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Granulite Facies Gneisses from the Pulur Region, Eastern Pontides

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Abstract: In the Pulur region in the Eastern Pontides a metamorphic basement outcrops under the Jurassic-Cretaceous sequence. The metamorphic rocks are divided into two tectonic units. At the base is the Hasso Group of greenschist facies metatuffs and phyllites, which are tectonically overlain by the Cenci Group of gneiss, migmatite, metaquartzite, amphibolite and variably deformed granitic rocks. The metapelitic gneisses of the Cenci Group contain the granulite facies mineral assemblage of cordierite + garnet + sillimanite + biotite + K-feldspar + plagioclase + quartz. Mineral equilibria in this assemblage indicate P-T conditions of 730 ± 50°C and 5 ± 0.5 kbar for the regional metamorphism. Regional tectonic considerations indicate that the granulite facies metamorphism is probably of Late Devonian age. In contrast, the Hasso Group can be compared with the Ağvanis Massif of probable late Triassic metamorphic age, which forms part of the Karakaya Complex and is located 90 km southwest of the Pulur metamorphic rocks. The tectonic juxtaposition of the two groups must have occurred during the latest Triassic Cimmeride orogeny.

Introduction

The geology of the Eastern Pontides is dominated by the Jurassic to Eocene volcanic and sedimentary rocks; the metamorphic basement is exposed only in a few small inliers. However, a careful study of these inliers is important to gain information on the pre-Jurassic geological evolution of the Eastern Pontides. One such area is the Pulur region southwest of Bayburt, where a metamorphic basement is described below the Liassic volcano-sedimentary rocks (Ketin, 1951; Ağar, 1977; Akdeniz, 1988; Tanyolu, 1988; Keskin et al., 1989). Here, I describe cordierite-sillimanite-garnet-bearing metamorphic rocks from the Pulur region and discuss their petrology, tectonic setting and significance. Cordierite-bearing gneisses are recently independently described from the same region by Topuz and Sadıklar (1994).

Geological Setting

Pulur region lies north of the Ankara-Erzincan Neo-Tethyan suture in the inner part of the Eastern Pontides in an Alpine fold and thrust belt; the metamorphic rocks in the Pulur region form a ~60 km long and ~5 km wide east-northeast trending belt unconformably overlain in the south by the Jurassic volcano-sedimentary rocks (Figure 1). Along their northern basal contact, the Pulur metamorphic rocks are thrust northward over the Jurassic volcano-sedimentary rocks (Ketin, 1951) and over the Upper Carboniferous shales and siltstones (Okay, 1993; Figure 1); the thrusting is of Late Paleocene-Early Eocene age.

Pulur Metamorphic Rocks

Two distinct metamorphic rock groups can be differentiated in the Pulur region. These are called as the Cenci and Hossa groups. The Hossa Group, named after the village of Hossa south of Saraycık (Figure 1), is composed mainly of green metatuffs and grey, fine-grained phyllites; the metamorphism is in low greenschist facies. The type section for the Hossa Group is the road from Saraycık to Hossa and farther south. In terms of their lithology and metamorphic grade the Hossa Group can be compared with the Ağvanis metamorphic rocks (Okay, 1984) located 90 km southwest of the Pulur region.

The Cenci Group, named after the village of Cenci, is composed of a heterogeneous lithological assemblage of garnet-cordierite-gneiss, microgneiss, migmatitic gneiss, metaquartzite, banded amphibolite, metadiorite and minor marble and metaserpentinite. The Cenci metamorphic rocks are poorly exposed and the best reference sections are the road between the villages of Yakupabdal and Pekesi, and the area around the village of Aşutka. Although no direct contact between the Cenci and Hossa groups were observed in the field, the abrupt increase in metamorphic grade from the Hossa to the Cenci Group suggests a tectonic contact and the attitude of the foliation indicates that the high-grade metamorphic rocks of the Cenci Group are thrust over the Hossa Group (Figure 1). The thrusting must have been pre-Jurassic as the Liassic volcano-sedimentary rocks cover the assumed thrust contact between the two groups (Figure 1).

