

Geochemical and biostratigraphic constraints on the genesis of mafic intrusive in the Buxa Dolomite (Neoproterozoic), Panging area of the Arunachal Lesser Himalaya, north east India

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ABSTRACT

Mafic intrusive within Neoproterozoic carbonates of Miri-Buxa Group in the Panging area of the Arunachal Lesser Himalaya, NE India has been reported for the first time. These mafic rocks have affinity to subalkaline-Mg-tholeiites and identified as low-Ti gabbro. Geochemically they are characterized by enrichment in LILE and LREE, depleted in HFSE with minor REE fractionated nature $[(La/Yb)_N = 2.70-3.29]$ and positive Eu anomalies $(Eu/Eu^* = 1.00-1.30)$. These rocks have the influence of a within plate signature which were intruded in a continental rift tectonic environment. Petrogenetic modelings of $[Mg]-[Fe]$ and REE suggest these mafic rocks probably derived from enriched mantle source similar to komatiitic composition at moderate to higher degree (35% - 50%) of partial melt. Based on the present reported microfossils viz. *Rivularia haematites* and Filamentous cyanobacteria in the chert lenses of the Buxa Dolomite from the Panging area, it is suggested that the gabbroic intrusion might have been taken place during Late Neoproterozoic which is probably close to the Precambrian–Cambrian boundary.

Keywords: Gabbro intrusive, Buxa Dolomite, geochemistry, microbiota, Panging area, Arunachal Lesser Himalaya, NE India

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INTRODUCTION

The Lesser Himalaya has an extensive record of mafic magmatism through Precambrian to Eocene. The mafic magmatism is preserved in the form of volcano-sedimentary sequences, sills/dykes and intrusives (Ahmad and Bhat 1987; Bhat and Ahmad 1990; Srivastava and Sahai 2001; Bhat and Le Fort 1992; Ahmad and Tarney 1994; Gautam et al. 1995; Sengupta et al. 1996; Ahmad et al. 1999; Chaudhari and Gupta 1997). In the last two decades, the mafic magmatic rocks of the eastern Himalaya particularly from Siang Window have been studied (Thakur and Jain 1974; Bhat 1984; Roychowdhury 1984; Bhat and Ahmad 1990; Sengupta et al. 1996; Singh 2006). However, most of the earlier publications are restricted to the mafic volcanics in the core of Siang Window. Till the date no information on gabbroic intrusion in Siang Window of eastern Himalaya has been reported. Hence, the purpose of this article is to report the petro-geochemical characteristics of gabbroic intrusion to evaluate their petrogenesis, depositional environment and age of the host rock i.e. Buxa Dolomite based on the microfossils.

GEOLOGICAL SETTING

In the Arunachal Lesser Himalaya the gabbroic intrusion took place along the Siang Valley, the major lithological and

tectonic units show a bend in their regional strike from NE-SW in the west to NW-SE in the east across the Siang gorge is known as the Eastern Syntaxis Bend (Wadia 1931). Western and eastern domains in this easternmost part of Himalaya is separated by the Siang Window directly south of the Eastern Himalayan Syntaxis (Singh 1993; Acharyya et al. 1986; Acharyya 1998; Fig. 1). This syntaxis has been folded across the Siang River into a major antiform and termed as Eastern Syntaxial Bend (Singh 1993; Gururajan and Choudhuri 2003). However, Eastern Himalayan syntaxis from the Chinese side have been also reported (Burg et al. 1998; Ding et al. 2001; Liu et al. 2004). The geological setting of these syntaxes in the Indian and Chinese sides is significantly consistent. Based on field studies, the core of the syntaxis in the Arunachal Lesser Himalaya has been named differently as Siang Antiform (Singh 1993) and Siang Window (Acharyya 1998). All the regional structural features such as the Main Central Thrust, Bame Thrust, and the Indus-Tsangpo Suture make sharp U-turns round the window. Kumar (1997) also has defined the window as a closed trace of the Main Boundary Thrust that places Lesser Himalayan Sequence strata. Intensity of metamorphism increases gradually from greenschist facies in the centre to upper amphibolite facies in the periphery (Singh 1993). The window is truncated to the south against the Siwalik sediments across the North Pasighat Thrust (Acharyya, 2007). At the core of the Siang Window sedimentary rocks

