Lithos 175–176 (2013) 16–29

Contents lists available at SciVerse ScienceDirect

Lithos

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

# Evolution of rodingites along stratigraphic depth in the Iti and Kallidromon ophiolites (Central Greece)

Basilios Tsikouras [a,b,*], Sofia Karipi [a], Konstantin Hatzipanagiotou [a]

[a] University of Patras, Department of Geology, Section of Earth Materials, GR-265 00 Patras, Greece
[b] University of Brunei Darussalam, Department of Petroleum Geosciences, Jalan Tungku Link, Gadong BE1410, Bandar Seri Begawan, Brunei Darussalam

ARTICLE INFO

*Article history:*
Received 28 July 2012
Accepted 27 April 2013
Available online 4 May 2013

*Keywords:*
Metasomatism
Rodingite
Isocon
Ophiolite
Iti
Kallidromon

ABSTRACT

Rodingitised rocks were collected from the neighbouring Iti and Kallidromon ophiolites. They comprise metasomatic assemblages after serpentinised lherzolite and harzburgite, gabbro and dolerite dykes. The main mineral phases in the metasomatised mantle and gabbroic rocks include grossularitic garnet, chlorite and diopside whereas epidote group minerals were mainly developed at the expense of the dolerite dykes. The fluid phase involved in the metasomatic reactions was highly alkaline in the metasomatising peridotites and less alkaline in the altered gabbro and dolerite. Under such conditions, Ti is assumed to have remained immobile in the whole process while Zr remained constant in the stratigraphically upper rodingitised gabbro and dolerite. Transportation of rare earth elements, Zr, Cr and Ni from the altered mantle segment to the upper gabbro level was assisted by the presence of carbonate and hydroxyl ligands. After consequent breakdown of the carbonate complexes, these elements were deposited in the rodingitised gabbro and dolerite. Rare earths were mainly integrated in the neoblastic diopside whereas Cr and Ni likely formed insoluble hydroxides in that less reducing environment. The metasomatic event happened in the mantle wedge close to the subduction of the Pelagonian carbonates that strongly enriched the fluid phase in $CO_2$. The entrance of an externally derived hydrothermal fluid was responsible for the reduction of pH at the higher levels and the calculated influx of Si in the system.



## 1. Introduction

Rodingites are known worldwide as Ca-rich, $SiO_2$-undersaturated rocks consisting of a variety of Ca–Al and Ca–Mg silicates. They are formed via Ca-metasomatism of varied silicate rock-types, though usually they are spatially associated with serpentinites of diverse age and geological setting (e.g. Capedri et al., 1978; Ferrando et al., 2010; Koutsovitis et al., 2008; Li et al., 2010; O'Hanley et al., 1992; Python et al., 2011; Schandl and Mittwede, 2001; Schandl et al., 1989; Tsikouras et al., 2009). Highly alkaline fluids containing $Ca^{2+}$-ions released from serpentinisation can transport the Ca required for rodingitisation. However, other authors (e.g. Hall and Ahmed, 1984; Hatzipanagiotou and Tsikouras, 2001) have argued that the Ca necessary to produce the calc-silicate assemblages in rodingites need not have been derived by serpentinisation of ultramafic rocks, but by introduction of Ca-rich hydrothermal solutions and/or leaching of gabbroic lithologies. The protolith of rodingite can range from gabbro to quartzite in terms of $SiO_2$ content (O'Hanley, 1996). Rodingites occur after gabbro in differentiated mafic–ultramafic sills in Archean greenstone belts (Anhaeusser, 1979; Schandl et al., 1989) or after gabbro or dolerite dykes in serpentinised mantle tectonites (Hatzipanagiotou et al., 2003; Tsikouras et al., 2009). They also occur as boudins in serpentine cataclasite in Phanerozoic ophiolites and in metasomatic alteration zones formed at the contact between serpentinite and its country rock (e.g. Coleman, 1967; Dubińska, 1989; Mittwede and Schandl, 1992; Yui et al., 1988). They have also been dredged from the modern ocean floor (Honnorez and Kirst, 1975).

This paper aims to examine rodingites found for the first time within the Iti and Kallidromon ophiolites (central Greece), in terms of mineralogical, textural and chemical features, in order to investigate their precursors, the frame of rodingitisation process, as well as to discuss their geochemical evolution.