The Cengi Group is strongly tectonised during the Alpide orogeny and is extensively intruded by Eocene dioritic and andesitic stocks, dykes and sills. Garnet-cordierite-gneisses of the Cenci Group form medium-to coarse-grained, light to dark-coloured massive, dense rocks full with large mesoscopic garnet crystalls, and represent metamorphosed pelitic rocks. They are intercalated with white clean metaquartzites, rare coarse-grained white marble and banded amphibolite (Figure 1). Amphibolites contain thin bands of diopside-plagioclase rock and a few-metre-thick, rare antigorite-serpentinite and anthophyllite-talc lenses. The small serpentinite lenses often associated with amphibolites are suggestive of small cumulate ultramafic bodies rather than ophiolite. Migmatisation is evident both in the gneisses and in the amphibolites with leucosomes cutting the unmelted portions of the rock. The medium grained thinly banded metagranitic rocks, which are associated with high-grade metamorphic rocks of the Cenci Group may represent larger quantities of syn-metamorphic granitic melts. Contrary to suggestion of Topuz and Sadıklar (1994) no change in metamorphic grade was observed in the Cengi Group. All the metamorphic rocks of the Cenci Group are variably mylonitised, and extensively altered.

Petrography and Mineral Chemistry

Garnet-cordierite gneisses consist of up to 2 cm large garnets that are associated with pinitised cordierite, quartz and sillimanite, and minor biotite and ilmenite. Almost all the cordierite in over 15 thin sections examined is altered to pinite. The rarer quartzofeldspathic cordierite-gneisses contain K-feldspar and plagioclase in addition to the other phases of the garnet-cordierite gneisses. Amphibolites consist of green hornblende and sericitised plagioclase, while the intercalated diopside-fels contains plagioclase and

