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MINERALOGY AND METAMORPHIC CONDITIONS OF A GARNETIFEROUS LENS FROM THE EASTERN CHALKIDIKI PENINSULA, NORTHERN GREECE

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ABSTRACT

A small lensoidal garnetiferous body, consisting of garnet + amphibole + epidote + quartz, and occuring within the gneisses, amphibolites and migmatites of the eastern part of the Chalkidiki main body, is studied in terms of petrography, mineralogy and metamorphic conditions. Garnet corresponds to almandine rich almandine-grossular solid solution and displays negligible core-rim compositional variations. Garnet grains exhibit alteration to amphibole (mainly ferropargasitic hornblende and ferropargasite) and epidote. The chemical composition of garnet and amphibole imply conditions of upper amphibolite facies. It is considered that the studied garnetiferous lens may represent a retroeclogite, lacking any relic eclogitic assemblage, which completely recrystallized and equilibrated extensively under the prevalent high-T amphibolite facies. The slight enrichment of epidote in Ce, La, Y, and consequent zoning are attributed to compositional variations of the fluid phase during the amphibolitization stage.

Key words: *Garnetiferous lens, amphibole, epidote, retroeclogites, Chalkidiki, Greece.*

RESUMEN

Se estudia la petrografía, mineralogía y condiciones metamórficas de un pequeño cuerpo lenticular, constituido por granate + anfidol + epidota + cuarzo, que aparece incluido en los gneises, anfibolitas y migmatitas del sector oriental de Chalkidiki. El granate es rico en almandino y muestra una pequeña variación composicional centro-borde. Los cristales de granate están parcialmente alterados a anfidol (hornblenda ferropargasítica y ferropargasita) y epidota. La composición química de granates y anfíboles implican condiciones de la facies de las anfibolitas. Se considera que estos cuerpos granatíferos representan retroeclogitas que han recristalizado y se han reequilibrado completamente bajo las nuevas condiciones metamórficas. El ligero enriquecimiento en La, Ce e Y de la epidota y la consecuente zonación se atribuyen a las variaciones de composición de la fase fluida durante el estadio de anfibolitización.

Palabras clave: *Cuerpos granatíferos, retroeclogitas, anfibol, epidota, Chalkidiki, Grecia.*

Introduction

Varied assemblages characterized as xenoliths (garnet bearing peridotites, garnet clinopyroxenites, eclogites «sensu lato», and similar mafic rocks) hosted in various lithologic environments and subjected to varied retrograde processes, have been reported in literature (e.g., Arculus and Smith, 1979; Sculze and Helmstaedt, 1979; Droop, 1983; Baker, 1986; Dodge *et al.*, 1988; Mukhopadhyay, 1991).

The present study deals with a garnetiferous lens, hosted in the metamorphic rocks of the eastern part of the Chalkidiki main body, near the village Vamvakies, in northern Greece (fig. 1). The purpose of this study is the investigation of the possible metamorphic conditions of this basic lens on the basis of textural observations and mineral chemistry.

Petrographic description

The studied garnetiferous lens (about 5 x 10 m in dimensions) occurs within the gneisses, amphibolites and migmatites of the area. The gneisses vary

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from biotite-gneisses (with main mineralogical assemblage: quartz + plagioclase + K-feldspar + biotite) to hornblende-gneisses (with main assemblage: quartz + plagioclase + hornblende). Hornblende + plagioclase + K-feldspar + quartz ± diopside comprise the mineralogical composition of the amphibolites, while the migmatites display a range of their leucosome component from plagioclastic to K-feldspathic. The contacts of the studied garnetiferous lens with the hosting rocks are not clear due to multiple deformation events, alteration and erosion. Details of the geological setting of these hosting lithologies are given in previous studies. Briefly, the broader area belongs to the Serbomacedonian massif. This tectonic unit is in fault contact with the Rhodope massif to the east and the Circum Rhodope belt to the west (Kauffmann *et al.,* 1976; Kockel *et al.,* 1977) (fig. 1). The Serbomacedonian massif, composed mainly of metamorphic and minor igneous rocks, is characterized by a complex tectonometamorphic evolution, which took place from pre-Carboniferous to post-Jurassic times (e.g., Kockel *et al.,* 1977; Kassoli-Fournaraki, 1981; Papadopoulos, 1982; Kassoli-Fournaraki *et al.,* 1985; De Wet *et al.,* 1989; Sakellariou, 1989; Kourou, 1991; Sidiropoulos, 1991).

The garnetiferous lens is granoblastic and contains the mineralogical assemblage: garnet, amphibole, epidote and quartz. Microscopic observation of thin sections showed that garnet constitutes nearly 55-60 % by volume of the specimens studied. The color of garnet is mostly reddish-brown and the grain size is usually 1-5 mm; the grains are mostly round in shape. Inclusions within the garnet grains are usually concentrated in the centers. Amphibole, epidote and quartz are commonly incorporated in this way. Spiral rotation patterns in the inclusions have not been observed.

