Lithos 263 (2016) 33–51

Contents lists available at ScienceDirect

Lithos

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

Petrogenesis of the Alaskan-type mafic–ultramafic complex in the Makkah quadrangle, western Arabian Shield, Saudi Arabia

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ARTICLE INFO

Article history:
Received 27 February 2016
Received in revised form 6 August 2016
Accepted 9 August 2016
Available online 18 August 2016

Keywords:
Alaskan-type
Fractional crystallization
Taftafan complex
Arabian Shield
Saudi Arabia

ABSTRACT

The Makkah quadrangle is a part of the Jeddah terrane in the Precambrian basement, Western Arabian Shield of Saudi Arabia. Gabal Taftafan mafic–ultramafic complex lies within the central part of the Makkah quadrangle. The Taftafan mafic–ultramafic complex is a well-differentiated rock association which comprises of dunite core, hornblende- and plagioclase-bearing peridotites, troctolite, clinopyroxenite and marginal gabbro, in a distinctive zonal structure. The bulk-rock geochemistry of the Taftafan mafic–ultramafic rocks is characterized by a tholeiitic/sub-alkaline affinity with high Mg in the ultramafic core (0.84) and is systematically decreased towards the marginal gabbro (0.60). The patterns of trace elements show enrichment in the fluid-mobile elements (Sr, Ba) and a pronounced negative Nb anomaly which reflect a hydrous parental magma generated in a subduction tectonic setting. The mafic–ultramafic rocks of the Taftafan complex have low total rare earth elements (REE) displaying sub-parallel patterns leading to the assumption that these rocks are comagmatic and are formed by fractional crystallization from a common magma type. The platinum-group elements (PGE) content of all rock types in the Taftafan complex is very low, with $\sum$PPGE > $\sum$IPGE; displaying slightly positive slopes of the PGE distribution patterns. The chemistry of ferromagnesian minerals is characterized by a high forsterite (Fo) olivine with wide range ($Fo_{91–67}$), from ultramafic core to the marginal gabbro, Ca-rich diopsidic clinopyroxene, and calcic hornblende. Orthopyroxene is almost absent from all rock types, or very rare when present. Hornblende and Ca-plagioclase possess the longest crystallization history since they are present in almost all rock types of the complex. Spinels in the dunite and hornblende-bearing peridotite core show homogeneous composition with intermediate Cr# (0.53–0.67). Plagioclase-bearing peridotite and troctolite have two exsolved types of spinel; Al-rich and Fe-rich varieties. All spinel varieties in the mafic–ultramafic rocks have high Fe^{3+} and TiO_2 contents. The estimated melt composition in equilibrium with Gabal Taftafan complex is mostly similar to that of the SSZ boninitic magmas. The Taftafan mafic–ultramafic rocks show many similarities with the Alaskan-type mafic–ultramafic complexes, including the internal zonal lithology, bulk rock geochemistry, and mineral chemistry. Thus, it is neither related to a fragment of ophiolite sequence nor to the stratiform mafic–ultramafic intrusion. The location of the Taftafan complex along a major fracture zone parallel to the suture between Jeddah and Asir terranes in addition to the aforementioned striking similarities to the Alaskan-type complexes, suggests a formation in subduction-related setting from a common hydrous mafic magma.

1. Introduction

Mafic–ultramafic rocks can be formed in a variety of tectonic environments, such as ophiolites in the active orogenic setting, Alaskan-type complexes in the subduction-related setting, and large stratiform complexes in non-orogenic areas. They have different geochemical features that can be used to identify the tectonic environment and constrain the nature of the mantle source (Deng et al., 2013; Dick and Bullen, 1984; Naldrett and Cabri, 1976; Wilson, 1989). The Alaskan-type mafic–ultramafic complexes can be distinguished from other mafic–ultramafic rocks in their morphological, petrographical, mineralogical and geochemical characteristics. There is a general consensus that the Alaskan-type mafic–ultramafic complexes are formed in the convergent margin settings via the island arc magmatism (Farahat and Helmy, 2006; Helmy and El Mahallawi, 2003; Helmy et al., 2014, 2015; Himmelberg and loney, 1995; Taylor, 1967). The roots of these island arcs are most probably exposed along the major structures forming the characteristic concentrically zoned (Alaskan-type) mafic–ultramafic complexes (Batanova et al., 2005; Helmy et al., 2015; Polat et al., 2012). The roots of these complexes are commonly ultramafic in composition,

