BLUESCHIST-FACIES ASSEMBLAGES IN THE PERI-RHODOPIAN ZONE, AND HINTS FOR AN EOHELLENIC HP-LT BELT IN NORTHERN GREECE

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ABSTRACT

High-Si phengite and glaucophane occur in Permo-Triassic metavolcanics and metapelites from the Circum-Rhodope units north and east of Thessaloniki. The estimated P-T conditions range from 6-7 kbar at 300oC to 8-9 kbar at 400°C. This HP-LT metamorphism occurred prior to the Eocene low-pressure, regional metamorphic-magmatic evolution, and likely before the emplacement of the Tithonian-Early Cretaceous granites in the adjoining zones. The peri-Rhodopian HP-LT assemblages, together with the Paikon blueschist-facies rocks and with the Rhodopian eclogites, would represent relics of an Eohellenic HP-LT belt.

INTRODUCTION

In the Hellenides, high-pressure, low-temperature (HP-LT) metamorphic rocks are widespread along two belts which have significantly different ages, I) the Cycladic belt, where the HP-LT recrystallisation occurred essentially during Eocene time (Maluski et al, 1987; Avigad and Garfunkel, 1991), and ii) the Phyllites-Quartzites External belt, where it occurred during Early Miocene (Seidel et al., 1982; Theye et al., 1992) (Fig. 1). The youngest belt only contains low-grade blueschist-facies rocks, while the more internal and older one includes both blueschist and eclogite-facies assemblages. The Cycladic belt disappears to the northwest under the virtually unmetamorphosed Pelagonian and ophiolitic nappes, and the last emergences of the belt are found in the Olympos, Kranea and Rizomata windows (Vergely and Mercier, 1990; Shermer et al., 1990; Kilias et al., 1991; Sfeikos et al. 1991). In northern continental Greece, HP-LT assemblages are rare and scattered. On one hand, low-grade, lawsonite-phengite and Mg-riebeckite bearing assemblages occur in the Paikon Triassic-Jurassic series (Mercier, 1968; Baroz et al., 1987) which appear in a tectonic window in the middle of the Vardar-Axios ophiolitic zone (Codfriaux and Ricou, 1991). On the other hand, relics of eclogitic assemblages are preserved in the barrovian, apmhiliote-facies rocks of the Rhodope and Serbo-Macedonian zones (Liati, 1986; Liati and Mposkos, 1990; Dimitriadis and Godelitsas, 1991; Mposkos and Liati, 1993). In contrast, the adjoining peri-Rhodopian, or Circum-Rhodope zone is thought to contain only greenschist-facies assemblages (Kockel and Mollat, 1977; Kougoulis et al., 1990; Mussallam

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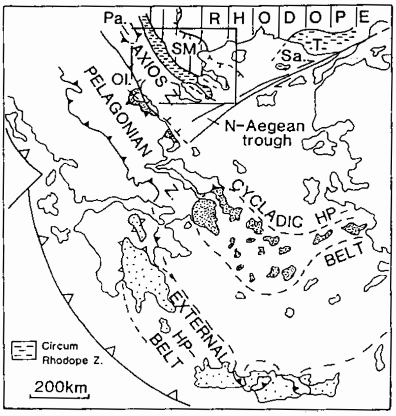

Fig. 1: Sketch map of the two HP-LT belts of the Hellenides, and location of the studied area (framed). Ol.: Olympe; Pa: Paikon; Sa: Samthrace; T: Thrace

and Young, 1986; Asvesta, 1992). In the following, we report new petrographical observations from the Circum-Rhodope zone which decisively change this previous conception and suggest the occurrence of an Eohellenic, Tithonian-Early Cretaceous HP-LT belt in the internal Hellenids.

GEOLOGICAL SETTING OF THE BLUESCHIST-FACIES ROCKS

The Circum-Rhodope zone is currently considered as a transitional, tectonic-metamorphic domain bounding the Rhodopian and Serbo-Macedonian massifs to the southwest (Macedo-nian-Chalkidiki province) as well as to the southeast, in the Samothraki Island and Thrace (Kaufmann et al., 1976; Kockel and Mollat, 1977). The HP-LT assemblages described hereafter were found in two different sub-zones of the Macedonian Circum-Rhodope zone (Fig. 2). The northernmost occurrence (sample 91/59) is located in the northern part of the internal, *Kilkis-Sithonia sub-zone,* which includes I) a Permian-Lower Triassic volcanoclastic, mainly acidic series, particularly developed in the Nea Santa area, ii) a Middle to Upper Triassic carbo-nate series, and iii) the Svoula-Melisso-chori