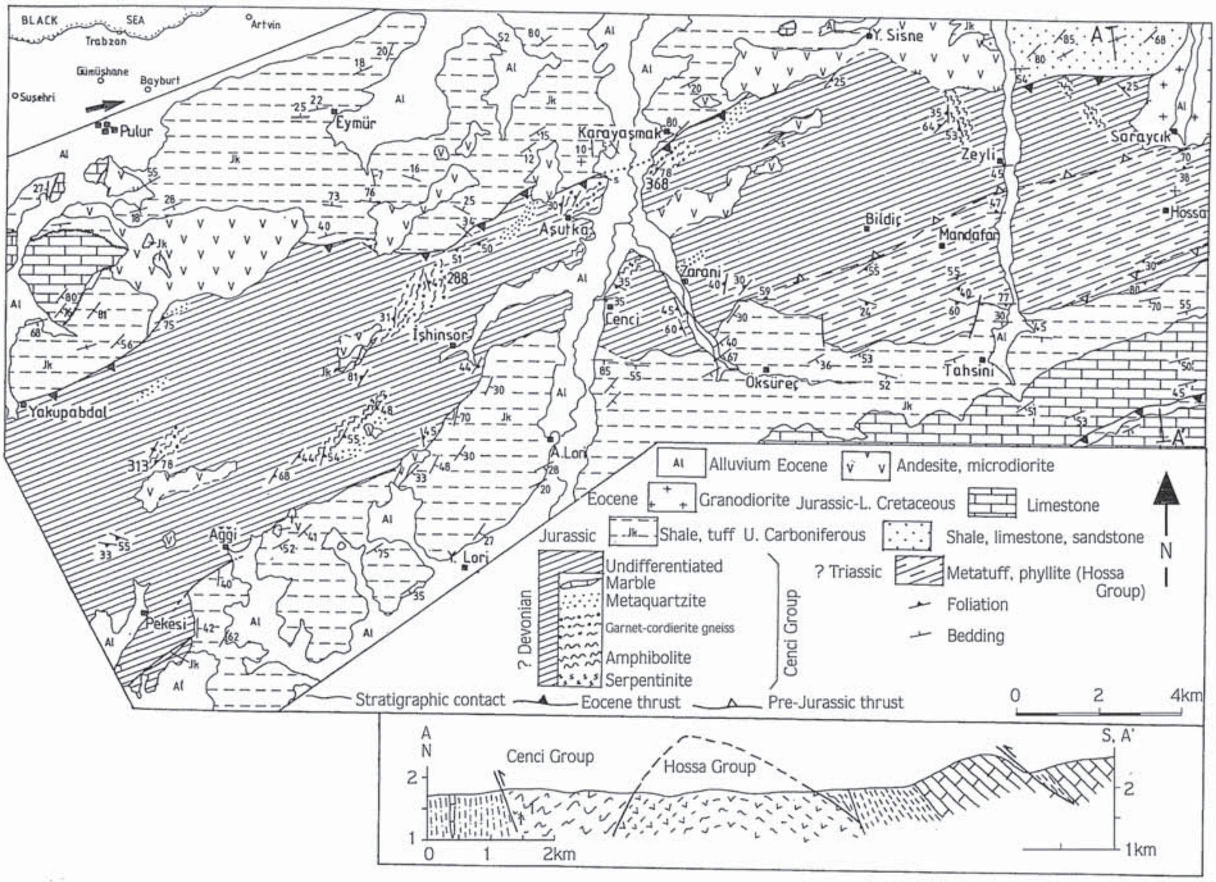

Figure 1. Simplified geological map of the Pulur area. The inset shows the location of the Pulur region in the Eastern Pontides. Specimen localities are also shown.

diopside. All the metamorphic rocks of the Cenci Group are strongly altered; cordierite is almost completely pinitised, biotite oxidised or chloritised and the feldspars sericitised. One relatively fresh quartzo-feldspathic cordierite-gneiss (sample 313B) and one garnet-cordierite gneiss (sample 288A) were analysed by electron microprobe.

Mineral compositions were analysed for twelve elements with an SX-50 Cameca electron microprobe in the Ruhr-University in Bochum using wave-length dispersive spectrometers. Operating conditons were generally 15-kV accelerating voltage, 15 nA beam current and 10-µm beam size.

Specimen 313B is a medium-grained, slightly foliated and banded gneiss with the primary mineral assemblage garnet + cordierite + sillimanite + biotite + K-feldspar + plagioclase + quartz + ilmenite. The banding is defined by discontinuous millimetre-thick bands of small (0.1-0.3 mm), idioblastic sillimanite aggregates set on a pinitised cordierite with minor dark reddish brown biotite and opaque (Figure 2a). These bands occur in a quartzo-feldspathic groundmass of up to 2 mm large perthitic K-feldspar, plagioclase and strained partially recrystallised quartz with minor biotite, garnet, cordierite and ilmenite (Figure 2b). Garnet forms elongate anhedral crystals with quartz inclusions and is semi-enclosed by pinitised cordierite. Over 90% of the cordierite in the section is pinitised and only rare patches of cordierite crossed by pinite veins remain. The quartzo-feldspathic groundmass includes rare mrymeckite crystals of drop-like albite grains in a quartz matrix.

Table 1. Estimated modal amounts of cordierite-gneisses from the Pulur Massif.

	Garnet-Cordierite Gneisses			
	288A	368B	368C	313B
Garnet	29	35	41	6
Cordierite	- (39)	- (5)	- (29)	2 (12)
Sillimanite	6	27	-	9
Biotite	5	4	4	12
K-feldspar	-	-	5	11
Plagioclase	-	-	15	
Quartz	19	26	3	47
Rutile	tr	1	tr	-
Ilmenite	2	2	3	1
	100	100	100	100

The numbers in parenthesis in the cordierite row indicate the percentage of pinite pseudomorphs after cordierite. tr, traces (<0.5%).

Sample 288A has the primary mineral assemblage garnet + cordierite + sillimanite + biotite + quartz + rutile + ilmenite. Subidioblastic to anhedral garnet, small sillimanite aggregates, dark reddish brown altered biotite and ilmenite are surrounded by pinitised cordierite.