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http://dx.doi.org/10.1016/j.lithos.2016.08.014
0024-4937/

while the shallow levels are more evolved mafic rocks (Jagoutz and Schmidt, 2013). Three possible reasons for the wide lithological, mineralogical and geochemical variations in the concentrically zoned mafic–ultramafic complexes are: (1) sub-volcanic level fractional crystallization of the arc magma (Spandler et al., 2003) (2) increase in the degree of partial melting of the mantle source through the subduction zone setting (Pettigrew and Hattori, 2006) and (3) mixing of different mantle sources during the arc evolution (Dhuime et al., 2009). Therefore, detailed study of the sub-arc magmatism represented by the Alaskan-type mafic–ultramafic complexes provides useful information on the crust–mantle evolution, and the deep-seated geodynamic processes beneath island arcs.

The Precambrian mafic–ultramafic rocks in the Arabian Shield are mainly represented by the ophiolite belts along the suture zones and concentrically zoned mafic–ultramafic intrusions. The ophiolites are varyingly dismembered and suffer from multiple phases of alteration, deformation and greenschist facies metamorphism. They are found in the various suture zones distributed along the Arabian Shield. Some of them are recently studied in detail for their petrogenesis (Ahmed and Habtoor, 2015; Ahmed et al., 2012) (Fig. 1a). In the Arabian Shield, there are some mafic–ultramafic complexes that display a similarity in appearance and composition to those of the Alaskan-type concentrically-zoned mafic–ultramafic complexes such as Wadi Kamal, Ha'il, and Lakathah (Chevremont, 1982, 1983; Collenette and Grainger, 1994; Harbi, 2008) (Fig. 1a). Although there are several localities for such concentrically zoned mafic–ultramafic complexes in the Arabian Shield, none of them have been studied in detail to check their petrological characteristics. A typical concentrically zonal Mafic–ultramafic complex located in the south of Makkah city, called Gabal Taftafan (Moore and Al-Rehaili, 1989), which is not previously defined as concentrically-zoned complex is selected to be studied in detail to characterize its geological, mineralogical and geochemical characteristics. The Gabal Taftafan area forms a small oval-shaped body (8–10 km^2) and is located at the base of the Al Taif escarpment (Fig. 1b). The objectives of the present study are (1) to document for the first time the geology, petrology and geochemistry of one of the Neoproterozoic Alaskan-type complex in the Arabia Shield named "Gabal Taftafan" mafic–ultramafic complex (2) to compare the Taftafan complex with other mafic–ultramafic complexes of different tectonic settings and (3) to check the nature of the mantle source and magma genesis from which the Taftafan complex is formed, using whole-rock data, platinum-group elements geochemistry, and mineral chemistry.

2. Geological setting

The Arabian Shield represents the exposed Precambrian basement of the Arabian Plate. It is exposed in the Western part of Saudi Arabia and is separated from the Nubian Shield of the African Plate by the Red Sea rift. The tectonic history of the Arabian-Nubian Shield started from the sea floor and its spread formed different types of arcs during the rifting of the Rodinia (Stern, 1994). Thereafter, arc accretion and amalgamation of these island arcs and some of the continental fragments led to the formation of the Neoproterozoic juvenile crust at distances of about 870 and 600 Ma close to the Mozambique Ocean (Abd-Allah et al., 2014; Stern, 1994; Stern et al., 2004). Shortly after, this amalgamation process caused crustal thickening, with orogenic collapse and tectonic escape along strike-slip shear zones until the end of the Precambrian (Johnson et al., 2011). The tectonic contacts between the Arabian Shield terranes are decorated by ophiolitic sutures, shear zones, faults superimposed on original sutures or post-suturing structures, and post-amalgamation fault zones (Abd-Allah et al., 2014; Stern et al., 2004). The ophiolitic suture zones represent relicts of ancient subduction and/or collisional zones. Terranes in the Western Arabian Shield are separated by three NE–SW oriented sutures and fault zones along