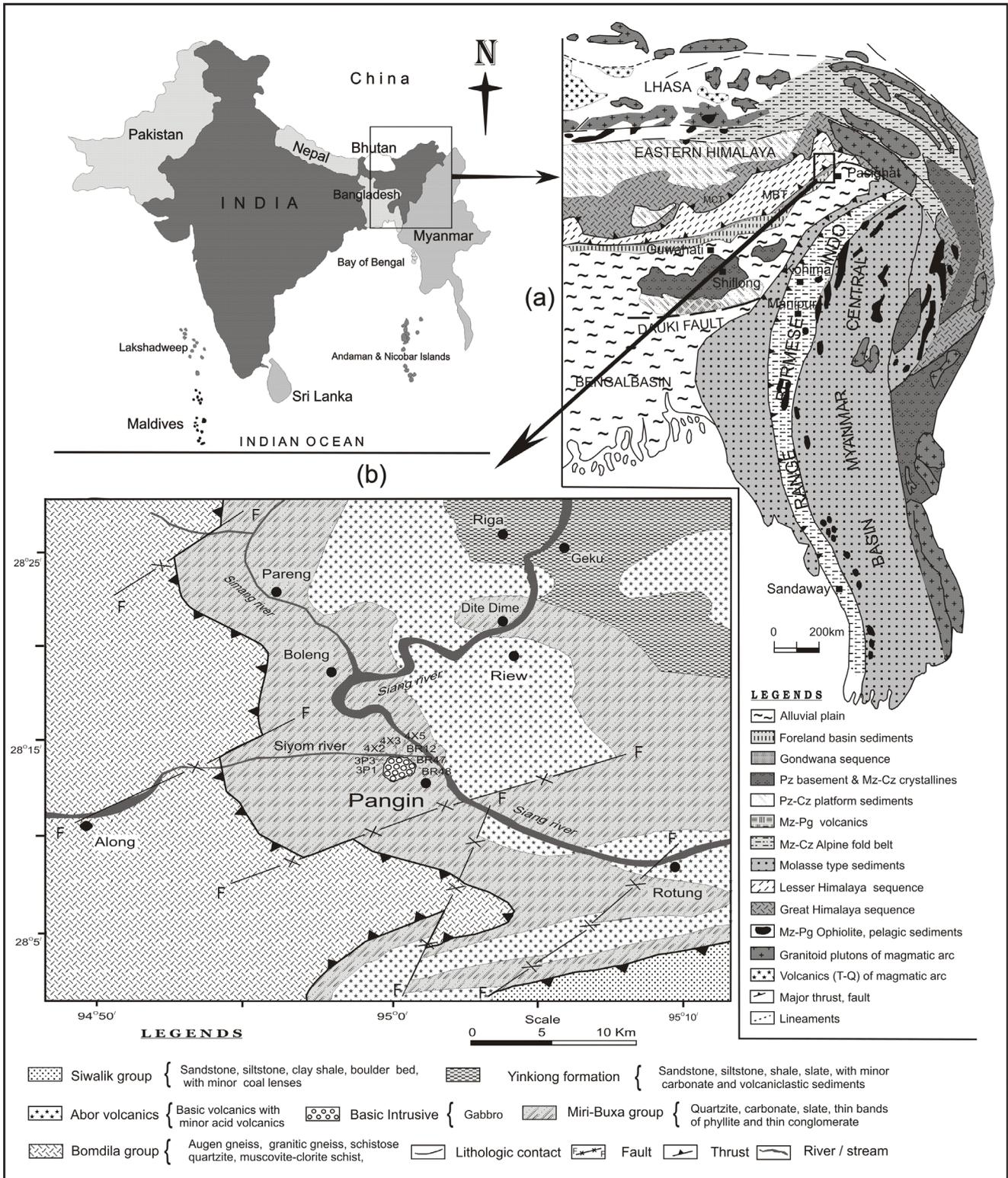


Fig. 1: (a) Generalized geological map of eastern Himalaya and Indo-Myanmar Range (Acharyya et al. 1986). (b) Geological map of the southern part of Siang Window in Eastern Syntaxial Bend, Arunachal Himalaya (modified after Singh 1993)

Table 1: Simplified lithostratigraphy of the Buxa-Miri Group Sedimentary succession in the Arunachal Lesser Himalaya, north east India (Tewari 2003)

Miri Group	Miri Formation	Lower Cambrian
Buxa Group	Dirang Formation	
	Dedza Formation	Neoproterozoic
	Rupa / Chillipam Formation	
	Tenga Formation	
	Panging Formation	
	(Present study area)	

of Miri-Buxa Group interbedded and co-folded with the mafic/felsic volcanics of Abor Formation and sedimentary rocks of Yinkiong Formation are well exposed (Fig. 1b).

The gabbro intrusive is emplaced (Lat. 28°13.91' N; Long. 94°59.55' E) within the Buxa Carbonates of Miri-Buxa Group (Fig. 1b). The contacts between the gabbros and country rocks are sharp. These intrusives do not show any primary flow alignment or deformation features. The intrusives are devoid of xenoliths of country rocks suggesting their permissive emplacement and lower structural level. The sedimentology, paleobiology and carbon isotopic studies of the Buxa Dolomite and Miri Quartzite have been done in the Kameng, Subansiri and Siang windows (Tewari 1998, 2001, 2002, 2003, 2007, 2009; Shukla et al. 2006). The generalized lithostratigraphy established in the Arunachal Lesser Himalaya (Tewari 2003) is given in Table 1. A Neoproterozoic–Lower Cambrian age has been suggested for the Buxa–Miri Group sediments based on recent discoveries from the Arunachal Lesser Himalaya (Tewari 2001, 2002, 2003, 2007; Shukla et al. 2006). However, the present paper records for the first time a well preserved cyanobacterial remains from the black chert lenses from the Buxa Dolomite exposed between Along and Panging section in the Arunachal Lesser Himalaya. Fig 2 shows the litholog of the Panging Limestone and the position of the black chert lenses yielding cyanobacterial microfossils in the lower part.

PETROGRAPHY

The gabbros are medium-grained and plagioclase, clinopyroxene, quartz, hornblende are the essential minerals whereas orthopyroxene, chlorite, epidote, sericite, titaniferous magnetite are accessories (Figs. 3a and 3b). These rocks display uniform mineral assemblages and textural relationships. In most of the samples the texture varies from subophitic to ophitic (Fig. 3c). Subhedral to anhedral grains of plagioclase, average 0.3 mm in diameter, make up about 40-50 modal percent. Plagioclase laths are mostly unzoned, subhedral with corroded margins and faint clouding. Usually plagioclases are tabular and they are sericitized and sassuritized, showing carlsbad twinning. However, fresh and small grains in the medium grained samples exhibit albite twinning. At places, they were partially resorbed and filled by groundmass composed of fine-grained

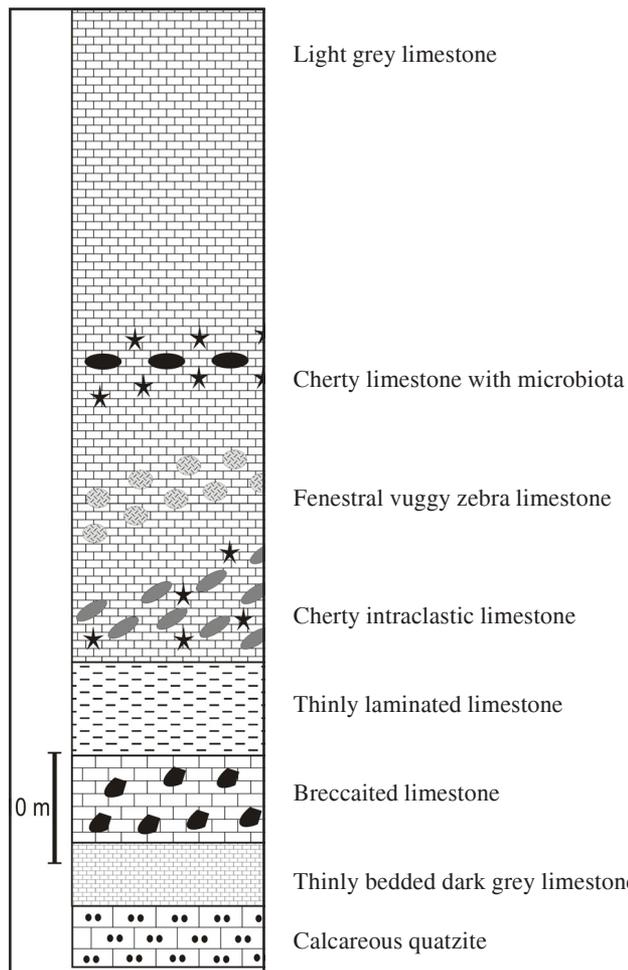


Fig. 2: Litholog of the Buxa Dolomite (Panging Limestone) Along-Panging Road section, Siang Window of the Arunachal Lesser Himalaya

