RETROGRADE OVERPRINT ON HIGH-GRADE METAMORPHIC ROCKS FROM THE DEEPEST PARTS OF THE ARDA UNIT, CENTRAL RHODOPE

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To constrain the complete evolution of the metamorphic basement, and to evaluate the mechanisms of exhumation of high-grade rocks a careful analysis of the spatial distribution and nature of low-grade reworked parts of the basement is needed. Traditionally in the Rhodopes low-grade reworking of the high-grade metamorphic basement is regarded to be localized along the contacts with the Tertiary basins or with the lower-grade rocks from Mandritsa – Makri unit. The classical contributions devoted to such reworking are based on the assumption that low-grade metamorphism and deformation are independent processes (Kozukharova, Ichev, 1989). Ivanov (1981) was first to recognize reworking of the deepest parts of the Rhodope metamorphic rocks in the area of Erma reka. He suggested progressive overprinting of lower grade tectonites on migmatitic gneisses and interpreted this as a result of thrusting in the deep levels of the crust. The Erma reka area could be regarded as a key area for understanding the retrograde path of the evolution of the high-grade basement of the Rhodopes also because of the existence of the major low-angle tectonic zones, which were recently described as detachments (Ivanov, 2000).

The Erma reka area represents a 4-10 km wide tectonic window situated below the Madan (from the west) and Startsevo (from the east) tectonic zones. The lowermost part of the metamorphic pile from the Bulgarian part of the Rhodope zone crops out there. This is the core of a regional-scale antiform structure described as South Rhodopian swell (Iaranov, 1960), Madan swell (Ivanov, 1961), Madan-Davidkovo swell (Koshucharov, 1965), or Central Rhodopian extensional structure (Sarov et al., 2003). On the basis of the existence of low-angle brittle fault zones Ivanov (1988) nominated several tectonic units and according to this scheme the high-grade metamorphics from Erma reka area are included in Arda unit. Using strain and kinematic analysis Burg et al. (1996) modified the model of Ivanov (1988) and interpreted Arda unit as a part of the intermediate thrust units in the Cretaceous synmetamorphic thrust system.

The typical Arda unit comprises highly melted rocks, including diatexites (Ivanov, 2000, Sarov et al., 2004). On the contrary, the deepest part of this lithotectonic unit in the Erma reka area displays a rather fine-grained fabric that is typically devoid of any indications for in situ melting. Other characteristic features of the rocks from this area are the pronounced medium-grade S/L metamorphic fabric and the numerous indicators for top-to-the SW shearing during cooling of the metamorphic pile. The intensive medium to low-grade reworking almost completely destroyed the evidence for earlier metamorphic events. But in rare low-strain domains indications for the initial stages of the evolution of these metamorphic rocks could be found. For example in some garnet-bearing amphibolites indications for early eclogite-facies metamorphism are supposed (see also Kozhouharov et al., 1995). The features suggesting melting in situ are rarely observed and they are restricted to thin domains that escaped the lower-grade reworking. Typical rock types for the Erma reka area are fine-grained biotite gneisses, amphibolites and mylonitic K-feldspar megacrystic granites. Judging from the microfabric data of narrow ultramylonitic zones, the top-to-the SW shearing continued during the cooling of the metamorphic pile down to the temperatures about 400°C. All these data are fitting well into the model proposed by Ivanov (1981), though there is not petrological information available on these rocks yet.

We have used garnet-bearing biotite gneiss and amphibolite samples to examine the retrogressive overprint described above. The samples are collected from outcrops along the Alamovska river, west from Zlatograd (samples location at 25°2'64"E and 41°23'19"N).

The garnet-bearing biotite gneiss displays macroscopic textures of metatexite type (solid-dominated) migmatite, which low-melt fraction formed millimetre scale garnet-bearing leucosome parallel to the foliation. The gneissic part is composed of plagioclase, biotite, quartz, zoned garnet porphyroblasts (2-5 mm), K-feldspar, and accessory ilmenite, rutile and zircon. Matrix foliation is defined by biotite. Biotite-rich pressure shadows are observed at the margins of garnet porphyroblasts parallel to foliation. Ilmenite inclusions are abundant in matrix biotite adjacent to garnet margins. Garnet porphyroblasts are strongly fractured and fragmented. Some grains preserve compositional zoning patterns with inclusions free core, wide concentric zone of abundant inclusions (mostly rutile and quartz, and sparse ilmenite, plagioclase and biotite), followed by thin inclusions free outer rim. Garnet composition is almandine dominated (Xalm 0.61-0.70). Although the compositional zoning for Mn, Fe, Mg, and Ca is broadly concentric, detailed examination reveals more complex patterns (Fig. 1). The concentrations of Mg and Mn display small variation in the core (Xprp 0.13-0.15 and Xsps 0.06) and slight decrease in the inclusions-rich zone (Xprp 0.12 and Xsps 0.04), keeping Fe/(Fe+Mg) ratio values in the range of 0.81 to 0.84.

