Chapter: Five

Chapter 5
Experimental Results

This chapter deals with the results of petrographical, geochemical and isotopic analyses that have been carried out in the present work. Petrographic studies consist of detailed thin section studies of lavas from the Barren Island volcano, samples from the Ophiolite Group of Andaman Islands and X- diffractometry of mud breccia samples. Geochemical studies include major and trace elemental characterization of lava flows and ash beds of Barren Island, samples from the Ophiolite Group and samples of breccia from mud volcanoes of Andaman Islands. Strontium, neodymium and lead isotopic ratios of lava and ash have been determined in order to ascertain the geochemical processes involved in their origin and evolution, whereas those of the rock clasts and sediments from the mud volcanoes for identification of their sources. Hydrogen and oxygen isotopic ratios have been determined for the water samples collected from the mud volcanoes and fresh water bodies of Andaman Islands to understand the chemistry of water in a subduction zone. Experimental results of all the above studies are discussed in the following paragraphs and the analytical data are presented in tabular form.

5.1 Petrographical descriptions

5.1.1 Thin section studies

Photomicrographs of thin sections are presented in Fig. 5.1 and 5.2. In these photomicrographs, Andaman ophiolites show evidences of low grade of metamorphism and hydrothermal alteration (Fig. 5.1a, b, d). They also contain spherulites, indicating the alteration of volcanic glass (Fig. 5.1f). Barren Island lavas are fresh and show large phenocryst and microphenocrsts of zoned plagioclase and phenocrysts of olivine and clinopyroxene (augite). The groundmass is mainly glassy, with plenty of

microlithic plagioclase crystals (Fig.5.2). In next chapter (Chapter - 6) we discuss the implications of our finding from petrography. The major petrographical observations are listed below.

a) Andaman Ophiolites

I) The predominant rock type of Andaman ophiolites is basalt, but dolerite, gabbro, pyroxenite (Fig. 5.1e) and plagiogranites (5.1c) are also observed. Mineralogically, the basalts contain phenocrysts of plagioclase (10-30 volume %), olivine (5-10 volume %), ortho and clino pyroxenes (2-5 volume %) with intergrowth of ilmenite and magnetite. Hematite is also observed which is tabular, needle-shaped (radiating, at places) and large grains show rarely lamellar twining. These rocks show generally porphyritic and hypocrystalline, and exhibits textures usually of hyalo-ophitic and, at places, intergranular, sub-ophitic and variolitic.

II) A majority of samples from Andaman ophiolites are altered, which is confirmed by presence of serpentine and spherulite (Fig 5.1b, f).

III) Presence of laumontite (zeolitite) and chlorite indicate very low grade metamorphism (burial) for the basaltic rocks of the ophiolite sequence.

IV) Presence of plagiogranites was confirmed by petrography (Fig. 5.1a, c) which indicate extensive fractional crystallization during the generation of this sequence.

V) Hybrid rocks are also detected in thin sections (Fig. 5.1d) which appear to have formed due to shearing and extensive underwater weathering.

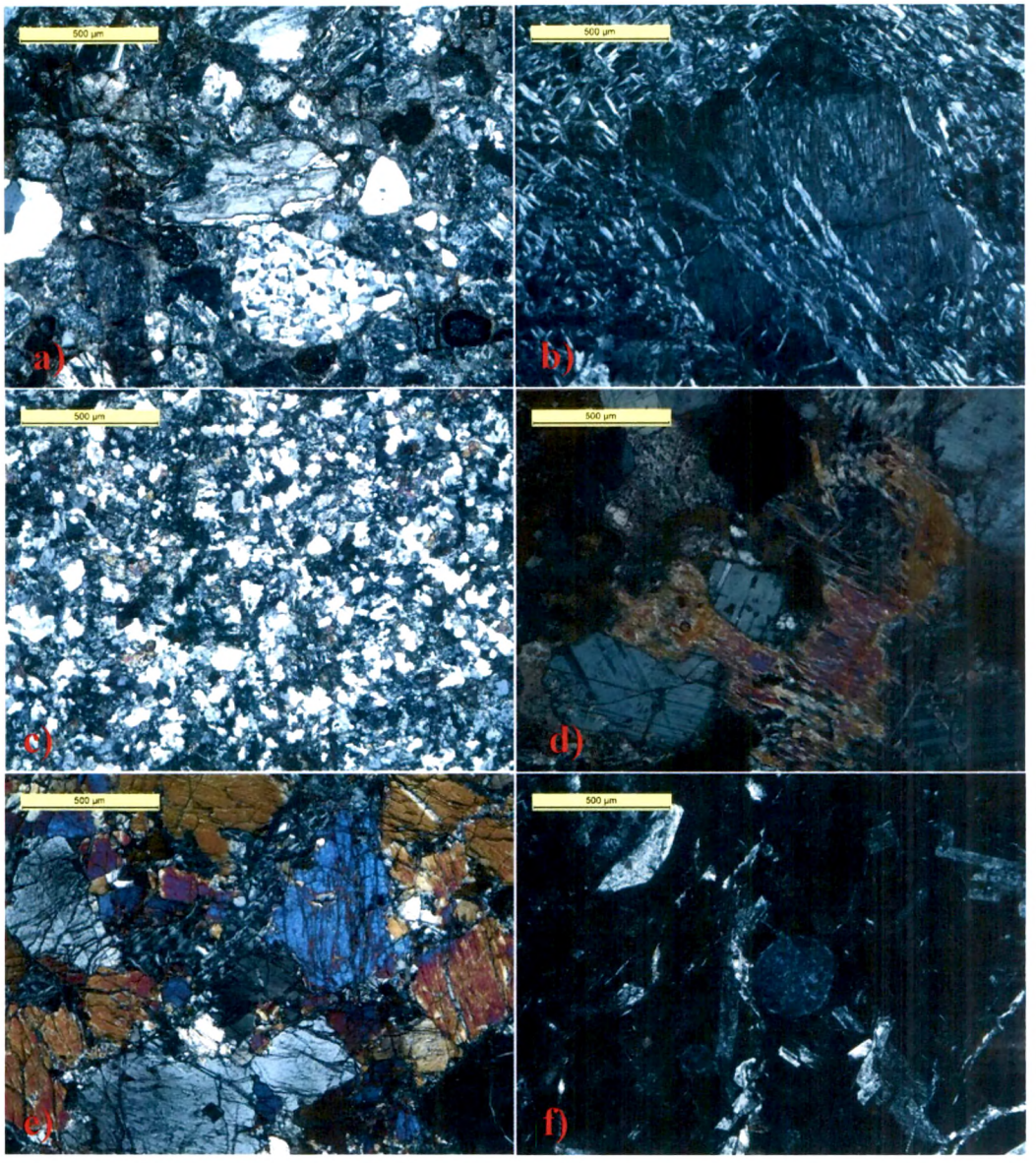

Fig.5.1 Photomicrographs of thin sections of various members of the Ophiolite Group under crossed polarized light a) Altered plagiogranite : secondary minerals replacing earlier minerals b) Altered Basalt : basalt changing to serpentinite c) Plagiogranite : quartz and plagioclase are abundant with small amounts of green amphibole d) Hybrid rock : formed due to shearing and weathering of basalt e) Pyroxinite: coarse grained pyroxene with altered plagioclase f) Altered Basalt : Spherulitic texture with laths of plagioclase.

b) Barren Island lavas

I) In Barren lavas, plagioclase is the dominant phenocrysts (~ 70%) with small amounts of phenocrysts of olivine and clinopyroxene (augite).

The groundmass of lavas is fine grained gray to dark gray, that generally glassy (Fig. 5.2). However, in most it is filled with microcrystalline plagioclase (Fig. 5.2d).

II) The phenocrysts of Barren lavas are well developed euhedral, tabular crystals and contain large numbers of glass (melt) inclusions (Fig. 5.2c-f).

III) Zoning and twinning are common in plagioclase and clinopyroxene phenocrysts (Fig. 5c-e). Pyroxene grains are mostly fractured and at times contain olivine inclusion (e.g. Fig. 5f).

IV) Corrosion of plagioclase and clinopyroxene minerals is observed in which the older minerals are corroded by new melts and the minerals show sieve structure in photomicrographs (Fig 5.2b, d).

V) Poikilitic texture is also not uncommon (Fig. 5.2g).

VI) Textures of the ground mass of the lava flows are different from flow to flow. It varies from holocrystalline to aphanitic.

VII) Flow structures are also observed, such type of feature are common in initial stage of lavas.

VIII) Cooling cracks are observed in olivine grains (Fig. 5.2g) and these grains are mostly resorbed and show zoning. These types of features are common in modern and postcaldera lavas, however, are absent in precaldera lavas.

