Ore Geology Reviews 70 (2015) 188–207

Contents lists available at ScienceDirect

Ore Geology Reviews

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

Petrology and geochemistry of high Cr# podiform chromitites of Bulqiza, Eastern Mirdita Ophiolite (EMO), Albania

Fahui Xiong [a,*], Jingsui Yang [a], Paul T. Robinson [a], Yildirim Dilek [b], Ibrahim Milushi [c], Xiangzhen Xu [a], Yanhong Chen [a], Wenda Zhou [d], Zhongming Zhang [a], Shengming Lai [e], Yazhou Tian [a], Zhu Huang [e]

[a] *CARMA, State Key Laboratory for Continental Tectonics and Dynamics, Institute of Geology, Chinese Academy of Geological Sciences, 100037 Beijing, China*
[b] *Department of Geology& Environmental Earth Science 116 Shideler Hall, Miami University Oxford, 45056 OH, USA*
[c] *Institute of Geosciences, Energy, Water and Environment, Polytechnic University of TIRANA, Albania*
[d] *Faculty of Earth Sciences, China University of Geoscience, 430074 Wuhan, China*
[e] *School of Earth Science and Mineral Resources, China University of Geosciences, 100083 Beijing, China*

ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form 8 April 2015
Accepted 9 April 2015
Available online 11 April 2015

Keywords:
Geochemistry
High Cr#
Podiform chromitite
Bulqiza
Albania

ABSTRACT

The ultramafic massif of Bulqiza, which belongs to the eastern ophiolitic belt of Albania, is a major source of metallurgical chromitite ore. The massif consists of a thick (>4 km) sequence, composed from the base upward of tectonized harzburgite with minor dunite, a transitional zone of dunite, and a magmatic sequence of wehrlite, pyroxenite, troctolite and gabbro. Only sparse, refractory chromitites occur within the basal clinopyroxene-bearing harzburgites, whereas the upper and middle parts of the peridotite sequence contain abundant metallurgical chromitites. The transition zone dunites contain a few thin layers of metallurgical chromitite and sparse bodies are also present in the cumulate section. The Bulqiza Ophiolite shows major changes in thickness, like the 41–50 wt.% MgO composition similar with forearc peridotite as a result of its complex evolution in a suprasubduction zone (SSZ) environment. The peridotites show abundant evidence of mantle melt extraction at various scales as the orthopyroxene composition change from core to rim, and mineral compositions suggest formation in a forearc, as Fo values of olivine are in 91.1–93.0 harzburgite and 91.5–91.9 in dunite and 94.6–95.9 in massive chromitite. The composition of the melts passing through the peridotites changed gradually from tholeiite to boninite due to melt–rock reaction, leading to more High Cr# chromitites in the upper part of the body. Most of the massive and disseminated chromitites have high Cr# numbers (70–80), although there are systematic changes in olivine and magnesiochromite compositions from harzburgites, to dunite envelopes to massive chromitites, reflecting melt–rock reaction. Compositional zoning of orthopyroxene porphyroblasts in the harzburgite, incongruent melting of orthopyroxene and the presence of small, interstitial grains of spinel, olivine and pyroxene likewise attest to modification by migrating melts. All of the available evidence suggests that the Bulqiza Ophiolite formed in a suprasubduction zone mantle wedge.

1. Introduction

Chrome spinel from both chromitites and residual mantle peridotites of ophiolites are used as indicators of their tectonic setting of formation (Dick and Bullen, 1984; Kamenetsky et al., 2001; Arai et al., 2006). A general agreement has emerged that chromitites form in the depleted mantle section of ophiolites from supra-subduction zone (SSZ) environments due to melt–rock or melt–melt interaction (Zhou et al., 1994, 1998; Ballhaus, 1998; Melcher et al., 1999; Uysal et al., 2005, 2007a,b,c).

Geochemical and field relationship studies of volcanic sequences in ophiolites are commonly applied to reconstruct the magmatic and tectonic history of a part of the oceanic lithosphere (Dilek et al., 2008). The volcanic sequence in an Oman ophiolite shows varying chemical characteristics, indicating spatial and/or temporal modification of the magmatic affinity in the ophiolite (e.g., Pearce et al., 1984). In contrast to the studies of volcanic rocks in the ophiolite, the evolutionary history of the mantle sections corresponding to changes in tectonic settings is not yet well understood.

