LAYERED PLUTONS UNDER THE EASTERN RHODOPE METAMORPHIC CORE COMPLEXES: EVIDENCE FROM CUMULATE XENOLITHS IN THE KRUMOVGRAD ALKALINE BASALTS

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Introduction

Studies of the xenoliths entrained in the Late Oligocene Krumovgrad alkaline basaltic dikes in the Eastern Rhodopes provide an unusually deep view into the mantle and lower crust of two metamorphic core complexes and an opportunity to test the models proposed for the role of magmatism in the core complex formation. Here we provide preliminary data on the composition of these xenoliths and calculate the P-T conditions of their crystallization. On the basis of these data we conclude that ultramafic/mafic magmas crystallized at depths of 40-30 km, close to or beneath the current Moho. We speculate that this magmatism may have provided the heat for thermal events and extensional tectonics during the Late Eocene (38-35 Ma).

Regional geology of the Eastern Rhodope region

Metamorphic rocks in the Eastern Rhodope region in Bulgaria and Greece consist of tectonometamorphic complexes, which are characterized by different degrees of metamorphism and geochronologic ages. These units are separated, at least locally, by tectonic contacts of predominantly extensional origin (Krohe and Mposkos, 2002). In Bulgaria, they are represented by the Gneiss-Migmatite Complex as the lowermost structural unit, and an overlying Variegated Complex of mixed meta-sedimentary and meta-igneous protoliths as an upper structural unit (Haydoutov et al., 2001). These metamorphic complexes represent the lower and upper plate rocks of the extensional low-angle detachment fault systems. The upper tectonic unit comprises interlayered amphibolites, marbles, various schists and gneisses enclosing eclogite lenses and meta-ophiolites. The lower tectonic unit is composed of para- and predominant ortho-gneisses, and migmatitic gneisses, intercalated at different stratigraphic levels with schists and amphibolites.

Late Alpine thermal events and magmatism

Extension along continuous low-angle detachment faults formed the Biala Reka and Kessebir metamorphic core complexes (Burg et al., 1996; Bonev et al., in press), and led to the formation of sedimentary basins and exhumation of ultrahigh pressure metamorphic lithologies. Continental clastic sedimentation started in Maastrichtian–Palaeocene time in the area north of the Kessebir dome structure (Goranov, Atanasov, 1992). Uplift and cooling of the Variegated Complex from 500°C to 300- 350°C was suggested in the age interval 45-39 Ma (Bonev et al., in press) on the basis of $^{40}Ar/^{39}Ar$ ages. Cooling and exhumation of the lower unit from the Kessebir dome occurred between 38-36 Ma (Bonev et al., in press and references therein) followed by normal faulting under brittle conditions.

Widespread Late Eocene-Oligocene volcanism (39-26 Ma) developed in several volcanic areas, coeval or subsequent to sedimentary basin formation. It is dominated by intermediate to acid lavas and subordinate basic varieties. Magmatic activity in the two dome structures terminated with emplacement of numerous xenolith-bearing dykes of intra-plate basalt (Marchev et al., 1998).

Host alkaline basalts

Xenolith-bearing alkaline basaltic dykes are located 20-30 km SE of the town of Krumovgrad. They were intruded into both the Gneiss-Migmatite and Variegated Complexes of the Biala Reka and Kessebir domes at ca. 26-28 Ma. Most of the dykes are 0.5-2 m thick, with a single dyke up to 40 m thick. Dykes have basanitic to lamprophyric compositions (Marchev et al., 1998). Olivine and clinopyroxene are the most common phenocrysts in the basanites, accompanied by amphibole megacrysts in the lamprophyres. Sanidine and biotite are rare. Holocrystalline groundmass of the basanites is composed of microlites of Ti-augite, plagioclase, amphibole, Fe-Ti-oxides and interstitial K-feldspar, analcite and biotite. The panidiomorphic groundmass is typical for the lamprophyres. It contains euhedral kaersutite and plagioclase, and lesser clinopyroxene and magnetite grains with abundant interstitial analcite and sanidine.

Krumovgrad alkaline basalts have high $^{143}Nd/^{144}Nd$, low $^{87}Sr/^{86}Sr$ and high $^{206}Pb/^{204}Pb$ at relatively low $^{207}Pb/^{204}Pb$ ratios, interpreted to indicate a source similar to the European asthenospheric reservoir (Marchev et al., 1998).

Petrology and age of xenoliths

Ultramafic and mafic cumulate xenoliths are rounded to sub-rounded, rarely rectangular, ranging in size from <1 to 7 cm. They are composed of variable amounts of olivine, clinopyroxene, orthopyroxene, amphibole, plagioclase, and minor sulfides, spinel and apatite; some contain interstitial fresh or devitrified glass. The xenoliths can be divided on the basis of mineral assemblages into two groups: ultramafic and gabbroic. The ultramafic xenoliths may be further subdivided into olivine websterites; websterites, clinopyroxenites; and orthopyroxenites. The gabbroic group is divided on the basis of the pyroxene composition into two-pyroxene gabbro and clinopyroxene gabbro.

Major element abundance patterns of websterite show high MgO (16.8 wt. %) and CaO concentrations, whereas gabbro is depleted in MgO (9.7 wt. %) and enriched in CaO and Al_2O_3. The rocks are silica undersaturated with low contents of TiO_2, K_2O, P_2O_5.