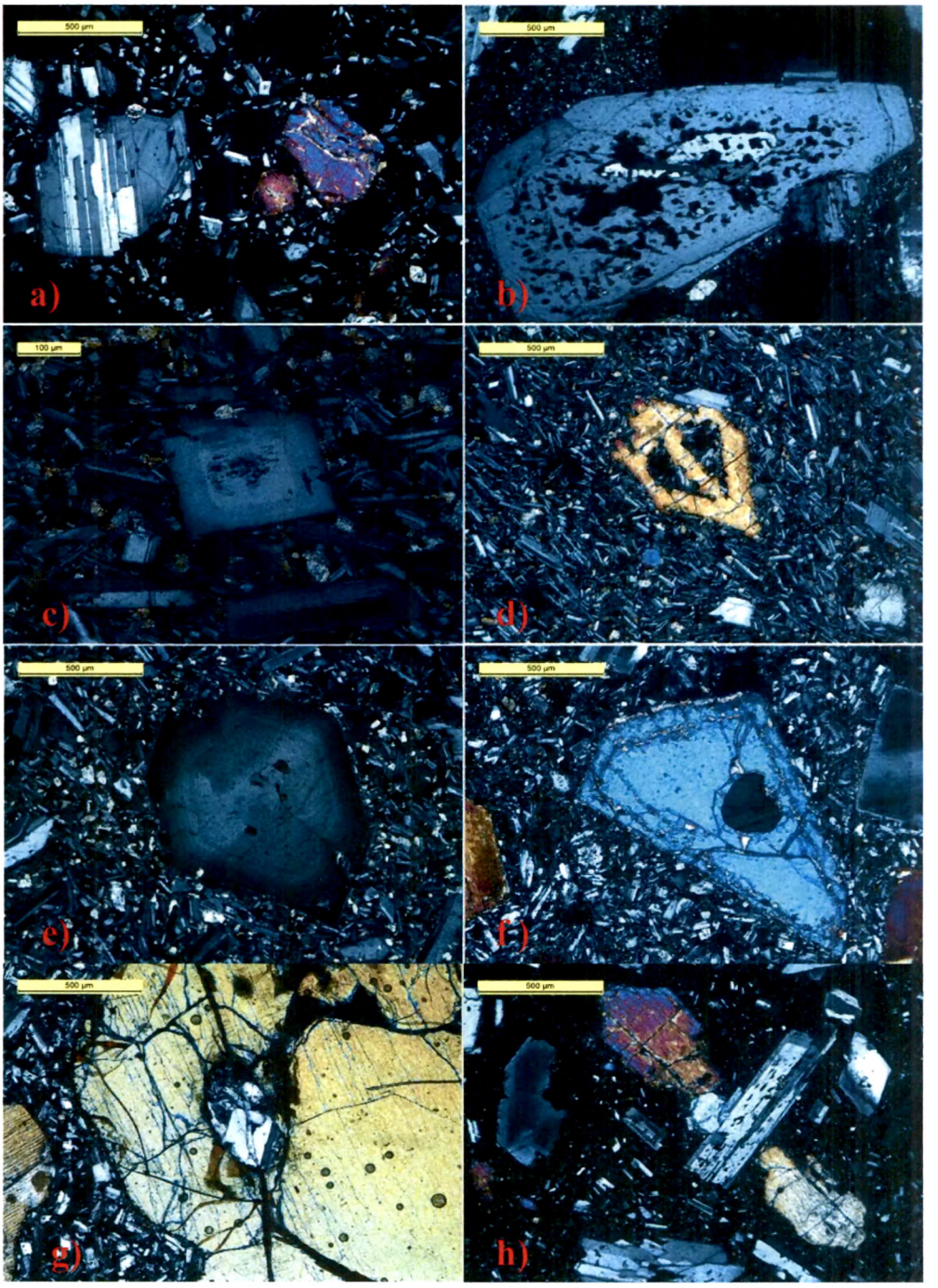

Fig. 5.2 Photomicrographs of thin sections of Barren Island lavas under crossed polarized light: a) Clinopyroxene and plagioclase as a phenocrsts b) Corroded plagioclase megacrysts c) Euhedral phencryst of plagioclase in a groundmass of fine grained of plagioclase and pyroxene d) Corroded pyroxene phenocrysts in a fine grained of plagioclase groundmass e) Euhedral plagioclase megacrsts with compositional zoning f) megacrsts of olivine, plagioclase and pyroxene g) Poikilitic texture: clinopyroxene crystals resorbed h) megacrsts of olivine, plagioclase and pyroxene

5.1.2 X-Ray diffractometry

As discussed in the chapter four, for identification of minerals in the mud breccias and serpentine clasts from mud volcanoes of Andaman, XRD

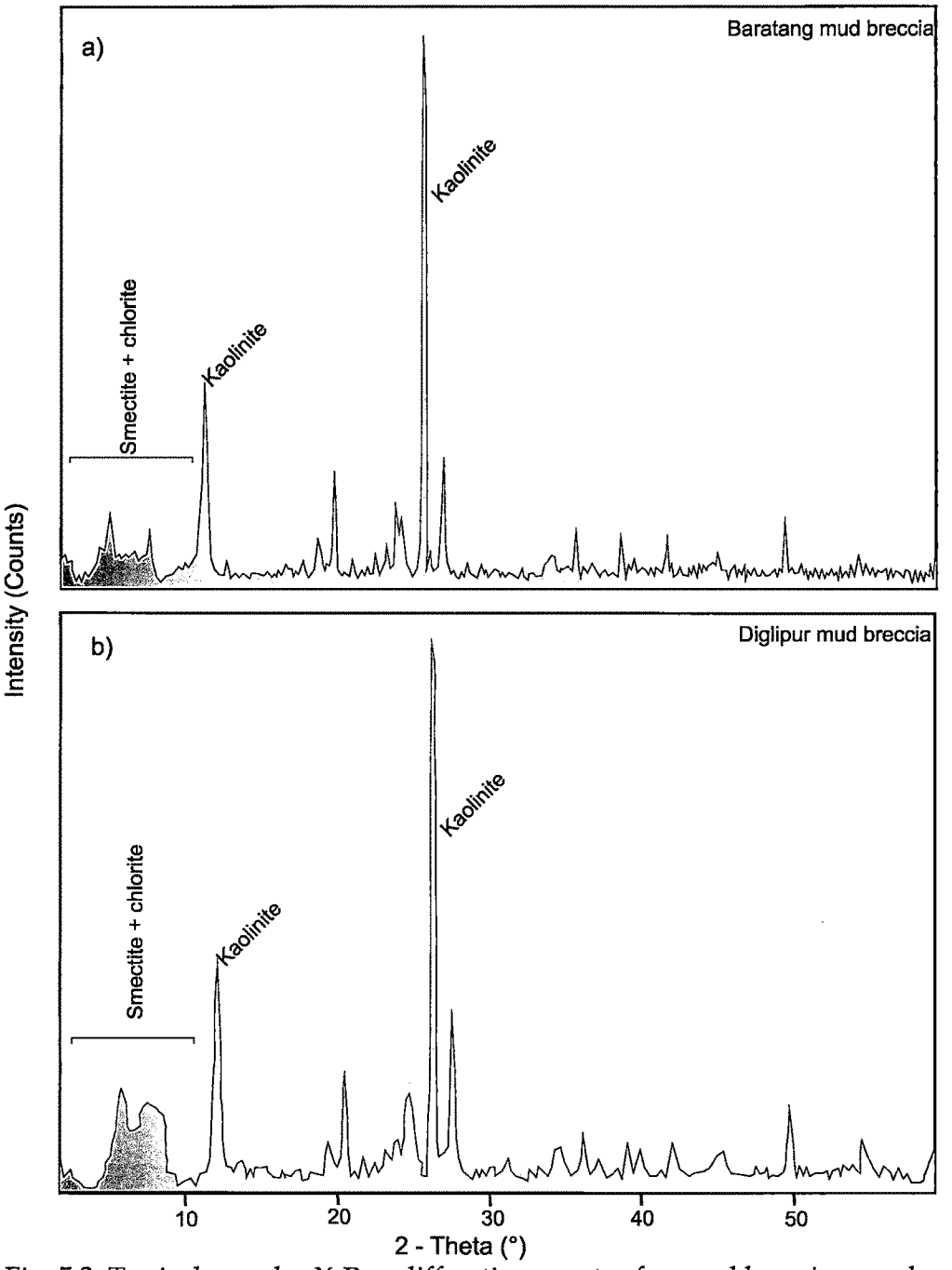

Fig. 5.3: Typical powder X-Ray diffraction spectra for mud breccia samples from mud volcanoes of Andaman Islands: a) Zarwa Creak, Baratang b) Hathilevel, Diglipur.

technique has used. Clay minerals were identified based on their 'd' spacing and characteristic peaks. Kaolin and chlorite groups of clay minerals are dominant in the mud breccias and serpentine clasts (Fig. 5.3, 5.4). Smectite group clay minerals are present in mud breccias but are absent in serpentinite clasts (Fig. 5.3, 5.4). Quartz with minor amount of calcite (mainly in Baratang mud breccia) and muscovite are also observed in these clay minerals and clasts. Since, we did not carryout XRD after glycolation or heating, we could not identify the individual minerals of the above groups.

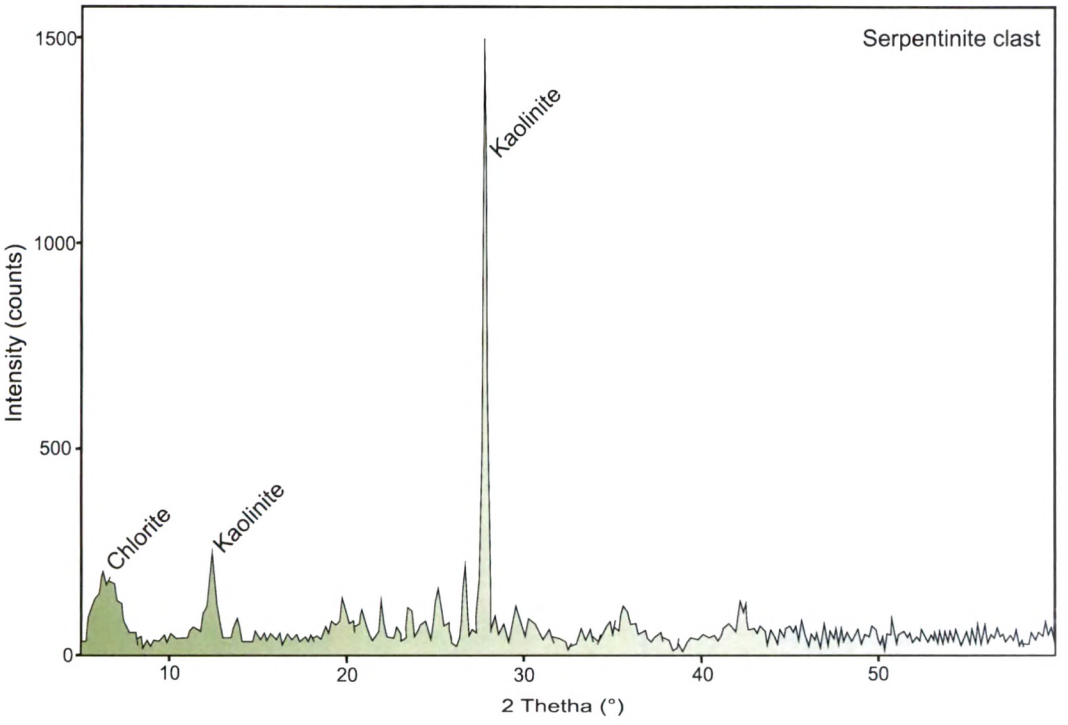

Fig. 5.4: A typical powder X-ray spectra for serpentinite clast (green mud) from a mud volcano of Zarwa creek, Baratang.

5.2 Geochemical Data

The data for major element and trace element contents, radiogenic isotopic ratios and stable isotopic ratios in samples of igneous rocks, sediments and water are presented in various tables in subsequent pages.

