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REGIONAL METAMORPHISM OF THE DETRITIC ROCKS IN ORTAKÖY (AKSARAY) AREA

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ABSTRACT.- The detritic rocks of Ortaköy area were undergone a regional metamorphism which caused development of the paragenesis: sillimanite + plagioclase ($An_{0.43}$) + orthoclase + quartz + biotite ($Ann_{0.08}$, $Phl_{0.012}$) + garnet ($Alm_{0.80-0.83}$, $^{pr}P_{0.10-0.08}$ $Sp_{0.048-047}$ $Grs_{0.048-0.045}$). By geothermobarometers of garnet-biotite and garnet-aliiminosilicate-quartz-plagioclase, the regional metamorphism conditions were determined as P= 3.3±0,36 kb and T=~600°C. The garnet has inverse mineralogical zoning due to homogenisation or exchange reaction between garnet and matrix. Decreasing of grossulerite content in the garnet towards its rim, and occurence of andalusite, chlorite and sericite show that P-T conditions in Ortaköy area follows a clockwise path in P-T-t trajectory.

INTRODUCTION

The assemblage of magmatic and metamorphic rocks situated in the triangular area, where is geologically bounded by the Tuzgölü fault to the west, the Ecemiş Fault to the east and the İzmir-Ankara-Erzincan Suture to the north, is called as the Central Anatolian Massif (CACC, Göncüoğlu et al., 1991). The study area is situated in Ortaköy area (Fig. 1), western CACC.

Metamorphites in the CACC were studied by Erkan (1975, 1976, 1977), Göncüoğlu (1977), Seymen (1981, 1984) and Tolluoğlu (1986, 1987). In the study area, Bayhan (1990) and Türeli (1991), also worked about geochemistry of the igneous rocks.

The lithostratigraphic units of the Ortaköy area show that the Tamadağ Formation of Silurian-Devonian age is the oldest formation and includes migmatitic gneiss, migmatitic granite, semipelitic-psammitic gneiss with interlayers of marble, quartzite, calcsilicate-gneiss and amphibolite (Koçak, 1993, Fig. 1). This is overlain by the Bozçaldağ Formation of Upper Paleozoic age, which is mainly made of marble with lesser quartzite, semipelitic-psammitic gneiss, rare amphibolite and tremolite bearing gneiss. Koçak (1993) has found out acritarch *Leiosphaeridia* and *Lophosphaeriduim* sp., together with possible graptolite fragments-questionably of *Retiolites* sp in the residue obtained from marble samples in Tamadağ Formation by treatment of acetic acid. The first certain macro fossil, Heliolitinae (Heliolitida fam.) *Paeckelmannophora* sp., was discovered in the marble near the top of the Tamadağ Formation. The acritarchs give a *broad* a Cambrian to Devonian range, while coral gives a range of Lower Silurian to Upper Devonian.

The metasediments, undergone metamorphism in upper amphibolite fades (second sillimanite degree) conditions, intruded by Upper Cretaceous-Paleocene aged Ortaköy pluton including hornblendite, hornblend-diorite, biotite-hornblende granitoid, microgranite and quartz-alkali syenite (Ataman, 1972; Erkan and Ataman, 1981; Güleç, 1993; Koçak, 1993; Koçak and Leake, 1994).

In order to determine the P-T conditions in the area, sampling were carried out from detritic rocks of the Tamadağ Formation where cropped out in small area, surrounded by marbles of Bozçaldağ Formation. Mineral assemblage of sillimanite, plagioclase (An>15), orthoclase, quartz, biotite and garnet, that allows to geothermobarometer studies on, determined in the semipelitic gneiss in Sırayalardağı area. Chemical composition of the minerals, in which the rim was preferred, were analysed at Geology Department (Glasgow University, UK) by microprobe (Table 1).

PETROGRAPHY

The paragenes developed by regional metamorphism in the detritic rocks are as follows: (between paranthesis are in minor amounts).