Garnets from both samples are rich in almandine (>65%) with minor pyrope (8-35%), and spessartine (1-9%) contents (Figure 3). The grossular + andradite components in all analysed garnet grains are below 6 mol%. Garnet exhibits minor zoning with an increase in almandine and spessartine at the expense of pyrope component towards the rim (Figure 3, Table 2). Cordierite in sample 313B contains about 44 mole per cent of Fe end member. As it is strongly pinitised zoning could not be checked in the cordierite. The low total of the cordierite analyses (Table 2) suggests that

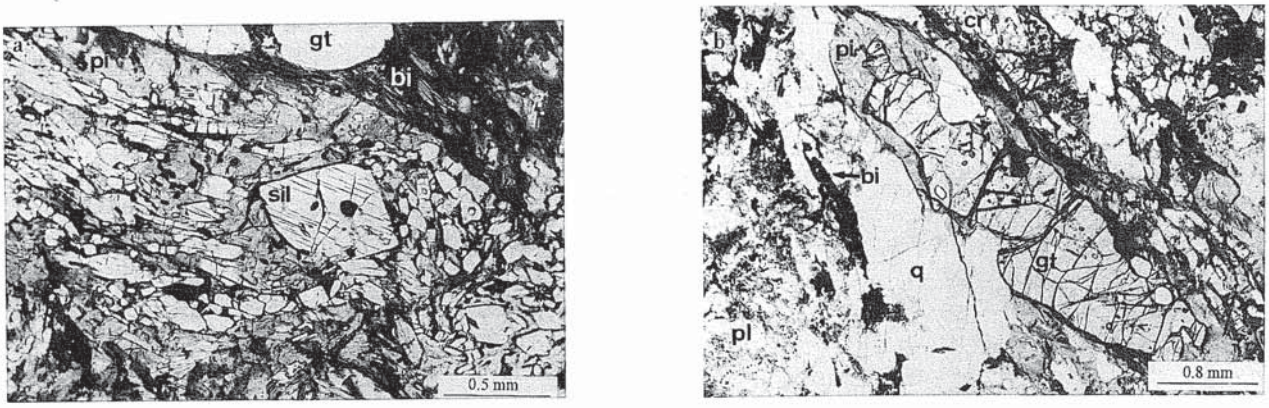

Figure 2. Photomicrographs in plane polarised light from the cordierite gneiss from the Cenci Group (specimen 313B). A. Subidiblastic sillimanite (sil) crystals surrounded by pinitised cordierite (pi) in contact with garnet (gt) and biotite (bi). B. Elongate anhedral garnet (gt) surrounded by pinitised cordierite (pi), quartz (q), biotite (bi) and plagioclase (pl). Small patches of cordierite (cr) have escaped pinitisation.