plagioclase, pyroxene, amphibole, quartz and Fe-Ti oxides. Clinopyroxene occurs as euhedral to subhedral phenocryst and either colourless or moderately pleochroic in green to yellowish purple and sometimes show twinning (Fig. 3d). Clinopyroxenes have been altered to chlorite and development of amphibole cleavage is quite common. Hornblende exhibits prismatic shape but the cross sections show hexagonal form. At places, it shows irregular form and along clinopyroxene/plagioclase boundaries small reaction zones of amphiboles are also observed. In most coarse-grained samples the quartz is intimately intergrowth with plagioclase giving rise to granophyric textures (Fig. 3e). In some of the coarse grained samples, granophyric texture is seen at interstitial space between laths of plagioclase feldspars and pyroxene grains. Fine to medium-grained crystals are widely disseminated in the groundmass. Titaniferous magnetite occurs in idiomorphic elongated rods across the plagioclase-pyroxene indicating its late origin (Fig. 3f).

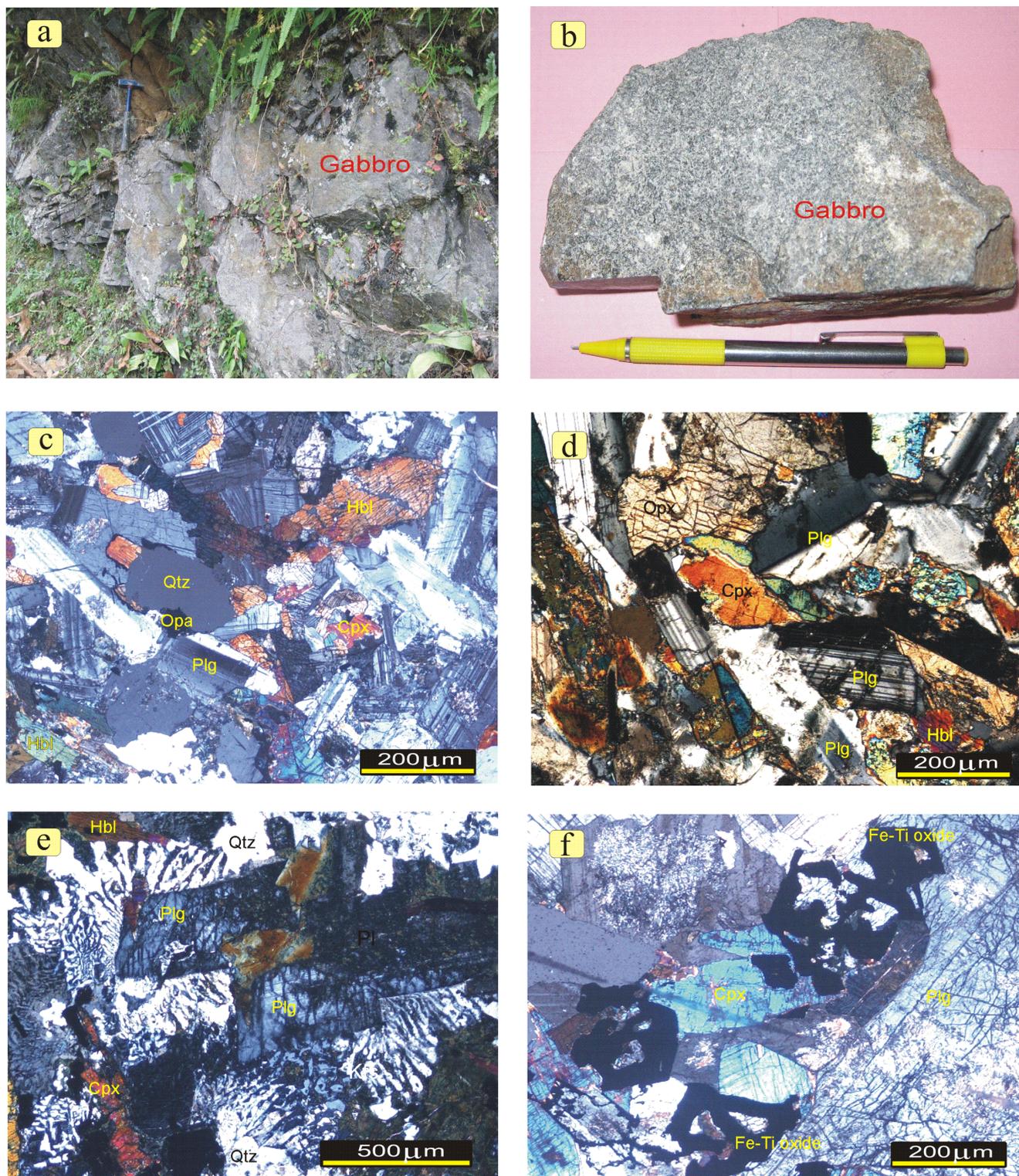


Fig. 3: (a) Outcrop of gabbro intrusive (Lat. 28°13.91' N; Long. 94°59.55' E). (b) Handspecimen of gabbro. (c) Hypidiophoric and sub-ophitic texture. (d) Carlsbad twinning in plagioclase. (e) Intergrowth of quartz and plagioclase produced granophyric texture. (f) Skeletal titaniferous magnetite grains.