Bt+sil+qtz

Bt+pl+qtz(+zr)

Bt+plg+qtz+sil(+ap)

Pl+bt+or+qtz+mic+(+tur)

Qtz+sil+bt+pl(+zr)

Qtz+pl+bt+or

Sil+or+qtz+pl+bt+grt (+opq)

Sil+bt+plg+qtz (zr+sph+rt+mag+cas+hem)

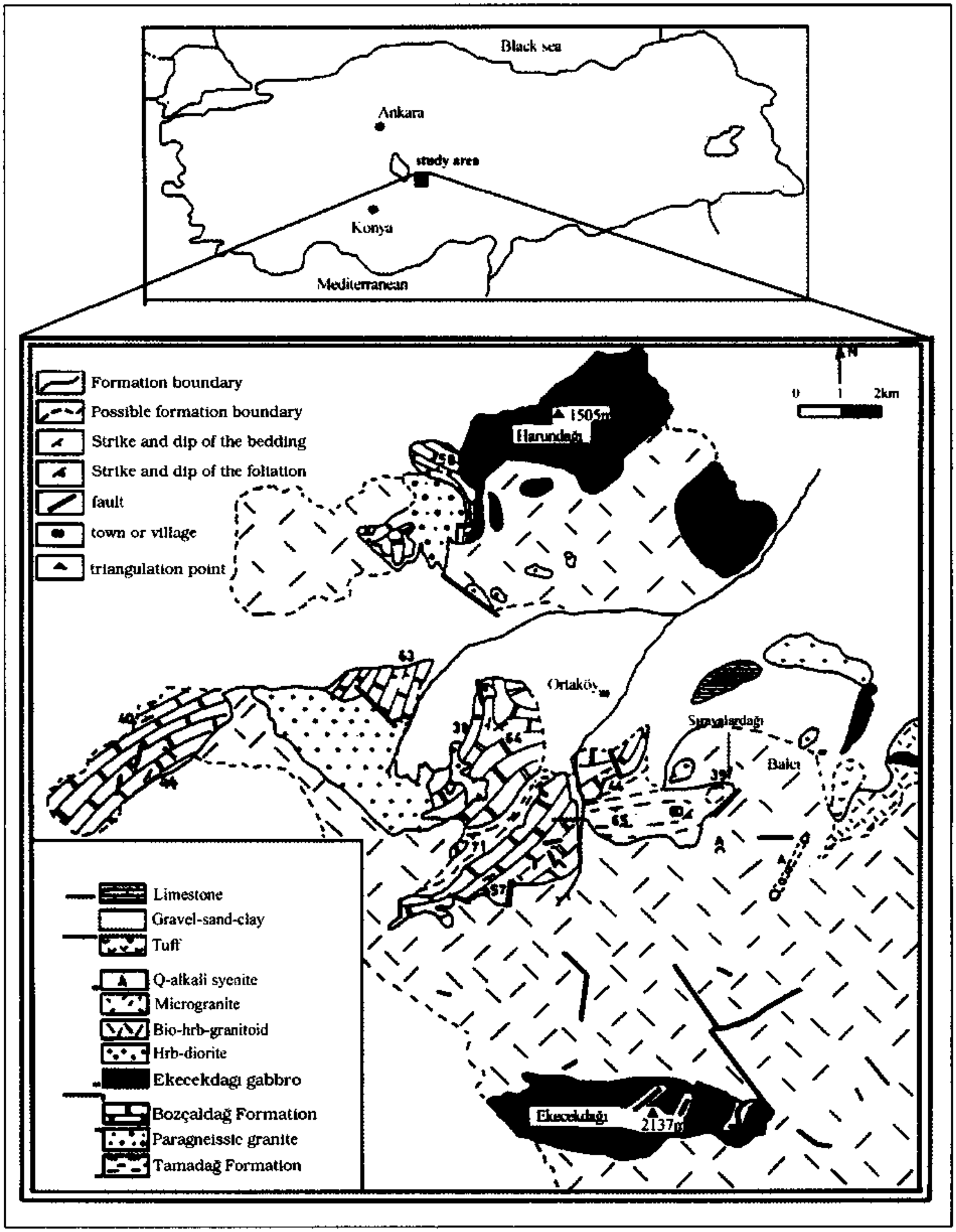

Fig. 1- Geological map of the studying area (Koçak, 1993).