Garnet grains are always rimmed by kelyphitic rims composed of amphibole-epidote intergrowths; the width of the rims varies from grain to grain. In most cases the same kelyphitic material replaces the inner part of the garnet grain in forms of veins or patches. The grain size of the constituent kelyphitic phases is quite often very fine and the extent of alteration varies. Backscattered electron imaging coupled with microanalyses showed that the kelyphitic products of the garnet alteration are amphibole and epidote in intergrowths. Garnet rims and kelyphitic amphibole are in textural equilibrium.

Amphibole is present in amounts of 15-30 % by volume. It either rims kelyphitically the garnet grains, or grows at the expense of garnet in the inner part of the garnet grains or even occurs as individual crystals in the matrix. In nearly all the modes of formation, it appears in intergrowths with

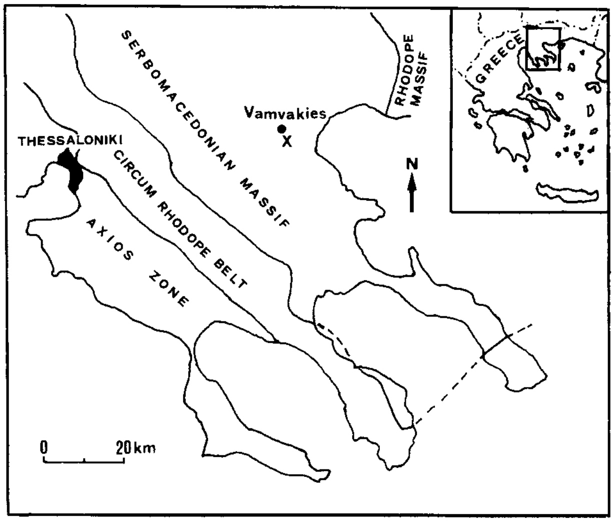

Fig. 1.—Simplified geotectonic map of a part of northern Greece, with location of the studied area. X: Location of the garnetiferous lens studied.

epidote and in many cases the amphibole crystals are epidote-cored. Its colour is deep olive-green with pronounced pleochroism.

Epidote is present in amounts varying from 10 to 20 % by volume. Average grain size is about 1 mm. Aggregates of euhedral or subhedral epidote crystals are abundant in the samples. Epidote occurs both as inclusions in garnet and amphilobe and as individual crystals.

Quartz occurs either as inclusions or aggregates surrounding garnets. No plagioclase, pyroxene or chlorite were observed, though some matrix amphibole grains display a characteristic picture of complete alteration after pyroxene.

Mineral chemistry

Minerals were analysed using a JEOL JSM-840 scanning electron microscope equipped with a LINK AN 10000 EDS microanalyzer, operated at an accelerating voltage of 15 kV and a sample current of 3 nA with beam diameter 1 μm. Corrections were made using the ZAF-4/FLS software provided by LINK. Natural minerals or synthetic equivalents and pure metals were used as microprobe standards. Backscattered electron images were obtained at the same operating conditions.

The analytical precision was found to be variable for different elements (average values in parentheses): Si (0.11), Ti (0.06), Al (0.08), Cr (0.04), Fe (0.25), Mn (0.08), Mg (0.05), Ni (0.10), Ca (0.10), Na (0.08), K (0.04), Y (0.12), Ce (0.15) and La (0.17).

Garnet

Table 1 gives the compositions, rim-core-rim, of two selected garnet grains from the studied garnetiferous lens. The content in andralite component was estimated on the basis of Fe^{3+} calculations after Ryburn *et al.* (1976). Generally, they are almandine-grossular solid solutions (58.68-64.69 % almandine, 30.11-36.60 % grossular) with minor pyrope (1.02-6.65 %) and even lower spessartine (0.00-3.17 %), andradite (0.00-1.35 %) and uvarovite (0.00-0.63 %) components. Their content in Cr, Ni, Ce, and La is unsignificant and sometimes below detection limit. Y displays relatively higher values. All the samples are mostly homogeneous with respect to their major element composition, showing only a small core-rim variation with increasing MgO and sometimes FeO an decreasing CaO and MnO values from core to rim (fig. 2).

The observed core-to-rim chemical variations of the garnets in the present study could not be considered significant and systematic; some garnet grains show a slight core-to-rim increase in Fe/Mg and decrease in Ca, while some others reveal quite the opposite. In general, the unaltered portions of the garnets in the present study, could be considered more or less homogeneous.

Epidote

Table 2 presents the chemical composition of two representative epidote grains from the garnetiferous lens. Formulae were calculated by normalizing to 12.5 oxygen atoms and on the basis of $Fe_{tot} = Fe^{3+}$.