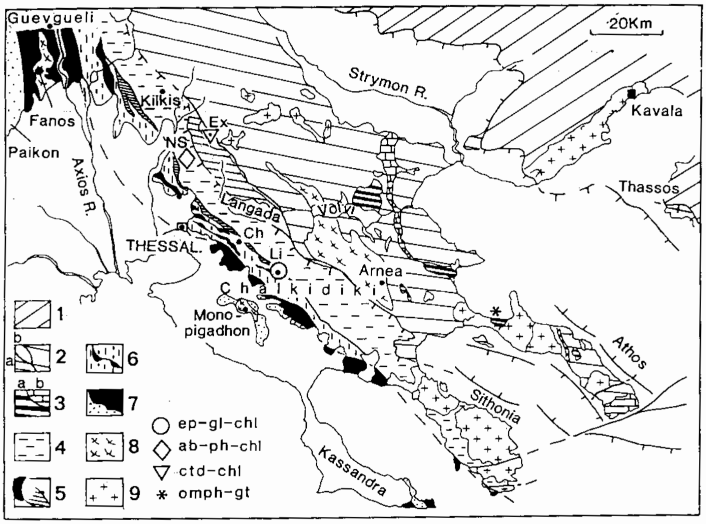

Fig. 2: Geological setting of the studied HP-LT samples. Sketch map elaborated from the geological map of Greece, 1/500 000 (I.G.M.E., Athens, 1983), Kockel and Mollat (1977), Dixon et Dimitriadis (1984), Musallan and Young (1986), De Wet et al. (1989), Dimitriadis and Godelitsas (1991), Sokoutis et al., (1993), and our field observations. 1: Rhodope. 2: Sebo-Macedonian (a: gneiss, micaschistes; b: Examili formation, and other likely Permian-Mesozoic formations). 3: Serbo-Macedonian (a: meta-ophiolites; b: marbles). 4: Circum-Rhodope internal zone. 5: Two-micas gneiss slivers. 6: Circum-Rhodope external zone (black: ophiolitic slivers). 7: Vardar-Axios zone (black: ophiolites). 8: Tithonian-Early Cretaceous foliated granites. 9: Eocene-Oligocene granites. Ch: Chortiatis; Ex: Examili; Li: Livadi; NS: Nea Santa.

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Table 1: Representative microprobe analyses of index minerals from the Nea Santa metarhyolites (no1 and 2, sample 91/59b) and the Livadi metapelites (no 3 to 5, sample 93/175b).

	1	2	3	4	5
	pheng	pheng	amphb.	Pheng.	Chl
SiO2	51.08	50.25	56.69	49.44	30.67
TiO2	0.00	0.00	0.00	0.45	0.00
Al2O3	23.91	25.48	3.01	26.12	18.59
FeO	3.82	3.84	15.78	5.19	10.54
MnO	0.00	0.00	0.17	0.00	0.18
MgO	3.53	3.72	12.50	2.93	26.99
CaO	0.02	0.00	0.98	0.06	0.04
Na2O	0.74	0.01	6.66	0.43	0.00
K2O	9.26	10.45	0.02	9.57	0.00
Sum	92.36	93.75	95.81	93.74	87.01
structural formulae					
Si	3,521	3.433	7.994	3.378	2.978
Ti	0.00	0.00	0.00	0.023	0.00
Al	0.478	0.566	0.006	0.598	1.022
Al	1.465	1.485	0.495	1.505	1.106
Fe3+	-	-	1.505	-	-
Fe2+	0.221	0.22	0.355	0.297	0.855
Mn	0.00	0.00	0.019	0.00	0.014
Mg	0.362	0.379	2.626	0.299	3.907
Ca	0.002	0.00	0.149	0.00	0.000
Na	0.009	0.0018	1.819	0.058	0.00
K	0.813	0.910	0.004	0.834	0.00
XMg	0.62	0.63	0.87	0.50	0.82
XFe3	-	-	0.75	-	-

Analyses were performed on a SX50 Cameca electron microprobe at Paris 6 University (15 kV, 10 nA, PAP correction procedure) using Fe2O3 (Fe), MnTi O3 (Mn, Ti), diposide (Mg, Si), CaF2(F), orthoclase (Al, K), anorthite (Ca), albite (Na) as standards. F is under detection limits. Amphibole analysis is calculated on a fixed number of cations (excluding Ca, Na, K) following Robinson et al. (1982). Chlorite and phengite are clalculated on 14 and 11 oxygens respectivly.