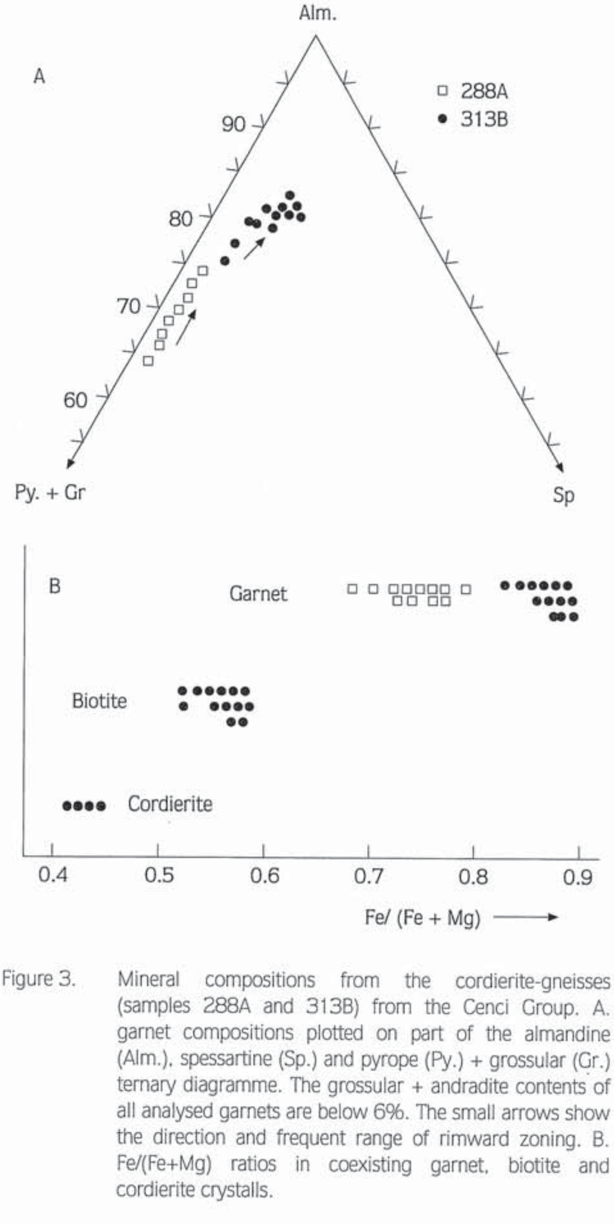

Figure 3. Mineral compositions from the cordierite-gneisses (samples 288A and 313B) from the Cenci Group. A. garnet compositions plotted on part of the almandine (Alm.), spessartine (Sp.) and pyrope (Py.) + grossular (Gr.) ternary diagramme. The grossular + andradite contents of all analysed garnets are below 6%. The small arrows show the direction and frequent range of rimward zoning. B. Fe/(Fe+Mg) ratios in coexisting garnet, biotite and cordierite crystalls.

some water is present in the cordierite structure. In sample 313B the Fe/(Fe+Mg) ration in the biotite ranges from 0.55 to 0.59. The TiO_2 content of the biotite varies from 2.0 to 4.3 weight per cent. Biotites from the sample 288A are strongly altered and analyses give low alkali contents. Albite content of the K-feldspars in the sample 313B range from 10 to 16 mol per cent and anorthite contents from 0 to 0.8 mole per cent. The plagioclase has about 20 mol per cent anorthite. Ilmenite from sample 313B contains about 0.5 mole per cent $MgTiO_3$ and 2.5 mole per cent $MnTiO_3$.

Pressure-Temperature Conditions of the Metamorphism

The absence of primary muscovite and presence of sillimanite + K-feldspar + quartz in the cordierite-garnet gneisses indicate that the temperatures during the metamorphism were above 650°C according to the reaction (Figure 4):

muscovite + quartz = sillimanite + K-feldspar + H_2O (1)

The garnet-biotite and garnet-cordierite geothermometers of Ferry and Spear (1978), and Martignole and Sissi (1981) respectively, give unrealistically low temperatures of about 550°C for garnet rim and 600°C for garnet core compositions using the data from Table 2 suggesting reequilibration of metamorphic rock during exhumation or during subsequent deformation. Furthermore, as the garnet compositions are close to the almandine end member, the temperatures obtained from garnet-biotite and garnet-cordierite geothermometers fluctuate widely between 550° to 800° depending on which garnet composition from sample 313B one utilises.

A commonly used geobarometer in high grade metamorphic rocks is:

anorthite = grossular + sillimanite + quartz (2)

Using the Koziol and Newton (1988) calibration, this geobarometer indicates 2.4 kbar for the garnet rim and 5.2 kbar for the garnet core compositions at a temperature of 730°C. The lower temperature and pressures obtained from the garnet rim compositions indicate that the zoning in garnet is a retrograde phenomenon, and the peak P-T conditions are better reflected in the garnet core compositions.

More precise P-T estimates were obtained from the updated version of the THERMOCALC programme of Holland and Powell (1990) using the almandine, pyrope, cordierite, Fe-cordierite, annite, phlogopite, eastonite and K-feldspar end-members, and sillimanite and quartz. The garnet (core composition), biotite and cordierite compositions, that are used in the calculations, are given in Table 2. As the garnet composition is close to almandine end member and as its grossular content is less than 5 mole per cent, ideal mixing-site activities for garnet as well as for biotite, cordierite and K-feldspar were used.

For the cordierite-gneiss 313B, THERMOCALC indicates an average metamorphic temperature of 730±50°C and an average metamorphic pressure of 5.0±0.5 kbar. Some of the reactions used for this thermobarometric calculation are shown in Figure 4.

Table 2. Mineral compositions from the cordierite-sillimanite gneisses from the Pulur region.

