Fe–Ti-enriched mafic rocks from south Andaman ophiolite suite: Implication of late stage liquid immiscibility

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Andaman ophiolite suite (AOS) is amongst one of the ophiolite complexes of the world, which comprises complete dismembered ophiolitic sequence. It consists of ultra-mafic and mafic cumulates, sheeted dykes, pillow lavas, felsic rocks (mainly plagiogranites), and sedimentaries, including ribbon chert. In the present communication, a mafic rock that is highly enriched in FeO–TiO_2 and encountered in the ophiolites of south Andaman is presented. Fe–Ti-enriched mafic rock is not yet reported from the south AOS. Genetically this rock may be associated with leucocratic rocks of AOS because it is experimentally proved that Fe-enriched basaltic melt and plagiogranite melt can be generated by late stage liquid immiscibility. Similar to most of the other plagiogranite occurrences of the world, Andaman plagiogranites are also supposed to be end-products of magmatic differentiation of a mafic magma. But the discovery of Fe–Ti-enriched mafic rocks supports liquid immiscibility process.

THE Andaman ophiolite suite (AOS) has been studied by several workers[1–3], but less attention has been paid to leucocratic rocks, particularly plagiogranites. Before presenting the petrological and geochemical characteristics of the reported Fe–Ti-enriched mafic rock, it is essential to give a brief account on plagiogranite because genesis of this rock may be associated with Fe–Ti-enriched mafic rock[4]. Vohra *et al.*[2] have presented geochemical data on the Andaman plagiogranites and suggested that these are end-products of fractional crystallization of a mafic magma. Plagiogranite is a leucocratic rock showing trondhjemitic/tonalitic characters and is associated with some of the ophiolite complexes[5,6]. It is essentially composed of quartz, sodic plagioclase feldspar and minor hornblende and epidote. It shows mainly hypidiomorphic texture but, at places, myrmekitic texture is also present. Chemically, it contains high silica, low to moderate alumina, low total iron, and extremely low potassium[4,5,7]. These characteristics were reported in the plagiogranites of the south AOS[2]. On the basis of mineralogy and chemistry of these plagiogranites, they may be classified as low-K trondhjemite/tonalite rocks. These plagiogranites are well exposed between Port Blair and Chiriyatapu in the south Andaman Island[2]. These rocks show intrusive nature and occur within the mafic cumulate sequences of the ophiolite suite. Exposures of these rocks occur in the form of irregular bands (dykes/dykelets), but sometimes regular bands are also observed.

There is no concurrence on the petrogenesis of plagiogranites. They may be formed either by crystal–liquid fractionation of gabbroic magma[5] or by late stage silicate liquid immiscibility process[4]. Dixon and Rutherford[4] have discussed this problem in detail and performed an experiment to explain genesis of leucocratic rocks associated with ophiolites or mid-oceanic ridge (MOR) rocks. According to them, if these leucocratic rocks (plagiogranites) are formed by the crystal–liquid fractionation process, intermediate liquid phases between gabbro and plagiogranite should be exposed. If this gap exists, some process other than crystal–liquid fractionation is supposed to have operated in the genesis of plagiogranites. According to their experimental work[4], plagiogranites may be generated by late stage silicate liquid immiscibility. They observed that after 95% crystallization of the mineral assemblage olivine, plagioclase, pyroxene and ilmenite from the original tholeiite, the residual liquid (i.e. a Fe-enriched basaltic melt) becomes immiscible. This immiscibility occurred at approximately 1010°C. They further observed that products of this immiscibility were a granitic liquid and a Fe-rich basaltic melt. This is not unusual because several workers have observed silicate liquid immiscibility involving an Fe-enriched basaltic composition and a granitic composition in a number of igneous complexes[8–11]. Dixon and Rutherford[4] have pointed out that if this process, i.e. late stage liquid immiscibility, had operated in any ophiolite complex, rocks representing plagiogranitic and Fe-enriched basaltic melts should be exposed; otherwise it will be difficult to establish their origin by immiscible process.

