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Petrology and Geochemistry of Gabbros from the Andaman Ophiolite: Implications for their Petrogenesis and Tectonic Setting

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Abstract

The Andaman ophiolite has almost a complete preservation of ophiolite sequence with mantle section and comparatively less well-developed crustal section. The crustal part of the ophiolite comprises both ultramafic cumulates; dunite, wherlite and pyroxenite and mafic cumulates or gabbros. The gabbros are olivine gabbro, and pyroxene gabbro. They are distinguished into cumulates and non-cumulates. Geochemical features indicate that they are tholeiitic, fractionated and are formed in an arc-related tectonic setting. The large- ion lithophile (LIL) elements (Rb, Ba, Th, Sr) are relatively more enriched than Normal-mid-ocean ridge basalts (N-MORB). The enrichment of Large-ion lithophile (LIL) elements over the High-field strength (HFS) elements and the depletion of Nb relative to other High-field strength (HFS) - elements suggest involvement of subduction component in the depleted mantle source, and suggest that they are formed in a supra-subduction zone tectonic setting.

Keywords: Andaman ophiolite; Gabbros; Petrology; Geochemistry; Petrogenesis; Tectonic setting

Introduction

Gabbros are created by the injection of basaltic melt from the underlying rising mantle and are regarded as formed by slow crystallization in a magma chamber. They are an integral part of the crustal section in an ophiolite suite and may range at the base from layered gabbros to isotropic to foliated gabbros at the top. Some ophiolites have a well-developed gabbroic section e.g., Semail Ophiolite Oman, and Bay of Island ophiolite, Newfoundland, Canada [1,2]. Unlike these Ophiolites Andaman Ophiolite has less developed gabbroic sections and consists of succession of ultramafic-mafic cumulates at the base. In several parts of south Andaman, ophiolite occurrences have been described by many researchers [3-8]. However, no detailed study has been made of the geochemical characters of its gabbroic rocks. In this paper we are going to discuss the petrogenesis and tectonic setting of the gabbros from Andaman ophiolite using their field features and petrography and geochemistry.

Andaman Ophiolites

The Andaman Ophiolite Belt marks the southern extension of the Manipur and the Burmese Arakan Yoma Belt, which is the easternmost continuation of the Tethyan Belt (Figure 1). The Tethyan Belt extends from Baltic Cordillera and rift of Spain and Africa eastwards through Alps, the Denirides in Yugoslavia, through Greece, Turkey, Iran, Oman, Pakistan and the Himalayas, Burma, Andaman-Nicobar islands and Indonesia [3]. The Andaman Ophiolite Belt belongs to a region of distinct structural and topographical belt that trends north-south and then curves eastward from Sumatra towards Java [5]. Further, the Andaman islands, the central part of Burma-Java subduction complex is also believed to expose tectono stratigraphic units of accretionary prism in an outer-arc setting [9]. From east to west there are four such structural cum topographic zones which are:

- Peripheral eastern massif of Shan Plateau, the Malay Peninsula and its western shelf, the Malacca strait and Sumatra.
- A zone of topographic lows including Irrawaddy Valley of Burma, the Andaman Basin and Mentwai through between Sumatra and Mentwai Islands.
- A zone of high relief including the Arakan Yoma of Burma, the Andaman-Nicobar Islands.
- The Java Trench which probably does not extend to the latitude of the Andaman Basin.

The overall physiographic trend of Andaman-Nicobar islands is the continuation of Arakan Yoma of western Burma, which is a southward trending branch of the eastern Himalayas. The Mentwai islands (south and west of Sumatra) are considered to be a southenly continuation of the Andaman-Nicobar trend. The Andaman-Nicobar group of islands form an arcuate chain extending for about 850 km bounded by latitude 6^{0}45'N to 13^{0}45'N and by longitude 92^{0}15'E to 94^{0}00'E. In some of these literatures, this ophiolite occurrence has been reported to be a dismembered ophiolite [8]. Although Saha reported the complete preservation of ophiolite suite from Port Blair (11^{0}39'N: 92^{0}47'E) to Chadiyatapu (11^{0}30'24": 92^{0}43'35"E) (Figure 2(a)).