Table 1- Microprobe analyses of some minerals in the gneiss sample

	Garnet (core)	Garnet (edge)	Garnet[b]	Plg[b]	Bio[j]	Garnet[j]	Plg
SiO_2	36,77	36.38	37.49	57.45	34.73	36.89	55.80
TiO_2	0,08	0,00	0,07	0,00	5,07	0,00	0,00
Al_2O_3	21,08	20,90	21,32	26,69	18,98	21,10	28,35
Fe_2O_3	0,00	0,74	0,00	-	2,71	0,12	-
FeO^A	36,48	35,88	36,49	0,14	19,88	36,95	0,06
MnO	1,94	2,11	2,132	0,03	0,08	2,07	0,00
MgO	2,39	2,67	2,60	0,00	5,87	2,02	0,16
CaO	1,56	1,51	1,71	8,76	0.01	1.58	10.55
Na_2O				6,36	0,41		5,35
K_2O				0,19	9,64		0,15
Cr_2O_3	0,02	0,00	0,07			0,02	
(Total)	100,32	100,19	101,88	99,62	97,38	100,75	100,42

Formula based on 24 oxygens for garnet, 32 oxygens for plagioclase and 22 oxygens for biotite

	Garnet (core)	Garnet (edge)	Garnet[b]	Plg[b]	Bio[j]	Garnet[j]	Plg
Si	5,93	5,89	5,96	10,32	5,60	5,95	9,98
Ti	0,01	0,00	0,00	0,00	0,61	0,00	0,00
Al	4,01	3,99	3,99	5,65	2,71	4,01	5,98
Fe^{3+}	0,00	0,09			0,37	0,01	
Fe^{2+}	4,92	4,86	4,85	0,02	2,68	4,98	0,01
Mn	0,26	0,29	0,29	0,00	0,01	0,28	0,00
Mg	0,58	0,65	0,61	0,00	1,41	0,48	0,04
Ca	0,27	0,26	0,29	1,69	0,00	0,27	2,02
Na				2,22	0,13		1,86
K				0,04	1,98		0,03
Cr	0,002	0,00	0,00			0,00	
An%				42,7			51,67
Ab%				56,2			47,4
Or%				1,1			0,89

[b] used for geobarometer calculations,

j used for geothermometer calculations,

[A] Fe/Fe2+F3+ in garnet is calculated according to Drop (1987)/ and Fe/Fe2+F3+=0.12 assumed for the biotite (Guidotti and Dyar, 1991; Holdaway and Mukhopadhyay, 1993).

The sample analysed mainly contains sillimanite (% 35, <0.4 mm), plagioclase+orthoclase (%30, <0.4 mm), quartz (%20, <0.4 mm), biotite (%5,~1 mm), garnet (%5, <0.8 mm), and andalusite+ chlorite+sericite+opaque iron ore (5%) in a lepidone-matoblastic texture (Fig. 2). The sillimanites, in which sericite developed around, usually have needless and sometimes fibrous shape. The plagioclase crystals often show polysynthetic and albite-carlsbad twinnings. The garnet containing plagioclase, biotite and quartz inclusions, is retrograted to biotite along its edge. The biotite, displayed light-dark brown colour and pleochroism, is altered to chlorite and opaque iron ore. The andalusite formed as small crystals within sillimanites (Fig. 3).