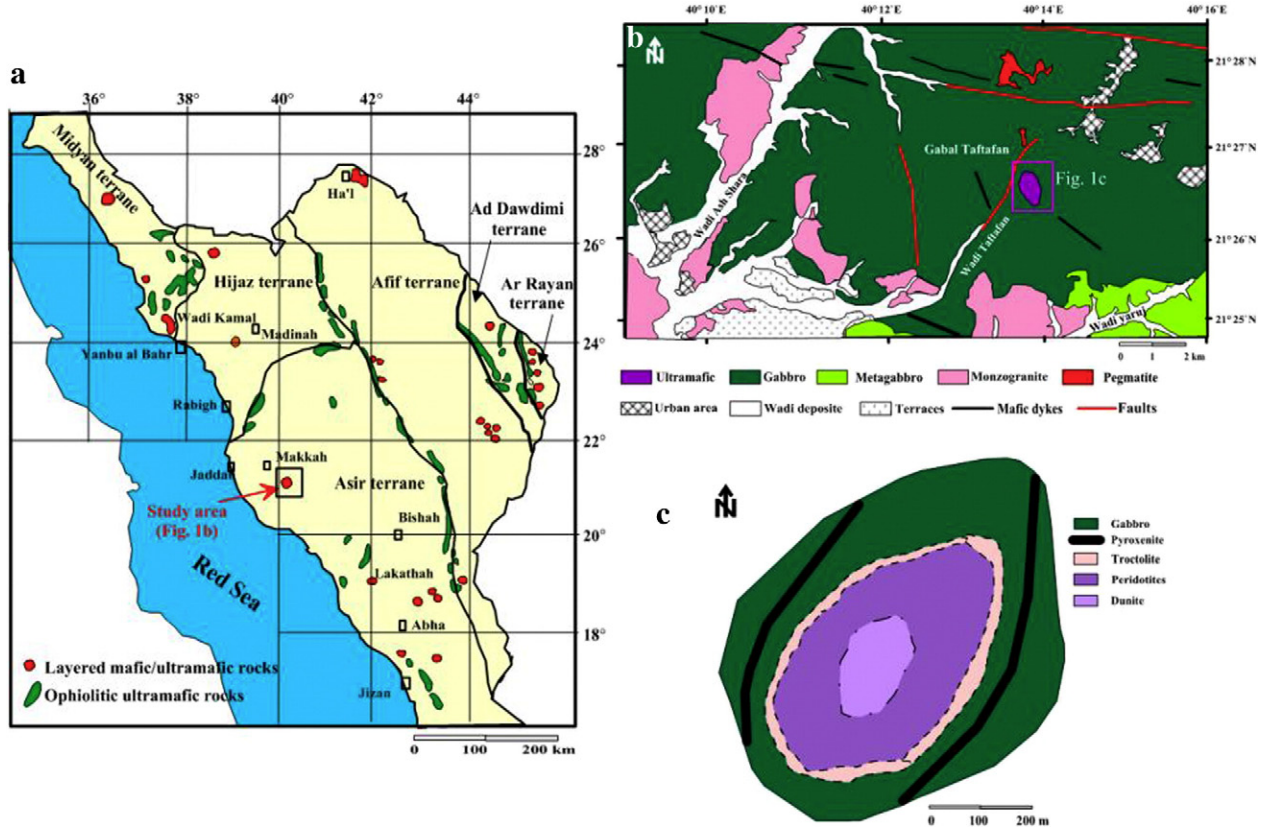

Fig. 1. (a) General map of the Arabian Shield showing the distribution of mafic–ultramafic rocks in the Kingdom of Saudi Arabia (Collenette and Grainger, 1994). (b) Part of the Geological map of the Makkah quadrangle showing the geology of Gabal Taftafan area (Moore and Al-Rehaili, 1989). (c) Lithological sketch showing the variation of rock types from ultramafic core to the marginal gabbro of Taftafan complex.