Table 1.—**Representative microprobe analyses of two garnets from the garnetiferous lens, Chalkidiki, Greece**

	Grain 1				Grain 2			
	rim	core	core	rim	rim	core	core	rim
SiO_2	38.54	38.53	38.27	38.30	37.81	38.14	37.95	38.47
Al_2O_3	20.30	20.53	20.59	20.38	19.63	20.28	19.85	19.71
TiO_2	0.07	0.12	0.22	0.04	0.08	0.15	0.18	0.08
FeO	27.21	26.61	26.76	28.35	27.88	28.24	28.44	28.35
MgO	0.93	0.55	0.52	0.87	0.66	0.92	0.63	0.70
CaO	11.58	12.69	12.51	11.36	11.89	11.47	11.42	11.46
MnO	0.45	0.40	0.97	0.11	0.32	0.20	0.13	0.00
Cr_2O_3	0.00	0.08	0.07	0.04	0.00	0.03	0.09	0.22
NiO	0.34	0.16	0.00	0.00	0.17	0.00	0.00	0.00
Ce_2O_3	0.00	0.15	0.00	0.00	0.09	0.00	0.15	0.00
Y_2O_3	0.72	0.47	0.32	0.54	0.81	0.61	0.43	0.79
La_2O_3	0.01	0.02	0.00	0.00	0.02	0.00	0.14	0.00
Total	100.15	100.31	100.23	99.99	99.36	100.04	99.41	99.78
	Cations on the basis of 12 [0]							
Si	3.066	3.057	3.042	3.055	3.048	3.037	3.050	3.076
Al	1.904	1.920	1.928	1.916	1.865	1.903	1.881	1.858
Ti	0.004	0.007	0.013	0.003	0.005	0.009	0.011	0.005
Fe	1.810	1.766	1.779	1.891	1.880	1.880	1.912	1.896
Mg	0.110	0.065	0.061	0.104	0.079	0.110	0.075	0.084
Ca	0.987	1.079	1.065	0.971	1.027	0.980	0.984	0.982
Mn	0.030	0.027	0.065	0.008	0.022	0.010	0.009	0.000
Cr	0.000	0.005	0.005	0.002	0.000	0.000	0.006	0.014
Ni	0.022	0.010	0.000	0.000	0.011	0.003	0.000	0.000
Ce	0.000	0.004	0.000	0.000	0.003	0.000	0.004	0.000
Y	0.030	0.020	0.003	0.023	0.035	0.026	0.020	0.034
La	0.000	0.001	0.014	0.000	0.008	0.000	0.004	0.000
Almandine %	61.63	60.13	59.89	63.62	62.52	63.08	64.17	64.02
Grossular	32.29	35.61	34.95	32.40	33.92	32.26	32.18	32.21
Pyrope	3.73	2.23	2.06	3.48	2.62	3.64	2.53	2.82
Spessartine	1.03	0.91	2.19	0.25	0.72	0.46	0.29	0.00
Andradite	1.32	0.87	0.67	0.13	0.23	0.46	0.55	0.25
Uvarovite	0.00	0.26	0.24	0.11	0.00	0.10	0.28	0.70

Table 2.—**Representative microprobe analyses of two epidotes from the garnetiferous lens, Chalkidiki, Greece**

	Grain 1					Grain 2					
	rim	int	core	core	rim	rim	int	core	core	int	rim
SiO_2	38.08	37.83	38.02	37.34	37.96	38.11	38.05	37.59	37.91	37.72	38.79
Al_2O_3	24.41	23.29	23.85	23.54	24.43	24.60	24.01	23.68	24.18	24.68	25.15
TiO_2	0.09	0.10	0.13	0.08	0.24	0.24	0.00	0.00	0.08	0.10	0.06
Fe_2O_3	11.52	12.59	11.85	12.22	11.47	10.82	11.50	12.33	11.94	11.30	10.43
MgO	0.00	0.03	0.00	0.00	0.07	0.00	0.14	0.07	0.10	0.18	0.00
CaO	20.09	18.90	19.88	18.45	20.05	21.64	19.68	18.38	19.24	19.66	21.63
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.11
Cr_2O_3	0.03	0.00	0.00	0.00	0.01	0.12	0.00	0.00	0.00	0.13	0.12
NiO	0.10	0.00	0.00	0.08	0.17	0.19	0.26	0.18	0.03	0.23	0.00
Ce_2O_3	1.81	2.87	1.90	3.49	1.21	0.30	1.75	3.06	2.19	1.89	0.00
Y_2O_3	0.00	0.30	0.39	0.00	0.28	0.51	0.40	0.24	0.26	0.37	0.42
La_2O_3	0.88	0.96	0.67	1.67	0.68	0.14	0.76	1.24	0.82	0.63	0.00
Total	97.01	96.87	96.69	96.87	96.57	96.67	96.55	96.77	96.75	96.98	96.71
	Cations on the basis of 12.5 [0]										
Si	3.058	3.074	3.070	3.050	3.053	3.044	3.072	3.057	3.061	3.034	3.076
Al	2.311	2.231	2.270	2.266	2.316	2.316	2.285	2.270	2.301	2.340	2.350
Ti	0.006	0.006	0.008	0.005	0.015	0.014	0.000	0.000	0.005	0.006	0.004
Fe	0.696	0.770	0.720	0.751	0.694	0.651	0.699	0.755	0.725	0.684	0.622
Mg	0.000	0.004	0.000	0.000	0.008	0.000	0.017	0.009	0.011	0.021	0.000
Ca	1.729	1.646	1.720	1.615	1.728	1.852	1.703	1.602	1.664	1.695	1.838
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.008
Cr	0.002	0.000	0.000	0.000	0.001	0.008	0.000	0.000	0.000	0.008	0.008
Ni	0.006	0.000	0.000	0.005	0.011	0.012	0.017	0.012	0.002	0.015	0.000
Ce	0.053	0.085	0.056	0.104	0.036	0.009	0.052	0.091	0.065	0.056	0.000
Y	0.000	0.013	0.017	0.000	0.012	0.022	0.017	0.010	0.011	0.016	0.018
La	0.026	0.029	0.020	0.050	0.020	0.004	0.023	0.037	0.025	0.019	0.000

The slight excess of silicon content (3.034-3.080), above the ideal three atoms per formula unit, is not significant since it keeps within the acceptable range of values (2.87-3.15) given by Deer *et al.* (1986).