## 2. Geological setting

### 2.1. Iti Mountain

The Iti Mountain lies to the south of Othrys Mountain and the Sperchios River, in Central Greece (Fig. 1). It belongs to the "Pelagonia terrane" (Stampfli, 1996; Stampfli et al., 1998), a carbonate platform equivalent to the "Internal carbonate platform" of Papanikolaou (1989). The geological structure of the Iti Mountain includes four westward verging tectono-stratigraphic zones, representing different paleotectonic domains. The Iti Mountain is composed of a stack of

* Corresponding author at: University of Patras, Department of Geology, Section of Earth Materials, GR-265 00 Patras, Greece. Tel./fax: +30 2610997560.
*E-mail address:* v.tsikouras@upatras.gr (B. Tsikouras).

0024-4937/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.lithos.2013.04.021

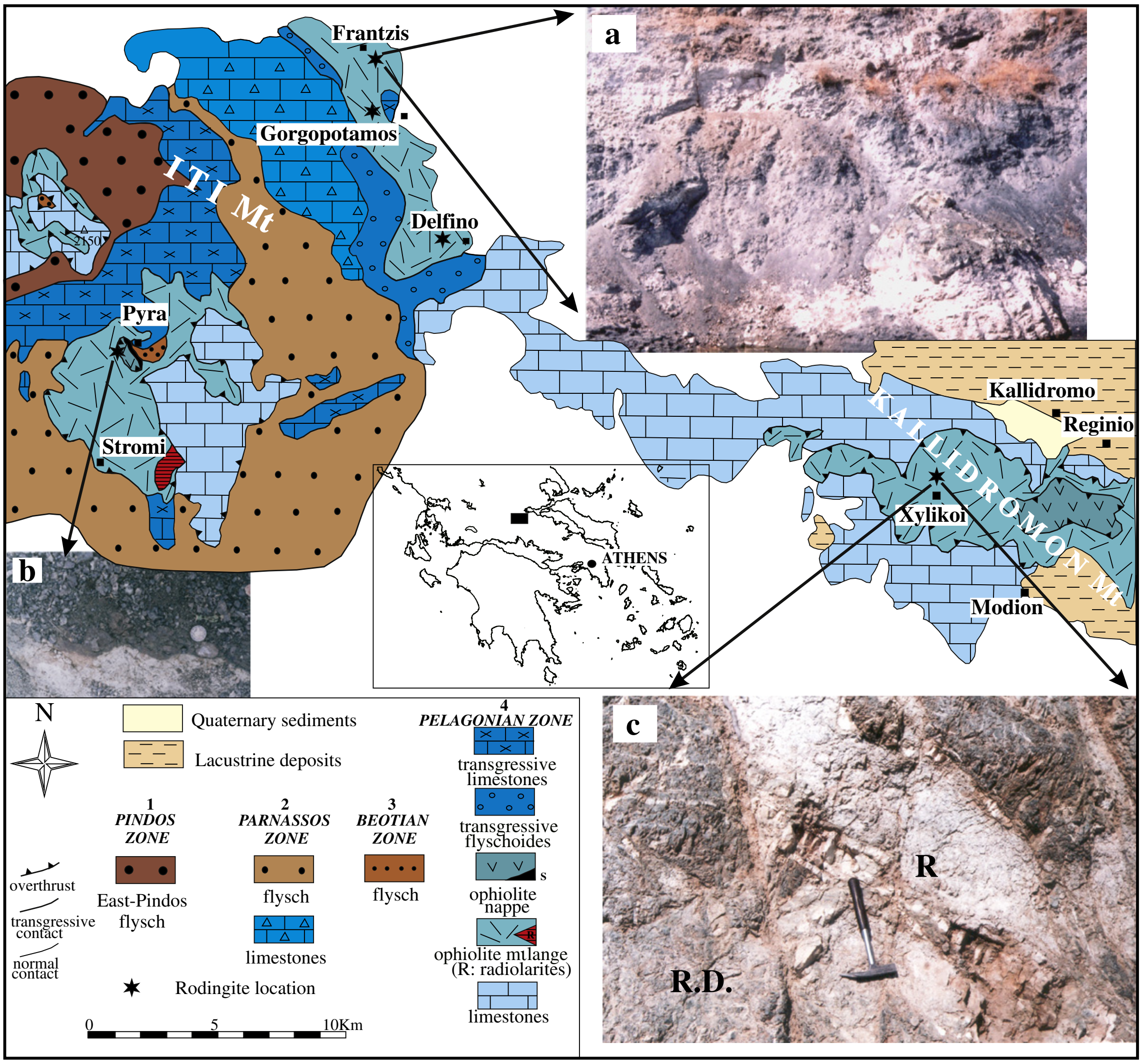


**Fig. 1.** Simplified geological map of the Iti and Kallidromon Mountains (Central Greece) where characteristic rodingite outcrops are indicated. Field photos: (a) irregular rodingite bodies (white areas) within serpentinised peridotite (dark areas) in the ophiolite mélange near the Frantzis village, Iti; (b) rodingite dyke (white) in sharp contact with the peridotite host (dark) of the remnant ophiolite nappe extending near the Pyra village, Iti; and (c) variably rodingitised doleritic rocks forming a characteristic outcrop of a net-dyke near the Xylikoi village, Kallidromon (R.D.: partially rodingitised dyke; R.: rodingite).

nappe units (Wigniolle, 1977). From bottom to top, they include: (1) the flysch of the East-Pindos syncline, (2) the Mesozoic platform carbonates along with flysch of the Parnassos zone, (3) the Beotian flysch, and (4) the Jurassic platform carbonates of the Pelagonian zone, and the overthrust ophiolite unit (Celet et al., 1977; Richter et al., 1997). The latter includes a lower ophiolite mélange, which is locally, tectonically overlain by a sub-ophiolitic metamorphic sole. Both formations are overthrust by a remnant ophiolite nappe of upper mantle tectonites (harzburgite and lherzolite; Karipi et al., 2006, 2008). The ophiolite unit is transgressively overlain by Upper Cretaceous formations (Wigniolle, 1977).