Concentrations of major elements are presented in 'wt%' of their oxides, whereas those of trace elements are in 'ppm'. Sr and Nd isotopic ratios are presented as $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$. Since variations in $^{143}Nd/^{144}Nd$ are extremely low, we make use of the $\varepsilon_{Nd}(0)$ parameter, which is defined as:

$$\varepsilon_{Nd}(0) = \left[\frac{\left({}^{143}Nd/{}_{144}Nd \right)_S^P}{\left({}^{143}Nd/{}_{144}Nd \right)_{Chond}^P} - 1 \right] \times 10^4 \qquad (5.1)$$

Where subscripts 'S' and 'Chond', respectively stand for sample and chondrite and superscript 'P' stands for present-day. The present-day $^{143}Nd/^{144}Nd$ ratio for chondrite is taken to be 0.512638 (Depaolo and Wasserburg, 1976). Stable 'O' and 'H' isotopic composition of water samples are expressed in $\delta^{18}O$ and δD, respectively with respect to V-SMOW in '‰' unit, as defined in chapter 4. The contents of 'C' and 'N' in the sediments are expressed in 'wt%'

5.2.1 Chemistry of mud breccias and rock clasts

The data for major element (oxide) and trace element contents in mud breccia samples and serpentinite clasts found in them are presented in Table 5.1a and 5.2. Sr and Nd isotopic ratio data for the samples for these samples are presented in Table 5.3a and their C and N contents are reported in Table 5.4. Major element and isotopic ratio data for rock clasts (other than serpentinites) found in mud volcano ejecta are reported in Table 5.1b and 5.3b, respectively. Above, we discuss our main observations of these data.

I) Mud breccia samples from Diglipur have higher percentages of silica, alumina, potassium and magnesium and lower percentage of iron and sodium compared those from mud breccia from Baratang (Table 5.1a). The rock clasts collected from these mud volcanoes show wide variations in major oxides (33-92% for SiO_2, 2-32% for CaO etc.) and their compositions indicating their derivation from both sedimentary and igneous rocks. High LOI contents in mud breccia samples reflect their clay contents.

II) Trace element contents in mud breccia samples from both the localities overlap (Table 5.2); however abundance of some trace elements (e.g. Ba, Th) are higher in Diglipur samples.

III) The Sr and Nd isotopic ratios of mud breccias from both localities generally overlap (Table 5.3) except that the average ε_{Nd} for Diglipur samples are slightly lower than that of Baratang samples. The rock clasts have wide ranging isotopic ratios (Table 5.3b) reflecting their multiple sources.

IV) Carbon and Nitrogen contents in mud breccias of Baratang (Table 5.4) vary from 0.08 to 0.11 and 0.50 to 1.05 respectively; whereas for Diglipur samples those vary from 0.6 to 0.13 and 0.52 to 0.88, respectively. The Baratang samples show wide variations in C/N ratio as compared with Diglipur.

Table 5.1a Major oxide compositions of mud breccia samples from mud volcanoes of Andaman Islands

Sample ID	Description	SiO_2	TiO_2	Al_2O_3	CaO	MgO	MnO	Fe_2O_3	K_2O	Na_2O	P_2O_5	LOI	Total
Baratang													
BTMV-2	Fine mud (Top part)	*56.57*	*0.84*	*13.57*	*1.43*	*2.71*	*0.07*	*8.16*	*1.92*	*7.97*	*0.08*	*6.67*	*99.96*
BTMV-3	Older fine mud	*55.85*	*0.85*	*13.76*	*1.41*	*2.73*	*0.06*	*8.28*	*1.99*	*3.74*	*0.08*	*6.45*	*95.19*
BTMV-4	Fine mud (deep part)	*54.86*	*0.85*	*13.27*	*1.34*	*2.66*	*0.06*	*8.28*	*1.95*	*2.62*	*0.07*	*5.33*	*91.29*
BTMV-5	Fine mud	*55.16*	*0.84*	*13.38*	*1.31*	*2.66*	*0.06*	*7.99*	*1.93*	*7.78*	*0.07*	*6.48*	*97.66*
BTMV-6	Fine mud	*55.50*	*0.83*	*13.30*	*1.38*	*2.67*	*0.06*	*8.00*	*1.90*	*8.24*	*0.07*	*6.43*	*98.39*
BTMV-7	Recent fine mud	*55.39*	*0.85*	*13.49*	*1.53*	*2.67*	*0.08*	*8.37*	*1.97*	*2.78*	*0.08*	*9.40*	*96.61*
BTMV-8	Older fine mud	*52.49*	*0.77*	*12.04*	*2.33*	*2.58*	*0.12*	*8.42*	*1.60*	*1.65*	*0.10*	*6.13*	*88.22*
BTMV-9	Green mud	*48.10*	*1.25*	*13.66*	*2.37*	*2.73*	*0.10*	*17.43*	*1.54*	*3.79*	*0.13*	*8.16*	*99.26*
BTMV-10	Fine mud (top part)	*55.10*	*0.87*	*13.56*	*1.41*	*2.71*	*0.06*	*8.66*	*1.99*	*1.86*	*0.07*	*5.24*	*91.53*
BTMV-12	Green mud	*49.83*	*1.38*	*14.24*	*5.62*	*3.19*	*0.29*	*6.67*	*1.28*	*2.81*	*0.41*	*7.68*	*93.40*
Diglipur													
HLMV-3	Fine mud (1ft deep)	*59.20*	*0.81*	*14.45*	*1.22*	*2.99*	*0.06*	*7.74*	*2.29*	*1.78*	*0.08*	*5.33*	*95.95*
HLMV-8	Recent fine mud	*57.22*	*0.88*	*13.95*	*1.40*	*2.72*	*0.07*	*7.87*	*2.15*	*2.92*	*0.09*	*6.31*	*95.57*
HLMV-12	Fine mud	*60.59*	*0.87*	*14.98*	*1.19*	*2.80*	*0.07*	*8.35*	*2.09*	*4.24*	*0.07*	*4.72*	*99.98*
HLMV-15	15mt away from vent	*59.41*	*0.87*	*14.57*	*1.27*	*2.79*	*0.07*	*8.24*	*2.06*	*3.98*	*0.08*	*6.58*	*99.92*
HLMV-16	Green mud	*52.54*	*0.76*	*13.45*	*4.63*	*5.89*	*0.11*	*4.98*	*2.02*	*1.35*	*0.14*	*8.16*	*94.03*

BTMV: Baratang mud volcano breccia, Middle Andaman; HLMV: Hathilevel mud volcano breccia, Diglipur, North Andaman; Oxides are in wt% and LOI is in %

Table 5.1b Major oxide compositions of rock clast (X) samples from mud volcanoes of Andaman Islands

Sample ID	Description	SiO_2	TiO_2	Al_2O_3	CaO	MgO	MnO	Fe_2O_3	K_2O	Na_2O	P_2O_5	LOI	Total
BTMV-01-X2	Flysch	*61.60*	*0.60*	*8.26*	*0.21*	*1.37*	*0.05*	*4.13*	*1.66*	*1.19*	*0.07*	*2.50*	*81.63*
BTMV-01-X5	Siliclastic	*48.73*	*0.78*	*13.50*	*4.80*	*2.81*	*0.17*	*10.83*	*1.18*	*1.77*	*0.11*	*5.20*	*89.86*
BTMV-01-X6	Igneous rock	*48.86*	*0.64*	*10.07*	*5.74*	*2.75*	*0.06*	*6.36*	*0.93*	*3.59*	*0.15*	*7.10*	*86.25*
BTMV-02-X4	Grit	*91.73*	*0.12*	*2.59*	*0.00*	*0.61*	*0.12*	*1.13*	*0.51*	*0.55*	*0.06*	*1.30*	*98.73*
BTMV-03-X1	Igneous rock	*50.11*	*0.79*	*10.36*	*3.70*	*2.75*	*0.09*	*6.74*	*0.76*	*3.48*	*0.12*	*5.50*	*84.39*
BTMV-03-X3	Sandstone	*50.34*	*0.53*	*14.78*	*10.16*	*2.16*	*0.47*	*13.66*	*1.93*	*1.66*	*2.09*	*4.60*	*102.38*
BTMV-03-X4	Graywacke	*63.49*	*0.72*	*12.50*	*2.64*	*0.80*	*0.09*	*2.34*	*0.45*	*4.76*	*0.08*	*9.80*	*97.68*
BTMV-03-X5	Shale	*33.24*	*0.39*	*7.98*	*31.83*	*2.10*	*0.35*	*12.72*	*0.99*	*0.90*	*0.32*	*11.50*	*102.32*

Oxides are in wt% and LOI is in %

Table 5.2 Trace element abundances of mud breccia samples from mud volcanoes of Andaman Islands

Sample ID	Co	Sc	Rb	Ba	Sr	Zn	Th	Ta	Zr	Hf	La	Ce	Nd	Sm	Eu	Gd	Tb	Yb	Lu
Baratang																			
BTMV-2	*18.88*	*18.41*	*73*	*234*	*188*	*81*	*8.00*	*0.63*	*134*	*4.35*	*23.39*	*47.26*	*21.71*	*5.11*	*1.21*	*4.51*	*0.74*	*2.76*	*0.41*
*BTMV-9**	*21.25*	*19.12*	*65*	*211*	*132*	*100*	*8.46*	*0.63*	*135*	*4.60*	*21.48*	*49.40*	*22.81*	*4.58*	*1.13*	*5.37*	*0.77*	*2.68*	*0.38*
BTMV-10	*19.57*	*17.53*	*99*	*192*	*160*	*86*	*7.72*	*0.59*	*163*	*4.34*	*21.97*	*45.26*	*20.61*	*4.65*	*1.04*	*4.06*	*0.67*	*2.51*	*0.37*
BTMV-12	*18.38*	*28.41*	*39*	*73*	*113*	*118*	*2.30*	*0.40*	*156*	*4.97*	*18.86*	*50.90*	*32.95*	*8.22*	*2.27*	*9.16*	*1.57*	*4.21*	*0.62*
Diglipur																			
HLMV-3	*23.76*	*18.58*	*79*	*233*	*179*	*100*	*9.74*	*0.71*	*166*	*5.14*	*24.99*	*54.80*	*23.48*	*4.75*	*1.10*	*4.78*	*0.76*	*2.78*	*0.40*
HLMV-15	*19.50*	*18.18*	*73*	*286*	*214*	*82*	*7.58*	*0.58*	*145*	*4.19*	*22.23*	*44.88*	*21.44*	*4.47*	*1.04*	*3.87*	*0.66*	*2.72*	*0.38*
*HLMV-16**	*9.50*	*19.20*	*ND*	*ND*	*472*	*40*	*0.53*	*0.11*	*89*	*2.61*	*8.34*	*19.80*	*13.36*	*3.87*	*1.80*	*4.60*	*0.88*	*2.80*	*0.40*

* Serpentinite clast, Element concentrations are in ppm; ND: not determined

Table 5.3a Strontium and Neodymium isotopic ratios of mud breccias and mud-water from mud volcanoes of Andaman Islands