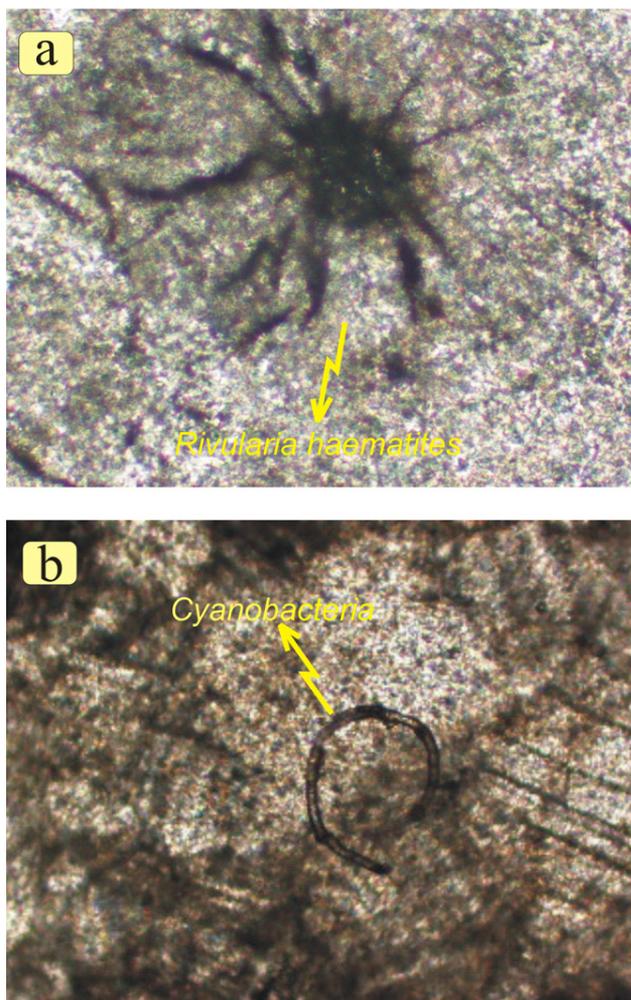


Fig. 4: Photomicrographs of (a) *Rivularia haematites* (Cyanophyta). (b) Coiled Cyanobacteria from the chert lenses in the Buxa Dolomite, Panging area, Arunachal Lesser Himalaya

The petrographic thin sections of the cherts from the Buxa Dolomite reveal the presence of slightly coiled and radiating cyanobacterial filaments (Figs. 4a and 4b). The petrography of the Buxa Dolomite (Panging Limestone) is characterized by the microfacies micrite, dolosparite, laminated light and dark (organic) carbonate – organic matter.

GEOCHEMISTRY AND PETROGENESIS

The major and trace elements were determined by XRF whereas rare earth elements (REE) were analysed by ICP-MS at Wadia Institute of Himalayan Geology, Dehradun. Analytical precision for major elements is well within ± 2 to 3% and for trace elements it is within ± 5 to 6%. Accuracy of measurement of rare earth elements ranges from 2 to 12% and precision varies from 1 to 8%. Major elements data and petrogenetic parameters are presented in Table 2 whereas Table 3 shows trace elements including rare earth elements.

These gabbros show low AI values, ranging from 34.97-50.75 wt.%, indicating least affected by secondary alteration processes (Lafleche et al. 1992; Sage et al. 1996). The least alteration effects are also supported by their LOI values (0.54 to 1.74). Although, for the magma type classification of these mafic rocks, the trivalent rare earth elements and the high field strength elements (HFSE) such as Th, Hf, Nb, Ta, Zr, Ti, Y which are not significantly affected by the alteration and are immobile during low grade metamorphism, are used (Mahoney et al. 2000). The analyzed samples while plotted in the immobile trace elements diagram of Nb/Y vs Zr/Ti distinguished sub-alkaline mafic rocks (Fig. 5a). Their low Nb/Y ratio (<1 i.e. 0.39-0.41) also indicate subalkaline magmatic rocks (Winchester and Floyd 1977; Pearce and Gale 1977). Based on the Ti/Y values (high-Ti = $Ti/Y > 500$; low-Ti = $Ti/Y < 500$) these mafic rocks have been classified as low-Ti mafic rocks ($Ti/Y = 402.86 - 477.88$) (Peate et al. 1992; Xu et al. 2001). It has been reported that the high-Ti lavas were generated at a lower degree of partial melting, whereas low-Ti lavas could be related to higher degrees of partial melting (Xu et al. 2001). Thus, these intrusives were generated with moderate to higher degree of partial melt. In the AFM diagram, these mafic rocks show iron enrichment trend which is a feature characteristics of tholeiitic magma and their Mg-tholeiitic nature is suggested by the Al-Fe+Ti-Mg plot (Jensen 1976) (Fig. 5b). The high field strength elements plot of $Ti/Y - Zr/Y$ (Fig. 5c) (Pearce and Gale 1977) reveals signature of the ‘within plate’ of these rocks and probably indicate generation of these intrusives in a continental rift/lithospheric extension tectonic environment (Thompson et al. 1983; Ahmad and Tarney 1994). Since a correlation of Nb/Th with Nb/Yb would be expected in the case of mixing between MORB and OIB source mantle (Munker 2000). The Nb/Th ratios of these rocks do not correlate with Nb/Yb ratios indicating significant role of OIB in the source can be ruled out.

