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# Petrology of Lasail plutonic complex, northern Oman ophiolite, Oman: An example of arc-like magmatism associated with ophiolite detachment

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ABSTRACT

Lasail plutonic complex (4.7×3.8 km), as a typical example of late stage intrusive rocks, is located to the south of Wadi Jizi, and intrudes into the base of V1 volcanic rocks and sheeted dike complex. The Lasail plutonic complex consists of various rock types ranging from ultramafic cumulates to tonalite, and is associated with minor amounts of axis stage gabbro to quartz diorite. These rocks are classified into the following eleven rock types: massive gabbro 1, quartz diorite 1 (axis stage intrusive rocks), olivine websterite, olivine gabbronorite, gabbronorite, hornblende gabbronorite, leucogabbronorite (layered gabbros), massive gabbro 2, diorite, quartz diorite 2, and tonalite (late stage intrusive rocks). The layered gabbros are intruded by the massive gabbro 2, and often occur as large irregular blocks in the massive gabbro 2. The massive gabbro 2 intrudes into the layered gabbros, and sometimes grades into hornblende gabbronorite layer of the layered gabbros. In some places, anastomosing veins of the hornblende quartz gabbronorite injected into the gabbronorite, which continue to the layer of leucogabbronorite. These gabbroic rocks are intruded by small intrusions of diorite, quartz diorite 2, and tonalite. The quartz diorite 2 forms rather larger intrusive bodies that intrude into the gabbroic rocks in the higher level. The tonalite occurs as thin dike and sheet mainly in the layered gabbros. N-MORB normalized trace element patterns for the massive gabbro 2 are characterized by enrichment of LILEs relative to REEs, and resemble to 'subduction component' from the island arc tholeiite except a weak enrichment for middle to light REE and P. In contrast, the massive gabbro 1 (axis stage gabbro) shows rather flat pattern similar to MORB with no remarkable 'subduction component'. From the examination of Sr and Nd isotopic signature, the Lasail plutonic rocks are characterized by higher $\varepsilon$-Sr values than those of MORB. This suggests that the primitive magma of Lasail complex was influenced by the rocks with higher $\varepsilon$-Sr values than those of MORB, e.g., the axis stage rocks interacted with seawater. These lines of evidence suggests that the massive gabbro 2 was formed by the partial melting of residual MORB mantle which is contaminated with slab melt derived from the axis stage rocks interacted with seawater. In addition, petrogenesis of felsic rocks in the Lasail complex can be explained by the partial melting model of pre-existing layered gabbro. U–Pb zircon ages analyzed by LA-ICPMS are 100±2 and 99±2 Ma for late stage tonalite and 100±1 Ma for axis stage quartz diorite. These ages are slightly older than the ages reported for felsic rocks in the Oman ophiolite (ca., 95 Ma), and suggest that the conversion from ridge stage to detachment stage took place rapidly.



## 1. Introduction

The Oman ophiolite is a sliver of the Neo-Tethys oceanic lithosphere obducted onto the Arabian plate during the late Cretaceous time. It contains a particularly well-preserved sequence; exposure is almost continuous both along strike and in vertical sections. However, there is a debate about whether the ophiolite formed in a mid-ocean ridge setting (Boudier and Coleman, 1981; Boudier et al., 1988; Nicolas, 1989), or a supra-subduction zone setting (Alabaster et al., 1982; Lippard et al., 1986; Pearce et al., 1981; Searle and Cox, 1999; Searle and Malpas, 1982). The evidence for this mainly comes from the geochemical features of the ophiolite volcanic sequence, therefore it is very important to elucidate the detailed petrogenesis of these rocks.

Three main volcanic episodes in the Oman ophiolite were distinguished on the basis of the geology and geochemistry of the extrusive sequence (Alabaster et al., 1982; Ernewein et al., 1988; Pearce et al., 1981). The first volcanic episode, V1 (Ernewein et al., 1988) or Geotimes (Alabaster et al., 1982; Pearce et al., 1981) is characterized by normal MORB-like chemistry (Godard et al., 2003, 2006; Kusano et al.,

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2012). The second volcanic episode, V2 (Ernewein et al., 1988), occurs shortly after V1, shows arc-like petrochemical signature. The last volcanic event consists of alkaline to transitional within-plate basalts, and is associated to obduction (Lippard et al., 1986) during the later stages of ophiolite emplacement. Among them, the V2 volcanic rocks have become a topic of major interest because of their arc-like petrochemistry. However, the 'primitive' geochemical signature of ophiolitic volcanic sequence has been questioned because of severe alteration (e.g., Hofmann, 2004). In this connection, equivalent plutonic rocks have a great advantage compared with subaqueous volcanic rocks, because of weak seawater alteration.

In addition, felsic to intermediate rocks in ophiolite suites, called plagiogranite (Coleman and Donato, 1979; Coleman and Peterman, 1975), attract special interest because of their arc-like petrochemical signature (Pearce et al., 1984). Lippard et al. (1986) classified the felsic rocks in the Oman ophiolite into three stages; high-level intrusive rocks of axis stage, late stage intrusive rocks, and younger biotite granites associated with emplacement stage. Rollinson (2009) described similar classification of the felsic rocks in the Oman ophiolite, and discussed petrogenesis of these felsic rocks.

