ΕΓΕ 2019
15th International Congress of the Geological Society of Greece
Athens, 22-24 May, 2019 | Harokopio University of Athens, Greece
Bulletin of the Geological Society of Greece, Sp. Pub. **7** Ext. Abs. GSG2019-118

Rodingitized Gabbroic Rocks in Vavdos Ophiolite, West Chalkidiki, North Greece

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Introduction

Rodingite is an infrequent lithology in Greek ophiolites (e.g. Hatzipanagiotou & Tsikouras, 2001; Tsikouras et al., 2013). In this paper rodingitized gabbroic rocks, from the Vavdos ophiolite (Innermost Hellenic Ophiolitic Belt) are studied for the first time. They are hosted in the crustal section of the ophiolite, consisting of gabbroic rocks. The rodingitized rocks appear as whitish a) in dikes cross-cutting gabbronorite or b) as contact zones between massive gabbronorite and peridotites. Rodingites typically are related to serpentinization demonstrating the paragenesis diopside + garnet ± vesuvianite (e.g. Hatzipanagiotou et al., 2003; Tsikouras et al., 2009). This is not the case in the present study; therefore the petrography, mineral chemistry and geochemistry of the rodingitized occurrences will be studied, in order to determine their protolith and the events that led to their greenschist-like paragenesis.

Geological Setting

Vavdos ophiolite is part of a dismembered ophiolite complex of west Chalkidiki, which is part of the NW-SE trending Innermost Hellenic Ophiolitic Belt (Bebien et al., 1986). The ophiolite is obducted on the metamorphic Serbomacedonian Massif at the SW and it is bounded by the Chortiatis Magmatic Suite and the Circum Rhodope Belt at the NE (e.g. Meinhold et al., 2009). Peridotite and pyroxenite consist the mantle section and the transitional zone of the ophiolite, respectively. Mafic rocks dominate the crustal section and they are distinguished into four categories: a) massive gabbronorite, b) gabbronorite dike intruding the massive counterpart, c) diabase and d) two types of rodingitized gabbroic rocks (rodingites). The first type forms dikes intruding gabbronorite (vein rodingite) and the second occurs as a narrow zone at the contact of gabbronorite with peridotites (massive rodingite).

Materials and methods

Mineral chemical analyses of one gabbronorite (b147) and five rodingitized gabbros (samples in Table 1) were carried out at the Scanning Microscope Laboratory, A.U.Th., using a JEOL JSM-6390LV Scanning Electron Microscope (SEM) equipped with an Energy Dispersive Spectrometer (EDS) INCA 250 with 20kV accelerating voltage and 0.4 mA probe current. Pure Co was used as an optimization element. For SEM observations, the samples were coated with carbon – average thickness of 200 Å – using a vacuum evaporator JEOL-4X. Whole rock geochemical analyses of two massive gabbronorites (b147, b153) and six rodingites (samples in Table 1 plus b5a), for REE concentrations were performed at ActLabs (Ontario, Canada) using the 4b-INAA package (method described in http://www.actlabs.com/).

Petrography and mineral chemistry

The adcumulate massive gabbronorites are subhedral to anhedral with granular and in places subophitic texture. Magnetite with embayed boundaries is commonly surrounded by tschermakite and chlorite. The rodingites demonstrate relict textures similar to gabbronorite including blasto-granular and blasto-subophitic textures. The leucocratic matrix mainly consists of clinozoisite that forms symplectites with quartz. Hornblende, actinolite and lesser chlorite and tremolite, comprise the mafic minerals. The opaque minerals (magnetite, ilmenite) are skeletal in texture and are exsolved from actinolite and chlorite$_{ex}$ (exsolved chlorite). There is also a case of an embayed almandine rich garnet corona around this exsolution. These gulfs are filled with clinozoisite. No primary plagioclase or pyroxene was observed. Rodingites' parageneses are listed in Table 1. Vein rodingites show a wider range in the total iron content of clinozoisite (0.46 to 9.76 wt %), while the massive counterparts do not exceed the 3.58 wt %. Low total iron contents in clinozoisite are consistent with actinolite and tremolite abundance, while elevation of the iron corresponds to hornblende dominance in the rodingitized gabbros.

Geochemistry

The REE concentration patterns of massive gabbronorites and rodingites demonstrate many similarities and they are divided in three groups. The first group includes massive rodingites and gabbronorites and is characterized of spoon-like LREE patterns and flat HREE profiles with a strong positive Eu anomaly. Fractionated LREE slopes and a positive Eu anomaly coupled with flat HREE profiles correspond to the second group, comprised of vein rodingites and their rodingitized wallrock. The third group includes one sample of vein rodingite demonstrating slightly fractionated LREE and an unfractionated HREE profile with a notable negative Eu anomaly. The geochemical affinities of the studied rocks display a spatial distribution, with the first group, consisting of massive rodingites and gabbronorites, occurring at the south of the ophiolite whilst the rest groups (vein rodingites) are located to the north of it.

Table 1 Paragenetic characteristics of the rodingitized samples, M: massive rodingite, V: vein rodingite and MV: vein rodingite's country rock.

samples	type	paragenesis
b32b	MV	clinozoisite + actinolite + tremolite + hornblende + chlorite + magnetite + pyrite + rutile + titanite + quartz
b5b	V	clinozoisite + actinolite + hornblende + tremolite + epidote + titanite + zircon + ilmenite + pumpellyite
b5c2	V	clinozoisite + actinolite + hornblende + chlorite + ilmenite + $chlorite_{ex}$ + garnet + albite + titanite + chalcopyrite + quartz
b4a3	M	actinolite + clinozoisite + chlorite + albite + titanite + spinel + pyrite + quartz
b4	M	hornblende + clinozoisite + actinolite + chlorite + tourmaline + pumpellyite + spinel + quartz

Discussion and conclusions

Rodingites are associated with massive gabbronorite either as dikes or as narrow zones adjacent to a gabbronorite-peridotite contact. Their textures are reminiscent of gabbronorite textures, thus indicating the latter (or other genetically related lithologies), as the most likely protolith. The gabbronorite and rodingite REE patterns demonstrate great resemblance; well defined positive Eu anomalies and unfractionated HREE. All Eu anomalies are considered as magmatic feature that was inherited to the metasomatic rocks. Vavdos rodingites paragenesis is different from the rest of the diopside + garnet ± vesuvianite bearing Greek counterparts. They are hosted in massive gabbronorite, unlike the other Greek rodingites, which are closely associated with ultramafic lithologies, being either their hosts or protoliths. Bach and Klein (2009) studied the formation of rodingites at mafic/ultramafic boundaries. They concluded that serpentinization fluids that had previously weakly reacted with gabbroic rocks will be able to crystallize grossular + diopside ± chlorite (200-300 ^{o}C). However, when fluids had time to react with gabbroic rocks, garnet was replaced by either epidote or prenhite and diopside by tremolite. In the extreme case of fluid's total modification after interacting with gabbro, the ideal paragenesis would be: albite + actinolite + chlorite + epidote. The aforementioned mineral replacements were identified in this paper; garnet was replaced by clinozoisite, tremolite is closely related to actinolite. Based on this assumption, actinolite dominated rodingites, with the lowest amounts of total iron in clinozoisite were produced from fluids, which had largely equilibrated with the country gabbronorite. The wide range of clinozoisite's total iron contents observed in the vein rodingites (one sample is garnet bearing) could depict the modification of the metasomatic fluid while reacting with the gabbronorite.

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