	Gneiss 313B							Gneiss 288A		
	garnet		cord.	biot.	K-field.	plag.	sill.	garnet		sill.
	core	rim						core	rim	
SiO_2	36.40	36.43	47.18	34.78	63.85	62.54	36.42	37.72	37.24	36.21
TiO_2	0.00	0.03	0.00	3.56	0.00	0.01	0.00	0.08	0.04	0.04
Al_2O_3	21.15	21.01	32.66	18.49	19.33	23.22	62.77	21.17	20.91	62.45
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.09	0.00	0.03	0.04
FeO	35.99	36.49	9.85	19.70	0.05	0.00	0.33	30.28	33.62	0.30
MgO	2.95	2.56	7.14	8.58	0.00	0.02	0.02	7.54	5.32	0.03
MnO	2.36	2.70	0.24	0.07	0.01	0.00	0.00	0.54	0.66	0.00
CaO	0.73	0.39	0.03	0.00	0.03	4.35	0.00	1.78	1.41	0.00
Na2O	0.01	0.04	0.14	0.19	1.60	8.44	0.02	0.01	0.02	0.01
K2O	0.00	0.00	0.00	9.64	14.04	0.33	0.01	0.01	0.00	0.00
Total	99.59	99.66	97.24	95.01	98.91	98.91	99.66	99.13	99.25	99.08
Structural formula based on										
	12 ox	12 ox	18 ox	11 ox	8 ox	8 ox	5 ox	12 ox	12 ox	5 ox
Si	2.960	2.970	4.958	2.671	2.962	2.792	0.988	2.973	2.981	0.988
Al^{IV}	0.040	0.030	1.042	1.329	1.057	1.222		0.027	0.019	
Σ	3.000	3.000	6.000	4.000	4.019	4.014		3.000	3.000	
Al^{IV}	1.987	1.989	3.002	0.345			2.007	1.939	1.953	2.008
Ti	0.000	0.002	0.000	0.206	0.000	0.000	0.000	0.005	0.003	0.001
Cr	0.000	0.000	0.000		0.000	0.000	0.002	0.000	0.002	0.001
Fe^{3+}	0.013	0.009	0.000		0.002	0.000	0.007	0.056	0.042	0.006
Σ	2.000	2.000	3.002		4.021	4.014		2.000	2.000	
Fe2+	2.435	2.479	0.865	1.265		0.000		1.939	2.208	
Mg	0.358	0.311	1.118	0.982	0.000	0.002	0.001	0.886	0.634	0.001
Mn	0.162	0.186	0.022	0.005	0.000	0.000	0.000	0.036	0.045	0.000
Ca	0.064	0.034	0.003	0.000	0.002	0.208	0.000	0.150	0.121	0.000
Na	0.002	0.006	0.028	0.028	0.144	0.730	0.001	0.001	0.003	0.001
K	0.000	0.000	0.000	0.944	0.831	0.019	0.000	0.001	0.000	0.000
S	3.021	3.017	2.036	0.972	0.977	0.957		3.013	3.011	
Total	8.021	8.016	11.038	7.775	4.998	4.973	3.006	8.013	8.011	3.006
alm.	80.6	82.4					alm.	64.4	73.4	
prp.	11.9	10.3					prp.	29.4	21.1	
sps.	5.4	6.2					sps.	1.2	1.5	
grs.+adr	2.1	1.1					grs.+adr	5.0	4.0	

All the calculations were performed assuming unit activity of H_2O. However, the P-T conditions are clearly above the melting of a H_2O-saturated metapelite (Figure 4), indicating that the activity of H_2O was less than one. However, reducing the H_2O activity to 0.8 leads to a decrease in temperature by only of about 30°C. In conclusion the estimated P-T conditions of the granulite facies metamorphism in the Cenci Group is 730±50°C and 5±0.5 kbar.

Discussion and Conclusions

The Pulur metamorphic rocks are subdivided into two tectonic groups. The Hossa Group consists of greenschist facies metatuffs and phyllites, while the overlying Cenci Group has undergone a HT/LP metamorphism with the formation of cordierite - garnet - sillimanite - K-feldspar - biotite - quartz paragenesis in metapelites. The estimated P-T conditions are 730°±50 C and 5±0.5 kbar. The presence of garnet + K-