We report here the occurrence of Fe–Ti-enriched mafic rocks from the south AOS. It is certainly an important observation with reference to the genesis of associated plagiogranites. These mafic rocks are also exposed around Chiriyatapu, in the southern part of South Andaman Island and show a intrusive relationship with mafic cumulates. Under the microscope, this rock shows inequigranular texture of porphyritic type but, at places, sub-ophitic texture is also noted. It contains clinopyroxenes (mainly augite), hornblende, plagioclase feldspar (most grains are altered), apatite and opaque minerals (mostly ilmenite). Fine-grained groundmass is ferruginous in nature. One sample of Fe–Ti-enriched rock was chemically analysed at the Department of Earth Sciences, Memorial University of Newfoundland, Canada by XRF. Table 1 presents the chemical compositions obtained. From the table it is observed that this rock contains low amounts of silica, alumina and calcium, and high amounts of iron and titanium. It is well established that rocks of ophiolite sequences are very low in potassium[4,5,7]. Fe–Ti-enriched

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Table 1. Chemical analyses of Fe–Ti-enriched mafic rock (wt% oxides) and average major wt% oxides values of plagiogranites from south AOS. Average chemical compositions of experimental Fe-enriched immiscible and experimental plagiogranite melts are also presented

	Fe–Ti-enriched mafic rock from south AOS	Average experimental Fe-enriched immiscible melt[4]	Average south Andaman plagiogranites	Average experimental plagiogranite melt[4]
		$n = 7$	$n = 8$	$n = 7$
SiO_2	34.26	43.90	68.76	68.50 ± 1.61
TiO_2	8.78	4.61	0.44	1.70 ± 0.57
Al_2O_3	8.18	7.00	13.78	11.10 ± 0.60
Fe_2O_3	4.68	–	4.22	–
FeO	23.88*	23.45	–	7.86 ± 1.27
MnO	0.27	0.55	0.06	0.16 ± 0.04
MgO	9.35	2.32	2.09	0.75 ± 0.21
CaO	7.17	10.18	3.59	3.82 ± 0.45
Na_2O	1.34	1.85	3.87	2.86 ± 0.69
K_2O	0.21	0.42	0.49	1.20 ± 0.39
P_2O_5	0.33	4.87	0.15	0.96 ± 0.62

*Calculated assuming $Fe_2O_3/FeO = 0.18$ or $FeO/(FeO + Fe_2O_3) = 0.85$, as recommended by Middlemost[13].

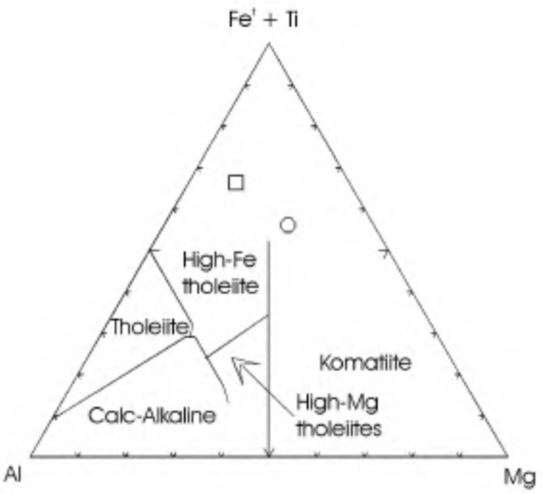

Figure 1. Jensen's cation diagram[12]. (Open circle) Natural Fe-enriched basalt from south Andaman ophiolite suite; (open square) Experimental Fe-enriched immiscible melt[4].

mafic rocks of the present study also contain very low potassium, suggesting their association with ophiolite complex. Dixon and Rutherford[4] have analysed products obtained by experiments, i.e. Fe-enriched immiscible melt and plagiogranite melt after the process of late stage liquid immiscibility. Average chemical compositions of these melts are presented in Table 1 which also contains average chemical compositions of south Andaman plagiogranites (analysed by the present authors; data may be obtained from the corresponding author) for comparison with experimental plagiogranite. Very close chemical similarities are observed between experimentally obtained Fe-enriched basalt melt and naturally exposed Fe–Ti-enriched mafic rock. Slight differences in chemical composition probably represent geochemical characteristics of Andaman ophiolite source regime. Compositions of both Fe-enriched basaltic melt and Fe–Ti-enriched mafic rock, are plotted on the Jensen's cation diagram[12] (Figure 1). Both samples fall at the Fe–Ti end of the triangle (see Figure 1), showing their high-Fe tholeiitic nature.

Another important point is that it is very difficult to explain occurrence of Fe–Ti melt in any ophiolite suite by simple crystal–liquid fractionation process[4]. Therefore, it is concluded that existence of Fe–Ti-enriched mafic rocks together with plagiogranites, in the AOS suggest the operation of late stage liquid immiscibility process in the formation of these two rocks.

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