Chemie der Erde 76 (2016) 605–620

Contents lists available at ScienceDirect

Chemie der Erde

journal homepage: www.elsevier.de/chemer

Evidence of Mid-ocean ridge and shallow subduction forearc magmatism in the Nagaland-Manipur ophiolites, northeast India: constraints from mineralogy and geochemistry of gabbros and associated mafic dykes

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ARTICLE INFO

Article history:
Received 26 March 2016
Received in revised form 30 August 2016
Accepted 8 September 2016
Editorial handling - A. Holzheid

Keywords:
Mafic intrusives
MOR magmatism
Forearc magmatism
Nagaland-Manipur ophiolites
India

ABSTRACT

We discuss here the mineralogical and geochemical characteristics of mafic intrusive rocks from the Nagaland-Manipur Ophiolites (NMO) of Indo-Myanmar Orogenic Belt, northeast India to define their mantle source and tectonic environment. Mafic intrusive sequence in the NMO is characterized by hornblende-free (type-I) and hornblende-bearing (type-II) rocks. The type-I is further categorized as mafic dykes (type-Ia) of tholeiitic N-MORB composition, having TiO_2 (0.72–1.93 wt.%) and flat REE patterns (La_N/Yb_N = 0.76–1.51) and as massive gabbros (type-Ib) that show alkaline E-MORB affinity, having moderate to high Ti content (TiO_2 = 1.18 to 1.45 wt.%) with strong LREE-HREE fractionations (La_N/Yb_N = 4.54–7.47). Such geochemical enrichment from N-MORB to E-MORB composition indicates mixing of melts derived from a depleted mantle and a fertile mantle/plume source at the spreading center. On the other hand, type-II mafic intrusives are hornblende bearing gabbros of SSZ-type tholeiitic composition with low Ti content (TiO_2 = 0.54 wt.%–0.86 wt.%) and depleted LREE pattern with respect to HREE (La_N/Yb_N = 0.37–0.49). They also have high Ba/Zr (1.13–2.82), Ba/Nb (45.56–151.66) and Ba/Th (84.58–744.19) and U/Th ratios (0.37–0.67) relative to the primitive mantle, which strongly represents the melt composition generated by partial melting of depleted lithospheric mantle wedge contaminated by hydrous fluids derived from subducting oceanic lithosphere in a forearc setting. Their subduction related origin is also supported by presence of calcium-rich plagioclase ($An_{16.6-32.3}$). Geothermometry calculation shows that the hornblende bearing (type-II) mafic rocks crystallized at temperature in range of 565°–625 °C ± 50 (at 10 kbar). Based on these available mineralogical and geochemical evidences, we conclude that mid ocean ridge (MOR) type mafic intrusive rocks from the NMO represent the section of older oceanic crust which was generated during the divergent process of the Indian plate from the Australian plate during Cretaceous period. Conversely, the hornblende-bearing gabbros (type-II) represent the younger oceanic crust which was formed at the forearc region by partial melting of the depleted mantle wedge slightly modified by the hydrous fluids released from the subducting oceanic slab during the initial stage of subduction of Indian plate beneath the Myanmar plate.

1. Introduction

Ophiolites are distinct assemblages of mantle rocks, ultramafic cumulates, mafic intrusive and extrusive crustal rocks, commonly associated with siliceous pelagic sediments (chert, clay and shale etc.), that have long been recognized as important components of orogenic belts around the world (Steinmann, 1906; Hess, 1955). At earlier times, ophiolites were mainly viewed as on-land analogues of the oceanic lithosphere formed at Mid-ocean ridges (MOR), but this paradigm had shifted to supra subduction zone (SSZ) origin during 1972–1984 (Evarts, 1977; Miyashiro, 1973; Pearce et al., 1981). The idea of subduction origin of the ophiolites was first

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http://dx.doi.org/10.1016/j.chemer.2016.09.002

proposed by Miyashiro (1973) as evidenced in the well-known Troodos ophiolite section. Since then the debate continued on much better understanding of ophiolite genesis. Over the years, many evidences were reported for the coexistence of MOR and SSZ ophiolitic complexes, with the latter predominant in most cases, in both Tethyan and Cordilleran ophiolites (Portnyagin et al., 1997; Beccaluva et al., 2004; Saccani et al., 2004; Aldanmaz et al., 2009; references therein). In addition to this, some recent studies have also mentioned that ophiolites may be originated in other tectonic environments of continental margin, plume-type and volcanic arc (Bedard et al., 2009; Saccani et al., 2011; Dilek and Furnes, 2011; Safonova et al., 2012).

As far as the origin and geodynamic evolution is concerned, the Nagaland-Manipur Ophiolite (NMO) of the Indo-Myanmar orogenic belt (IMOB) in northeast India is a subject of debate. The NMO is interpreted to be a part of the Tethyan ophiolite sequences that extends in the NNE-SSW direction representing the eastern suture of the Indian plate which was obducted on land due to the collision of the Indian plate and Myanmar plate (Gansser, 1980; Mitchell and Mckerrow, 1975; Acharyya et al., 1989; Bhattacharjee, 1991).Some workers proposed that it was originated from multiple subduction processes (Agrawal and Kacker, 1980; Mitchell, 1993). There was also proclamation claiming it as a melange of rootless sub-horizontal nappes, which was westward-propagated from the eastern ophiolite belt of Myanmar (Acharyya et al., 1990; Bhattacharjee, 1991). Some recent studies however concluded that NMO was originally initiated at Mid-oceanic ridge (MOR) tectonic setting (Singh, 2009, 2013; Ningthoujam et al., 2012). So, the question remains whether the NMO was formed by single magmatism at MOR or SSZ or formed by multiple magmatic events at different tectonic settings during the course of Indian plate movement. Therefore with an attempt to find the answer to these queries, we did detailed mineralogical and geochemical studies for mafic intrusive rocks collected from various localities of the southern part of the NMO, and the results are discussed in this paper.