Sample ID	Location	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	ε_{Nd} (0)
BTMV-2	Zarwa creek, Baratang	*0.70879*	*0.512538*	*-2.0*
BTMV-3		*0.70933*	*0.512494*	*-2.8*
BTMV-4		*0.70917*	*0.512515*	*-2.4*
BTMV-5		*0.70944*	*0.512496*	*-2.8*
BTMV-6		*0.70917*	*0.512512*	*-2.5*
BTMV-7		*0.70920*	*0.512525*	*-2.2*
BTMV-8		*0.70895*	*0.512485*	*-3.0*
*BTMV-9**		*0.70607*	*0.512464*	*-3.4*
BTMV-11		*0.70947*	*0.512505*	*-2.6*
BTMV-12		*0.70686*	*0.512910*	*5.3*
Baratang mud-water Leached sample		*0.70701*	*ND*	*ND*
BTMV-2		*0.711338*	*0.512489*	*-2.9*
BTMV-4		*0.712747*	*ND*	*ND*
BTMV-6		*0.712829*	*0.512407*	*-4.5*
HLMV-1	Hathilevel, Diglipur	*0.70986*	*0.512476*	*-3.2*
HLMV-3		*0.70959*	*0.512485*	*-3.0*
HLMV-6		*0.70982*	*0.512489*	*-2.9*
HLMV-8		*0.70905*	*0.51247*	*-3.3*
HLMV-12		*0.70906*	*0.512525*	*-2.2*
HLMV-15		*0.70854*	*0.512552*	*-1.7*
HLMV-16*		*0.70756*	*0.512810*	*3.4*
Hathilevel mud-water Leached sample		*0.70713*	*ND*	*ND*
HLMV-8		*0.71174*	*0.512347*	*-5.68*
HLMV-12		*0.711875*	*0.512460*	*-3.47*

* Serpentinite clast, ND: Not determined

Table 5.3b Strontium and Neodymium isotopic ratios of rock clast (X) from mud volcanoes of Andaman Islands

Sample ID	Location	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	ε_{Nd} (0)
BTMV-01-X2	Zarwa creek, Baratang	*0.71574*	*0.512136*	*-9.8*
BTMV-01-X5		*0.70784*	*0.512537*	*-2.0*
BTMV-01-X6		*0.70561*	*0.512769*	*2.6*
BTMV-02-X2		*0.71124*	*0.512291*	*-6.8*
BTMV-02-X4		*0.71238*	*0.512291*	*-6.8*
BTMV-03-X1		*0.70780*	*0.512690*	*1.0*
BTMV-03-X3		*0.70933*	*0.512494*	*-2.8*

Table 5.4 Nitrogen (N) and Carbon (%) abundances of mud breccia samples collected from mud volcanoes of Andaman Islands

Sample ID	Description	Nitrogen (%)	Carbon (%)	C/N
Baratang				
BTMV-2	Fine mud (Top part)	*0.10*	*0.63*	*6.32*
BTMV-3	Older fine mud	*0.09*	*0.59*	*6.89*
BTMV-4	Fine mud (deep part)	*0.09*	*0.60*	*6.74*
BTMV-5	Fine mud	*0.11*	*0.61*	*5.73*
BTMV-6	Fine mud	*0.09*	*0.59*	*6.89*
BTMV-7	Recent fine mud	*0.10*	*0.71*	*7.26*
BTMV-8	Older fine mud	*0.09*	*0.50*	*5.59*
BTMV-9	Green mud	*0.03*	*0.03*	*0.89*
BTMV-10	Fine mud (top part)	*0.08*	*0.65*	*8.15*
BTMV-11	Fine mud	*0.11*	*0.66*	*5.77*
BTMV-12	Fine mud (30cm below)	*0.10*	*1.05*	*10.43*
BTMV-13	Dry dome	*0.10*	*0.86*	*8.87*
BTMV-14	Older mud	*0.08*	*0.61*	*7.26*
Diglipur				
HLMV-1	Recent fine mud	*0.11*	*0.81*	*7.50*
HLMV-3	Fine mud (1ft deep)	*0.12*	*0.84*	*7.28*
HLMV-5	Fine mud	*0.13*	*0.87*	*6.85*
HLMV-6	Older mud	*0.11*	*0.81*	*7.63*
HLMV-7	Mixed fine mud	*0.07*	*0.52*	*7.32*
HLMV-8	Recent fine mud	*0.06*	*0.56*	*8.68*
HLMV-9	Fine mud	*0.07*	*0.54*	*7.30*
HLMV-11	Older mud	*0.07*	*0.54*	*7.44*
HLMV-12	Fine mud	*0.07*	*0.56*	*7.67*
HLMV-13	Fine mud	*0.08*	*0.78*	*9.75*
HLMV-14	Older mud	*0.12*	*0.88*	*7.29*
HLMV-15	15mt away from vent	*0.08*	*0.52*	*6.99*

5.2.2 $\delta^{18}O$ and δD of waters from mud volcanoes

The $\delta^{18}O$ and δD of water samples from mud volcanoes and other water bodies of Andaman Islands are presented in Table 5.5. The $\delta^{18}O$ of mud waters from Baratang are close to the seawater composition (average = 0.12‰) compared to that of mud water from Diglipur (average = 1.7‰).

δD of waters from both mud volcanoes are highly variable. The fresh water bodies have $\delta^{18}O$ close to that of the local rain or slightly enriched whereas their δD is highly enriched with the ground waters showing the highest values.

Table 5.5 Oxygen and hydrogen isotopic ratios of water samples from Mud Volcanoes and other water bodies, Andaman Islands

Sample ID	Location	Description	$\delta^{18}O_{Smow}$ (‰)	δD_{Smow} (‰)
BTMVW-1	Zarwa creek, Baratang	Mud water	*0.2*	*-19*
BTMVW-2		"	*0.1*	*-23*
BTMVW-3		"	*0.5*	*-21*
BTMVW-4		"	*0.4*	*-24*
BTMVW-5		"	*-0.2*	*-20*
BTMVW-6		"	*0.5*	*-14*
BTMVW-7		"	*-0.2*	*-22*
ZRWW-1		Ground water	*-2.2*	*-11*
PWSW-1		Spring water	*-3.8*	*-19*
HLMVW-2	Hathilevel, Diglipur	Mud water	*1.3*	*-26*
HLMVW-3		"	*2.0*	*-21*
HLMVW-4		"	*1.5*	*-21*
HLMVW-5		"	*1.9*	*-22*
HLMVW-6		"	*1.4*	*-24*
HLMVW-7		"	*2.2*	*-18*
HLMVW-8		"	*1.6*	*-23*
HLMVW-9		"	*1.7*	*-22*
LBSW-1		Spring water	*-3.7*	*-18*
PBRW	Port Blair	Rain water	*-5.5*	*-33*
NSW-1	Narcondam Island	Spring water	*-4.6*	*-25*
NSW-2	"	"	*-4.9*	*-27*
NSW-3	"	"	*-4.8*	*-26*

BTMVW: Baratang Mud Volcano Water, Middle Andaman;
ZRWW: Zarwa Creek Well Water, Baratang Middle Andaman;
PWSW: Panchwati Spring Water, Middle Andaman;
HLMVW: Hathilevel Mud Volcano Water, Diglipur, North Andaman
LBSW: Lamiya Bay Spring Water, Kalipur, North Andaman
PBRW: Port Blair Rain Water, South Andaman
NSW: Narcondam Spring Water, Narcondam Island

5.2.3 Chemistry of rocks from Andaman Ophiolite Group

The result of major oxides (in wt %), trace element abundances (ppm) and isotopic ratios for samples from the Ophiolite Group are presented in Tables 5.6, 5.7 and 5.8, respectively. The following are the major observations in these data sets.

I) Based on major element contents (SiO_2 and MgO) the rocks from the Ophiolite Group can be divided into three groups: 1) Low SiO_2 (39 – 45%) and high MgO (13 to 20%) rocks, 2) Intermediate SiO_2 (45 to 50%) and MgO (10 to 14%) rocks, which also have high Fe_2O_3 (10-15%) and CaO (10-16%) contents, and 3) High silica (60 to 75%) but low MgO (~5%) rocks. The rock type of third group represents plagiogranites.

II) Na_2O and MnO in some of these rocks are unusually high because of alteration.

III) The rare earth element contents of most of the ophiolite samples analyzed are low (Table. 5.7), however, that for compatible elements like Cr and Sc are very high. In some samples Cr is in % level.

IV) The Sr isotopic ratio of Andaman ophiolites varies from 0.70342 to 0.70899 and the Nd isotopic ratio ranges from 0.512762 to 0.512240, with corresponding $\varepsilon_{Nd}(0)$ ranging from 2.4 to 11.7 (Table 5.8). High Sr isotopic ratios are observed in visibly altered (by seawater) samples.

Table 5.6 Major oxide compositions of samples collected from the Ophiolite Group, Andaman Islands

Sample ID	Rock type	SiO_2	TiO_2	Al_2O_3	$(Fe_2O_3)^T$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
PB07-03	Basalt	*44.68*	*0.98*	*15.75*	*11.88*	*0.41*	*15.85*	*5.78*	*3.28*	*1.08*	*0.08*	*ND*	*99.77*
PB07-04A	Basalt	*48.89*	*1.09*	*13.60*	*10.30*	*0.16*	*9.71*	*11.75*	*3.59*	*0.44*	*0.08*	*ND*	*99.60*
PB07-04B	Basalt	*46.27*	*1.03*	*11.91*	*9.67*	*0.14*	*9.00*	*15.38*	*3.19*	*0.32*	*0.09*	*ND*	*96.99*
PB07-05A	Plagiogranite	*61.35*	*0.75*	*12.68*	*7.07*	*0.10*	*5.69*	*8.98*	*1.08*	*0.12*	*0.23*	*ND*	*98.04*
PB07-05B	Basalt	*48.34*	*0.82*	*13.86*	*20.44*	*0.12*	*10.32*	*2.97*	*1.67*	*0.20*	*0.11*	*ND*	*98.85*
PB07-06	Pillow Basalt	*44.84*	*0.30*	*14.68*	*7.61*	*0.11*	*12.96*	*14.93*	*0.73*	*0.66*	*0.00*	*ND*	*96.83*
PB07-09	Basalt	*44.98*	*0.90*	*10.46*	*8.31*	*0.11*	*8.09*	*19.72*	*3.28*	*0.09*	*0.09*	*ND*	*96.01*
PB07-10A	Basalt	*48.94*	*1.31*	*14.68*	*12.51*	*0.23*	*7.37*	*9.36*	*3.35*	*0.86*	*0.15*	*ND*	*98.78*
PB07-10B	Basalt	*48.46*	*0.99*	*18.39*	*9.72*	*0.12*	*2.00*	*16.68*	*0.17*	*0.02*	*0.16*	*ND*	*96.69*
PB-08-01	Plagiogranite	*63.66*	*0.64*	*11.32*	*5.86*	*0.09*	*4.92*	*10.13*	*0.39*	*0.04*	*0.21*	*ND*	*97.25*
PB-08-02(A)	Gabbro	*44.26*	*0.27*	*13.51*	*8.61*	*0.13*	*14.31*	*14.96*	*0.76*	*0.14*	*0.06*	*2.74*	*99.75*
PB-08-02(B)	Gabbro	*49.45*	*0.76*	*12.93*	*12.28*	*0.16*	*11.18*	*11.73*	*2.22*	*0.22*	*0.09*	*ND*	*101.01*
PB-08-03	Gabbro	*44.31*	*0.32*	*15.25*	*8.06*	*0.11*	*11.52*	*15.12*	*0.83*	*0.26*	*0.05*	*ND*	*95.82*
PB-08-03(A)	Gabbro	*44.85*	*0.19*	*17.38*	*6.27*	*0.09*	*12.72*	*15.34*	*0.89*	*0.31*	*0.05*	*3.00*	*101.09*
PB-08-04	Gabbro	*47.95*	*0.51*	*12.48*	*6.64*	*0.12*	*16.35*	*13.92*	*0.94*	*0.14*	*0.10*	*3.00*	*102.15*
PB-08-05	Pillow Basalt	*42.92*	*1.36*	*11.03*	*10.97*	*0.17*	*14.65*	*10.11*	*0.90*	*0.07*	*0.09*	*2.60*	*94.86*
PB-08-06	Basalt	*43.42*	*1.18*	*13.89*	*9.13*	*0.13*	*6.25*	*12.85*	*1.50*	*0.00*	*0.12*	*4.30*	*92.76*
PB-08-11	Green rock	*75.28*	*0.51*	*9.40*	*3.55*	*0.10*	*1.07*	*3.56*	*2.08*	*1.03*	*0.17*	*7.90*	*104.65*