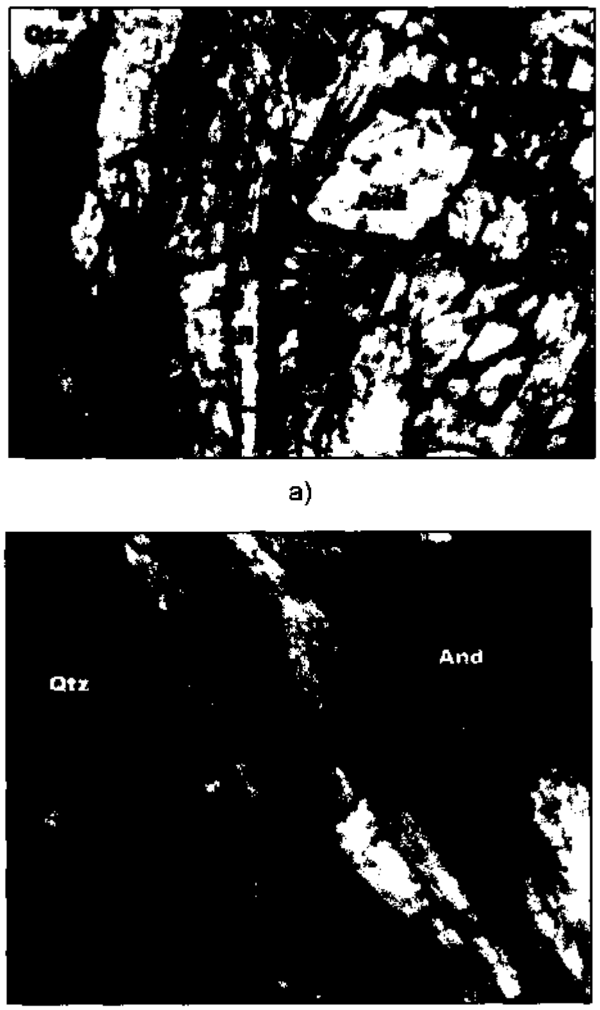

Fig. 2- Andalusite within the sillimanite a) Single polar *40 b) Cross polars *40 N.(S: sillimanite, Qtz: quartz, A: andausite).

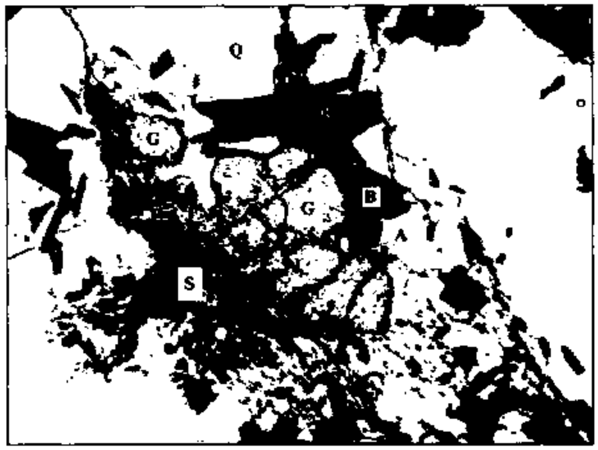

Fig. 3- Mineral relations in the samples analysed (G: garnet, S: sillimanite, B: biotite, Q: quartz, A: plagioclase (anorthite) single polar* 20.

The existence of biotite, plagioclase and quartz inclusions in the garnet indicates that a reaction took place between the inclusion and their host. The garnet has contact with biotite,plagioclase and quartz due to that the reaction possibly went back:

An > gros + 2/3sil + 1/3qtz
(Kretz, 1959; 1964) (1)

Fe-garnet + Mg-biotite > Mg-garnet + Fe-biotite
(Kretz, 1959; 1964). (2)

Co - existence of orthoclase and sillimanite show brekdown of muscovite.