The age of the host basalts constrains the age of the xenoliths to 26-28 Ma. However, findings of pyroxene xenocrysts, similar to those from some xenoliths in the 32-31 Ma lavas of the neighboring volcanic rocks, suggest that the age of cumulates might be older than 31 Ma.

Estimates of intensive parameters for xenoliths

Pyroxene pairs, indicate temperatures of 1070-900°C, decreasing from olivine websterite towards gabbro. Coexisting olivine-clinopyroxene in olivine websterite yields a temperature of ~1200 °C, considerably higher than that of the clinopyroxene-orthopyroxene pair (1074°C). The Fe-Ti oxide pair in a clinopyroxenite yields the lowest temperature, 850°C, in the xenolith suite. Estimated fO_2 at this temperature (-13.89) is slightly above the Ni-NiO buffer.

Most pyroxene Al^{VI}/Al^{IV} ratios (0.05-2.84) plot in the granulite-clinopyroxenite field of Aoki and Shiba (1973), implying pressures close to the lowermost crust and possibly in the uppermost mantle. This is confirmed by the Cpxbar program of Nimis and Ulmer (1998) and Nimis (1999), giving an equilibration pressure range for all the investigated xenoliths of 14-9 kb (45-30 km).

Rare findings of olivine-bearing varieties, pressure estimates and chemistry of pyroxenes of the xenoliths match very well the experiments of Müntener et al. (2001), suggesting crystallization from comparatively hydrous primitive magma with more than 3 wt. % H_2O. Additional evidence for high water content in the ultramafic magma stems from the presence of early high-Cr amphibole in some websterites and comparatively low temperature of crystallization of the rock.

Cumulate bodies and core complex formation

Clustering of most geobarometry results for ultramafic xenoliths around 11-13 kb indicates that the base of the ultramafic part of the complex crystallized at depths near 35-40 km, whereas the more evolved two-pyroxene gabbros seems to have equilibrated at 30 km or less. Thus, these data provide evidence for the emplacement of the plutonic rocks within an interval of ~10-15 km. The present-day Moho below the Eastern Rhodope area is estimated at about 30-35 km (Velev, 1996), which appears to be ~5-10 km above the base of the equilibration depth of the deepest ultramafic xenoliths.

Thermal and experimental modeling predicts that magmatic underplating of large masses of hot magma at the base of the crust may significantly modify its thermal and mechanical properties, thus enhancing deformation and strain localization in an extensional environment (see for review Corti et al., 2003). Overprint and retrogression of the older metamorphism by younger thermal events is indicated by abundant Late Eocene (40-35 Ma) K-Ar and $^{40}Ar/^{39}Ar$ biotite and muscovite ages (Bonev et al., in press), with temperatures reaching 300-350°C; the blocking temperature of biotite and muscovite. We suggest that this thermal effect may have been caused by underplating of mafic magma at the crust-mantle boundary and lower crustal levels. Underplated magma would have been cooled for several million years, producing a stratified ultramafic/gabbroic plutonic sequence, heat the lower and middle crust above the normal geothermal gradient and facilitate the extension and deformation. Findings of similar xenoliths in the alkaline basalts from other areas of extension and core complex formation (e.g. SE Basin and Range Province, USA; Wilshire, (1990) and Menderes Massif, SW Turkey; Çakir et al. (1999) indicate that underplating of mafic magma(s) seem to be a fundamental process causing extension.

Late Oligocene intraplate magmatism, subsequent to the Late Eocene magmatism and thermal metamorphism, indicates further upwelling of the asthenosphere under the Eastern Rhodopes and decompression melting of the mantle which produced OIB-type magmas. This event does not seem to result in prograde metamorphism, which is probably due to the fast transport of the magma from asthenosphere to the surface.

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СЛОИСТИ ИНТРУЗИИ ПОД ИЗТОЧНОРОДОПСКИТЕ МЕТАМОРФНИ ЯДРЕНИ КОМПЛЕКСИ: ДОКАЗАТЕЛСТВА ОТ КУМУЛАТНИ КСЕНОЛИТИ В КРУМОВГРАДСКИТЕ АЛКАЛНИ БАЗАЛТИ

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Ултрамафичните ксенолити, изнесени от горно-олигоценски дайки с вътререшноплочов (WP) характер, предоставят информация за състава на долната кора и процесите, протичащи под източнородопските метаморфни комплекси Бяла река и Кесебир. Кумулатите изграждат серия от високо- до среднобарични скали, представени от оливинови вебстерити, ортопироксенити, клинопироксенити, вебстерити и габра. Термобарометричните изследвания и сравнението с експериментални работи подсказват, че кумулатната серия се формира от водни (>3 % H_2O) мафични магми, при налягания от 14 – 9 kb (45 – 30 km) и температура от 1200 – 850°C.

Предполага се, че внедряването (underplating) на такива горещи и водни мафични интрузии на границата кора - мантия модифицира термичните и механични характеристики на долната и средна кора, което рефлектира в термичен метаморфизъм и екстензия. Находките от подобни ксенолити в алкалните базалти от други екстензионни региони показват, че underplating играе важна роля във формирането на ядрените комплекси.