Electron microprobe analysis revealed that the studied epidotes are frequently enriched in Ce (up to 3.69 wt% Ce_2O_3). La and Y participate in lower amounts (up to 1.82 wt% La_2O_3 and up to 1.46 wt% Y_2O_3).

Although under the optical microscope the crystals do not appear to be zoned, backscattered images reveal either core-rim zonation (fig. 3) or patchy domains. The bright and dark zones in backscattered images are respectively Fe, Ce-rich and Al-rich. The shape of distribution profiles suggests a complex texture of superimposed discontinuous and continuous zoning. The zoning pattern is sometimes asymmetric as opposite rims of some crystals differ in concentration of elements (table 2). In general, the cores and enriched in Fe, Ce and La and depleted in Y, relative to the rims (fig. 4).

Electron microprobe traverses across epidote crystals, revealed that those which grew freely and slightly enriched in iron relative to the epidote inclusions in garnet or amphibole but they have similar patterns of compositional zoning.

Ce, La and Fe display negative correlations with Ca, suggesting substitution processes. Similarly, negative correlations are expressed by Ce and La versus Y. Al shows a good negative correlation with Fe indicating that the majority of Fe is trivalent and substitutes for Al.

Amphibole

Amphibole is calcic-amphibole (table 3). Unit-cell formulae were obtained following the method of Robinson *et al.* (1982) by assumig initially that all Fe is FeO and then calculating Fe^{3+} from a charge balance on 13 cations exclusive of Ca^{2+}, Na^+ and K^+. According to Leake (1978) classification, its composition corresponds mostly to ferropargasitic hornblende and ferropargasite (especially in the kelyphitic rims) and less to Mg-hastingsitic and ferrotschermakitic hornblende. It is iron-rich (23-25 wt% FeO) and contains considerable amounts of sodium (2.5-3.0 wt% Na_2O). Al^{IV} is high (1.59-1.84) and the total amount of Ca + Na + K ranges between 2.54 and 2.77.

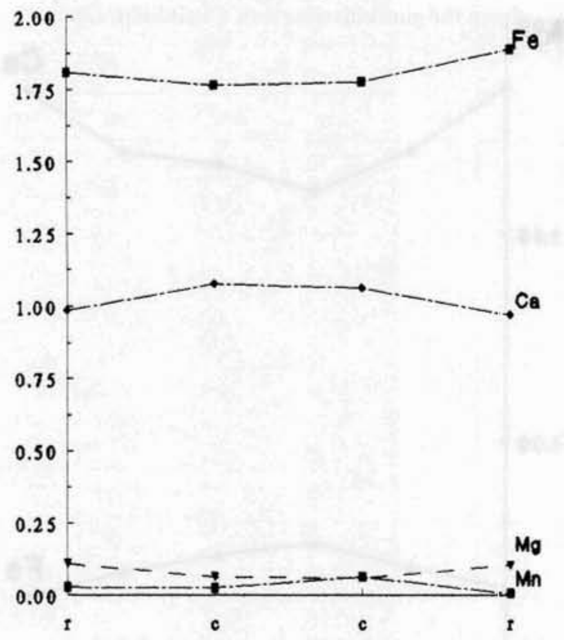

Fig. 2.—Rim-to-rim compositional data, expressed as cations per formula unit, of one representative garnet grain from the garnetiferous lens, Chalkidiki, Greece.