The Andaman ophiolite consists of a plutonic complex, a volcanic sequence and pelagic sedimentary rocks (Figure 2(b)) Continuous ophiolite sections are rare owing to a thick weathering profile, tropical forest cover, and pervasive east-west and north-south fault systems. Regional mapping over a large part of the Andaman Islands has determined local contact relationships and allowed development of a regional ophiolite stratigraphy. The lower part (80% of the total ophiolite outcrop) comprises foliated and highly serpentinized peridotite. The upper part comprises a layered sequence of ultramafic-mafic rocks, an intrusive section of homogeneous gabbro-plagiogranite-diorite-dolerite and an extrusive section of boninite and tholeiitic basalt lavas Figure 2(c).

An assemblage of plutonic and extrusives represents the crustal

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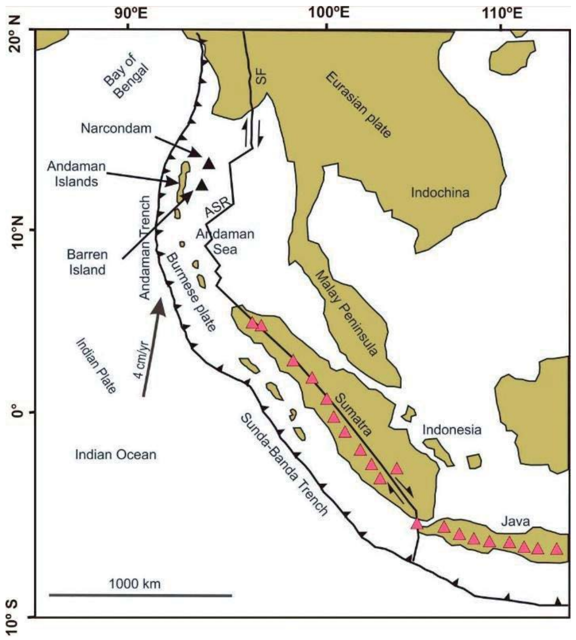

Figure 1: Map of Southeast Asia and Northeastern Indian Ocean showing major geological and tectonic features, ASR: Andaman Sea Ridge; SF: Saigang Fault.

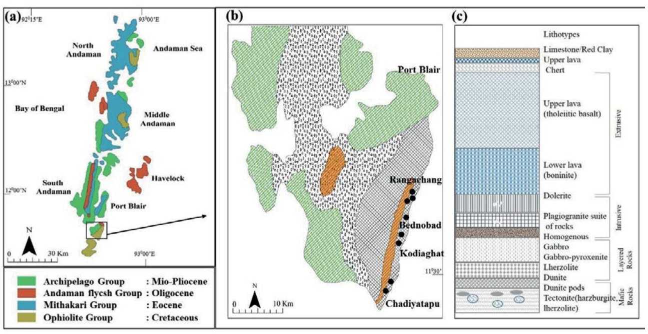

Figure 2: (a) Generalized geological map of Andaman Islands showing distribution of the ophiolites and sedimentary units with their stratigraphic relationship and tectonic setting. (b) Detailed geological map of part of South Andaman (modified after Pal [9]), with sample location. (c) Composite stratigraphic section of the Andaman ophiolite showing lithological units and mineral occurrences.

sequence of Andaman Ophiolites. The plutonic unit of crustal sections is represented by layered cumulates of peridotite-gabbro, overlain by non-cumulate gabbro and high level intrusives of a plagiogranite-diorite andesite suite of rocks with thin dykes of basalt and diabase. It comprises of layered sepentinized dunite, harzburgite, lherzolite wehrlite, pyroxenite and gabbro with pods and stingers of chromitite.

