Thermobarometry and $^{40}Ar/^{39}Ar$ ages of eclogitic and gneissic rocks in the Sredna Gora and Rhodope terranes of Bulgaria

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The basement of southeastern Europe is a collage of blocks of both continental and oceanic origins with diverse geologic histories that were amalgamated at different times beginning in the Neoproterozoic-early Paleozoic interval. Within Bulgaria, several blocks are recognized. In the northern sector of Bulgaria, two terranes – the Moesian and Balkan, comprise the Protomoesian microplate. South of the Balkan Terrane is the Sredna Gora Terrane, and farther south is the Rhodope Massif, which straddles the Bulgaria/Greece border. Both the Sredna Gora and Rhodope terranes are dominated by tectonized peridotites, pyroxenite cumulates and amphibolitized eclogites that, at least in the Rhodope region, are tectonically imbricated with intensely metamorphosed and migmatized paragneisses, orthogneisses, and carbonate components.

The Sredna Gora and Rhodope terranes are important for their location, which is along strike with the Bohemian Massif to the NW and the Bolu, Menderes and Bitlis massifs of Turkey and Midyan terrane of the Arabian Shield to the SE. Together, all of these terranes lie along strike with the Avalonia-Cadomian peri-Gondwana arc hypothesized by Murphy and Nance (1991). The Sredna Gora and Rhodope terranes are also important for containing superbly preserved rocks that may have a pre-Variscan and pre-Alpine history. They are comparable to the Moldanubian Terrane of the Bohemian massif. To the southeast, resemblance of the Bitlis and Menderes massifs in Turkey and Midyan Terrane in the Arabian Shield have been noted, though age relationships in the former are still not well established.

The impetus for our study is only limited availability of thermobarometric constraints and a lack of isotopic age data for the Sredna Gora terrane and Bulgarian side of the Rhodope Massif. The occurrence of eclogite is evidence of high-pressure metamorphism in both regions. Most previous studies of the metamorphic pressure-temperature (P-T) conditions have focused on the Greek Rhodopes, and only a few studies have been published on eclogites of the Bulgarian Rhodopes. Temperatures between 555–590 °C and minimum pressures of 14 kbar were determined for the peak of the eclogite-facies metamorphism in the lower tectonic unit of the Greek Rhodopes. Peak metamorphic conditions of 530–540 °C and 12–13 kbar (minimum pressure) are reported for eclogitic rocks from the Bela Reka Antiform of the Eastern Rhodopes within Bulgaria.

Various isotopic measurements on the Greek side of the Rhodope massif have supported the interpretation that these rocks represent an amalgamation of continental and oceanic terrane fragments assembled at a subduction margin entirely during the Cretaceous and younger Alpine orogeny. As such, the rocks are not thought to have had a coherent pre-Alpine identity. However, evidence is emerging on the Bulgarian side of the massif, including our new study that some of the rocks have a Paleozoic and Neoproterozoic history.

We present data on the P-T conditions of eclogites from the Variegated Formations of the eastern Rhodopes along with the first reported P-T conditions of eclogites from the Sredna Gora Terrane. We also report the first $^{40}Ar/^{39}Ar$ ages obtained on mineral separates from the gneisses that enclose the eclogites in both regions.

Temperature estimates were made using the garnet-clinopyroxene Fe-Mg exchange thermometer (Krogh, 1988). The average temperatures obtained for the Rhodopean sample using this thermometer was as follows: 440 °C for $garnet_{core}$-$clinopyroxene_{core}$ pairs and 520 °C for $garnet_{rim}$-$clinopyroxene_{rim}$ pairs. The average temperature obtained for the Sredna Gora samples was 630 °C, significantly higher than the Rhodopean temperatures.

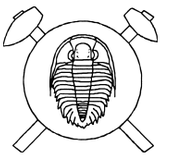
Pressure estimates were made using the jadeite contents of clinopyroxenes for the reaction albite = jadeite + quartz (Holland, 1983). These calculations give lower pressure limits, because the plagioclase in these rocks formed later than and did not equilibrate with the eclogite assemblage. The average lower pressure limits obtained for the Rhodopes were 10 kbar for $garnet_{core}$-$clinopyroxene_{core}$ pairs and 12 kbar for $garnet_{rim}$-$clinopyroxene_{rim}$ pairs. For the Sredna Gora samples this value was 14 kbar. A retrograde metamorphic path from eclogite to amphibolite to greenschist facies conditions is indicated by the garnet – omphacite, hornblende – epidote, and clinopyroxene – plagioclase – amphibole (symplectite) associations, respectively. The barroisite inclusions in garnets support the idea that the retrograde eclogites of the Eastern Rhodope Mountains were formed from the subduction of amphibolites.