2. Geological setting

The NMO is a graveyard of Tethyan oceanic lithosphere preserving along the eastern margin of the NNE–SSW trending IMOB of northeast India that represents the eastern suture of the Indian plate (Gansser, 1980; Acharyya et al., 1989; Bhattacharjee, 1991). The NMO has an extension of ~200 km in length, ~2–20 km in width, covering an area of ~2000 km^2 within the Nagaland and Manipur states of India. This region is surrounded by four tectono-stratigraphic units to its eastern and western sides. To the east are the Nimi Formation/Naga Metamorphicsof Pre-Mesozoic that consists of quartz mica-schist, garnet mica-schist, quartzite, and granitic gneiss and the Jopi/Phokphur Formation that unconformably overlie the NMO (Brunnschweiler, 1966; Roy and Kacker, 1980; Chattopadhyay et al., 1983) (Fig. 1). Whereas, flysch-like sediments of theupper Cretaceous-upper Eocene Disang formations (Acharyya et al., 1986) and Oligocene to Upper Eocene Barail Formations (Mallet, 1876; Evans, 1932) and a belt of Schuppen underlie this section to the west, along an east-dipping thrust contact (Fig. 1c). The boundary thrust between the ophiolites and the Disang flysch is marked by brecciation, silicification and presence of fault gouge and intermixing of litho-units. Small-scale irregular joints are developed in the rocks with prominent features of slickenside and striations. The Belt of Schuppen is a molassic basin developed during Late Paleogene and Neogene time onthe western margin of the Disang Flyschand its imbrication into a series of thrust faults was a result of the welding and collision of the Indian and Myanmar Plates (Evans, 1932; Mathur and Evans, 1964).

Part of the Disang sediments immediately bordering the ophiolitic rock is olistostomal in facies which was deposited on the distal Indian continental shelf (Sengupta et al., 1989) and these olistolith bodies have been assigned middle Eocene to Paleocene age (Mitra et al., 1986; Vidyadharan et al., 1989). Dark grey to black splintery shales, siltstone and fine to medium grained sandstones of grey to brown colour are the various litho-units of Disang group, intermixed with pelagic cherts and limestone (Bhattacharjee, 1991). The Barails are unconformably overlain by the molasse sediments characterized as the Surmas (Evans, 1932) and Tipams (Mallet, 1876) of Miocene to Oligocene age. On the basis of faunal assemblages (radiolaria, nanoccoliths and planktonic foraminefera), the NMO has been assigned to be Cretaceous to Paleocene age (Chattopadhyay et al., 1983; Acharyya et al., 1986; Chungkham and Jafar, 1998). However, Baxter et al. (2011) reported radiolarians of upper Jurassic (Kimmeridgian – lower Tithonian) affinity from the ophiolitic melange zone in the northern part of the NMO. This has led to the alterative suggestion that the NMO ranging in age between Middle Mesozoic and early Cenozoic. This new radiolarians of upper Jurassic age is also supported by earlier single (only from one sample) radiometric age of 148 ± 4 Ma (whole rock K-Ar) from an associated basaltic flow with cherts in the northern part of the NMO (Sarkar et al., 1996). Consequently, the mechanism of emplacement of the NMO and their ages are still controversial.

3. Field observation and petrography

Lithology in the study area predominantly consists of well-preserved mantle sequence ofserpentinized ultramafic tectonite (dunite – harzburgite – lherzolite), ultramafic-mafic cumulates (peridotites – pyroxenite – gabbronorite – gabbro), minor dolerite, mafic volcanics and volcano-clastics dominated by basalt and spilite with felsic and mafic intrusives, and marine sediments containing radiolaria (Mitra et al., 1986; Ghose and Agrawal, 1989; Ghose et al., 2010; Singh et al., 2013; Singh, 2013). The ophiolitic suite of rocks in the study area are highly tectonised and dismembered, showing three phases of deformational events broadly comparable to the Himalayan orogeny and sea floor spreading of the Indian Ocean (Ghose et al., 1986). Altered peridotites are typically pale green, whereas least altered are black to dark green.Well-preserved basaltic flows exhibiting pillow structures are also observed in this area (Singh et al., 2008; Khogenkumar et al., 2016). Mafic volcanic rocks are closely associated and interbedded with radiolarian chert and occasionally with carbonates. Sheeted dykes which are considered as major litho-units in other ophiolites are missing in the study area. Their absence may be due to gabbroic intrusion at upper levels of the oceanic crust sequence (Ghose et al., 2010). At places, podiform chromitites are exposed predominantly in the southern part of the NMO, associated with peridotites. Massive chromitite is the most abundant while the nodular type is the least abundant in the study area (Singh et al., 2013). Dismembered mafic and ultramafic rocks of this belt are closely associated with oceanic pelagic sediments. Ultramafic rocksshow sharp contact with Disangargillceous and flyschoid sediments. Mafic intrusives that range from coarse grained gabbros to fine grained dykes are intruded within the ultramafic body and pelagic sediments. They also occur as oval-shaped intrusive bodies within the pelagic sediments having various dimensions ranging from 5 m to 25 m in length. Sharp contacts between the mafic intrusive and ultramafic rocks were observed in the field (Fig. 2a). Their intrusive nature is clearly distinguished in the field and show no cumulate layering. In places, they represents the typical lower crustal part of an ophiolite section which is overlain by a layer of pillow basalts.

Based on the mineralogical assemblages, investigated mafic intrusive rocks are identified as Hornblende-free mafic intrusive