Upper Triassic-Jurassic flysch forma-tion (Mercier, 1968; Kaufmnn et al., 1976; Kockel and Mollat, 1977; Stais and Ferrière, 1991; Dimitriadis and Asvesta, 1993).

In contrast, the Livadi blueschist occurrence (sample 93/175d) is located in the more external (westerly) sub-zone of the Macedonian Circum-Rhodope zone, which includes several ultrabasic or gabbroic slivers and gives way to the Vardar-Axios-Chalkidiki ophiolitic zone more to the west. This external, *Thessaloniki -Chortiatis sub-zone,* sometimes referred to as "Eastern Vardar zone" (Musallam and Jung, 1986), is frequently from the Svoula metaflysh by slivers of two-micas gneiss. West of the tectonic contact marked by these slivers, the Livadi blue-schists are associated with phyllites, phengitic quartzites, prasinites and marbles. The stratigraphic age proposed for this associa-tion is Triassic, while the adjoining Chortiatis metavolcanics would be Jurassic (Kockel and Mollat, 1977).

We also investigated the Permian-Lower Triassic volcano-clastic rocks of the *Examili Formation* (Kockel and Mollat, 1977). These rocks are found close to the roughly coeval Nea Santa volcano-sedimentary sequence, but outside of the Circum-Rhodope belt properly said (Kaufmann et al., 1976, fig. 1), in an alignement of faulted synforms pinched in the western part of the Serbo-Macedonian schists (Kougoulis et al., 1990). The Examili metapelites yielded chloritoid-bearing assemblages without HP-LT indication (samples 91/63 and Aex92).

THE METAMORHIC ASSEMBLAGES

In the Nea Santa rhyolitic metatuffites, high-Si phengite (Table 1, 1-2) occurs with albite and very scarce epidote crystals in pseudomorphs probably after Na-K feldspar megacrysts. Patchy calcite invades some of the pseudomorphs, the foliated matrix of which consists of quartz, plengite, chlorite and subordinate calcite. Metamorphic white K-micas with high celadonite content (Si=3.510-3.485 p.f.u. for 11 oxygen atoms) are also reported by Asvesta (1992) from metase-diments of the same area associated with the stratiform iron formation of Akritas village.

The Livadi blue-schists consist of quartz-phengite-glaucophane-epidote-chlorite-albite-calcite assemblages (Fig. 3). The compo-sition of the blue amphibole (Table 1, 3) corresponds to the limit of the crossite and magnesio-riebeckite fields (al=0.248; mg=0.88; agln=0.036; Evans, 1990), without any variation from the core to the rim of the prisms. The associated phengite (Table 1, 4) develops in the foliation lamellae together with a magnesian chlorite (XMg=0.73; Tabke 1, 5). The epidote composition is Si3AlAl1.2Fe3+O.8Ca1.9. The glaucophane prisms are partly replaces by patchy calcite-chlorite (XMg~0.7) assemblages, and muscovite (Si=3.0) is found in the adjoining opening sites (pressure shadows). These calcite, secondary chlorite and muscovite minerals form, together with scattered poikilitic albite grains, a retrograde association superimposed to the earlier, epidote-blueschist one.

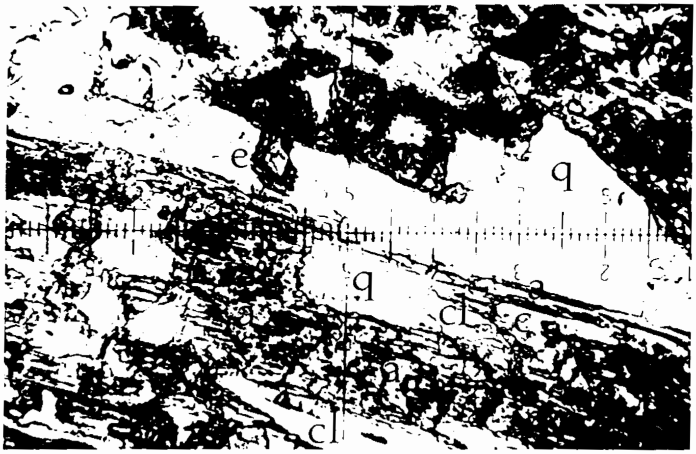

Fig. 3: Blue amphibole crystals (a) partly replaced by chlorite © and calcite © in the Livadi epidote-blueschists. Natural light. Ten divisions equal 0.1 mm.

In the Examili metapelites, chloritoid with XMg(Mg/Mg+Fe+Mn)=0.16 was found in association with quartz, low-Si phengite (Si=3.15), and chlorite. This assemblage is not critical for an early, HP-LT prograde evolution.