Table 5.6 continued

Sample ID	Rock type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
PB-08-12	Meta. Basalt	*18.88*	*0.02*	*0.98*	*2.57*	*0.86*	*3.24*	*69.13*	*0.11*	*-0.01*	*0.17*	*4.00*	*99.95*
AND-09-17	Serpentinite	*45.90*	*0.87*	*12.67*	*10.55*	*0.21*	*15.76*	*6.05*	*3.09*	*0.03*	*0.08*	*5.40*	*100.61*
AND-09-29	Pillow Basalt	*42.24*	*1.08*	*10.13*	*13.27*	*0.21*	*13.86*	*8.31*	*1.76*	*0.24*	*0.12*	*9.73*	*100.94*
AND-09-35	Limestone	*45.07*	*0.49*	*10.73*	*6.54*	*0.12*	*9.67*	*19.96*	*0.37*	*0.08*	*0.11*	*3.20*	*96.33*
AND-09-46	serpentinite	*39.92*	*0.99*	*11.08*	*15.10*	*0.21*	*18.64*	*7.28*	*1.39*	*0.01*	*0.07*	*ND*	*94.68*
AND-09-58	Plagiogranite	*69.43*	*0.48*	*13.15*	*3.27*	*0.05*	*1.95*	*4.36*	*5.16*	*0.02*	*0.28*	*ND*	*98.14*
AND-09-62	Pillow Basalt	*44.00*	*1.50*	*11.39*	*10.70*	*0.16*	*15.50*	*9.08*	*0.61*	*0.09*	*0.10*	*7.90*	*101.02*

Major oxide and LOI contents are in wt%; LOI: Loss on Ignition; Superscript 'T': Total, ND: Not Determined

Table 5.7 Element concentration data (INAA) for Andaman Ophiolite Samples

Sample ID	Rock type	Co	Sc	Ba	Sr	Zn	Hf	La	Ce	Nd	Sm	Eu	Gd	Tb	Yb	Lu	Cr	Ca	Fe	Na
PB-07-06	Basalt	*43.7*	*51.3*	*158*	*204*	*90.6*	*0.3*	*1.3*	*3.0*	*14.5*	*0.6*	*0.26*	*1.46*	*0.1*	*0.3*	*0.09*	*377*	*11.7*	*5.60*	*0.60*
PB-07-09	Basalt	*36.9*	*30.5*	*ND*	*132*	*84.7*	*1.7*	*2.9*	*7*	*1.6*	*3.4*	*0.89*	*2.20*	*0.6*	*3.8*	*0.58*	*639*	*20.9*	*5.97*	*3.01*
PB-08-01	Plagiogranite	*11.3*	*19*	*101*	*134*	*62.1*	*6.2*	*10.2*	*25.3*	*8.7*	*4.3*	*1.21*	*7.10*	*0.9*	*3.5*	*0.51*	*71.80*	*3.4*	*4.13*	*2.16*
AND-09-32	Serpentinite	*90.7*	*11.4*	*ND*	*ND*	*42.9*	*ND*	*1*	*ND*	*ND*	*0.1*	*0.02*	*0.34*	*ND*	*0.2*	*0.04*	*2196*	*ND*	*5.19*	*ND*
AND-09-60	Gabbro	*62.3*	*47.5*	*ND*	*ND*	*119.2*	*0.1*	*0.7*	*0.8*	*1.1*	*0.4*	*0.16*	*0.21*	*ND*	*0.3*	*0.05*	*2794*	*12.1*	*3.65*	*0.06*

Trace element contents are in 'ppm' and major element contents are in wt%; ND: Not Determined

Table 5.8 Strontium and Neodymium isotopic ratios of samples collected from the Ophiolite Group, Andaman Islands

Sample ID	Rock type	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(0)$
PB-07-03	Basalt	*0.70632*	*0.512975*	*6.6*
PB-07-04A	Basalt	*0.70483*	*0.513102*	*9.1*
PB-07-05A	Plagiogranite	*0.70377*	*0.513017*	*7.4*
PB-07-05B	Basalt	*0.70407*	*0.513000*	*7.1*
PB-07-06	Basalt	*0.70382*	*0.513022*	*7.5*
PB-07-09	Pillow Basalt	*0.70542*	*0.513131*	*9.6*
PB-07-10	Basalt	*0.70462*	*0.513109*	*9.2*
PB-08-01	Plagiogranite	*0.70384*	*0.513020*	*7.5*
PB-08-02 _ Host	Gabbro	*0.70363*	*0.513026*	*7.6*
PB-08-02 _Tchy	Gabbro	*0.70375*	*0.512968*	*6.4*
PB-08-04	Gabbro	*0.70440*	*0.512987*	*6.8*
PB-08-06	Basalt	*0.70478*	*0.513077*	*8.6*
PB-08-12	Meta. Basalt	*0.70629*	*0.512220*	*-8.2*
AND-09-29	Pillow Basalt	*0.70582*	*0.512762*	*2.4*
AND-09-31	Basalt	*0.70801*	*ND*	*ND*
AND-09-32	Serpentinite	*0.70899*	*0.513240*	*11.7*
AND-09-46	Serpentinite	*0.70501*	*0.513095*	*8.9*
AND-09-50	Serpentinite	*0.70584*	*0.513123*	*9.5*
AND-09-58	Plagiogranite	*0.70402*	*0.513027*	*7.6*
AND-09-60	Gabbro	*0.70342*	*0.513091*	*8.8*

ND: Not determined.

5.2.3 Chemistry of lavas and ash of Barren Island Volcano

The major oxide, trace element abundances and isotopic ratios of Sr and Nd of Barren Island lavas and ash beds are presented in Tables 5.9, 5.10 and 5.11 respectively. The following observations can be made based on these data sets. Detailed discussions of data sets are presented in next chapter.

I) The lavas and ash samples have very high Al_2O_3 contents compared to similar arc lavas in this region.

II) The MgO content range from 2.39 to 9.28 wt % and Mg number varies from 39 to 68. The majority of samples have Mg# in the range of 45-55, which indicate that Barren lavas and ash samples are moderately evolved. L.O.I. content for lavas and ash samples of Barren Island volcano vary from – 1.75 to + 4.19%, but the majority have very low LOI content that indicate the lavas of Barren Island are fresh.

III) The 'Precaldera' lavas show high contents of Ba, Nd, Zr, Sm, Eu, Cr, Co and low contents of Cs and Th compared with 'Postcaldera' and 'Modern' lavas flows.

IV) Sr and Nd isotopic ratios of lava flows range from 0.70407 to 0.70415, 0.512861 to 0.512990 respectively and $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ vary from 17.824 to 18.405, 15.324 to 15.744, and 37.762 to 38.846, respectively.

Table 5.9 Major oxide compositions (in wt %) of samples from lava flows and ash beds of the Barren Island Volcano

Sample ID	Description	SiO_2	TiO_2	Al_2O_3	$(FeO)_T$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Mg#
Precaldera														
BI-07-01	Old aa lava	*56.88*	*0.93*	*19.56*	*6.55*	*0.18*	*2.39*	*8.21*	*4.44*	*0.69*	*0.19*	*-0.12*	*100.62*	*39.09*
BI-07-02	Red colour lava	*52.73*	*0.91*	*16.19*	*6.49*	*0.18*	*7.22*	*7.92*	*5.16*	*0.64*	*0.18*	*1.77*	*100.10*	*67.73*
BI-07-03	Aa lava (plg.-cpx)	*49.63*	*0.87*	*16.74*	*9.33*	*0.17*	*8.98*	*10.58*	*2.44*	*0.24*	*0.09*	*0.33*	*100.43*	*64.46*
BI-07-07	Aa lava (core)	*52.35*	*0.99*	*18.71*	*9.07*	*0.18*	*4.01*	*9.17*	*3.91*	*0.49*	*0.15*	*-0.09*	*99.93*	*45.46*
BI-07-08	Red ash	*46.70*	*0.68*	*19.45*	*7.66*	*0.14*	*7.44*	*11.88*	*2.47*	*0.26*	*0.08*	*1.19*	*98.80*	*67.06*
BI-07-09	Aa lava	*51.31*	*1.02*	*18.65*	*9.63*	*0.17*	*3.87*	*9.22*	*3.71*	*0.49*	*0.13*	*0.13*	*99.40*	*43.11*
BI-07-10	Aa lava (core)	*52.37*	*1.05*	*18.65*	*9.44*	*0.20*	*3.32*	*9.28*	*3.67*	*0.48*	*0.15*	*-0.03*	*99.62*	*39.87*
BI-07-12	Aa lava	*53.20*	*0.86*	*18.15*	*7.70*	*0.17*	*5.03*	*9.29*	*3.95*	*0.51*	*0.13*	*0.30*	*100.13*	*55.20*
BI-07-13	Aa lava	*52.98*	*0.89*	*18.81*	*7.68*	*0.19*	*4.69*	*9.55*	*3.72*	*0.44*	*0.14*	*0.45*	*100.38*	*53.11*
BI-08-05	Aa flow (bottom)	*52.05*	*0.86*	*19.02*	*8.26*	*0.16*	*6.43*	*9.73*	*3.41*	*0.46*	*0.11*	*-0.08*	*101.29*	*62.0*
BI-08-06	Aa flow (Top)	*52.25*	*0.90*	*19.02*	*7.72*	*0.17*	*6.34*	*9.79*	*3.38*	*0.44*	*0.16*	*-0.04*	*100.98*	*60.76*
BI-08-08	Aa lava (plg.-cpx)	*50.22*	*0.73*	*18.43*	*8.41*	*0.17*	*8.87*	*10.60*	*2.96*	*0.31*	*0.14*	*-1.75*	*100.02*	*66.65*
BI-08-10	Aa lava (plg.-cpx)	*50.38*	*0.73*	*18.20*	*8.45*	*0.16*	*8.59*	*10.63*	*2.95*	*0.33*	*0.12*	*-0.04*	*101.43*	*65.71*
Post Caldera														
BI-07-04	Scoria	*49.39*	*0.83*	*22.60*	*7.68*	*0.15*	*4.31*	*11.21*	*3.01*	*0.36*	*0.07*	*-0.19*	*100.27*	*54.05*
BI-07-05	Scoria	*49.24*	*0.81*	*22.78*	*7.38*	*0.14*	*4.58*	*11.31*	*2.69*	*0.35*	*0.10*	*0.06*	*100.27*	*53.94*
BI-07-06	Ash (mixed)	*49.59*	*0.88*	*20.91*	*8.02*	*0.14*	*5.72*	*10.35*	*2.42*	*0.31*	*0.07*	*1.42*	*100.71*	*59.92*