These gabbros show REE patterns with enriched LREE and the slightly depleted HREE pattern with significant positive Eu anomalies ($Eu/Eu^* = 1.00-1.30$) (Fig. 6a). The significant positive Eu anomalies may be due to melting of plagioclase bearing source or accumulation of plagioclase during fractionalization of parental liquid. Their REE patterns are moderately steep $(Ce/Yb)_N$ (2.47-3.33) and sub-parallel to one another, indicating fractionation of REE in relatively constant proportions over a significant range of composition. The enrichment in LREE can be produced by melting of an enriched LREE mantle source, by crystal fractionation or by assimilation of continental crust (Moraes et al. 2003). The close bunching of the REE curves and trace elements patterns of the samples suggests that they belong to a chemically coherent group. These mafic rocks have smooth REE and coherent multi-elemental patterns of HFSEs indicating the incompatible trace elements and REEs are less affected and may reflect primary chemical characteristics of these rocks. Their primitive mantle normalized of these rocks shows gentle slope from left to right indicating their enrichment in the incompatible elements (Fig. 6b). These patterns display insignificant negative Nb, P, Ti anomalies with comparable

Table 2: Major elements data and petrogenetic parameters of gabbro intrusive from the Panging area in Siang Window, the Arunachal Lesser Himalaya

Sample No.	3P1	3P3	4X2	4X3	4X5	BR12	BR47	BR48
Major elements								
SiO ₂	53.42	53.1	53.76	53.46	52.64	51.07	52.7	51.35
TiO ₂	1.59	1.64	1.58	1.62	1.63	2.28	1.25	1.68
Al ₂ O ₃	14.78	14.65	14.07	14.3	15.09	13.06	14.73	14.41
FeO	9.14	8.98	8.54	9.2	9.34	10.13	8.58	9.72
Fe ₂ O ₃	1.79	1.76	1.67	1.8	1.83	1.99	1.68	1.91
MgO	5.71	6.09	6.96	7.12	6.43	9.46	8.72	7.5
CaO	6.37	6.48	7.48	6.63	9.55	7.93	7.13	9.5
Na ₂ O	3.6	3.84	3.59	3.85	3.32	2.33	2.38	3.15
K ₂ O	0.94	0.69	0.74	1.04	0.49	0.62	1.08	0.41
MnO	0.14	0.13	0.13	0.14	0.14	0.15	0.13	0.15
P ₂ O ₅	0.13	0.12	0.18	0.18	0.22	0.29	0.15	0.2
LOI	1.56	1.74	1.19	1.44	0.94	1	1.51	0.54
Total	99	99.04	99.72	100.02	101.44	100.11	99.87	100.32
Na ₂ O+K ₂ O	4.54	4.53	4.34	4.9	3.81	2.95	3.46	3.56
Na ₂ O/K ₂ O	3.82	5.53	4.82	3.69	6.78	3.76	2.2	7.68
Fe ₂ O ₃ /MgO	1.88	1.74	1.44	1.52	1.71	1.26	1.16	1.52
CaO/TiO ₂	4.02	3.96	4.75	4.08	5.86	3.48	5.7	5.65
Al ₂ O ₃ /TiO ₂	9.32	8.96	8.93	8.81	9.26	5.73	11.78	8.58
Agpaitic								
Index	40	39.65	41.03	45.22	34.97	49.56	50.75	38.47
CaO\Al ₂ O ₃	0.43	0.44	0.53	0.46	0.63	0.61	0.48	0.66
Fe ₂ O ₃ \TiO ₂	6.78	6.46	6.38	6.67	6.74	5.23	8.07	6.8
Petrogenetic parameters								
Mg #	52.68	54.71	59.21	57.94	55.08	62.46	64.43	57.9
[Mg]%	16.63	17.45	18.61	19.41	16.21	20.04	20.16	17.35
[Fe]%	13.92	13.42	12.06	13.27	12.21	13.19	12.25	13.07
Kd _{Mg}	5.87	5.66	5.25	5.1	5.51	3.9	4.3	4.77
Kd _{Fe}	2.38	2.27	2.11	2.01	2.24	1.59	1.77	1.92
KDX	0.4	0.4	0.4	0.39	0.41	0.41	0.41	0.4
Fo-ol	72.21	74.07	77.37	76.79	74.02	77.61	78.9	74.38
T° liqC	1,333	1,344	1,355	1,380	1,309	1,391	1,386	1,339

[Mg] and [Fe] = compositionally corrected Mg and Fe abundances in cation mole percent using Ford et al. (1983) equation-3 based on compositionally corrected olivine-melt kds' for MgO and FeO; Kd_{Mg} = concentration of Mg in olivine/concentration of Mg in liquid; Kd_{Fe} = concentration of Fe olivine / concentration of Fe in liquid; $KDX = Kd_{Fe} / Kd_{Mg}$; Fo-ol = forsterite content of olivine with which liquid in equilibrium; T° liqC = one atmosphere (0.001kb) liquid olivine temperature calculated using equation -3 of Ford et al. (1983). A, B and C are calculated solidii for 25 k bar and 1 atm. pressure respectively

concentrations of large ion lithophile elements (such as K, Rb, Th, Ba and Sr). Crustal materials are rich in LILE, K₂O and Na₂O and depleted in P₂O₅ and TiO₂, hence, crustal contamination will increase K₂O, Na₂O and LILE, and decrease P₂O₅ and TiO₂. Lightfoot et al. (1993) suggested the primitive mantle normalized patterns with negative Nb, P, Ti anomalies and variable anomalies in Rb, K, Ba, Sr indicating crustal contamination in the rocks. Low concentrations and narrow ranges of LILE with K₂O and Na₂O, high contents of Fe₂O₃ with insignificant negative Nb, P, Ti anomalies in the

gabbros suggest that these rocks have not undergone considerable crustal contaminations (Arndt and Jenner 1986; Lightfoot et al. 1993; Ahmad et al. 1999). These mafic rocks also do not show any subduction zone signature and they have lower and higher trace elements concentrations as compared with those of OIB and N-MORB respectively.

Petrogenetic parameters for these mafic rocks are calculated based on the [Mg]-[Fe] modeling (Hanson and Langmuir 1978; Langmuir and Hanson 1980; Rajamani et al.