Methodology

Petrology

The mafic cumulates (Gabbro) are mainly located at and around the road sections of Kodiyaghat (11^{0}31'16.8"N:92^{0}43'02.8"E)- Bednabad (11^{0}34'42"N:92^{0}43'21.2"E) and Rangachang (11^{0}34'13.6"N: 92^{0}43'36"E) Figure 2(b). The mafic cumulates shows the repetitive and undeformed parallel layers of alternating olivine gabbro, norite, gabbro norite and pyroxenite. The gabbroic rocks can be divided into layerd and homogenous gabbro. The gabbro has anhedral granular texture and consists of large clinopyroxen and plagioclase crystals.

Petrographically gabbroic rocks are holocrystalline, fine to coarse grained and subophitic texture. In gabbro's preferential arrangement of mineral grains is clearly evident which is indicative of primary cumulus texture. Plagioclase occurs as stout, latch shape crystals that show variable degree of sausitirizaton. Plagioclase occurs as both a cumulus and post cumulus phase with an An_{95} composition. Complete sausitirization of plagioclase appears as dusty (Figure 3). The pyroxenes occur as small (20-30 μm) subhedral crystals with two sets of cleavage. Quartz occurs as high relief subhedral crystal within gabbros. The patches of anhedral to subhedral crystals of chlorite are seen throughout gabbros which are alteration products of clinopyroxene. Highly brecciated and mylonitised gabbro indicating post emplacement shearing related to tectonic evolution of the region.

Cumulate gabbro grades from olivine gabbro to olivine norite to gabbro, with 1-12 vol% olivine and 30-68 vol% of plagioclase. In olivine gabbro, clinopyroxene occurs as large adcumulus crystals and large anhedral grains that contain many olivine inclusions. Homogenous gabbros are coarse to medium garined, hypidiomorphic granular texture. Clinopyroxene are mostly altered to amphibole and plagioclase to sausurite. Plagioclase has an An_{93} composition, similar to cumulate gabbro magnetite and ilmenite are present as accessory phase.

Geochemistry

Analytical methods: Eight samples of gabbros were analysed for major and trace elements and five for rare earth elements (REE). The samples were crushed in a jaw crusher. The weathered surfaces were removed and the fresh parts were powdered using a tungsten carbide mill to the size of <200 mesh. Then the required number of grams of the powder of each sample was heated in a porcelain crucible to 9000C for 2 hr to determine the loss on ignition (LOI).

For major elements, the sample powder was thoroughly mixed with lithium tetra-borate (flux) with a 1:5 sample flux ratio and the glass beads were formed. Then the fused beads were analysed for major elements composition using a X-Ray Fluorescence (XRF) at the Central Instrumentation Facility, Pondicherry University, Pondicherry. For

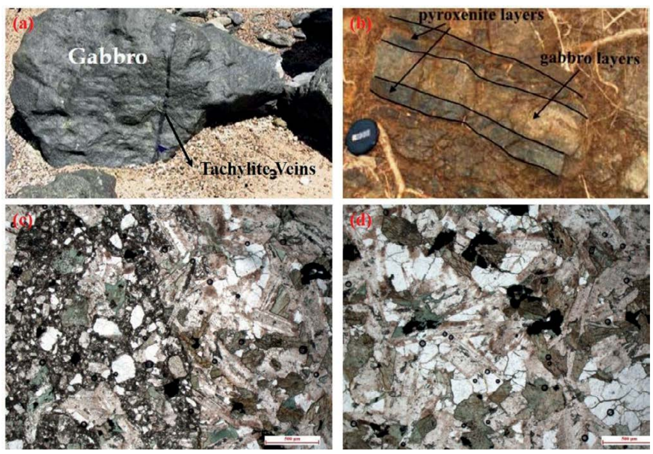

Figure 3: (a) Field photographs of gabbro with tachylite vein. (b) Repitative cumulate layers of olivine gabbro or norite and pyroxenite. (c & d) Pictomicrograph of gabbro shows plagioclase as stout latch shape and anhedral to subhedral crystal of chlorite.