Mus+qtz > sil+or+H_2O (Ewans and Guidotti, 1966; Thompson, 1976, 1982; Vielzeuf and Boivin 1984). (3)

Conversion of biotite to chlorite, sillimanite to sericite and andalusite can take place owing to retrograde metamorphism

3sil+3qtz+2K^++3H_2O > 2mus+2H^+
(Chinner, 1961; Carmichael, 1969) (4)

sil > and (Holdaway, 1971; Richardson et al., 1969; Kerrick, 1987). (5)

MINERAL CHEMISTRY

The garnet shows inverse chemical and mineralogical zoning; spessartine (0,03 mole) and pyrobe (0,07 mole) increase while almandine (0,06 mole) and grossularite (0,01 mole) decrease towards rim (Fig. 4). The inverse zoning, common in high grade rocks, may be explained by exchange reaction between garnet and matrix (Loomis, 1975), resorbtion of garnet (Grant and Weiblen, 1971), or homogenisation of zoned garnet (Blackburn, 1969). Minimum crystallisation temperature of the garnet-biotite pair (600°C) is high enough to

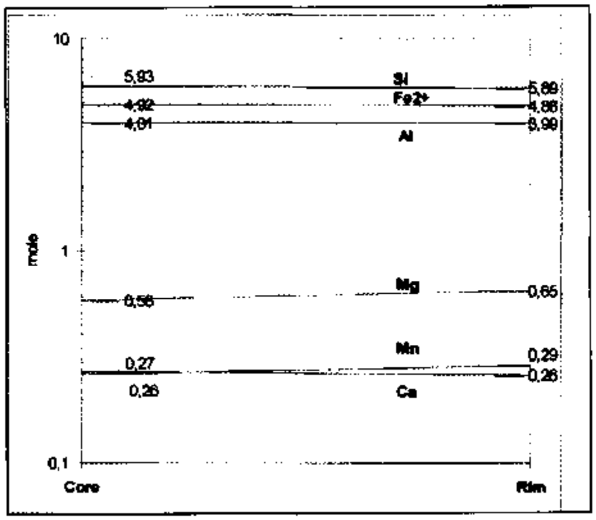

Fig. 4- Mineralogical zonation in the garnet.

allow homogenisation of the zoned garnet. As no resorbtion observed in the sample, either the exchange reaction and/or homogenization of the zoned garnet could be responsible for the zoning.

Decreasing grossularite content towards rim of the garnet, as well as crystallisation of the andalusite, chlorite and sericite indicates that pressure-temperature-time (P-T-t) path follows a clockwise pattern in the area (Fig. 5).

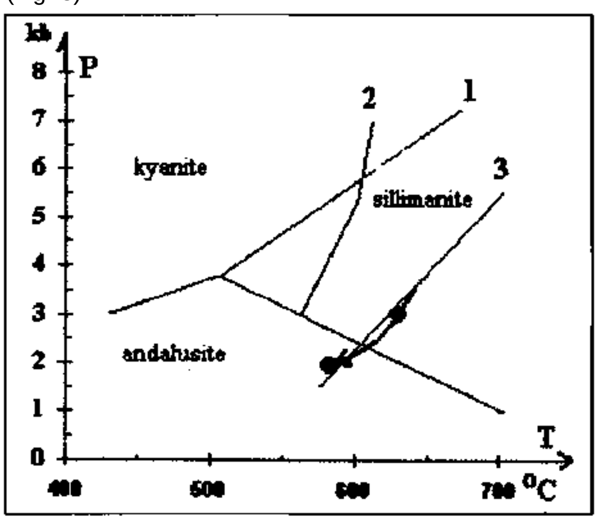

Fig. 5 - Conditions of,the regional metamorphism in the Ortaköy area and P-T-t path (error in the geothermobarometer calculations is taken account plotting of the P-T values in the diagram). 1- Al_2SiO_5 diagram of Holdaway and Mukhopadhway (1993a) 2- Chl + Mus - And + Bio + Qtz + H_2O (Bird and Fawcett, 1973) 3- Mus+Qtz > Kfs+ Als+H_2O reaction is calculated for a H_20 =0.8 (Reinhardt,l992).

In the sample, free garnet is poorer in Ca (0.03 mole) than the garnets in contact with plagioclase while it is poorer in Fe^{2+} (0.12 mole) and richer in Mg^{2+} (0.17 mole) with respect to the garnet in contact with biotite. Similarly, the plagioclase in contact with the garnet is poorer in An (8.97 mol) than free plagioclase.