Table 3: Trace and rare earth elements data of gabbro intrusive of Panging area in Siang Window of the Arunachal Lesser Himalaya

Sample No.	3P1	3P3	4X2	4X3	4X5	BR12	BR47	BR48
Trace elements								
Rb	24	19	22	29	11	10	27	9
Nb	9	9	8	8	10	13	8	11
Sr	286	305	310	286	313	605	336	316
Ba	192	178	166	239	127	254	128	106
Ni	51	51	49	47	43	124	116	45
Cr	235	155	133	119	240	610	301	154
Co	31	31	34	31	39	42	39	41
Cu	40	21	27	37	60	21	26	60
Zr	68	68	71	70	93	108	99	95
Zn	94	103	90	98	102	127	84	106
V	166	170	256	254	207	156	156	229
Y	22	22	22	20	23	31	18	25
U	1	1	1	1	1	1	1	1
Th	1	1	1	1	1	1	1	1
Sc	19	21	16	20	30	17	29	28
Ga	22	22	22	19	20	19	19	21
Pb	4	7	9	8	1	7	8	1
Rare earth elements								
La	5.81	6.72	5.76	5.65	6.72	nd	4.21	nd
Ce	14.2	16.74	13.44	13.38	16.61	nd	11.61	nd
Pr	2.12	2.45	1.94	1.93	2.45	nd	1.92	nd
Nd	9.81	11.06	8.91	9.04	11.19	nd	9.34	nd
Sm	4.22	4.25	3.06	2.98	3.22	nd	2.98	nd
Eu	1.56	1.67	1.44	1.32	1.12	nd	1.16	nd
Gd	4	4.31	3.77	3.73	3.67	nd	3.29	nd
Tb	0.62	0.67	0.63	0.61	0.59	nd	0.53	nd
Dy	3.93	4.11	3.63	3.6	3.35	nd	3.08	nd
Ho	0.76	0.79	0.69	0.7	0.66	nd	0.6	nd
Er	1.82	1.87	1.59	1.66	1.6	nd	1.42	nd
Tm	0.24	0.26	0.22	0.24	0.22	nd	0.2	nd
Yb	1.44	1.53	1.3	1.37	1.38	nd	1.16	nd
Lu	0.17	0.18	0.17	0.19	0.2	nd	0.16	nd
Ratios								
Ti/Y	428.52	451.84	437.73	477.88	424.86	440.92	416.32	402.86
Ti/Zr	139.13	144	132.21	139.13	105.07	126.56	75.69	106.02
Zr/Ti	0.007	0.005	0.008	0.007	0.01	0.008	0.013	0.009
Zr/Y	3.08	3.14	3.31	3.43	4.04	3.48	5.5	3.8
Zr/Sm	22.36	22.82	16.93	16.46	28.88	--	33.22	--
Zr/Nb	7.54	7.9	8.55	8.75	9.59	8.31	12.38	8.64
Nb/Y	0.41	0.4	0.39	0.39	0.42	0.42	0.44	0.44
Y/Nb	2.45	2.52	2.58	2.55	2.37	2.38	2.25	2.27
Nb/La	1.54	1.33	1.38	1.41	1.44	--	1.9	--
(La/Yb) _N	2.763	2.981	2.706	2.946	3.26	--	2.54	--
(Ce/Yb) _N	2.478	2.639	2.508	2.783	3.06	--	0.905	--
(Ce/Nd) _N	1.078	1.099	1.054	1.102	1.08	--	1.13	--
Eu/Eu*	1.22	1.308	1.167	1.199	1	--	1.13	--

nd = not determined

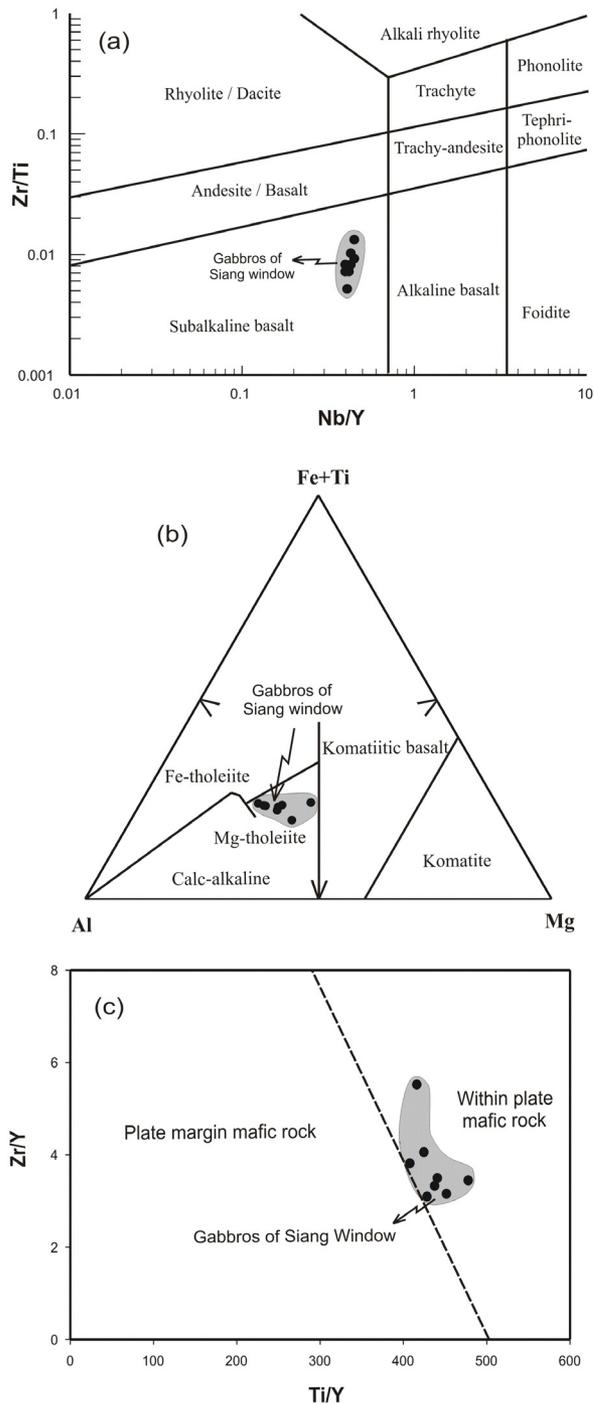


Fig. 5: (a) Nb/Y vs Zr/Ti diagram (after Pearce 1996). (b) Cation percent Al-(Fe+Ti) - Mg plot (after Jensen 1976). (c) Ti/Y vs Zr/Y plot for gabbro intrusive of Pangang area, the Arunachal Lesser Himalaya

1993). The [Mg]-[Fe] values plot in the calculated melt fields on the [Mg]-[Fe] diagram (Fig. 7a) for theoretical melting of garnet-lherzolite with MgO = 37.9 and FeO = 10.2 at 0, 3 (~100 km depth) and 5 Ga pressure (Rajamani et al. 1993). The solidii for 0, 3 and 5 GPa pressures are based on the