trace elements the powdered pellets of all the samples were prepared by putting 5-7 grams powdered sample (< 200 mesh) in an aluminium cup and compressed between two tungsten carbide plates (within circular briquettes) at about 20 ton per square inch pressure in a hydraulic press. Then these pellets were analysed for trace elements composition using a XRF at Central Instrumentation Facility, Pondicherry University, Pondicherry. For REE study the powder was dissolved in 30 ml of 10% HNO_3 and 20 ml of deionized water. Samples for REE analysis were prepared by a standard Teflon vial acid-digestion procedure using a mixture of HF ± $HClO_4$-HNO_3. All samples were spiked to 50 mg/ml with indium to serve as an internal standard. REE analyses for this study were calibrated against a set of multi-element working standard solutions. All the solutions were introduced via a peristaltic pump, and analyses were performed by Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at the Department of Earth Science, Pondicherry University, Pondicherry.

Classification: The Andaman ophiolite gabbros are classified by plotting on total alkali versus SiO_2 diagram [10]. All the samples plot in the gabbro field confirming their gabbroic character (Figure 4). Most of the gabbro samples have very low values of total alkali and SiO_2 may be due to their cumulate nature or it could be due to alteration. The concentration of major, trace and REE of all the gabbros samples are reported in Table 1.

Major element characteristics: The Andaman gabbros have low concentration (wt%) of SiO_2 (45.67-49.58), TiO_2 (012-1.16), Na_2O+K_2O (.53-4.6), P_2O_5 (.01-.14) and wide range of Al_2O_3 (7.44-16.91), Fe_2O_3 (5.03-11.69), MgO (5.06-15.41) and CaO (11.81-18.16). The high concentration of CaO and low concentration of SiO_2 are due to the ateration and the presence of small vinelets of Calcite. The very low Total Alkali content can be explained by cumulate nature of the rocks .the cumulate nature becomes more evident when SiO_2 and MgO are plotted against the selected major elements as fractionation index (Figure 5). In most of the plots the samples cluster together with only minor degree of scattering. The clustering of samples indicates that the most of these gabbros are less affected by fractionation and where they scattered, they show their cumulate nature.

	GB/ AN-1	GB/AN-15	GB/AN-11	GB/AN-10	GB/ AN-3	GB/ AN-7	GB/ AN-6	GB/AN-14
SiO_2	49.38	49.58	47.12	46.21	46.12	45.91	48.38	45.67
TiO_2	1.11	0.64	0.54	0.28	0.12	0.33	1.16	0.24
CaO	15.47	15.89	18.16	18.05	14.6	15.56	16.14	11.81
Al_2O_3	11.65	11.71	12.17	15.67	16.91	7.44	11.55	13.76
Fe_2O_3	10.54	8.82	11.27	8.59	5.03	11.69	9.49	8
MnO	0.22	0.19	0.34	0.18	0.11	0.16	0.19	0.12
MgO	5.06	8.25	8.02	9.71	14.77	14.74	6.45	15.41
Na_2O	3.94	2.81	1.49	0.8	0.56	1.17	4.14	0.45
K_2O	0.48	0.67	0.03	0.04	0.56	1.33	0.46	0.08
P_2O_5	0.14	0.14	0.09	0.01	0.03	0.01	0.14	0.14
LOI	1.99	1.29	0.17	0.45	1.74	1.75	1.9	4.34
Total	99.98	99.99	99.4	99.99	100.55	100.09	100	100.02
Sc	32.5	17.6	39.6	43.4	40.2	52.4	35.6	51
V	28.9	42.6	159.3	171.4	89.4	172.3	245	110
Cr	28.9	21.4	14.3	105.2	888.8	61.3	59	1874
Co	50	29.3	66.3	70	59.9	67.7	35	70
Ni	25	22.7	14.2	39.7	194.1	49.4	50	303
Zn	85	5.6	100	32.7	14.7	21.1	40	46
Ga	17.5	25.6	28.1	25.3	19.4	23.8	15.7	8
Sr	251.3	394.7	297	237.9	194	196	289	165
Y	5.9	6.9	7.8	6.3	7	4.9	4.5	5
Zr	34.1	20	15.1	13.1	31.1	10.8	25.2	26
Nb	0.05	0.5	0.4	0.3	0.5	0.2	0.11	5
Ba	227.5	44.7	44.7	33.5	12.6	20.8	113.8	-
La	3.5	8.9	4.2	4	0.8	11.9	0.17	-
Ce	7.1	8.1	8.4	7.7	15.9	0.5	0.78	-
Nd	8.5	0.1	3	7.3	36.8	7.8	1.24	-
Yb	2.7	0.66	0.8	0.64	14.1	0.37	0.55	0.44
Sm	3.3	-	0.96	2.8	9.6	-	0.56	-
Th	2.4	1.9	2.1	3.6	0.9	0.94	0.01	2.5