GARNET-ALUMINOSILICATE-QUARTZ GEOTHERMOBAROMETER

Pelitic schist and gneisses are secure qualitative indicator for metamorphic grade over wide P-T conditions. Gamet-aluminosilicate quartz-plagioclase (GASP) geobarometer is used widely in conditions ranging from greenschist to granulite fades (Ghent, 1976; Aranovich and Podlesskii, 1980; Newton and Haselton, 1981; Hodges and Crowley, 1985; Koziol and Newton, 1988). In reaction, mass-balance equation is as follows:

$$CaAl_2Si_20_8 \quad CaAl_{0.67}SiO_4 + 2/3\ Al_2SiO_5 + 1/3\ Si0_2 \quad (1)$$

An component in plagioclase — grossuler component in garnet — sillimanite — quartz

Volume change in the reaction is considerably high and hence increasing pressure moves equation towards right, increases activity ratio (agrs/ aan) and Ca content of the garnet relative to plagioclase. GASP applied to the sample and 3.35 kb is obtained as minimum crystallisation pressure (Table 2). GASP geobarometer of Powell and Holland (1988) also applied to the sample and 3.27 kb is found for 600°C. The results obtained are almost identical for two geobarometer. Taken into consideration of the uncertainty of calculation (0,36 kb, Powell and Holland, 1988) minimum crystallisation pressure would be 3-3.5 kb for the semipelite.

GARNET-BIOTITE GEOTHERMOMETER

A range of geological thermometer has been developed in pelitic systems, however best calibrated one is garnet-biotite exchange geothermometer (Hodges and Crowley, 1985; Holdaway and Mukhopadhyay, 1993b).

$$Fe_3A_{l2}Si_3O_{12}+KM_{g3}Al_2Si_3O_{10}(OH)_2Mg_3Al_2Si_3O_{12}+KFe_3AlSi_3O_{10}(OH)_2 (2)$$

Fe-garnet + Mg-biotite Mg-garnet + Fe-biotite

As volume change in the reaction is quite small, to increase the temperature makes biotite rich in Fe and garnet rich in Mg. Several garnet-biotite geothermometers have been applied to the semipelite:

Table 2- GASP geobarometer.

Garnet	Almandine	Spessartine	Pyrobe	Grossularite
	0,803	0,048	0,101	0,048
Plagioclase	**An**	**Ab**	**Or**	
	0,428	0,562	0,01	
Barometer calibrations				
Temperature used °C		600		
	ln K	log K		**P(kbar)**
Grs + 2Sil + Qtz = 3 An	7,873	3,419		**3,35**

Table 3- Calculations of the geothermometer.

	Mg/(Mg+Fe) Garnet end member							Biotite	
	Grt	Bt	KD	Alm	Sps	Prp	Grs	X(Ti)	X(AlVI)
	0,088	0,344	5,45	82,9%	4,7%	8,0%	4,5%	0,122	0,062
RESULTS				**TEMPERATURE (deg °C)**					
	P kbar	HS82	T76	HL77	FS78	PL83	Dasg91	B92-HW	B92-GS
	3	**600**	**590**	**580**	**582**	**584**	**476**	**581**	**572**

Thompson (1976) geothermometer was calibrated by correlation of KD values of natural garnet-biotite association against estimated temperatures based on experimental phase equilibrium. Ferry and Spear (1978), and Perchuk and Lavrent'eva (1983) experimentally calibrated thermometers in a system with Fe/Fe+Mg ~0,9 and Fe/Fe+Mg ~0,6 respectively. Bhattacharya et al., (1992) and Hodges and Spear (1982) considered unideal conditions in geothermometer calibrations. An empirical thermometer was developed by Dasgupta et al., (1991) via statistical regression of Ferry and Spear's (1978) experimental data.