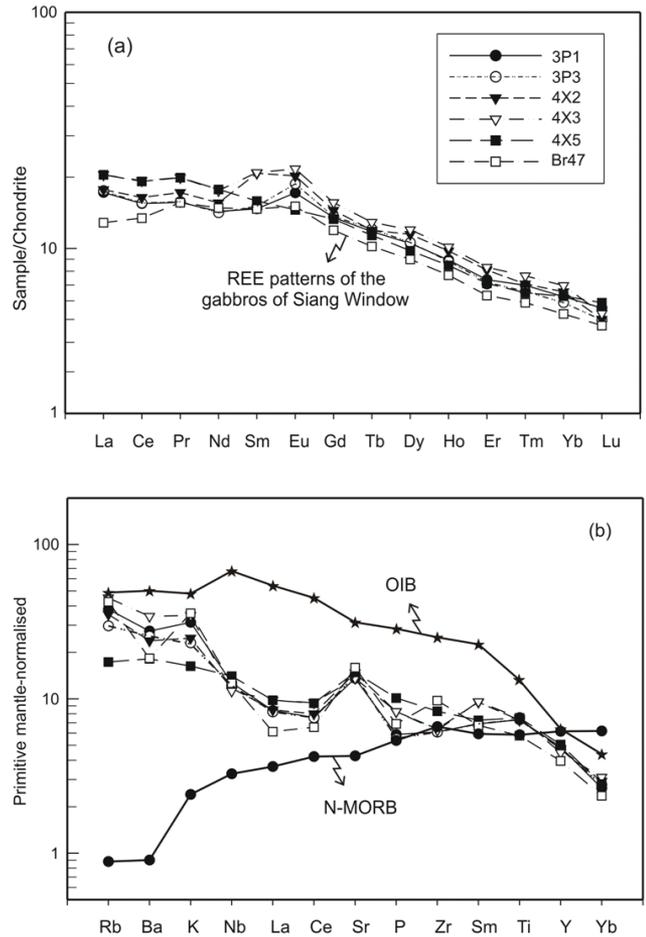


Fig. 6: (a) Chondrite-normalized REE plots (normalizing factors are from Nakamura 1974). (b) Primitive mantle normalized elements patterns (normalizing factors are from Sun and McDonough 1989) for gabbro intrusive of Pangang area, the Arunachal Lesser Himalaya

experimental work of Takahashi (1986). These mafic rocks are cluster outside the melt field, suggesting that they are not genetically related with the garnet-lherzolite source. Even if we assume that they had undergone 20% olivine fractional crystallization, their parental magma would still plot outside the melt field. Hence, the source rock of this gabbroic magma had a much higher Fe/Mg ratio relative to garnet-lherzolite/pyrolite source (Rajamani et al. 1989; Ahmad and Tarney 1991).

The lithospheric sources have a higher Fe/Mg ratio than that of pyrolite or lherzolite as a result of addition of melts generated at deeper levels (Ahmad and Rajamani 1991). The Komatiitic amphibolites reported from Kolar Schist Belt have higher Fe/Mg ratio than garnet-lherzolite (Rajamani et al. 1985). Calculated [Mg]-[Fe] melt fields for a Komatiitic source having 29.21 mole % MgO and 8.47 mole % FeO for 1 atmosphere and 25 kb pressures are shown in Fig. 7a. The primitive samples (4X2, 4X3, BR12, BR47) plot inside the

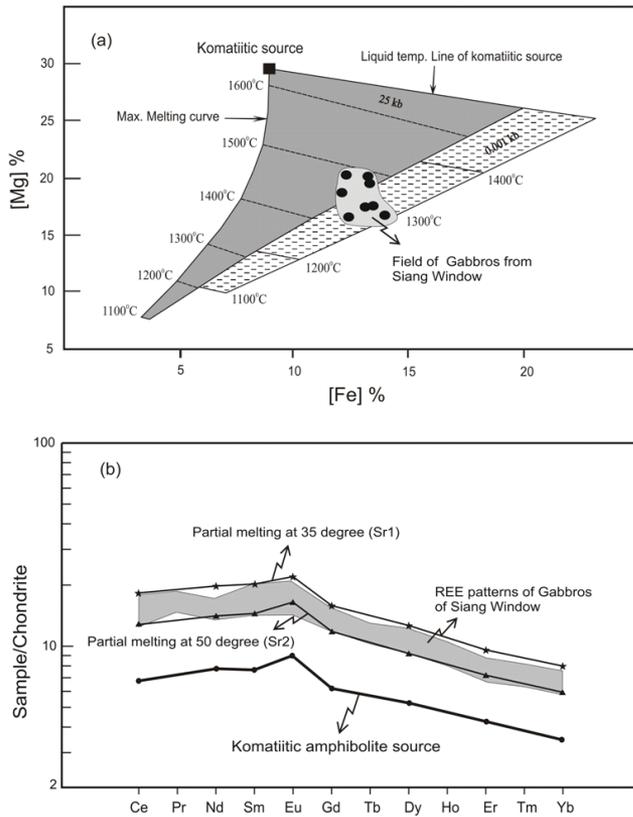


Fig. 7: (a) Calculated [Fe]-[Mg] plot for gabbro intrusive of Panging area, Eastern Himalaya are plotted in the melt field of Komatiitic source at 1 atm. and 25 kb (after Rajamani et al. 1985). (b) Chondrite-normalized REE plot showing the zone for the mafic intrusive of Panging area and their calculated source. The Sr₁ and Sr₂ represent REE patterns of this model source were calculated using Batch melting equation (Schilling 1966) based on Kd values (McKenzie and O’Nions 1991) assuming a Komatiitic mantle source (37% ol; 51% opx; 12% cpx) leaving a residue with 35% ol; 50% opx; 15% cpx at 35% and 50% partial melting respectively.

melt field suggesting that they represent primary melt composition having high Mg (57.94 - 64.43) and liquidus olivine temperature (1355°C - 1386°C). The linear trend of incompatible elements like Zr, Nb and P in the primitive mantle normalized suggests that they may be cogenetic in nature (Keppler 1996). Values of highly incompatible trace elements such as Nb/La and Ce/Nd normally change very little with moderate degrees of fractional crystallization and are expected to reflect the source characteristics (Saunders et al. 1988). However, these ratios may be fractionated to some extent by extremely low degrees of partial melting (McKenzie 1989) or due to compositional heterogeneities, in the source region (Ahmad and Tarney 1994). Thus, the narrow variation of Nb/La (1.33 - 1.90) and (Ce/Nd)_N (1.05 - 1.38) ratios in these rocks suggest that they are derived from similar sources. Enrichment of incompatible trace elements

in the source of these rocks is indicated by the Zr-Y relationship.