Table 5.9 continued

Sample ID	Description	SiO_2	TiO_2	Al_2O_3	$(FeO)_T$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Mg#
BI-08-01	Scoria	*49.44*	*0.82*	*21.91*	*7.68*	*0.15*	*4.34*	*11.26*	*2.89*	*0.34*	*0.12*	*0.44*	*100.24*	*51.58*
BI-08-02	Toothpaste lava	*49.00*	*0.81*	*23.45*	*7.11*	*0.14*	*3.79*	*11.39*	*2.69*	*0.36*	*0.10*	*-0.08*	*99.54*	*50.14*
BI-08-03	Older aa flow	*49.51*	*0.77*	*23.23*	*6.76*	*0.14*	*3.71*	*11.10*	*2.93*	*0.38*	*0.10*	*-0.04*	*99.34*	*50.88*
BI-08-04	Scoria	*50.00*	*0.85*	*22.40*	*7.23*	*0.15*	*3.74*	*11.20*	*3.06*	*0.36*	*0.12*	*-0.08*	*99.82*	*49.35*
BI-08-09	loose Ash	*47.48*	*0.83*	*17.17*	*9.45*	*0.18*	*9.28*	*11.21*	*1.99*	*0.30*	*0.11*	*0.30*	*99.35*	*64.94*
BI-08-11	Aa lava	*49.35*	*0.80*	*23.25*	*6.88*	*0.14*	*3.73*	*11.11*	*2.90*	*0.37*	*0.10*	*-0.01*	*99.38*	*50.59*
BI-08-12	Aa lava	*50.79*	*0.84*	*23.20*	*7.30*	*0.15*	*3.27*	*11.35*	*3.22*	*0.38*	*0.12*	*0.03*	*101.47*	*45.80*
BI-08-13	Aa lava (Top)	*49.09*	*0.80*	*23.82*	*7.10*	*0.14*	*3.86*	*11.41*	*2.63*	*0.35*	*0.10*	*0.16*	*100.25*	*50.63*
BI-08-14	Toothpaste lava	*51.13*	*0.80*	*22.24*	*6.81*	*0.14*	*3.51*	*10.92*	*3.53*	*0.43*	*0.10*	*-0.11*	*100.25*	*51.93*
BI-08-15	Toothpaste lava	*50.58*	*0.73*	*21.74*	*6.50*	*0.14*	*3.91*	*10.99*	*3.23*	*0.41*	*0.12*	*0.07*	*99.12*	*53.12*
BI-09-03	Toothpaste lava	*49.45*	*0.86*	*22.63*	*8.62*	*0.15*	*3.76*	*11.26*	*2.92*	*0.39*	*0.08*	*-0.18*	*99.93*	*48.85*
BI-09-04	Toothpaste lava	*50.72*	*0.86*	*22.32*	*8.04*	*0.14*	*3.23*	*11.09*	*3.12*	*0.40*	*0.12*	*-0.34*	*99.69*	*45.71*
BI-09-05	Toothpaste lava	*50.43*	*0.87*	*22.03*	*8.33*	*0.14*	*3.41*	*11.06*	*3.09*	*0.40*	*0.12*	*-0.32*	*99.56*	*47.18*
BI-07-TL-02	Loose Ash	*50.52*	*0.98*	*18.41*	*10.60*	*0.16*	*6.17*	*10.08*	*2.76*	*0.43*	*0.10*	*0.60*	*100.81*	*54.96*
BI-07-TL-03	Coarse Ash	*46.43*	*0.81*	*11.85*	*14.17*	*0.15*	*11.48*	*6.83*	*2.66*	*0.24*	*0.08*	*4.19*	*99.98*	*62.94*
Modern														
BI-07-11	Older Ash	*48.91*	*0.87*	*19.68*	*7.94*	*0.16*	*6.26*	*10.28*	*2.59*	*0.36*	*0.10*	*1.86*	*99.88*	*59.79*
BI-08-07	Scoria (2005)	*49.49*	*0.80*	*22.32*	*6.94*	*0.15*	*4.13*	*11.51*	*2.71*	*0.32*	*0.11*	*-0.03*	*99.23*	*52.87*

Table 5.9 continued

Sample ID	Description	SiO_2	TiO_2	Al_2O_3	$(FeO)_T$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Mg#
BI-09-01	2009 lava	*50.83*	*0.84*	*21.72*	*8.36*	*0.15*	*4.67*	*11.15*	*2.89*	*0.40*	*0.14*	*-0.51*	*100.61*	*67.70*
BI-09-02	2009 Ash	*50.65*	*0.93*	*20.72*	*9.58*	*0.16*	*5.21*	*10.65*	*3.01*	*0.43*	*0.08*	*-0.49*	*100.93*	*67.70*
BI-07-TL-01	Loose ash	*52.97*	*1.17*	*17.48*	*10.48*	*0.18*	*3.85*	*8.87*	*3.31*	*0.58*	*0.11*	*ND*	*99.00*	*43.50*

Table 5.10a Trace element abundances (in ppm) of samples from lava flows and ash beds of the Barren Island Volcano

Sample ID	Description	Cs	Rb	Ba	Th	Nb	Ta	La	Ce	Pr	Pb	Sr	Nd	Hf	Zr	Sm
Precaldera																
BI-07-01	Old aa lava	*0.17*	*13.43*	*120.30*	*1.69*	*1.33*	*0.10*	*6.39*	*15.71*	*2.31*	*3.15*	*222.2*	*11.11*	*2.51*	*96.26*	*3.26*
BI-07-02	Red colour lava	*0.15*	*9.71*	*115.80*	*1.71*	*1.15*	*0.09*	*6.02*	*14.91*	*2.18*	*4.89*	*239.0*	*10.48*	*2.27*	*89.00*	*3.04*
BI-07-03	Aa lava (plg.-cpx)	*0.13*	*3.46*	*59.95*	*0.44*	*0.75*	*0.08*	*2.64*	*7.33*	*1.20*	*1.17*	*175.7*	*6.34*	*1.44*	*55.91*	*2.11*
BI-07-07	Aa lava (core)	*0.13*	*7.25*	*86.73*	*0.61*	*0.72*	*0.09*	*3.37*	*9.62*	*1.59*	*1.81*	*209.0*	*8.45*	*2.04*	*78.37*	*2.84*
BI-07-08	Red ash	*0.18*	*5.27*	*49.54*	*0.33*	*0.52*	*0.05*	*1.80*	*5.09*	*0.85*	*1.37*	*196.1*	*4.51*	*1.08*	*42.23*	*1.54*
BI-07-09	Aa lava	*0.24*	*7.73*	*86.44*	*0.67*	*0.80*	*0.06*	*3.52*	*10.01*	*1.66*	*2.34*	*201.1*	*8.78*	*2.15*	*78.71*	*2.95*
BI-07-10	Aa lava (core)	*0.31*	*9.06*	*90.70*	*0.62*	*0.83*	*0.05*	*3.55*	*9.85*	*1.65*	*3.40*	*204.8*	*8.72*	*2.05*	*77.94*	*2.90*
BI-07-12	Aa lava	*0.20*	*9.16*	*87.23*	*0.67*	*0.54*	*0.05*	*3.81*	*10.57*	*1.77*	*3.47*	*201.3*	*9.24*	*2.11*	*82.23*	*2.94*
BI-07-13	Aa lava	*0.25*	*7.79*	*84.80*	*0.67*	*0.56*	*0.05*	*3.76*	*10.66*	*1.72*	*1.51*	*191.2*	*8.91*	*2.17*	*79.64*	*2.87*
BI-08-05	Aa flow (bottom)	*0.20*	*8.87*	*89.09*	*1.11*	*0.61*	*0.08*	*5.22*	*13.28*	*1.99*	*1.20*	*234.3*	*9.61*	*1.76*	*70.56*	*2.68*