Minimum crystallisation temperature of the garnet and biotite, determined by using the geothermometers, was given in Table 3 with same data used in calculation. The results (581, 572, 600°C) obtained from geothermometers (except Dasgupta et al., 1991), based on unideal solid solution assumption between garnet-biotite are nearly same with the ones determined by using geothermometer based on ideal solid solution between garnet and biotite (582, 590 and 584). That is, equilibrium constant (K) is nearly equal to the equilibrium distribution constant (KD). This can be explained by (1) small deviation of biotite-garnet from ideal solid solution, (2) tendency to equilibria, and (3) application of the geothermometer to the sample containing similar Fe/Mg in experiment. As calculation error taken into account (e.g. ± 25°C of Ferry and Spear, 1978), minumum crystallisation temperature of garnet and biotite in the semipelite would be about 600°C.

DISCUSSION AND CONCLUSIONS

Paragenes of plagioclase ($An_{0,43}$), biotite ($Ann_{0.08,}$ $Phl_{0,012}$), garnet ($Alm_{0.08-0.83}$ $Prp_{0,10-0,08}$ $Sp_{0,048-047}$ $Grs_{0,048-0,045}$) and sillimanite were determined in the semipelites metamorphosed under upper amphibolite fades conditions.

The garnet shows inverse mineralogical and chemical zoning: spessartine and pyrobe increase while almandine and grossularite decrease towards rim. It can be explained by exchange reaction between garnet and matrix and/or homogenisation of the zoned garnet.

By using various garnet-biotite and garnet-aluminosilicate-quartz-plagioclase geothermobarometers, minimum crystallisation pressure and temperature in Ortaköy area were succesfully determined as 3.3±0.36 kb ve ~600±25 (Table 2, 3). Erkan (1976) determined three different isograds which corresponds to > 500 ˚C, -600 ˚C and ~700 ˚C temperature (< 5 kb) in northeast of the city of Kırşehir while Seymen (1984) estimated P-T conditions of 400-700 ˚C at - 1.5-2 kb pressure, on the basis of index minerals in northwest of Kırşehir. The P-T values obtained in Ortaköy area therefore correspond to Erkan (1976) and Seymen's (1984) data However, the Ortaköy values, determined by stoichiometric calculations based on mineral chemistry obtained via microprobe analyses, are much more sensitive and definitive than the others based on investigations of polarizan microscope.

Whitney and Dilek (1997-1998) were suggested that the Niğde metasedimentary protoliths were buried to 16-20 km (5-6 km) depth at >700 ˚C temperature in relation with the closure of Tethyan seaways in Early Cenozoic and were later, following cooling and rifting, undergone second heating (<10 km and <600˚C) event during Miocene magmatism. The sillimanites were tightly folded during first metamorphism and then scarn zone including andalusite and cordierite were developed by intrusion of the granitoids into the metadetritic rocks. Development of andalusite was followed by asecond, prograde episode of sillimanite growth during low-pressure-high-temperature metamorphism in the central part of the massif, where magmatism was most extensive. In Ortaköy area, decreasing grossuler content of the garnet towards its rim indfcates that the garnet was grown >3.3± 0,36 kb pressure. Crystallisation of the andalusites, situated within the sillimanites as small crystals, as well as chlorite and sericite indicates decreasing pressure. Therefore, Ortaköy metasedimantery protoliths were buried >10-13 km depth during crustal thickening in relation with closure of the Neo-Tethyce (Göncüoğlu et al., 1991) and then the massif were uplifted, inducing crystallisation of andalusite, sericite and chlorite. Alternatively, P-T in Ortaköy area follows a clockwise pattern in P-T-t projectory (Fig. 5). As no occurence of secondary sillimanite observed in the Ortaköy area, it is possible to say that Miocene magmatism, suggested by Whitney and Dilek (1997, 1998), has not taken place in the study area.

There is no substantial difference between the results obtained by, geothermometer based on ideal and unideal solid solution. This can be explained by deviation of garnet-biotite from ideal solid-solution, and/or tendency of the garnet-biotite pairs-towards equilibrium or application of the geobarometer tq the sample containing similar Fe/Mg in the experiment

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