A primitive mantle is considered as source rock that consists of 49.9 wt.% SiO₂, 35 wt.% MgO, 8 wt.% FeO, 2000 ppm Ni and 8.3 ppm Zr (Taylor and McLennan 1985). REE patterns for 5% and 10% melting of the primitive mantle source has been calculated using Batch melting equation: $C_L/C_O = 1/D(1-F) + F$ (Schilling 1966) based on Kd values of McKenzie and O’Nions (1991) where C_L = concentration of element in the melt, C_O = concentration of element in the original source, D = bulk distribution coefficient and F = degree (5) of partial melt. Melt generated by 5% partial melting of the primitive mantle source leaving 40% olivine, 34% opx, 15% cpx and 11% plagioclase in the residue whereas 10% partial melting of the same source leaving a residue comprised 33% olivine, 45% opx and 19% cpx has been calculated. The calculated melt at 5% and 10% are plotted much lower than the REE patterns of these mafic rocks. Hence, different degrees of partial melting of the primitive mantle can not explain the various elemental abundances in these mafic rock samples. It also suggests that the source of the mafic rocks has lower Ni and higher Zr and REEs than the primitive mantle source.

To evaluate the source rock of the present investigated mafic intrusive rocks, a komatiitic amphibolite sample (no. SB 27-2) from Kolar Schist Belt (Balakrishnan 1986) has been considering as the source. This source has 47.80% SiO₂, 11.02% FeO, 24.47% MgO, 1490 ppm Ni and 36 ppm Zr and the normative mineralogy is 33% olivine and 67% pyroxene. It shows LREE enriched chondrite normalized with marked the positive Eu anomaly REE pattern. Fig. 7b shows chondrite normalized REE patterns for partial melts derived from the source and zone for the REE concentrations of gabbroic intrusive. Sr₁ and Sr₂ represent REE patterns of source derived by 32% and 47% partial melting leaving a similar residue with 35% olivine; 50% opx; 15% cpx. The calculated melt (Sr₁) at 35% partial melting closely approaches the higher REE abundances whereas the calculated melt (Sr₂) at 50% partial melting closely approaches the lower REE abundances of the gabbros of Panging area. The similarity of REE patterns of the gabbro intrusive to the calculated REE patterns suggest that the REE abundances of these gabbros are possibly derived from the komatiitic amphibolite source. Hence, this gabbro intrusive could have been derived by different degrees of partial melting of source rock similar of komatiitic amphibolites / picritic composition.

MICROFOSSILS, DEPOSITIONAL ENVIRONMENT AND AGE OF THE BUXA – MIRI SEDIMENTS OF THE ARUNACHAL LESSER HIMALAYA

Radiating filaments of *Rivularia haematites* (Cyanophyta) has been recorded for the first time from the Panging Limestone (Fig. 4a). It is also found to be associated with semi coiled filament showing septae (Fig. 4b). Both microfossils are cyanobacterial remains of Neoproterozoic

age. The genus *Rivularia* belongs to the family Rivulariaceae, a non motile filamentous cyanobacterial form. The radiating filaments are found in the microenvironments favourable for autochthonous calcite precipitation. The marine species of the *Rivularia* generally do not form Stromatolites; therefore, no Stromatolitic structures have been recorded from the Panging Limestone. A shallow marine depositional environment is suggested for the Panging Limestone. The present microfossils are indicative of an intertidal to supratidal zone which is also suggested by the fenestral vuggy and zebra fabric found in the Panging Limestone (Fig. 2). Neoproterozoic to Lower Cambrian age has been suggested to the Buxa–Miri Group sediments of the Arunachal Lesser Himalaya from Kameng, Subansiri and West Siang districts on the basis of organic walled microfossils, stromatolites, microstromatolites, sponge spicules, sponges and ichnofossils (Tewari 1998, 2001, 2002, 2003, 2007, 2009, Shukla et al. 2006). The carbon and oxygen isotopic profiles obtained for the Buxa (Menga, Chillipam and Dedza) Dolomites (Tewari 2002, 2003, 2007) also suggest that these isotopic values are comparable with other Neoproterozoic (Ediacaran/Vendian) carbonates of the western Lesser Himalaya and their equivalents in other parts of the world.

CONCLUSIONS

Geochemically the gabbro intrusive in Panging area is Mg-tholeiitic in nature (enriched in LILE and LREE; depleted in HFSE; minor REE fractionated nature) and classified as low-Ti ($Ti/Y = 416.32 - 477.88$; $Nb/La = 1.33 - 1.90$) mafic rocks. Similarity, in immobile trace element and REE abundances reveal their cogenetic nature. These mafic intrusive rocks do not show any subduction zone signature in their chemistry and their trace element concentrations are much lower and higher as compared with those of OIB and N-MORB respectively. It is also suggested that these intrusive rocks have the influence of a within plate signature which were intruded in a continental rift/lithospheric extension tectonic environment. The [Mg]-[Fe] and REE petrogenetic modellings indicate that these rocks derived from enriched mantle source with higher Fe/Mg ratio than primitive mantle source. The comparable REE patterns for these intrusive rocks and calculated parent melt suggest that these mafic rocks might have derived from a source similar to komatiitic composition at moderate to higher degree of partial melt. The age of the Buxa–Miri Group as already discussed that range from Neoproterozoic to Lower Cambrian. The present record of the microfossil *Rivularia haematites* and other coiled cyanobacterial remains indicate Neoproterozoic age for the Buxa (Panging Limestone). Therefore, based on the present reported microfossils, it is concluded that gabbroic intrusion in the Panging Limestone is probably post Neoproterozoic and pre Lower Cambrian in age which is probably close to the Precambrian-Cambrian boundary.

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