Many ophiolites are now proposed to have formed in the "supra-subduction zone" (SSZ) setting (Beccaluva et al., 1984, 1994; Miyashiro, 1974; Pearce et al., 1984). Shervais (2001) reviewed the petrological and geochemical signatures of SSZ ophiolites and suggested that SSZ ophiolites underwent a sequence of events during their evolution in response to the change in tectonic setting from oceanic lithosphere formed at mid-ocean ridges to the initiation of subduction. The Albanian ophiolites occur within the Dinaride–Hellenide segment of the Alpine orogenic system and represent the remnants of the Mesozoic Neo-Tethyan ocean (Shallo and Dilek, 2003; Dilek and Furnes, 2009).

---

* Corresponding author at: 26 Baiwanzhuang Road, Beijing, 100037, China.
E-mail address: xiongfahui@126.com (F. Xiong).

http://dx.doi.org/10.1016/j.oregeorev.2015.04.011
0169-1368/© 2015 Elsevier B.V. All rights reserved.

The Albanian ophiolites are generally divided into western- and eastern-types based on petrological and mineralogical data, as discussed by many authors (Bébien et al., 2000; Beccaluva et al., 1994; Bortolotti et al., 1996; Dilek and Polat, 2008; Hoeck et al., 2002; Nicolas et al., 1999; Shallo, 1990; Shallo et al., 1987, 1990 and references there in). The northern Albanian ophiolite belt, the Mirdita ophiolite, shows that MORB and SSZ affinities are dominant in the west and the east, respectively (Beccaluva et al., 1994; Bortolotti et al., 1996, 2002; Dilek et al., 2008; Shallo, 1990; Shallo et al., 1987, 1990). It should be emphasized that in this paper we specifically focus on the eastern region of the Mirdita ophiolite (the Eastern Mirdita Ophiolite). Based on the petrology of the mantle section combined with geochemical signatures of volcanic rocks in the eastern part, it was concluded that the eastern part of the Mirdita ophiolite was formed in supra-subduction settings (Beccaluva et al., 1994). Bizimis et al. (2000) examined the trace element composition of clinopyroxene in some peridotites from the mantle sections of ophiolite complexes from the Hellenic Peninsula including one peridotite body (Bulqiza) from the Mirdita ophiolite. They suggested that the trace element composition of clinopyroxene in these ophiolites is similar to modern arc peridotites recovered from Izu–Bonin–Mariana arc (Parkinson and Pearce, 1998; Zanetti et al., 2006). Detailed geochemical mapping in several supra-subduction zone ophiolites has recently revealed the presence of distinct units within the mantle section of an ophiolite (Arai et al., 2006; Batanova and Sobolev, 2000; Choi et al., 2008; Tamura and Arai, 2006; Uysal et al., 2009).

Our recent studies in the eastern ophiolite belt in Albania, known as the Bulqiza zone, show that the geochemical data are related to a complex melt evolution in a single supra-subduction zone environment (Bizimis et al., 2000). This study is based on detailed systematic peridotites and chromitite of different types in the eastern parts of the Bulqiza Ophiolite. We use petrogenetic and geochemical interpretations to develop a regional geodynamic process for the evolution of the Bulqiza Ophiolite, new data provide a testable hypothesis for the tectonomagmatic evolution of SSZ tectonic setting of chromitite.

2. Geology of the Bulqiza Ophiolite

The Tethyan ophiolites (Fig. 1) are highly diverse in terms of their structural architecture, geochemical features, isotopic finger prints, and emplacement ages and mechanisms (Dilek and Flower, 2003). In the Alpine orogenic system the Tethyan ophiolites occur along curvilinear suture zones bounding a series of Gondwana derived continental fragments (Fig. 2) and represent the remnants of Tethyan marginal basins that evolved between these microcontinents (Dilek et al., 2008; Parlak et al., 2013; Karaoglan et al., 2012).