Table 1: Major elements (wt %), trace and REE elements (ppm) composition of the gabbros from the Andaman ophiolite.

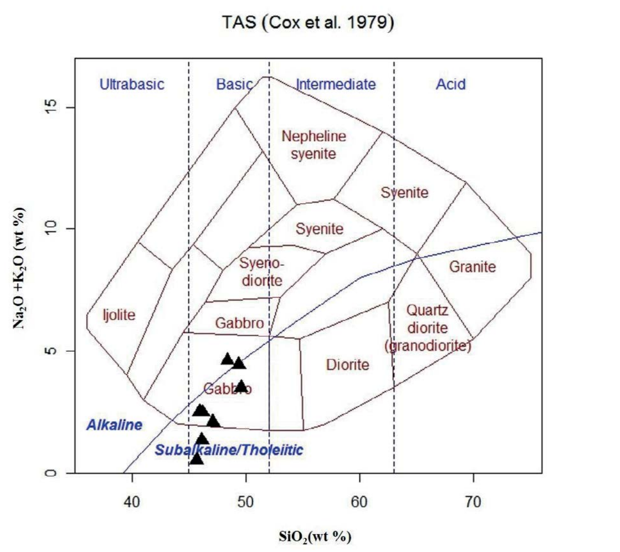

Figure 4: Total Alkali versus SiO_2 diagram of the gabbroic rocks from the Andaman Ophilite (after Cox [10]), Key; Filled trainagles are gabbros from Andaman Ophiolites.

Trace and REE characteristics: The Andaman gabbros have variable concentration of both large ion lithophile (LIL) elements (in ppm) such as Ba (12-227.5), Sr (165-394.7), Ce (0.5-15.9) and HFS elemnts like Zr (10.8-34.1), Y (4.5-7.8) and Nb (0.05-5). The alteration is obvious from the wide range of CaO (11.8-18.16) and LOI content (0.17-4.34). So it is expected that the LIL elements (Rb, K, Ba, Sr) have been remobilized to variable degree during the ateration process [11,12]. Zr s plotted against the high field strength (HFS) elements (Nb, Y, Ti, P) in (Figure 6). These plots shows a linear relationship with some degree of scatter.These trends shows that all the gabbroic rocks are probably formed through the process of fractional crystallization. These gabbros also show high (FeO^T/MgO) ratio (0.88-2.08) which is considered as indicator of advanced fractional crystallization [13,14]. It is further confims that the HFS elements are less affected by alteration so the data for these elements will be reliable to use for the petrogenesis and tectonic setting of these rocks.