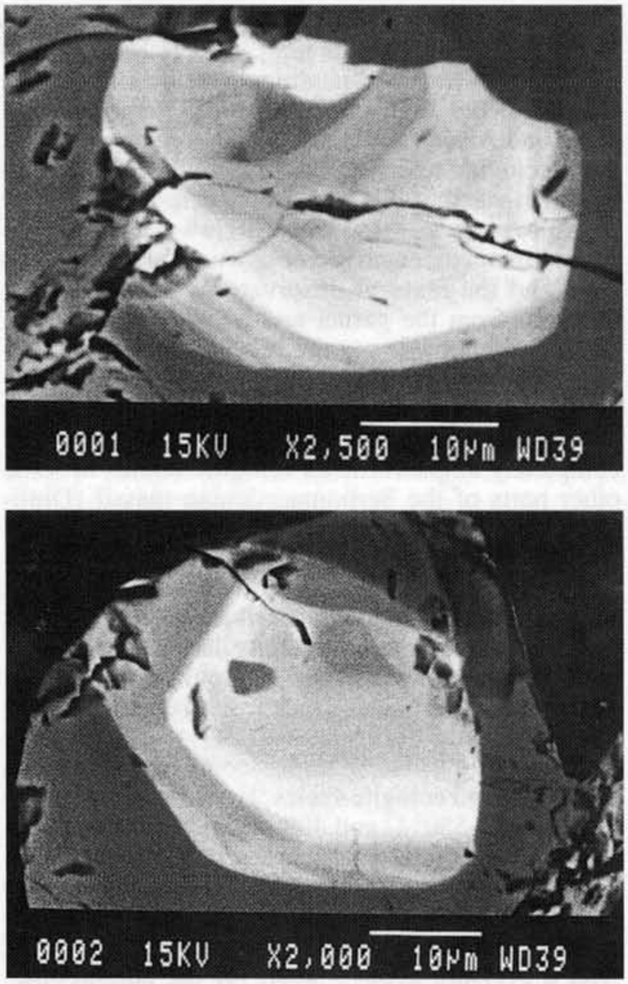

Fig. 3.—Backscattered electron images showing epidote's zonation.

Despite the different varieties of calcic amphibole determined, no chemical zonation or heterogeneities were observed in the individual grains. This is the reason why only representative analyses of each variety are given in table 3.

Results and discussion

The metamorphic history of the Serbomacedonian rocks is extremely complicated and not sufficiently clarified. Numerous studies suggest a great variety of metamorphic events ranging in number from two to five episodes (e.g., Kockel and Walther, 1968; Kockel *et al.,* 1971, 1977; Dimitriadis, 1974; Papadopoulos, 1982; Chatzidimitriadis *et al.,* 1985; Sakellariou, 1989; Kourou, 1991; Sidiropoulos, 1991, and others). Within this large divergence of opinions the metamorphic evolution of the studied garnetiferous lens could hardly be placed precisely in a generally accepted framework of metamorphic processes in the area.

The studied garnetiferous body is characterized by a very limited number of components, which makes the P-T estimations very difficult. Besides, the only three components which are garnet, amphibole and epidote (quartz is a ubiquitous phase) display a more or less constant chemical composition making, thus, uneffective a chemographic representation of the phase relations. However, an investigation of the approximate metamorphic conditions is attempted according to the data which resulted from the examination of the minerals.

The homogeneity of garnet cores and slight chemical variation to the garnet grain margins can be interpreted as the result of homogenization at elevated temperatures. This homogeneity together with the large iron content of garnets implies formation temperatures >650° C (Miyashiro, 1973; De Bethune *et al.,* 1975; Tracy *et al.,* 1976). Application of the garnet-hornblende $FeMg_{-1}$ exchange geothermometer of Graham and Powell (1984) gave the same temperature range, 564-672° C, both for the garnet core-amphibole inclusion as well as for the garnet rim-kelyphitic amphibole pairs.

The precise estimation of pressure was impossible with the existing mineral assemblage. Nevertheless, the amphibole's composition (high Al^{VI} and Na contents), is consistent with crystallization under high pressure conditions (see Ungaretti *et al.,* 1983). Furthermore, the Na/(Na + Ca) vs. Al/(Si + Al) ratios of amphiboles indicate pressure between the trends of high and medium pressure amphiboles (closer to the high pressure trend), according to Laird and Albee (1981) discrimination diagrams.

As eclogitic relics are lacking, it is not possible to establish whether this rock has undergone an earlier high-pressure metamorphism. However, both the mode of occurrence of the garnetiferous lens in field and the textural observations as well as the obtained from the garnet and amphibole compositions could not rule out the hypothesis that the present rock might be a reequilibrated retroeclogite. To this hypothesis contributes the occurrence of a limited number of small eclogitic, meta-eclogitic and completely amphibolitized eclogitic bodies in some other parts of the Serbomacedonian massif (Dimitriadis and Godelitsas, 1991; Kourou, 1991; Sidiropoulos, 1991). Extended periods of metamorphism and polymetamorphism should considerably reduce the probability of eclogite survival and thus account for its scarcity in the area. Sakellariou (1989) suggests an eclogite-facies metamorphic event for the rocks of the Serbomacedonian massif, while Kourou (1991) and Sidiropoulos (1991) accept a first metamorphic episode under conditions between blueschist and eclogite-facies. Equilibrium temperatures of 520-550° C and 400-500° C have been estimated for eclogitic parageneses in the Serbomacedonian massif by Dimitriadis and Godelitsas (1991) and Sidiropoulos (1991), respectively. Sidiropoulos (1991) reports a range of temperature 697-777° C with a pressure about 5 kbar, for the amphibolite-facies event which affected the eclogites, based on geothermobarometry obtained by garnet-amphibole and amphibole-plagioclase equilibrations.

The rock of the present study, displays a pervasive re-equilibration under the prevalent hight-T amphibolite facies, being completely recrystallized and not retaining any relic of high pressure asemblages. Such cases have been also previously reported (e.g., Gil Ibarguchi *et al.,* 1990; Thelin *et al.,* 1990; Messiga *et al.,* 1992).