Table 5.10a continued

Sample ID	Description	Cs	Rb	Ba	Th	Nb	Ta	La	Ce	Pr	Pb	Sr	Nd	Hf	Zr	Sm
BI-08-06	Aa flow (Top)	*0.17*	*7.68*	*90.36*	*1.13*	*0.61*	*0.06*	*5.90*	*14.86*	*2.22*	*1.20*	*238.6*	*10.66*	*1.87*	*71.40*	*2.96*
BI-08-08	Aa lava (plg.- cpx)	*0.12*	*4.87*	*55.71*	*0.40*	*0.49*	*0.06*	*2.22*	*6.46*	*1.07*	*1.04*	*180.6*	*5.73*	*1.34*	*52.20*	*1.94*
BI-08-10	Aa lava (plg.-cpx)	*0.14*	*5.05*	*57.27*	*0.42*	*0.53*	*0.06*	*2.32*	*6.68*	*1.12*	*0.80*	*183.7*	*5.95*	*1.43*	*55.73*	*2.02*
BI-08-TL-01	Yellow Ash	*0.33*	*12.26*	*80.50*	*1.06*	*ND*	*0.04*	*2.36*	*10.80*	*ND*	*ND*	*687.0*	*5.72*	*1.67*	*54.18*	*1.92*
BI-08-TL-02	Red Ash	*0.47*	*12.57*	*79.50*	*1.03*	*ND*	*0.08*	*4.51*	*12.70*	*ND*	*ND*	*254.0*	*8.28*	*1.57*	*63.70*	*2.60*
Post Caldera																
BI-07-04	Scoria	*0.36*	*10.32*	*79.27*	*1.19*	*0.50*	*0.07*	*4.07*	*10.52*	*1.59*	*2.21*	*220.7*	*7.88*	*1.59*	*61.77*	*2.35*
BI-07-05	Scoria	*0.38*	*10.73*	*78.77*	*1.13*	*0.59*	*0.06*	*4.21*	*10.79*	*1.63*	*1.55*	*217.5*	*8.00*	*1.60*	*59.25*	*2.38*
BI-07-06	Ash (mixed)	*0.34*	*10.12*	*75.41*	*1.10*	*0.59*	*0.05*	*3.91*	*10.39*	*1.58*	*2.11*	*212.5*	*7.89*	*1.63*	*60.66*	*2.36*
BI-08-01	Scoria	*0.34*	*10.28*	*78.59*	*1.05*	*0.42*	*0.07*	*3.82*	*9.93*	*1.52*	*1.40*	*225.40*	*7.53*	*1.55*	*61.33*	*2.26*
BI-08-02	Toothpaste lava	*0.37*	*11.33*	*85.10*	*1.22*	*0.43*	*0.08*	*4.31*	*11.15*	*1.70*	*1.49*	*245.60*	*8.41*	*1.70*	*67.57*	*2.50*
BI-08-03	Older aa flow	*0.39*	*11.94*	*89.11*	*1.29*	*0.48*	*0.06*	*4.56*	*11.79*	*1.80*	*3.21*	*256.10*	*8.88*	*1.80*	*71.09*	*2.63*
BI-08-04	Scoria	*0.35*	*10.50*	*79.76*	*1.09*	*0.41*	*0.06*	*3.95*	*10.25*	*1.57*	*1.35*	*231.00*	*7.75*	*1.60*	*63.08*	*2.31*
BI-08-09	loose Ash	*0.19*	*6.46*	*59.58*	*0.54*	*0.73*	*0.05*	*2.87*	*7.65*	*1.22*	*1.27*	*196.60*	*6.38*	*1.36*	*51.58*	*2.07*
BI-08-11	Aa lava	*0.41*	*12.45*	*94.47*	*1.37*	*0.50*	*0.06*	*4.75*	*12.34*	*1.89*	*2.05*	*266.50*	*9.32*	*1.90*	*74.26*	*2.77*
BI-08-12	Aa lava	*0.36*	*11.11*	*83.34*	*1.19*	*0.44*	*0.05*	*4.15*	*10.77*	*1.64*	*1.68*	*237.60*	*8.12*	*1.66*	*65.59*	*2.43*
BI-08-13	Aa lava (Top)	*0.38*	*11.52*	*86.23*	*1.26*	*0.47*	*0.05*	*4.37*	*11.30*	*1.72*	*6.44*	*244.40*	*8.55*	*1.75*	*68.97*	*2.54*
BI-08-14	Toothpaste lava	*0.31*	*11.20*	*89.12*	*1.31*	*0.48*	*0.10*	*4.59*	*11.87*	*1.82*	*1.64*	*255.60*	*8.99*	*1.83*	*70.82*	*2.68*

Table 5.10a continued

Sample ID	Description	Cs	Rb	Ba	Th	Nb	Ta	La	Ce	Pr	Pb	Sr	Nd	Hf	Zr	Sm
BI-08-15	Toothpaste lava	*0.34*	*10.83*	*81.62*	*1.20*	*0.44*	*0.05*	*4.26*	*11.01*	*1.68*	*1.62*	*236.00*	*8.32*	*1.69*	*65.55*	*2.46*
BI-09-03	Toothpaste lava	*0.42*	*11.37*	*93.49*	*1.18*	*0.84*	*0.08*	*4.80*	*12.25*	*1.78*	*2.00*	*242.30*	*8.79*	*1.73*	*65.46*	*2.58*
BI-09-04	Toothpaste lava	*0.46*	*11.98*	*70.76*	*1.24*	*0.89*	*0.07*	*4.99*	*12.77*	*1.87*	*1.76*	*182.70*	*9.02*	*1.75*	*50.00*	*2.67*
BI-09-05	Toothpaste lava	*0.41*	*11.34*	*73.40*	*1.19*	*0.89*	*0.07*	*4.91*	*12.49*	*1.81*	*2.20*	*183.00*	*8.89*	*1.79*	*52.20*	*2.62*
BI-TL-07-04	Old laminated ash	*0.76*	*9.71*	*65.60*	*0.62*	*ND*	*0.08*	*4.25*	*8.73*	*ND*	*ND*	*391*	*6.96*	*1.62*	*48.70*	*2.45*
Modern																
BI-07-11	Older Ash	*0.30*	*9.01*	*77.06*	*0.96*	*0.65*	*0.05*	*3.82*	*9.77*	*1.50*	*1.44*	*199.10*	*7.44*	*1.50*	*58.69*	*2.23*
BI-08-07	Scoria (2005)	*0.33*	*9.84*	*77.94*	*1.03*	*0.37*	*0.08*	*3.69*	*9.61*	*1.48*	*1.26*	*226.90*	*7.32*	*1.52*	*59.48*	*2.21*
BI-09-01	2009 lava	*0.41*	*11.41*	*71.87*	*1.20*	*0.86*	*0.09*	*4.95*	*12.49*	*1.81*	*1.71*	*190.80*	*8.80*	*1.72*	*48.27*	*2.59*
BI-09-02	2009 Ash	*0.45*	*12.48*	*82.99*	*1.30*	*1.00*	*0.06*	*5.27*	*13.27*	*1.92*	*1.81*	*184.20*	*9.26*	*1.89*	*56.05*	*2.76*

Table 5.10b Trace element abundances (in ppm) of samples from lava flows and ash beds of the Barren Island Volcano

Sample ID	Description	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	V	Cr	Co	Ni	Zn
Precaldera																
BI-07-01	Old aa lava	*1.14*	*4.01*	*0.72*	*4.85*	*1.04*	*3.16*	*0.49*	*3.21*	*0.49*	*25.74*	*218.6*	*9.36*	*16.06*	*10.59*	*74.48*
BI-07-02	Red colour lava	*1.08*	*3.77*	*0.67*	*4.55*	*0.98*	*2.95*	*0.46*	*2.98*	*0.46*	*24.51*	*179.8*	*18.2*	*15.51*	*18.21*	*74.69*
BI-07-03	Aa lava (plg.-cpx)	*0.81*	*2.76*	*0.51*	*3.51*	*0.76*	*2.28*	*0.35*	*2.28*	*0.34*	*40.68*	*271.3*	*369.0*	*39.75*	*172.90*	*82.97*

Table 5.10b continued

Sample ID	Description	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	V	Cr	Co	Ni	Zn
BI-07-07	Aa lava (core)	*1.09*	*3.75*	*0.70*	*4.78*	*1.04*	*3.10*	*0.48*	*3.14*	*0.48*	*41.85*	*422.9*	*24.2*	*27.60*	*17.50*	*84.85*
BI-07-08	Red ash	*0.63*	*2.06*	*0.38*	*2.65*	*0.57*	*1.71*	*0.27*	*1.73*	*0.26*	*36.74*	*227.6*	*285.6*	*34.21*	*115.70*	*53.19*
BI-07-09	Aa lava	*1.12*	*3.90*	*0.72*	*4.98*	*1.08*	*3.24*	*0.50*	*3.31*	*0.50*	*40.74*	*397.5*	*28.1*	*26.86*	*16.69*	*84.36*
BI-07-10	Aa lava (core)	*1.10*	*3.79*	*0.70*	*4.83*	*1.04*	*3.12*	*0.48*	*3.15*	*0.48*	*40.84*	*403.2*	*22.6*	*26.30*	*16.69*	*88.12*
BI-07-12	Aa lava	*1.02*	*3.81*	*0.69*	*4.70*	*1.02*	*3.07*	*0.48*	*3.10*	*0.47*	*32.11*	*202.1*	*62.0*	*25.57*	*35.92*	*74.04*
BI-07-13	Aa lava	*1.02*	*3.42*	*0.67*	*4.56*	*0.99*	*2.97*	*0.46*	*3.01*	*0.46*	*31.35*	*219.8*	*64.4*	*24.90*	*34.98*	*81.29*
BI-08-05	Aa flow (bottom)	*0.95*	*3.21*	*0.56*	*3.74*	*0.81*	*2.42*	*0.37*	*2.45*	*0.38*	*31.99*	*265.0*	*278.3*	*32.05*	*122.20*	*82.71*
BI-08-06	Aa flow (Top)	*1.04*	*3.51*	*0.61*	*4.08*	*0.87*	*2.61*	*0.40*	*2.63*	*0.40*	*33.20*	*284.0*	*278.7*	*32.24*	*122.60*	*66.05*
BI-08-08	Aa lava (plg.-cpx)	*0.76*	*2.57*	*0.48*	*3.29*	*0.71*	*2.14*	*0.33*	*2.17*	*0.33*	*39.36*	*263.2*	*524.0*	*41.44*	*200.60*	*72.83*
BI-08-10	Aa lava (plg.-cpx)	*0.78*	*2.67*	*0.50*	*3.43*	*0.74*	*2.24*	*0.34*	*2.26*	*0.34*	*40.81*	*289.6*	*541.7*	*42.40*	*204.30*	*69.64*
BI-08-TL-01	Yellow Ash	*0.88*	*2.45*	*0.55*	*ND*	*ND*	*ND*	*ND*	*2.08*	*0.33*	*30.31*	*ND*	*302*	*28.44*	*ND*	*3124.3*
BI-08-TL-02	Red Ash	*0.88*	*3.09*	*0.54*	*ND*	*ND*	*ND*	*ND*	*2.01*	*0.35*	*31.94*	*ND*	*572*	*36.62*	*ND*	*587.7*
Post Caldera																
BI-07-04	Scoria	*0.88*	*2.92*	*0.52*	*3.50*	*0.75*	*2.26*	*0.35*	*2.27*	*0.34*	*29.34*	*274.0*	*88.9*	*24.99*	*60.16*	*61.96*
BI-07-05	Scoria	*0.89*	*2.94*	*0.52*	*3.52*	*0.76*	*2.26*	*0.35*	*2.28*	*0.35*	*27.21*	*256.3*	*75.2*	*24.15*	*56.19*	*61.54*
BI-07-06	Ash (mixed)	*0.89*	*2.91*	*0.52*	*3.53*	*0.75*	*2.26*	*0.35*	*2.29*	*0.35*	*31.37*	*246.0*	*133.5*	*26.12*	*71.67*	*63.48*
BI-08-01	Scoria	*0.83*	*2.81*	*0.51*	*3.40*	*0.73*	*2.20*	*0.34*	*2.22*	*0.34*	*28.81*	*275.0*	*331.4*	*25.85*	*64.34*	*69.23*
BI-08-02	Toothpaste lava	*0.93*	*3.13*	*0.56*	*3.76*	*0.81*	*2.42*	*0.37*	*2.45*	*0.37*	*31.07*	*299.6*	*93.4*	*23.44*	*32.53*	*66.84*