Discussion

The Andaman ohiolite gabbros include olivine gabbro, gabbro-norite and gabbro. They show the charcteristics of theolitic Igneous rocks as evident by low ration of Zr/Ti (0.0036-.043) and Nb/Y (0, 0085-.080) and their plot as basaltic rocks on Zr/Ti-Nb/Y diagram (Figure 7a) of Pearce [15] and a theolitic with mild alkaline affinity on

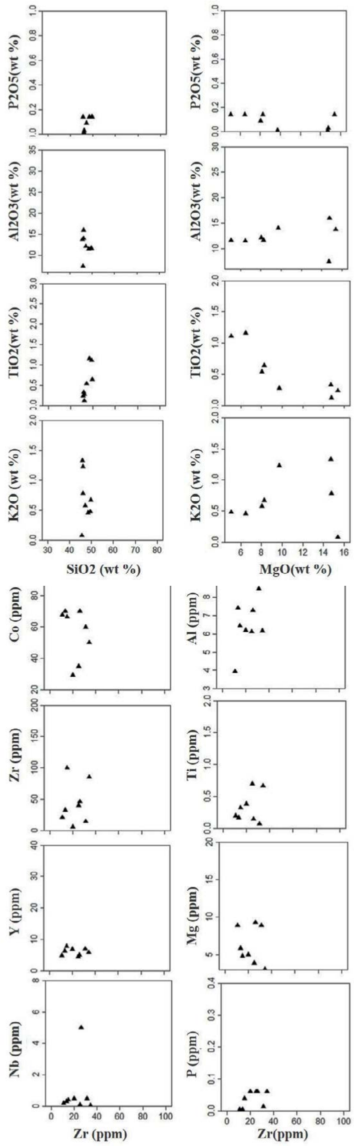

Figure 5: SiO_2 and MgO versus selected major elements plots of Andaman Ophiolites. Key: same as in Figure 4.

TiO_2 versus $Zr/P_2O_5*10^4$ (Figure 7b) by Winchester and Floyd [16].

Several attributes of gabbroic rocks of Andaman ophiolites point out the tectonic setting of magma generation responsible for their formation. The tectonic discrimination diagram e.g., Ti/100-Zr-Y*3 diagram (Figure 7c) of Pearce and Cann [17] classify the gabbros as Island arc theolittic (IAT) with mild affinity to depleted mantle oceanic fllor basalts (N-MORB). There is apossibly that these gabbros have a transitional charcter between the IAT and N-MORB and so it is likely that these gabbros have formed by fractionation directly over a subduction zone or in the supra-subduction zone. The Supra subduction setting of the gabbroic rocks from the Andaman ophiolites is further confirmed when major elements composition is plotted on the AFM diagram of Beard. Most of the samples plot in the arc related mafic cumulate field, where as some some samples plot in the arc related non cumulates field (Figure 8). This implies that the gabbroic rocks are formed in suprsubduction zone tectonic setting.