During the upper amphibolite facies stage hydration of the rock took place due to the fluids released from the surrounding meta-pelites and gneisses and primary pyroxene disappeared totally giving place to amphibole while garnet began to alter to amphibole-epidote intergrowths. The amphibole's composition varies slightly (mosaic equilibrium) depending on its position in the rock and the mineral it replaces. However, its high aluminum content, substituting for Si in the tetrahedral site, the high iron and sodium contents and the high sum of Ca + Na + K support a high metamorphic grade. Diffusion processes during the high temperature amphibolite-facies event must be responsible for the absence of characteristic zonation in garnets and consequent homogeneity (see also Yardley, 1977;

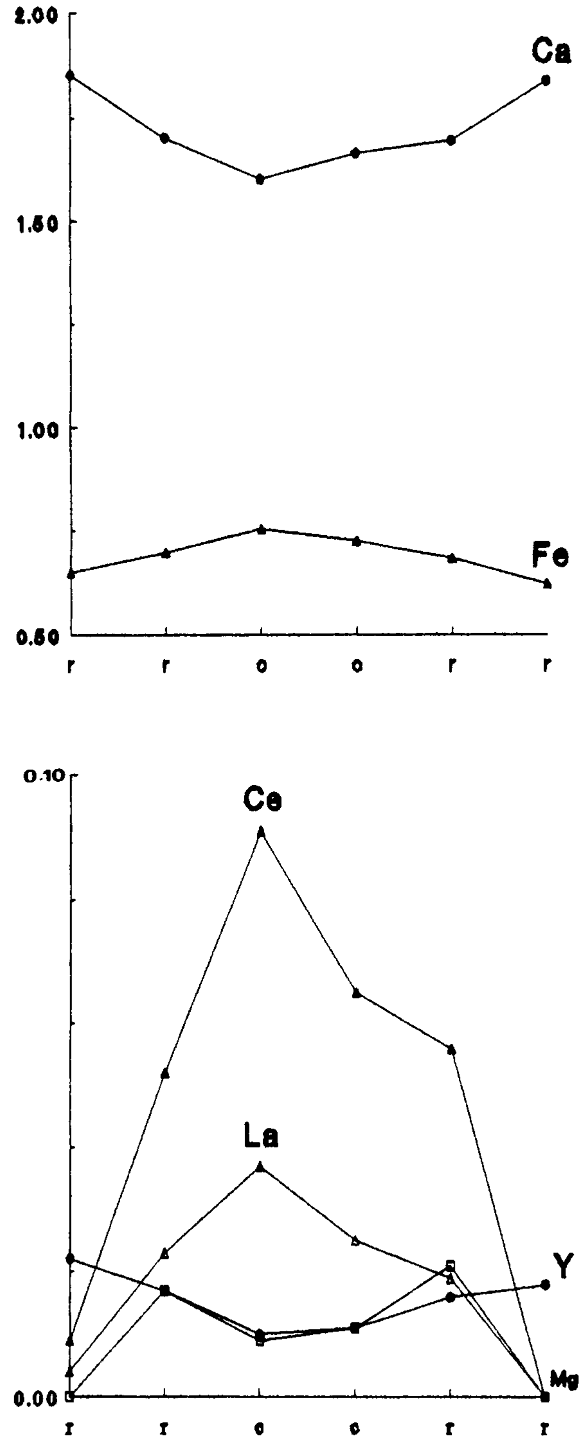

Fig. 4.—Rim-to-rim profile, expressed as cations per formula unit, of one representative epidote grain from the garnetiferous lens, Chalkidiki, Greece.

Table 3.—**Representative microprobe analyses of amphiboles from the garnetiferous lens, Chalkidiki, Greece**

	1	2	3	4
SiO_2	40.46	39.78	40.98	41.06
Al_2O_3	13.46	14.32	12.73	13.30
TiO_2	0.27	0.82	0.62	0.55
FeO^t	24.97	24.31	23.44	25.10
MgO	4.10	4.17	5.53	4.13
CaO	10.65	10.29	10.14	10.22
MnO	0.00	0.04	0.00	0.00
K_2O	0.22	0.04	0.44	0.47
Na_2O	2.77	2.88	2.98	2.67
Cr_2O_3	0.00	0.00	0.17	0.00
Total	96.90	96.65	97.04	97.50
Cations on the basis of 23 [0]				
Si	6.300	6.160	6.310	6.330
Al^{IV}	1.700	1.840	1.690	1.670
Al^{VI}	0.770	0.780	0.620	0.750
Ti	0.030	0.100	0.070	0.060
Fe^{3+}	0.450	0.520	0.620	0.570
Fe^{2+}	2.800	2.630	2.400	2.670
Mg	0.950	0.960	1.270	0.950
Ca	1.780	1.710	1.670	1.690
Mn	0.000	0.010	0.000	0.000
K	0.040	0.080	0.090	0.090
Na	0.830	0.860	0.890	0.800
Cr	0.000	0.000	0.020	0.000

1: ferropargasitic hornblende
2: ferropargasite
3: Mg-hastingsitic hornblende
4: ferrotschermakitic hornblende

Elphich *et al.,* 1982). The kelyphitic rims around garnet grains are interpreted as retrograde metamorphic features during this amphibolitization stage.