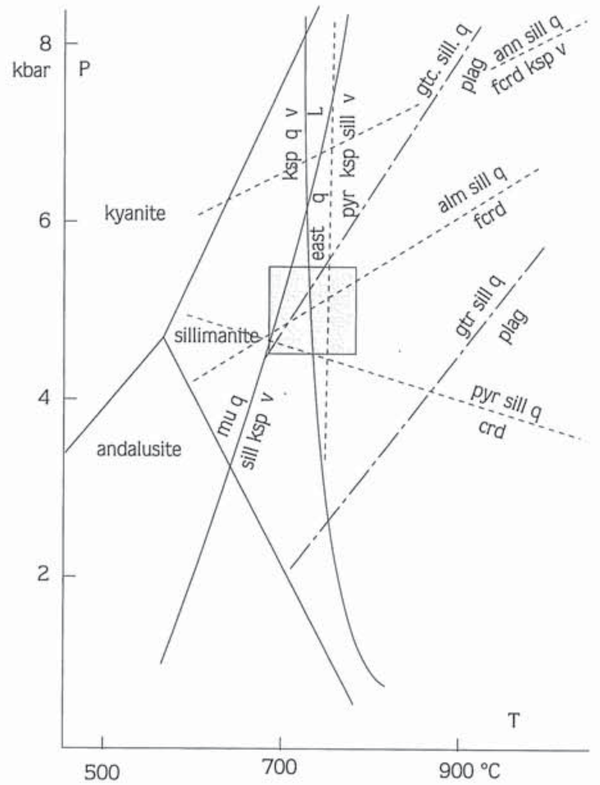

Figure 4. Pressure-temperature diagram showing the constraining equilibria for the P-T conditions of metamorphism in the Cenci Group. The solid lines are end member reactions calculated from THERMOCALC of Holland and Powell (1990) except the wet melting of K-feldspar and quartz, which is after Thompson and Tracy (1979). The dashed lines are some of the mineral equilibria calculated using THERMOCALC for the mineral compositions in Table 2. The dash-dot line shows the garnet-sillimanite-plagioclase-quartz geobarometric reactions for garnet core (gt_c) and rim (gt_r) compositions using the Koziol and Newton (1988) calibration. The estimated P-T conditions of the granulite facies metamorphism in the Cenci Group are also shown. The abbreviations are: alm, almandine; ann, annite; crd, cordierite; east, eastonite; fcrd; Fe-cordierite; ksp, K-feldspar; L, liquid; mu, muscovite; plag, plagioclase; pyr, pyrope; q, quartz; sill, sillimanite; v, H_2O.

feldspar + cordierite subassemblage in the metapelites is generally taken as indicative of granulite facies (e.g., Vielzeuf, 1988; Yardley, 1989); the estimated P-T conditions also lie in the lower granulite facies P-T area. The age of the granulite facies metamorphism is not known but is most probably older than the Upper Carboniferous sedimentary sequence in the Pulur region. In the Gümüşhane region to the north of the Pulur-Bayburt plain, the pre-Jurassic Gümüşhane and Köse granodiorites intrude a low-grade metamorphic basement (Yılmaz, 1975) and give a Rb/Sr whole rock isochron age of 360±2 My (earliest Carboniferous; Bergougnan, 1987). It is likely that the HT/LP metamorphism of the Cenci Group is related to the thermal event, which gave rise to the Gümüşhane and Köse plutons; this suggests a Late Devonian age (late Hercynian) for the granulite facies metamorphism. A plausible tectonic environment for the HT/LP metamorphism and associated granodiorite plutonism is the deeper parts of an ensialic magmatic arc. Late Hercynian HT/LP metamorphic rocks, similar to those of the Cenci Group, and associated granodiorites have been described from the Caucasus (Khain, 1975; Abesadze et al., 1982; Adamia et al., 1982). In the Caucasus these rocks are unconformably overlain by Upper Carboniferous molasse-type sedimentary rocks (Khain, 1975), as was probably the case in the Pulur region. Thus, the pre-Jurassic basement of the Eastern Pontides is similar to that of the Caucasus, and all were probably situated during the Late Paleozoic along the southern margin of Laurasia.

An important tectonic problem in the Eastern Pontides is the relation between the Cenci and Hasso groups. The Hasso Group can be compared in terms of its lithology and metamorphic grade with the Ağvanis Massif (Okay, 1984), located 90 km west of the area studied. Ağvanis Massif forms part of the Permo-Triassic Karakaya complex and its age of metamorphism is probably latest Triassic (Okay, 1984). Thus, the Cenci Group was thrust over the Hasso Group during the latest Triassic Cimmerian orogeny prior to the deposition of the Jurassic sedimentary rocks.

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