The most striking feature that affects all elements distribution is the increasing Ca concentration up to Xgrs 0.23 in the inclusions rich zone. The composition of the outermost rim marks abrupt Mn enrichment to Xsps 0.15 and Ca depletion to Xgrs 0.12 corresponding to retrogressive garnet consumption and diffusion reequilibration. The latter seems to be supported by biotite and plagioclase compositions. Matrix biotite is enriched in Fe and Al (Fe/(Fe+Mg) 0.50-0.54; $Al^{[IV]}$ 2.66-2.81) when compared with biotite inclusions in garnet porphyroblasts (0.44-0.46; 2.46-2.58 respectively). Plagioclase grains adjacent to garnet rims are more calcic (An37-41) when compared with the common matrix plagioclase An_{26-30}. The highest An content (52) is observed for plagioclase inclusions in the Ca-enriched zone of the garnet porphyroblasts. The diffusivity of Ca in garnet is considerably less than that of Fe and Mg (Spear, 1993), hence the grossular profiles should be modified much less than those of Fe, Mg and Fe/(Fe+Mg). This suggests grossular growth zoning for Ca pattern described above. The corresponding abundance of inclusions in the Ca-enriched zone should be explained by reactions consuming Ca- and Ti-rich phases (titanite, clinozoizite, plagioclase, biotite) to produce grossular, and to release rutile and quartz.

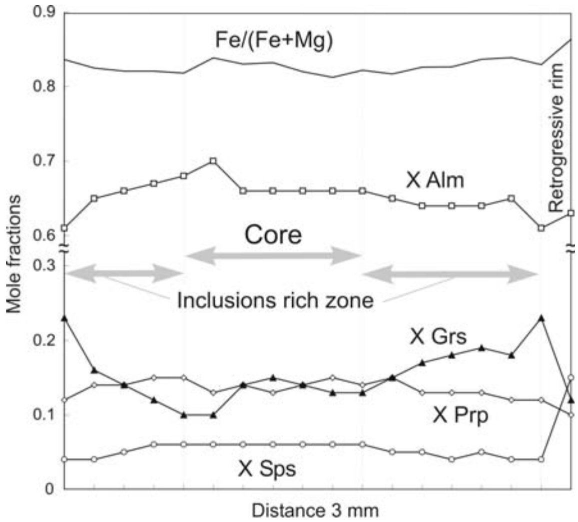

Fig. 1. Compositional zoning of garnet porphyroblast in garnet-bearing biotite gneiss.

The amphibolite is fine-grained and strongly foliated. The foliation is defined by amphibole crystals alignment. Amphibolite comprises plagioclase, quartz, amphibole, biotite, epidote, chlorite, and accessory ilmenite and magnetite. Amphibole grains display bluish-green colour. Their compositions vary from tschermakite to magnesiohornblende (Mg/ ($Mg+Fe^{2+}$) 0.68-0.82), marking Si enrichment towards grain rims and recrystallized fine-grained amphibole ($Si^{[IV]}$ from 6.45 to 7.24 apfu). Plagioclase forms 1-2 mm size lens-shaped inhomogeneous grains, which compositional characteristics show large variation in the range of An16 to An30. Biotite grains (Fe/(Fe+Mg)) 0.33-0.39; $Al^{[IV]}$ 2.37-2.50) underline the foliation displaying straight line contacts with adjacent amphibole. Chlorite replaces both amphibole and biotite keeping Mg-enriched composition (Fe/(Fe+Mg) 0.30-0.37). Epidote appears always as euhedral grains included in plagioclase or associates with the finest grained amphibole. Epidote composition is relatively Fe poor (12-16 wt % pistacite). In metabasic rocks epidote persists above the breakdown of chlorite (3.3 kbar; Spear, 1993) giving rise to assemblage typical of epidote-amphibolite facies (epidote-amphibole-plagioclase-quartz).

