T conditions of about 10 kbar and 500 0C for the peak of the HP-event. However, the calculated reaction curve Grt+Rt+Qtz+W→Ttn+Czo, taken place in the Kastania metagranite during the first stages of decompression, indicates minimum pressures of 22 kbar at 500 ^{0}C for the peak of the HP event, assuming that the fluid phase consisted of pure water.

Recrystallization at albite-epidote-amphibolite facies conditions accompanied by penetrative deformation imprints the dominant mineral assemblages and textures in the orthogneisses, the metapelites and the metabasites.

U/Pb isotope dating on zircons from the undeformed domain of the Pieria metagranodiorite, part of which is the orthogneisses and the Kastania metagranite, yielded crystallization ages of 302±5 Ma (Yarwood & Aftalion, 1976). Therefore, the metamorphic events recorded on the orthogneisses and the overlying high-alumina metapelites are of alpine age. ^{39}Ar/^{40}Ar and Rb/Sr isotope dating on phengites from Olympos and High Pieria areas (Schermer et al.,1990, Yarwood and Dixon, 1977), documents the effect of two alpine metamorphic events on the lithologies of Pelagonian nappe. The first metamorphic event took place under greenschist to epidote-amphibolite facies conditions in Lower Cretaceous (Yarwood & Dixon, 1977) and is related to the ophiolites obduction. The second metamorphic event is of Eocene age (Schermer et al., 1990) and took place under blueschist facies conditions contemporaneous to the blueschist facies metamorphism of the underlying Ambelakia tectonic unit. Isotope dates from the Southern Vermion area have not been reported. Nevertheless, the first metamorphic event was of HP/LT conditions followed by decompression under albite-epidote-amphibolite facies similar to that referred by Yarwood and Dixon (1977) for the Lower Cretaceous event.

The second metamorphic event, leading to the formation of fine grained phengite aggregates (Si=6.6-6.7) replacing large phengite flakes, green biotite replacing brown biotite and garnet, stilpnomelane replacing garnet, and the growth of blue amphiboles (riebeckite) in orthogneisses, is possibly related to the Eocene metamorphism.

REFERENCES

BARTON, C.M. 1976. The tectonic vector and emplacement age of an allochthonous basement slice in the Olympos area, N.E. Greece. *Bull.Soc. Geol. France*, 18, 253-258.

BERMAN, R.G. 1990. Mixing properties of Ca-Mg-Fe-Mn garnets. *Am. Mineral.,* 75, 328-344.

BERMAN, R.G. 1991. Thermobarometry using multiequilibrium calculations: a new technique with petrologic applications. *Can. Mineral.,* 29, 833-855.

BUCHER, K. & FREY, M. 1994. *Petrogenesis of metamorphic rocks* (Springer Verlag).

EVANS, W.B. & PATRICK, B.E. 1987. Phengite-3T in high-pressure metamorphosed granitic orthogneisses, Seward Peninsula, Alaska. *Can. Mineral.* 25, 141-158

GUIDOTTI, V.C. 1984. Micas in metamorphic rocks. *In Bailey S. M. (ed). Micas.Min.Soc.Am. Reviews in Mineralogy,* 13. 357-456.

KILIAS, A. & MOUNTRAKIS, D. 1989. The Pelagonian nappe. Tectonics, metamorphism and magmatism. *Bull. Geol. Soc. Greece*, V23/1, 29-46.

KOTOPOULI C.N., PE-PIPER, G., PIPER, D.J.W. 2000. Petrology and evolution of the Hercynian Pieria Granitoid Complex (Thessaly, Greece): paleogeographic and geodynamic implications. *Lithos*, 50, 137-152.

MASSONE, J.H. & SHREYER, W. 1987. Phengite geobarometry based on the limiting assemblage with K-feldspar, phlogopite and quartz. *Contrib. Mineral. Petrol.*, 96, 212-224.

MOTTANA, A., CARSWELL, D.A., CHOPIN, C. & OBERHAENSLI, R. 1990. Eclogite facies mineral parageneses, *in Eclogite facies rocks: edited by D.A. Carswell.* Blackie, New York, 14-52.

MPOSKOS, E. 1987. The chemical composition of calcic and sodic-calcic amphiboles in metabasic rocks from the Pelagonian Zone (Greece) as indicator of pressure and temperature. *Chem. Erde*, 46, 161-169.

MPOSKOS, E. 1989. High-pressure metamorphism in gneisses and pelitic schists in the Eastern Rhodope Zone (N. Greece). *Miner. Petrol.*, 41, 25-39.

MPOSKOS, E., KOSTOPOULOS, D. & KROHE, A. 2001. Low P/T prealpine metamorphism and medium-P

alpine overprinting of Pelagonian Zone documented on high alumina metapelites of the Vernon Massif, Western Macedonian, Northern Greece (this volume).
SCHERMER, E.R., LUX, D.R. & BURCHFIELD, B.C. 1990. Temperature-time history of subducted continental crust, Mount Olympos region, Greece. *Tectonics*, 9, 1165-1195.
YARWOOD, G.A. & AFTALION, M. 1976. Field relations and U-Pb geochronology of a granite from the Pelagonian Zone of the Hellenides (High Pieria, Greece). *Soc. Geol. De France Bull.*, 18, 259-264.
YARWOOD, G.A. & DIXON, J.E. 1977. Lower Cretaceous and younger thrusting in the Pelagonian rocks of High Pieria, Greece. *Colloq. Aegean Region*, Athens 6th, 1, 269-280.