The formation of epidote is attributed to a progressive sequence of hydration reactions. In the rock studied, epidote appears to crystallize along with amphibole at the expense of garnet. During the amphibolite-facies event the fluid phase must have been slightly enriched in Ce, Y and La, which were trapped in epidote's structure. The observed zoning of epidote, with cores enriched and rims depleted in Ce and La, could be attributed to the progressively depletion of the fluid composition in these elements. The differences of Ce, La, Y contents betweeen epidote grains could be attributed to fractionations of the fluid composition betwee different samples. Millimeter-scale compositional heterogeneities in metamorphic fluids have been also reffered by Philippot and Selverstone (1989 a, b). The variations of Ce, La, Y, within epidote grains may in part reflect local and time-dependent changes of fluid compositions.

Conclusions

The small garnetiferous lens of the present study, hosted in the gneisses, amphibolites and migmatites of the eastern part of the Chalkidiki main body, is composed of garnet, epidote, amphibole and quartz.

Its mineralogical study revealed that garnet is an almandine rich almandine-grossular solid solution, displaying negligible compositional variation across the grains and considerable alteration in amphibole-epidote intergrowths. Amphibole (mostly ferropargasitic hornblende and ferropargasite) is unzoned displaying high Al, Fe and Na contents. The homogeneous composition of amphibole implies equilibrium. Epidote is slightly enriched in Ce, La and Y. Ce and La display a prominent core-rim decrease, reflecting gradual depletion of these elements in the fluid composition of the metamorphic system in which epidote formed. Variations of Ca, Ce, La, Y and Fe within zoned grains indicate a continuous nature of many substitutions of M2+ and M3+ cations in epidote.

The chemical composition of garnet and amphibole imply conditions of upper amphibolite facies. It is considered that the studied garnetiferous lens may represent a retroeclogite, lacking any relic eclogitic assemblage, which equilibrated extensively under the prevalent high-T amphibolite facies. This is what appears to be pointed out by the data, including the relative compositional homogeneity of the phases and the absence of relicts of any earlier high-pressure assemblage.

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References

Arculus, R. J., and Smith, D. (1979). Eclogite, pyroxenite, and amphibolite inclusions in kimberlites and other volcanics in Sullivan Butters latite, Chino Valley, Yavapai county, Arizona. In: F. R. Boyd and H. O. A. Meyer (Editors), The Mantle Sample. *Amer. Geophys. Union Mon.,* 309-317.

Baker, A. S. (1986). Eclogitic amphibolites from the Gramphian Moines. *Miner. Mag.,* 50: 217-221.

Chatzidimitriadis, E., Kilias, A., and Staikopoulos, G. (1985). Nuovi aspetti petrologici e tettonici del massiccio Serbomacedone e delle regioni adiacenti della Grecia del Nord. *Boll. Soc. Geol. Italiana,* 104: 515-526.

De Bethune, P., Laduron, D., andd Bocquet, J. (1975). Diffusion processes in resorbed garnets. *Contr. Miner. Petrol.,* 50: 197-204.

Deer, W. A., Howie, R. A., and Zussman, J. (1986). *Rock-forming minerals. Disilicates and Ring Silicates,* 1B. J. Wiley and Sons, Inc., New York.

De Wet, A. P., Miller, J. A., Bickle, M. J., and Chapman, H. J. (1989). Geology and geochronology of the Arnea, Sithonia and Ouranoupolis intrusions. Chalkidiki Peninsula, Northern Greece. *Tectonophysics,* 161: 65-79.

Dimitriadis, S. (1974). *Petrological study of the migmatitic gneisses and amphibolites of Rentina-Asprovalta-Stavros-Olympias area.* Thesis, University of Thessaloniki, 231 pp. (in Greek).

Dimitriadis, S., and Godelitsas, A. (1991). Evidence for high pressure metamorphism in the Vertiskos group of the Serbomacedonian Massif. The eclogite of Nea Roda, Chalkidiki. *Bull. Geol. Soc. Greece,* 25: 67-80.

Dodge, F. C. W., Lockwood, J. P., and Calk, L. C. (1988). Fragments of the mantle and crust from beneath the Sierra Nevada batholith: xenoliths in a volcanic pipe near Big Creek, California. *Geol. Soc. Amer. Bull.,* 100: 938-947.

Droop, G. T. R. (1983). Pre-Alpine eclogites in the Pennine Basement Complex of the Eastern alps. *J. Metamorphic Geol.,* 1: 3-12.

Elphich, S. C., Ganguly, J., and Loomis, T. P. (1982). Experimental study of Fe-Mn interdiffusion in aluminumsilicate garnet. *Geol. Soc. Amer. Abstr. with Progr.,* 14 pp. 483.

Gil Ibarguchi, J., Mendia, M., Girareau, J., and Peucat, J. (1990). *Lithos,* 25: 133-162.

Graham, C. M., and Powell, R. (1984). A garnet-hornblende geothermometer: calibration, testing and application to the Pelona Schist, Southern California. *J. Metamorphic Geol.,* 2: 13-31.

Kassoli-Fournaraki, A. (1981). *Contribution to the mineralogical and petrological study of amphibolitic rocks of the Serbomacedonian massif.* Thesis, University of Thessaloniki, 231 pp. (in Greek).

Kassoli-Fournaraki, A., Eleftheriadis, G., and Michailidis, K. (1985). Amphiboles chemistry as a pressure and temperature indicator in amphibolites from the Serbo-Macedonian massif (Greece). *Schweiz. Mineral. Petrogr. Mitt.,* 65: 247-264.

