Spectrochimica Acta Part A 73 (2009) 477–483

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

journal homepage: www.elsevier.com/locate/saa

Single and multiphase inclusions in metapelitic garnets of the Rhodope Metamorphic Province, NE Greece

Evripidis Mposkos *, Maria Perraki, Sarra Palikari

National Technical University of Athens, School of Mining & Metallurgical Engineering, Division of Geosciences, 9 Heroon Politechniou St., GR-15773 Zografou, Greece

ARTICLE INFO

Article history:
Received 27 June 2008
Received in revised form 21 December 2008
Accepted 22 December 2008

Keywords:
Multiphase inclusions
Fluid
Metapelite
Garnet
Rhodope
Raman spectroscopy

ABSTRACT

Single and multiphase inclusions in garnet porphyroblasts from the diamond-bearing pelitic gneisses were studied by means of combined Raman Spectroscopy and Electron Scanning Microscopy (SEM/EDX). They are either randomly distributed or with preferred orientation within the garnet host and their dimensions vary from less than 5 up to 60 μm. In the single-phase inclusions quartz, rutile, kyanite and graphite dominate. Biotite, zircon, apatite, monazite and allanite are also common. Two types of multiphase inclusions were recognized, hydrous silicate (Type I) and silicate–carbonate (Type II) ones. The carbon-bearing multiphase inclusions predominantly consist of Mg-siderite + graphite + CO_2 + muscovite + quartz formed by a high density carboniferous fluid rich in Fe, Mg, Si and less Ca, Mn, Al and K trapped in the growing garnet in a prograde stage of metamorphism at high-pressure (HP) conditions. The carbon-free multiphase inclusions predominantly consist of biotite + quartz + rutile ± kyanite + muscovite formed through decompression-dehydration/melting reactions of pre-existing phengite. Single and multiphase inclusions are characterized by polygonal to negative crystal shape formed by dissolution-reprecipitation mechanism between the garnet host and the inclusions during the long lasting cooling period (>100 Ma) of the Kimi Complex.

1. Introduction

Mineral inclusions in metamorphic minerals have been extensively studied as they are a useful tool for reconstructing the physicochemical conditions of the metamorphic evolution of the host rocks. Single solid inclusions provide information about strain directions and are used for geothermometry/geobarometry [1]. Their identity, their distribution and their relationship to chemical zoning in the host mineral reveal the conditions during the crystal growth. Fluid inclusions, when their original densities are preserved, may record entrapment conditions (e.g. [2]). When entrapped during extensional tectonics they are informative for retrograde events (e.g. [3–5]).

In ultrahigh-pressure metamorphic (UHPM) rocks inclusions (e.g. coesite) in robust minerals as garnet, zircon, pyroxene, epidote bear testimony of the UHPM stage. However, although the research to date has tended to focus on single solid and fluid inclusions, studies on multiphase inclusions have been limited. Multiphase solid/fluid inclusions in host minerals as garnet, pyroxene, kyanite in high-pressure (HP)/UHP metamorphic terranes may also provide valuable information about fluids/melts trapped during the (U)HP metamorphic stage or/and the possible partial melting of the (U)HP metamorphic rocks [6–11].

In this paper, we study single and multiphase solid and solid/fluid inclusions in garnets from the diamond-bearing garnet–kyanite–biotite gneisses of the Rhodope Metamorphic Province, NE Greece, in order to (a) study their distribution within the garnet host, (b) establish the textural relations between the multiphase inclusions and the host garnet as well as among the phases composing the multiphase inclusions and (c) combine all the analytical results provided to estimate the mechanism of their formation.

2. Geological setting

The Rhodope HP province in the easternmost part of the Hellenic Orogen is an Alpine synmetamorphic thrust and nappe complex [12–15] that incorporates several tectonic slivers of UHP and HP metamorphic rocks [14,16–18]. It is subdivided into several tectonometamorphic units bounded by thrust and normal faults. In eastern Rhodope, the UHP Kimi Complex represents the uppermost metamorphic unit.

The UHP Kimi Complex (Fig. 1) consists of continental crustal and mantle rocks. Predominant are migmatitic quartz–feldspar gneisses (diamondiferous) garnet–kyanite-bearing pelitic gneisses [17,19–21] and marbles that host large boudins of amphibolites,

* Corresponding author. Tel.: +30 210772099.
E-mail address: mposkos@metal.ntua.gr (E. Mposkos).