Rocks mineralogy makes possible geothermobarometric calculations using garnet-biotite-plagioclase equilibriums for the biotite gneiss and amphibole-plagioclase equilibrium for amphibolite sample. The retrogressive change in the biotite gneiss sample produced a spessartine-rich outermost rim (Xsps 0.15) of garnet porphyroblast that equilibrated with the adjacent matrix biotite. The rather high Mn-concentration itself is an evidence for a low-temperature conditions of garnet rim re-equilibration. The same feature however prevents a correct application of conventional garnet-biotite thermometry. The equilibriums of biotite and plagioclase inclusions with Ca-rich garnet zone yield 585-615°C / 8-9 kbar (Fig. 2) reflecting P-T conditions at some point of garnet porphyroblast growth. It is worth noting that because of Mg and Fe diffusivity small biotite inclusions change their compositions towards lower Fe/(Fe+Mg) that causes lower calculated temperatures, e. g. the garnet interior might have formed at higher temperature than calculated. The later assumption is supported by the relatively constant Fe/(Fe+Mg) ratio in the garnet porphyroblasts that should be explained by high-temperature re-equilibration obscuring garnet growth zoning except for Ca. The latter suggests a considerable pressure increase during grossular-rich zone growth. A possible equilibrium of the richest in Ca garnet zone with common matrix plagioclase (An_{26-30}) and matrix biotite yield 660-710°C / 12-14 kbar (Fig. 2).

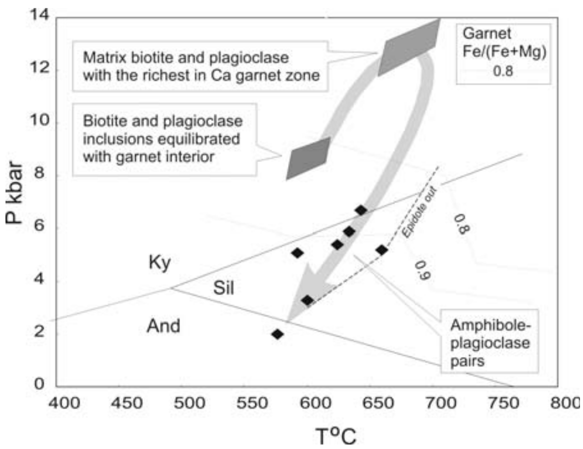

Fig. 2. P-T grid and thermobarometric estimates using garnet-biotite geothermometer (Ferry, Spear, 1978; Perchuk, Lavrent'eva, 1983), garnet-plagioclase-biotite geobarometer (Hoisch, 1990), amphibole-plagioclase geothermometer (Holland, Blundey, 1994), amphibole-plagioclase geobarometer (Fershtater (1990).

The field and macroscopic indications of migmatization in the biotite gneiss and the availability of garnet both in gneiss and leucosome suggest the operation of pressure sensitive dry-melting reaction: biotite + plagioclase + quartz = garnet + melt (+ K-feldspar). Experimental data give evidence for significant grossular growth zoning that can be expected in metapelitic rocks undergoing partial melting at high pressure by the same reaction (Auzanneau, Vielzeuf, 2003).

The amphibolite sample and the mineral chemistry reflect incomplete equilibration between amphibole and plagioclase during epidote formation. The amphibole-plagioclase thermobarometric estimates yield a range of T and P values, which trace the retrogressive path from 640°C / 6.7 kbar to 600°C / 3.3 kbar in the epidote stability field (Fig. 2). Advanced retrogression (590°C / 2 kbar) corresponds to the above mentioned Al depletion in amphibole and plagioclase compositional inhomogeneity marking an incipient transition to greenschist facies conditions at lower pressure out of the epidote stability field.

Some features of the rocks studied testify to fast operation of the retrogressive overprint, namely: rather thin Mn-enriched garnet rims in the gneiss sample, and incomplete equilibration of amphibole and plagioclase compositions in the amphibolite sample. Indications of prior high grade metamorphism survived even in strongly reworked rocks that give courage to further detailed examination of the Rhodope metamorphic history and correlation of the Rhodope region metamorphic rocks. Similar low-grade reworking of the high-grade basement is well known from the lowermost part of the Sidironero unit (e.g. Gautier et al., 2002).

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