Kauffmann, G., Kockel, F., and Mollat, H. (1976). Notes on the stratigraphic and paleogeographic position of the Svoula formation in the Innermost zones of the Hellenides (Northern Greece). *Bull. Soc. Geol. France,* 18: 225-230.

Kockel, F., and Walther, H. W. (1968). Zur geologischen entwicklung des sudlichen Serbo-Mazedonischen Massivs (Nord Griechenland). *Bull. of the Geol. Inst. ser Geotect. strat. lithol.,* 17: 133-142.

Kockel, F., Mollat, H., and Walther, H. W. (1971). Geologie des Serbo-Mazedonischen Massivs and seines mesozoischen Rahmens (Nord-Griechenland). *Geol. Jb.,* 89: 529-551.

Kockel, F., Mollat, H., and Walther, H. W. (1977). Erlauterungen zur Geologischen Karte der Chalkidiki und angrenzender Gebiete 1:100000 (Nord Griechenland). Bundesanstalt fur Geowissenschaften und Rohstoffe, Hannover, 119 pp.

Kourou, A. (1991). *Lithology, tectonism, geochemistry and metamorphism of the western part of the Vertiskos group. The area N. E. of the Agios Vasilios Lake.* Thesis, University of Thessaloniki, 461 pp. (in Greek).

Laird, J., and Albee, A. (1981). Pressure, temperature and time indicators in mafic schists: their application to reconstructing the polymetamorphic history of Vermont. *Amer. J. Sci.,* 281: 127-175.

Leake, B. E. (1978). Nomenclature of amphiboles. *Amer. Mineral.,* 63: 1023-1052.

Messiga, B., Tribuzio, R., and Caucia, F. (1992). Amphibole evolution in Variscan eclogite-amphibolites from the Savona crystalline massif (Western Ligurian Alps, Italy): Controls on the decompressional P-T-t path. *Lithos,* 27: 215-230.

Miyashiro, A. (1973). *Metamorphism and metamorphic belts.* G. Allen und Unwin, London, 492 pp.

Mukhopadhyay, B. (1991). Garnet breakdown in some deep seated garnetiferous xenoliths from the central Sierra Nevada: Petrologic and tectonic implications. *Lithos,* 27: 59-78.

Papadopoulos, C. (1982). Geologie des Serbomazedonischen Massivs nordlich des Volvi Sees (Nord Griechenland). Dissertation, University of Wien, 176 pp.

Philippot, P., and Selverstone, J. (1989a). Fluid inclusions in eclogite veins: Evidence for fluid heterogeneities and high-field-strength element mobility. *Geol. Soc. Amer. Abstracts with Programs,* 21: A359.

Philippot, P., and Selverstone, J. (1989b). Fluid heterogeneities, migration pulses, and channelized flow of eclogite facies fluids: Evidence for Zr, Ti, Ba, and K mobility in subduction zones. *Eos,* 70: 1377.

Robinson, P., Spear, F. S., Schumacher, J. C., Laird, J., Klein, C., Evans, B. W., and Doolan, B. I. (1982). Phase relations of metamorphic amphiboles: Natural occurrences and theory. In: *Reviews in Mineralogy,* 9B:1-227, Mineralogical Society of America.

Ryburn, R. J., Raheim, A., and Green, D. H. (1976). Determination of the P, T paths of natural eclogites during metamorphism-record of subduction. *Lithos,* 9: 161-164.

Sakellariou, D. (1989). *Geology of Serbo-Macedonian massif, in Northeastern Chalkidiki, N. Greece - Deformation and metamorphism.* Thesis, University of Athens, 177 pp. (in Greek).

Sculze, D. J., and Helmstaedt, H. (1979). Garnet pyroxenite and eclogite xenoliths from the Sullivan Butters Latite, Chino Valley, Arizona. In: F. R. Boyd and H. O. A. Meyer (Editors), The Mantle Sample, *Amer. Geophys. Union Mon.,* 318-329.

Sidiropoulos, N. (1991). *Lithology, Geochemistry, Tectonism and Metamorphism of the Northwestern Part of the Vertiskos Group. The area of Mount Disoro to the North of Kilkis.* Thesis, University of Thessaloniki, 592 pp. (in Greek).

Thelin, P., Sartori, M., Lengeler, R., and Schaere, J. (1990). Eclogites of Paleozoic or early Alpine age in the basement of the Penninic Siviez-Mischabel nappe, Wallis, Switzerland. *Lithos,* 25: 71-88.

Tracy, R. J., Robinson, P., and Thompson, A. B. (1976). Garnet composition and zoning in the determination of temperature and pressure metamorphism, central Massachusetts. *Amer. Mineral.,* 61: 762-775.

Ungaretti, L., Lombardo, B., Domeneghetti, C., and Rossi, G. (1983). Crystal-chemical evolution of amphiboles from eclogitised rocks of the Sesia-Lanzo Zone, Italian Western Alps. *Bull. Mineral.,* 106: 645-672.

Yardley, B. W. D. (1977). An empirical study of diffusion in garnet. *Amer. Mineral.,* 62: 793-800.

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