The Jurassic Mirdita Ophiolite occurs in a 30–40 km wide belt bounded by the conjugate passive margin sequences of Apulia in the west and Korabi–Pelagonia in the east (Figs. 2 and 3; Dilek et al., 2005). Large peridotite massifs of the upper mantle units are exposed in the western and eastern parts of this ophiolite belt. The massifs adjacent to the Apulian margin sequences in the west are mainly plagioclase lherzolites, whereas those close to Pelagonia in the east are harzburgites with major chromite deposits (Nicolas et al., 1999; Hoxha and Boullier, 1995). These upper mantle rocks are overlain by plastically deformed flaser gabbros. Isotropic gabbros and sheeted dikes are rare in crustal sections, and mylonitic peridotites and deformed gabbros are locally overlain by basaltic lavas (Fig. 3) and intruded by diabasic dikes and sills. These will subsequently be referred to as the Western Mirdita Ophiolite (WMO) and the Eastern Mirdita Ophiolite (EMO), and the Bulqiza belongs to the Eastern Mirdita Ophiolite (EMO) suture. The WMO has a much thinner crust (2–3 km) and shows mainly MORB affinities, whereas the EMO is up to 10–12 km thick and shows predominantly SSZ geochemical affinities (Dilek et al., 2008). Extrusive rocks, composed mainly of massive to pillow lavas, form a nearly 600 m thick sequence that rests directly on serpentinized peridotites and gabbroic rocks along primary tectonic contacts (Figs. 3; Dilek et al., 2005). The lavas are overlain by 5 to 20 m thick radiolarian cherts that are late Bajocian–early Bathonian (~168–166 Ma) to late Bathonian–early Callovian (~165–163 Ma) in age (Marcucci et al., 1994; Marcucci and Prela, 1996).

The Mirdita zone has been interpreted to have two distinct ophiolite types based on the differences between the upper mantle peridotites and the internal stratigraphy and chemical compositions of crustal units (Shallo et al., 1985, 1990; Shallo, 1990; Beccaluva et al., 1994; Bortolotti et al., 1996, 2002; Tashko, 1996; Bébien et al., 1998, 2000; Nicolas et al., 1999; Robertson and Shallo, 2000; Shallo and Dilek, 2003; Saccani and Photiades, 2004; Dilek et al., 2008). The thinner Western Mirdita ophiolite (WMO) shows mainly MORB affinities, and the nearly 10–12 km thick Eastern Mirdita ophiolite (EMO) displays MORB to island arc tholeiite (IAT) geochemical affinities (Saccani and Photiades, 2004; Beccaluva et al., 2005). Structural and geochemical studies by Dilek et al. (2008) have shown that these two ophiolite types are both laterally (from west to east) and vertically transitional in time and space, although the original igneous contacts have been locally modified by late Cenozoic, collisional thrust faults (Dilek et al., 2005).

The EMO represents a typical Penrose-type ophiolite pseudo stratigraphy (Dilek and Flower, 2003) complete with sheeted dikes and a nearly 1.1 km thick extrusive sequence (Fig. 4). The upper mantle peridotites in the EMO consist of harzburgite tectonite, harzburgite dunite

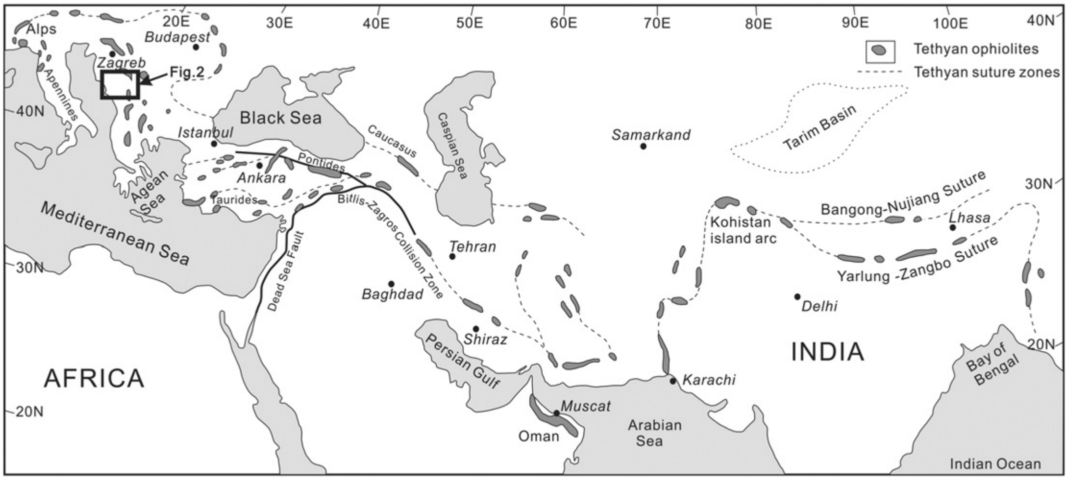

Fig. 1. A. Distribution of major Tethyan ophiolites and suture zones in the Alpine-Himalayan orogenic system. Modified from Dilek and Flower (2003) and Dilek and Furnes (2009).