1386-1425/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.saa.2008.12.035

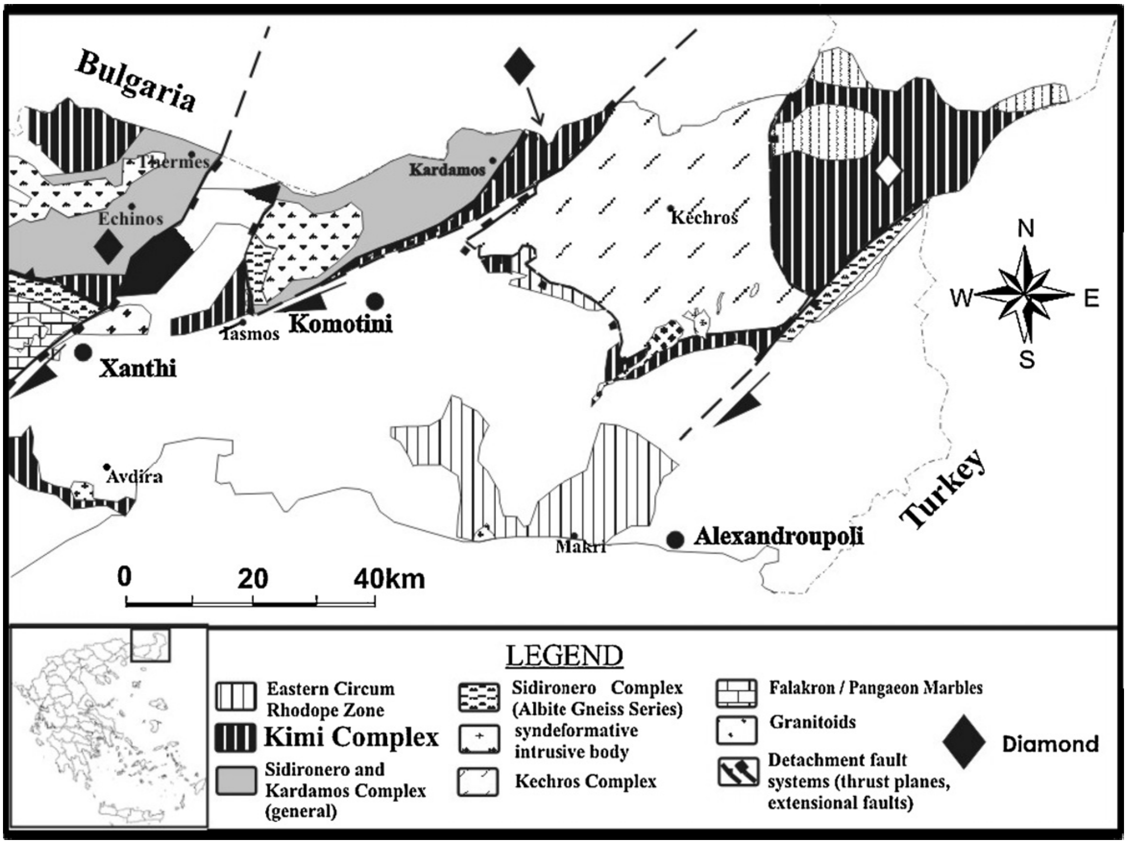

Fig. 1. Simplified geological map of Central and Eastern Rhodope [14].

eclogite-amphibolites, dioritic to granitic metaplutons as well as an ultramafic association mostly made up by garnet-spinel metaperidotites and spinel garnet pyroxenites [14,22].

Pressure–temperature (*P*–*T*) paths and microtextural and geochronological data reveal that crustal and mantle parts juxtaposed against each other at a depth corresponding to ~1.5 GPa had previously separate ascent histories [14].

The crustal rocks document UHP metamorphism with maximum *P*–*T* conditions of ~4.5 GPa at ~1000 °C, as determined by diamond inclusions in garnet and rutile needle exsolutions in Na-bearing garnet in pelitic gneisses. Decompression was accompanied by minor cooling before 1.5 GPa, followed by significant cooling between 1.5 and 1.0 GPa. The *P*–*T* path probably reflects ascent of UHP rocks within a subduction channel followed by accretion in the lower crust of a thickened wedge. Although the first ascend phase was probably rapid, the overall time span for UHP metamorphism and final exhumation may have extended over more than 100 Ma.

SHRIMP ages, mineral inclusions and trace element contents from zircons from amphibolitized eclogites and garnet–kyanite pelitic gneisses constrain the UHP stage between 288 Ma (age of the gabbroic protolith) and ~150 Ma recording an eclogite–HT granulite facies event [2,23]. A high-*P* metamorphic event (~1.5 GPa, ~750 °C) is recorded by Sm–Nd garnet-clinopyroxene-whole rock age at ±119 Ma from a garnet pyroxenite from the mantle assemblage [24]. Similar ages (~115 Ma) from metamorphic zircon overgrowths in the amphibolitized eclogites and pelitic gneisses record the time of a common history for the mantle and crustal assemblages. A subsequent metamorphic overprint (at amphibolites facies conditions) is recorded by metamorphic zircon overgrowth at 79–73 Ma [23,25]. Widespread muscovite pegmatites intruded in a depth of ~20–25 km and crystallized at ~63–65 Ma [25,26] intersect the lithological succession. Exhumation of the Kimi Complex was between 65 and >48 Ma as Lutetian transgressive sediments indicate.

3. Petrography

The rocks studied are garnet–kyanite–biotite gneisses with the mineral assemblage garnet + kyanite + muscovite + biotite + quartz + plagioclase + rutile ± K-feldspar ± staurolite ± chlorite. Garnet porphyroblasts show resorbed rims and are commonly replaced by biotite, kyanite and plagioclase. Textural relationships indicate two generations of kyanite: Large kyanite porphyroblasts (Ky1) up to 1 cm in length associated with garnet porphyroblasts and thin kyanite prisms or needles (Ky2) associated with biotite and replacing garnet and muscovite. Ky1 contains single quartz and rutile inclusions. Cuboid and flaky-shaped carbon inclusions also occur. The nature of the carbon inclusions was not feasible to be determined with Raman Spectroscopy because of the high fluorescence of kyanite when excited with the 632.8 nm line of an He–Ne laser. However, their flaky shape, in most cases, suggests graphite. The inclusion distribution within the Ky1 porphyroblasts is random. The formation of Ky2 reflects a late stage of major recrystallization in the upper amphibolite facies with garnet + muscovite reacting to kyanite + biotite + quartz. Muscovite coexists with biotite of equal grain size and is more rarely replaced by small biotite flakes along grain boundaries. Partial melting and melt crystallization at static conditions are indicated by leucosome pockets in the matrix consisting of undeformed plagioclase + quartz + muscovite ± biotite + kyanite (rods).

Garnets are generally homogeneous in composition. Only a retrograde zoning is developed in the outermost rim with decreasing Mg and increasing Fe, Mn and Ca depending on the neighbouring mineral [27].