The ophiolite mélange dominates the ophiolite unit at Iti and comprises a multicoloured, heterogeneous formation (approximately 200 m thick) with a chaotic internal structure that consists of slices and/or blocks of variable shape and size of both ocean- and continent-derived rocks. Fragments, of size up to a few tens of metres, include variably serpentinised peridotites (lherzolite and harzburgite), olivine gabbro, gabbro, diorite, dolerite, pillow lavas, fine- and coarse-grained amphibolites, garnet-bearing amphibolite, rodingite, scarce listwaenite, granite, radiolarite, sandstone and Mesozoic limestone. The matrix of the mélange commonly consists of pelitic, sandstone and intensely tectonised serpentinite material; rarely altered and fragmented basaltic material was observed. According to Karipi et al. (2008), the Iti ophiolite mélange forms a “block-in-matrix” type with loose structure and a coherent type. Radiolarian age determination from the radiolarite blocks indicates an Upper Jurassic–Lower Cretaceous age (Baumgartner, 1984). The ophiolite mélange is dismembered in several thrust sheets imbricated together with platform carbonates and/or flysch sediments of the Parnassos, Beotian, and Pelagonian zones, finally emplaced over the flysch of the East-Pindos syncline during Upper Eocene–Middle Oligocene (Richter et al., 1993). Locally, the ophiolite mélange is overlain by an Upper Cretaceous transgressive flyschoid formation.

The remnant ophiolite nappe extends to the northwest of Pyra village (Fig. 1) and comprises variably serpentinised harzburgite and lherzolite. It is thrust over the ophiolite mélange and the sub-ophiolitic metamorphic sole of coarse-grained amphibolite. For the emplacement of the Iti ophiolites and the genesis of the mélange, an Upper Jurassic age was suggested by Celet et al. (1977) and Wigniolle (1977).

The rodingites comprise whitish rocks with local preservation of igneous relics, occurring either as fragments and/or thrust sheets within the ophiolite mélange, or as pods or dykes within variably serpentinised peridotite of the relic ophiolite nappe. In the first case, most of the rodingitic samples were collected from the ophiolite mélange that outcrops among the Frantzis, Gorgopotamos and Delfino villages (Fig. 1). At