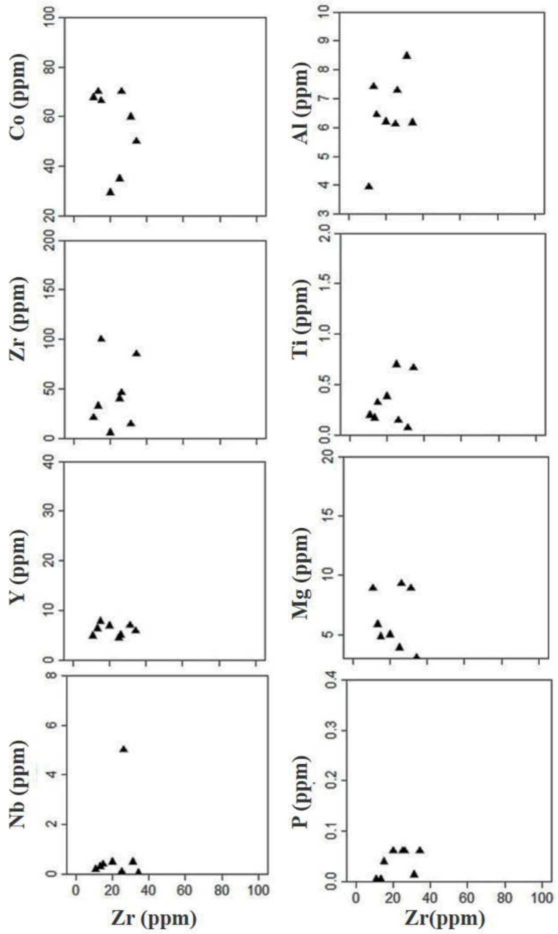

Figure 6: Zr versus major and trace elements plots of the Andaman Ophiolite. For symbols see Figure 4.

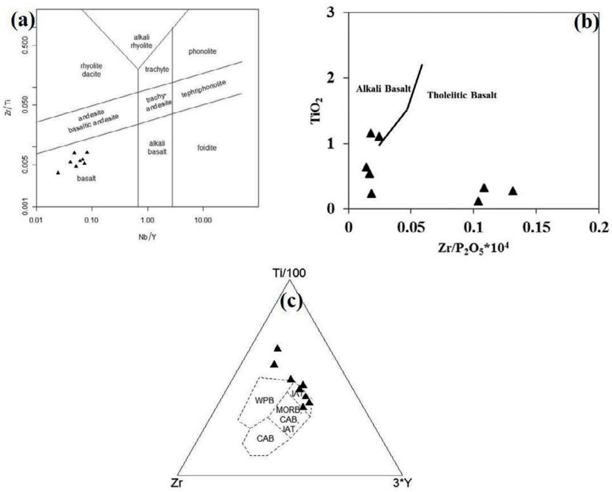

Figure 7: a) Zr/Ti–Nb/Y plot (after Pearce [15]); b) TiO_2 versus Zr/ ($P_2O_5*10^4$) (after Winchester and Floyd [16]) c) Ti/100 – Zr – Y*3 triangular plot (after Pearce and Cann [17]). Key for Figure d; A = Island arc, B = Ocean floor, C = Calc alkali and D = within plate.

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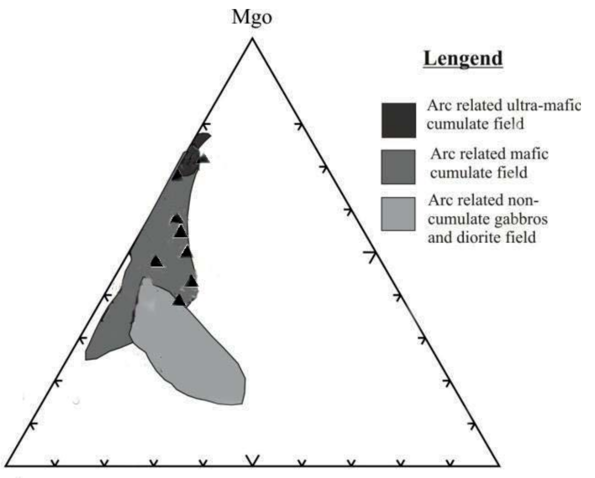

Figure 8: AFM composition of Andaman Gabbros.Fields of cumulate and non cumulate rocks are from Beardv.

Conclusion

Tectonically, the Andaman -Nicobar Island are know to be the part of the outer sedimentary arc of the Sunda-Burmese double chain arc system, where the Indian Oceanic plate is being subducted. Geochemical data suggest that the Andaman gabbros are theoleittic with mild alkaline affinity. The crustal part of the Andaman Ophiolite has less developed gabbroic section with average thickness of ultrmafic-mafic cumulate section. The agbbros are olivine gabbro, gabbro norite. They are identified both cumulates and non cumulates. The enrichments of LIL elemnets and depletion of Nb, transitional characterization between the N-MORB and IAT suggest Supra-subduction zone tectonic setting of Andaman gabbros.

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