P-T ESTIMATES OF HP-LT METAMORPHISM

From the observed metamorphic mineral assemblages and their currently admitted stability fields we can propose P-T estimates for the prograde metamorphic stages of the Nea Santa and Livadi rocks (Fig. 4). In the Nea Santa metarhyolites, the complete alteration of the sodi-potassic feldspar would reflect a high water activity at $T>300^{o}C$, while the plagioclase composition and the lack of biotite limit T below 400oC. In this temperature range, the observed Si=7.0 phengite composition points to P=7-8 kbar (Massonne, 1991).

The prograde epidote-blueschist facies of the Livadi rocks corresponds, taking into account the composition of the na-amphibole, to pressure conditions above 6-7 kbar at $T=300-400^{o}C$ (Evans, 1990). From the Si=3.4 composition of the associated phengite a minimum pressure of 7-8 kbar might be proposed in the same temperature range. The minimum temperature value is indicated by the presence of epidote instead of

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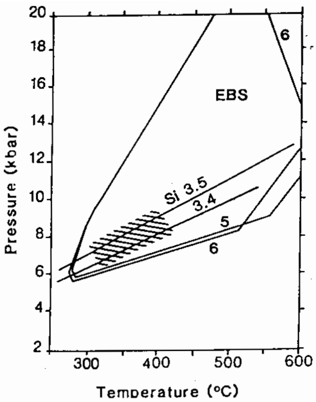

Fig. 4: P-T conditions of the early, HP-LT metamorphism in Macedonian Circum-Rhodope (hatched field). Stability fields no5 and 6 of the epidote blueschist-facies for blue amphiboles similar to the Livadi amphiboles according to Evans (1990). Phengite Si 3.4 and Si 3.5 stability curves after Massonne (1991).

lawsonite, while the maximum T=400oc value is suggested by the lack of biotite and garnet.

DISCUSSION AND CONLUSION

P-T conditions of about 7-8 kbar, 300-400^{o} can be proposed for the prograde metamorphism of both the internal (Kilkis-Sithonia) and external (Thessaloniki-Chortiatis) sub-zones of the Macedonian Circum-Rhodope belt. Also in the Thracian Circum-Rhodope belt, high P/T phengitic muscovites (Si=6.850-6.750) are known form low grade metavolcanic and metasedimentary rocks (Liati and Mposkos, unpubl. data).

In the Livadi blueschists, this HP-LT evolution clearly predates a low-pressure retrogression. It can be suggested that the latter, low P/T evolution is coeval with the youngest metamorphic events in the adjoining Serbo-Macedonian zone, which were dated at 43-32 Ma (Dixon and Dimitriadis, 1984), resulting roughly contemporaneous with the emplacement of several Eocene granites in the area (Fig. 2). In the southern part of the Circum-Rhodope belt itself, the Sithonia granite emplaced at 40-43 Ma (Kondopoulou and Lauer, 1984; De Wet et al., 1989). Then the age of the HP-LT event in the Circum-Rhodope belt could be bracketed between Liassic (the youngest dated layers at the base of the Svoula flysch) and Eocene. It is not unlikely that this HP-LT event could be correlated with the Late Jurassic, pre-Tithonian low-grade metamorphic event evidenced in the Axios-Chalkidiki ophiolitic belt (Mercier, 1968; Kockel and Mollat, 1977) and particularly with the low-grade HP-LT even evidenced in the Paikon massif (Vergely, 1984; Baroz et al., 1987). These supposedly coeval Eohellenic events would shortly predate the emplacement of 150 Ma to 136 Ma-aged granites (Spray et al., 1984; De Wet et al., 1989) in both the Axios-Vardar and Serbo-Macedonian zones (Fig. 2). A Late Jurassic age could also be suggested for the undated eclogite-facies event in the Rhodopian and Serbo-Macedonian massifs, instead of the Cretaceous age previously hypothetisized (Liati, 1986; Liati and Kreuzer, 1990; Liati and Mposkos, 1990). If correct, the Rhodopian, Serbo-Macedonian, Circum-Rhodope and Paikon HP rocks would represent relics of a Late Jurassic, Eohellenic HP belt, severely overprinted first, by the Late Tithonian-Early Cretaceous HT evolution, and then by the Eocene thrusting and metamorphic-magmatic events. The low-grade Circum-Rhodope units and the high-grade Serbo-Macedonian units would be juxtaposed through a tectonic contact involving a strong metamorphic omission (Michard, 1993). This contact could have originated as a late-metamorphic, low-angle normal fault, which would have operated during or after late Eocene-Oligocene time.

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