According to Rollinson (2009), the later plagiogranites are formed by differentiation from a mafic parental magma derived from a highly depleted mantle peridotite, implying earlier basalt melt extraction. Rollinson (2009) also described that the later plagiogranites are relatively enriched in fluid-mobile elements as well as V2 volcanic rocks (Godard et al., 2006), implying the influence of 'subduction zone' fluids. Although, Adachi and Miyashita (2003) and Yamasaki et al. (2006) showed plutonic equivalents to the V2 volcanic unit, however, very little has been stated about petrochemical details of coexisting mafic plutonic rocks. Therefore, petrogenesis of mafic magmas of late magmatism should be further studied in detail.

Lasail plutonic complex, feeds the Lasail unit (V2) volcanic rocks around Lasail Mine (Alabaster et al., 1982; Lippard et al., 1986), and is a typical example of late magmatism. The Lasail complex consists of various plutonic rocks ranging from ultramafic cumulates to tonalite, and shows the possibility of preservation of crystallization history of late intrusive magmas. Therefore, the petrogenesis of the Lasail plutonic complex is of particular importance to understand not only the petrogenesis of felsic rocks in ophiolite but also origin of primitive island arc magmatism. The purpose of this study is to describe petrology and petrochemistry of the mafic to felsic rocks from the Lasail plutonic complex as an example of late intrusive rocks, and to elucidate the petrogenesis of these rocks.

## 2. Geology and petrography

### 2.1. General geology

The Oman ophiolite contains a particularly well-preserved sequence, and is exposed for over 20,000 km$^2$ as an almost complete oceanic crustal sequence. From bottom to top, harzburgites and dunites are exposed at the lowest levels, through layered gabbros, high level intrusive

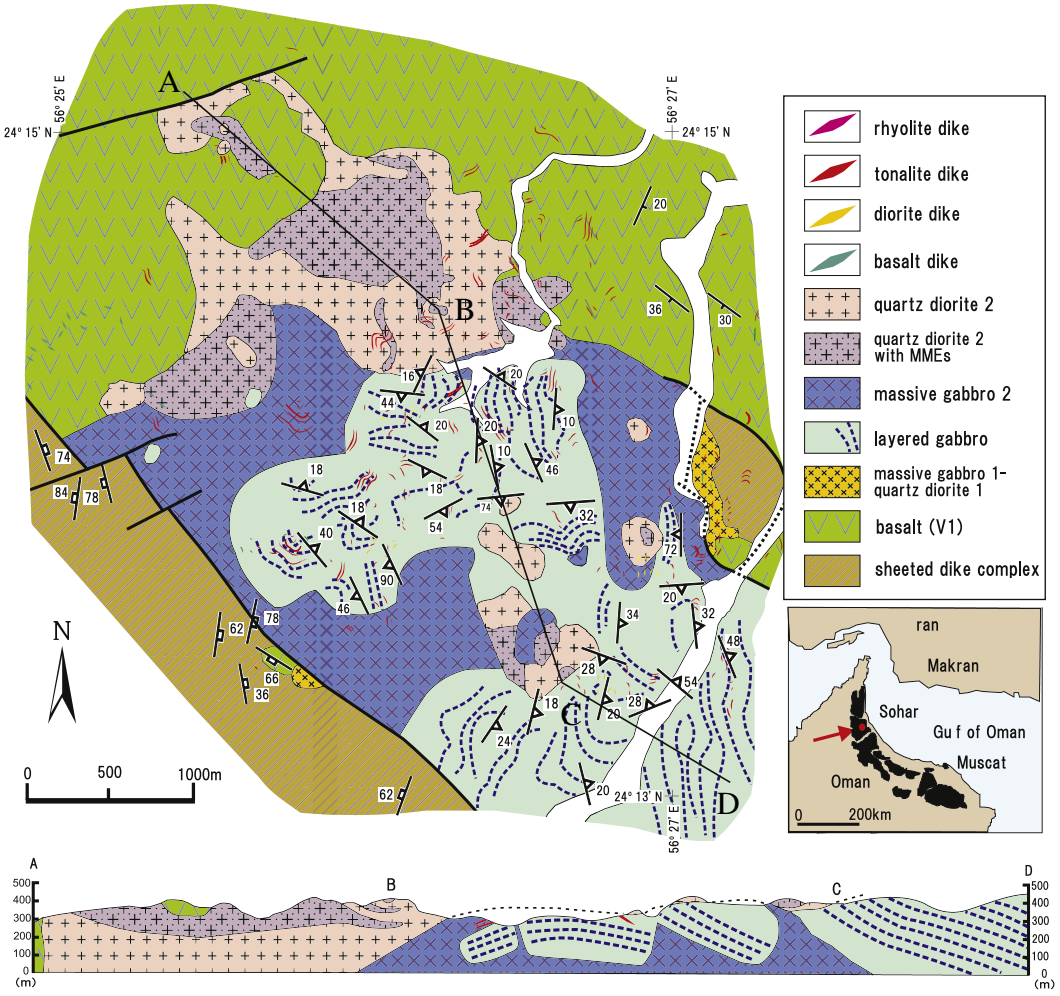


**Fig. 1.** Geological map and geological cross section through A to D of the Lasail plutonic complex.