Our $^{40}Ar/^{39}Ar$ measurements on two samples from the Rhodope Massif have yielded Alpine ages: 45 ± 2 Ma for amphibole from a retrograded eclogite we collected in Belopolci and 39 ± 1 Ma for muscovite from the metapelites that enclose the ultramafic and eclogitic rocks

near the village of Kazak. These $^{40}Ar/^{39}Ar$ ages are broadly in agreement with the geochronology that has been done on the Greek side of the Rhodopean Massif. However, given the much older U-Pb ages of related rocks, we interpret the $^{40}Ar/^{39}Ar$ ages to represent cooling following the overprinting metamorphism.

The ages obtained for the Sredna Gora zone do not show an overprint by Alpine metamorphism. Biotite ages from mica-rich gneisses yielded ages of 113.4 ± 1.0 Ma, 112.3 ± 1.5 Ma, and 110.7 ± 1.7 Ma. Muscovite ages from the same gneisses yielded ages of 110.8 ± 1.0 Ma, 101.3 ± 0.6 Ma, and 106.2 ± 1.0 Ma, respectively. Also, a hornblende-rich gneiss yielded a biotite age of 95.6 ± 1.0 Ma and a hornblende age of 247.3 ± 1.8 Ma. (This significantly older hornblende age may reflect incomplete re-equilibration of this mineral). Since the metamorphic basement rocks of the Sredna Gora must be older than numerous unmetamorphosed Variscan (~300 Ma) intrusive rocks, these cooling ages indicate either prolonged residence at a temperature between the closure temperatures for the micas and hornblende, or a minor reheating event in the Cretaceous. These data verify the suspicion that the Rhodope and Sredna Gora terranes have undergone very different metamorphic histories.

Quartz and feldspar fabrics in igneous rocks of the Eastern Erzgebirge Pluton (Germany, Czech Republic): evidence of multiple magma mixing



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The Eastern Erzgebirge Pluton (EEP) is situated in the eastern most part of the Fichtelgebirge-Erzgebirge anticline where late- to post-orogenic Variscan uplift and exhumation processes were accompanied by intense felsic (rhyolitic and granitic) magmatism controlled by brittle fracture tectonics. During orogenic collapse a volcanotectonic depression – the Altenberg-Teplice caldera (ATC) – developed in the central part of the EEP. The study includes (1) the Older Intrusive Complex granites, particularly the Niederbobritzsch granites, (2) the Schönfeld rhyodacites, (3) the Teplice rhyolites, (4) the rapakivi-textured microgranite of Altenberg-Frauenstein (caldera ring dyke filling), and (5) the Younger Intrusive Complex granites, particularly the Schellerhau granite complex.

The study is focused on the characterisation of quartz and feldspar phenocrysts from different magmatic stages by cathodoluminescence (CL) and by trace element profiling. We evaluate the extent to which variations in mineral chemistry reflect either magma mixing or other processes caused by magma dynamics during the magma evolution of the EEP.

We present a model of the temporal, spatial and chemical evolution of the EEP mainly based on textural and chemical observations of quartz and feldspar phenocrysts and whole rock chemistry. The results verify the suitability of quartz and feldspar phenocrysts as a record of differentiation trends, magma mixing and recharge events, and suggest that much heterogeneity in plutonic systems may be overlooked on a whole rock scale. Multiple resorption surfaces and zones and element concentration steps in zoned quartz and feldspar phenocrysts indicate mixing of the silicic magma with a more mafic, mantle-derived (?) magma.

Based on the presence and absence of quartz phenocryst populations confirmed by the whole rock chemistry and previous melt inclusion studies, three levels of magma reservoirs are supposed: (1) at the root zone of the Variscan orogen at 60 km depth, (2) between 21–27 km, and (3) between 21 and 3 km. At least three sub-reservoirs exist in the third level till the collapse of the ATC.

Several intrusion stages of the EEP display textural and chemical evidence for multiple interaction of mafic and silicic magmas during their genesis, particularly, the Niederbobritzsch granites, the Schönfeld rhyodacites, the Teplice rhyolites (phase TR3c), and the microgranite of Altenberg-Frauenstein. The heterogeneous nature of mixing is indicated by the varying distribution of textures between and indeed within lithologies. Currently, a number of studies indicate that such textures, especially rapakivi textures, are present on a regional scale within the granite belts of the Variscan orogen. This regional distribution of mixing-compatible textures suggests that magma mingling and mixing were major processes during evolution of late-Variscan magmatism.

The ATC represents an unique example of the long supposed association between late-Variscan plutonism and volcanism which has been proven chemically and texturally as well. It is the only known example from the inner part of the Variscan orogen, where late-Variscan plutonism and related volcanism can be studied in such detail.