Table 5.10b continued

Sample ID	Description	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	V	Cr	Co	Ni	Zn
BI-08-03	Older aa flow	*0.98*	*3.28*	*0.59*	*3.96*	*0.85*	*2.54*	*0.39*	*2.57*	*0.39*	*31.89*	*312.7*	*103.3*	*24.11*	*32.26*	*77.44*
BI-08-04	Scoria	*0.87*	*2.91*	*0.52*	*3.50*	*0.75*	*2.26*	*0.35*	*2.28*	*0.35*	*28.72*	*278.1*	*129.0*	*24.78*	*55.29*	*68.40*
BI-08-09	loose Ash	*0.79*	*2.76*	*0.49*	*3.35*	*0.72*	*2.15*	*0.33*	*2.14*	*0.32*	*39.47*	*266.5*	*389.5*	*41.02*	*162.20*	*63.89*
BI-08-11	Aa lava	*1.03*	*3.46*	*0.62*	*4.17*	*0.89*	*2.68*	*0.41*	*2.71*	*0.41*	*33.45*	*327.7*	*100.4*	*25.07*	*34.30*	*74.75*
BI-08-12	Aa lava	*0.90*	*3.02*	*0.54*	*3.64*	*0.78*	*2.34*	*0.36*	*2.37*	*0.36*	*29.66*	*289.6*	*91.76*	*22.78*	*32.15*	*67.07*
BI-08-13	Aa lava (Top)	*0.94*	*3.17*	*0.57*	*3.82*	*0.82*	*2.46*	*0.38*	*2.49*	*0.38*	*31.04*	*303.5*	*107.9*	*23.90*	*34.00*	*70.24*
BI-08-14	Toothpaste lava	*0.99*	*3.35*	*0.60*	*4.03*	*0.87*	*2.60*	*0.40*	*2.62*	*0.40*	*32.59*	*312.0*	*101.6*	*25.01*	*35.36*	*72.68*
BI-08-15	Toothpaste lava	*0.91*	*3.08*	*0.55*	*3.71*	*0.79*	*2.39*	*0.37*	*2.40*	*0.37*	*29.60*	*289.2*	*97.88*	*22.78*	*31.78*	*65.75*
BI-09-03	Toothpaste lava	*0.96*	*3.12*	*0.56*	*3.73*	*0.81*	*2.38*	*0.37*	*2.39*	*0.37*	*32.53*	*303.8*	*38.86*	*22.76*	*29.36*	*70.13*
BI-09-04	Toothpaste lava	*0.98*	*3.21*	*0.57*	*3.82*	*0.82*	*2.45*	*0.38*	*2.44*	*0.37*	*25.04*	*235.2*	*17.23*	*16.68*	*17.88*	*69.19*
BI-09-05	Toothpaste lava	*0.97*	*3.19*	*0.57*	*3.77*	*0.82*	*2.43*	*0.37*	*2.41*	*0.37*	*25.50*	*237.2*	*22.84*	*17.48*	*22.17*	*72.32*
BI-TL-07-04	Old laminated ash	*0.79*	*2.27*	*0.51*	*ND*	*ND*	*ND*	*ND*	*2.27*	*0.36*	*32.40*	*ND*	*469*	*28.02*	*ND*	*1467.9*
Modern																
BI-07-11	Older Ash	*0.83*	*2.78*	*0.50*	*3.33*	*0.71*	*2.13*	*0.33*	*2.14*	*0.32*	*33.94*	*250.8*	*193.9*	*34.27*	*116.50*	*66.06*
BI-08-07	Scoria (2005)	*0.83*	*2.77*	*0.50*	*3.34*	*0.72*	*2.16*	*0.33*	*2.17*	*0.33*	*27.44*	*264.2*	*115.4*	*23.85*	*55.20*	*61.61*
BI-09-01	2009 lava	*0.95*	*3.11*	*0.56*	*3.69*	*0.79*	*2.37*	*0.36*	*2.34*	*0.36*	*25.20*	*224.6*	*63.54*	*19.43*	*49.52*	*67.40*
BI-09-02	2009 Ash	*0.99*	*3.32*	*0.58*	*3.94*	*0.85*	*2.51*	*0.39*	*2.49*	*0.39*	*25.82*	*243.4*	*51.06*	*20.37*	*48.21*	*74.17*

Trace element contents are in 'ppm'; ND: Not Determined

Table 5.11 Strontium, Neodymium and lead isotopic ratios of rock and ash samples from Barren Island Volcano

Sample ID	Description	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(0)$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Precaldera							
BI-07-01	Old aa lava	*0.70407*	*0.512896*	*5.0*	*18.344*	*15.995*	*38.765*
BI-07-02	Red colour lava	*0.70459*	*0.512877*	*4.7*	*18.207*	*15.565*	*38.404*
BI-07-03	Aa lava (plg.-cpx)	*0.70387*	*0.512966*	*6.4*	*ND*	*ND*	*ND*
BI-07-07	Aa lava (core)	*0.70391*	*0.512976*	*6.6*	*18.251*	*15.603*	*38.534*
BI-07-08	Red ash	*0.70394*	*0.51297*	*6.5*	*18.096*	*15.472*	*38.143*
BI-07-09	Aa lava	*0.70398*	*0.512992*	*6.9*	*17.935*	*15.324*	*37.762*
BI-07-10	Aa lava (core)	*0.70399*	*0.512976*	*6.6*	*17.990*	*15.441*	*38.063*
BI-07-12	Aa lava	*0.70400*	*0.51299*	*6.9*	*ND*	*ND*	*ND*
BI-07-13	Aa lava	*0.70398*	*0.512983*	*6.7*	*ND*	*ND*	*ND*
BI-08-05	Aa flow (bottom)	*0.70387*	*0.512882*	*4.8*	*18.254*	*15.604*	*38.484*
BI-08-06	Aa flow (Top)	*0.70388*	*0.512915*	*5.4*	*ND*	*ND*	*ND*
BI-08-08	Aa lava (plg.-cpx)	*0.70383*	*0.512964*	*6.4*	*18.254*	*15.654*	*38.595*
BI-08-10	Aa lava (plg.-cpx)	*0.70379*	*0.512963*	*6.3*	*ND*	*ND*	*ND*
BI-08-TL-01	Yellow Ash	*0.70395*	*0.51291*	*5.3*	*ND*	*ND*	*ND*
BI-08-TL-02	Red Ash	*0.70399*	*0.51296*	*6.3*	*ND*	*ND*	*ND*
Plagioclase	Mineral separated	*0.70397*	*ND*	*ND*	*ND*	*ND*	*ND*
Pyroxene	Mineral separated	*0.70392*	*0.513012*	*7.3*	*ND*	*ND*	*ND*

Table 5.11 continued

Sample ID	Sub Group	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(0)$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Post Caldera							
BI-07-04	Scoria	*0.70402*	*0.512907*	*5.2*	*18.405*	*15.744*	*38.846*
BI-07-05	Scoria	*0.70405*	*0.512904*	*5.2*	*ND*	*ND*	*ND*
BI-07-06	Ash (mixed)	*0.70402*	*0.512889*	*4.9*	*18.294*	*15.602*	*38.545*
BI-08-01	Scoria	*0.70396*	*0.512892*	*5.0*	*18.120*	*15.584*	*38.295*
BI-08-02	Toothpaste lava	*0.70400*	*0.512879*	*4.7*	*17.824*	*15.573*	*38.012*
BI-08-03	Older aa flow	*0.70395*	*0.512895*	*5.0*	*18.140*	*15.595*	*38.334*
BI-08-04	Scoria	*0.70400*	*0.512919*	*5.5*	*17.934*	*15.273*	*38.023*
BI-08-09	loose Ash	*0.70389*	*0.512940*	*5.9*	*ND*	*ND*	*ND*
BI-08-11	Aa lava	*0.70398*	*0.512892*	*5.0*	*ND*	*ND*	*ND*
BI-08-12	Aa lava	*0.70397*	*0.512889*	*4.9*	*ND*	*ND*	*ND*
BI-08-13	Aa lava (Top)	*0.70400*	*0.512891*	*4.9*	*ND*	*ND*	*ND*
BI-08-14	Toothpaste lava	*0.70396*	*0.512877*	*4.7*	*ND*	*ND*	*ND*
BI-08-15	Toothpaste lava	*0.70398*	*0.512881*	*4.7*	*ND*	*ND*	*ND*
BI-09-03	Toothpaste lava	*0.70405*	*0.512872*	*4.6*	*ND*	*ND*	*ND*
BI-09-04	Toothpaste lava	*0.70415*	*0.512862*	*4.4*	*ND*	*ND*	*ND*
BI-09-05	Toothpaste lava	*0.70409*	*0.512868*	*4.5*	*ND*	*ND*	*ND*
BI-07-TL-02	Loose Ash	*0.70398*	*0.512943*	*5.9*	*ND*	*ND*	*ND*
BI-07-TL-03	Coarse Ash	*0.70391*	*0.512959*	*6.3*	*ND*	*ND*	*ND*

Table 5.11 continued

Sample ID	Sub Group	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(0)$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Modern							
BI-07-11	Older Ash	*0.70405*	*0.512884*	*4.8*	*ND*	*ND*	*ND*
BI-08-07	Scoria (2005)	*0.70402*	*0.512920*	*5.5*	*18.055*	*15.395*	*37.992*
BI-09-01	2009 lava	*0.70403*	*0.512864*	*4.4*	*ND*	*ND*	*ND*
BI-09-02	2009 Ash	*0.70409*	*0.512861*	*4.4*	*ND*	*ND*	*ND*
BI-07-TL-01	Loose ash	*0.70411*	*0.512865*	*4.4*	*ND*	*ND*	*ND*
Not well constrained							
BI-07-TL-04	Old laminated ash	*0.70402*	*0.512892*	*5.0*	*ND*	*ND*	*ND*
BI-07-TL-05	Ash between lava	*0.70407*	*0.512917*	*5.4*	*ND*	*ND*	*ND*
BI-07-TL-06	Older ash	*0.70394*	*0.512978*	*6.6*	*ND*	*ND*	*ND*

ND: Not Determined