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COMPOSITION OF NEOGENE SHALES FROM THE SURMA GROUP, BENGAL BASIN, BANGLADESH: IMPLICATIONS FOR PROVENANCE AND TECTONIC SETTING

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KEYWORDS

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ABSTRACT

The geochemical composition of the Neogene shales from the Surma Group in the Bengal Basin, Bangladesh encountered in petroleum exploration wells were analyzed by lithium metaborate/tetraborate fusion Inductively Coupled Plasma (ICP) and Inductively Coupled Plasma Mass spectrometry (ICP-MS).

Geochemically, the mean major element composition of the Neogene shales is similar to that of the average shale with the exception of the CaO content, which is lower here. The low CaO content (1.37 wt %) could be due to lower carbonate content. The Neogene shales are enriched with V, Cr, Co, Ni in compared to UC (Upper Crust. The REE content (186-228) is higher than those of UC and NASC but is in agreement with those of PAAS. The Eu/Eu* (~0.68), (La/Lu)cn (~0.43), La/Sc (~2.64), Th/Sc (~1.06), La/Co(~2.71), Th/Co (~1.08), and Cr/Th (~5.59) ratios as well as Chondrite-normalized REE patterns with flat HREE, LREE enrichment, and negative Eu anomaly indicate the derivation of the Neogene Surma Group shales from felsic rock sources.

The geochemical characteristics suggest the active continental margin setting for the Neogene Surma Group shales and preserve the signatures of recycled provenance field that have undergone significant weathering at the source areas.

Die geochemische Zusammensetzung neogener Tone der Surma–Gruppe aus Erdöl-Explorationsbohrungen des Bengal Beckens, Bangladesh, wurde mit Hilfe von Lithium-Metaborate/Tetraborat Fusion Inductively Coupled Plasma (ICP) und Inductively Coupled Plasma Mass spectrometry (ICP-MS) untersucht.

Geochemisch ist die Hauptelementzusammensetzung neogener Tone vergleichbar einer durchschnittlichen Tonzusammensetzung, abgesehen von geringeren CaO-Gehalten (1,37 wt %), die auf geringere Karbonatgehalte zurückzuführen sind. Die neogenen Tone sind angereichert in V, Cr, Co, Ni gegenüber der Durchschnittsgehalte der oberen Kruste (UC). Die REE Gehalte (186-228) sind höher als die der UC and NASC, aber stimmen mit jenen von PAAS überein. DieEu/Eu* (~0.68), (La/Lu)cn (~10.43), La/Sc (~2.64), Th/Sc (~1.06), La/Co(~2.71), Th/Co (~1.08) und Cr/Th (~5.59) Verhältnisse als auch Chondrite-normalisierte REE Muster mit flachen HREE, LREE-Anreicherungen und negativen Eu-Anomalien belegen die Herkunft der Tone der neogenen Surma-Gruppe von felsischen Ausgangsgesteinen.

Die geochemische Charakteristika der Tone der neogenen Surma-Gruppe legen einen aktiven Kontinentalrand nahe und zeigen die Signatur wiederaufgearbeiteter Gesteine, die signifikanter Verwitterung im Herkunftsgebiet unterworfen waren.

1. INTRODUCTION

This paper describes the geochemical composition of Neogene shales sampled from the Surma Group of the Bengal Basin. Core samples were taken from three petroleum exploration wells: Shahbazpur-1(SB), ShaldaNadi-1(SN) and Titas-11 (TT) (Fig.1). Tertiary-Recent shallow-marine to continental clastic sediments and some minor shelf carbonates in the Bengal Basin, Bangladesh are considered to represent the erosional detritus from a growing Himalayas to the north and the Indo-Burman ranges to the east (Uddin and Lundberg, 1999) (Fig.1). Miocene sediments of the Surma Group comprise the early to middle Miocene Bhuban Formation and the middle to late Miocene Boka Bil Formation. The Neogene Surma Group sediments have been selected because the huge pile of Neogene sediments (~4 km) comprising interbedded mudrocks and sandstones record uplift and exhumation history of Himalaya and Indo-Burman Ranges. Moreover, the bulk of the deltaic deposits are Miocene and younger (Fig. 2). These thick accumulations of interbedded mudstones and sandstones were deposited during repeated transgression and regression and hydrocarbons (oil and gas) discovered so far in the Bengal Basin have been located in the Neogene Surma Group.

The sandstone framework components of the subsurface Neogene Surma Group are dominantly quartzolithic and a more quartzose one although some sandstones are quartzofeldspathic and quartzarenites with abundant sedimentary and low-grade metamorphic grains, but lesser amounts of feldspars and volcanic constituents (Rahman, 1999), which are diagnostic of a quartzose recycled orogen province (sensu Dickinson, 1985). The geochemistry of the shales is of similar importance, because such studies can give information about the provenance, tectonic setting and weathering history of the source rocks. Bhatia (1985) differentiated four major tectonic provinces of mud rocks (oceanic island arc, continental island arc, active continental margin, passive margin) on the basis of trace element geochemical parameters. Roser and Korsch (1986) used the ratio of K_2O/Na_2O and SiO_2 content of published data from ancient sedimentary suites to refine passive margin (PM), active continental margin (ACM) and oceanic island arc (ARC) settings. For sandstones and argillites of selected New Zealand terranes, Roser and Korsch (1988) used a discriminant function analysis of major elements TiO_2, Al_2O_3 Fe_2O_3 tot., MgO, CaO, Na_2O and K_2O in discriminating four different provenance groups: (1) mafic, (2) intermediate-dominantly andesitic detritus, (3) felsic - and plutonic and volcanic detritus and (4) recycled-mature polycyclic quartzose detritus from sandstones and argillites of selected New Zealand terranes.

Elements La, Ce, Nd, Y, Th, Zr, Hf, Nb, Ti and Sc are most suited for provenance and tectonic setting determinations because of their relatively low mobility during sedimentary processes and their low residence time in sea water (Holland, 1978). These elements are transported quantitatively into clastic sedimentary rocks during weathering and transportation, reflecting the composition of long-eroded source rocks (review by Bhatia and Crook, 1986), and thus is an invaluable tool in sediment source evolution. In this study, mudrocks were sampled because of growing interest on mudrock geochemistry. The earlier work (Rahman and Faupl, 2003) demonstrated that the shales were of geochemical interest for provenance and source weathering of this thick accumulation of the Bengal Basin sediments. It is common that sandstones in a given sequence have lower CIA (Chemical Index of alteration) indices than interbedded muds, as sands typically contain more feldspar, whereas muds contain more of the clay weathering products. In this situation, the CIA ratios in the mudrocks are a more accurate measure of the intensity of source weathering. In a previous study, Rahman and Faupl (2003) reported the composition of Neogene shales from the Surma group in the Sylhet Trough (north-eastern part of Bengal Basin) based on major and trace element geochemistry. This study builds on the earlier work by adding samples from the eastern, central and southern parts of the Bengal Basin. In this study, REE has added to major and trace elements composition. These new results will give a more complete image of Bengal Basin Neogene shale geochemistry and thus their provenance and weathering signatures.

2. Geological setting

The Bengal Basin had its origin during the collision of India with Eurasia and Burma, building the extensive Himalayan and Indo-Burman Ranges and thereby loading the lithosphere to form flanking sedimentary basins (Uddin and Lundberg, 1998).The Bengal basin is well known for the development of a thick (±22km) Early Cretaceous-Holocene sedimentary succession (Curray, 1991a; Curray and Munasinghe, 1991). The Cretaceous to Holocene Bengal basin forms a “remnant

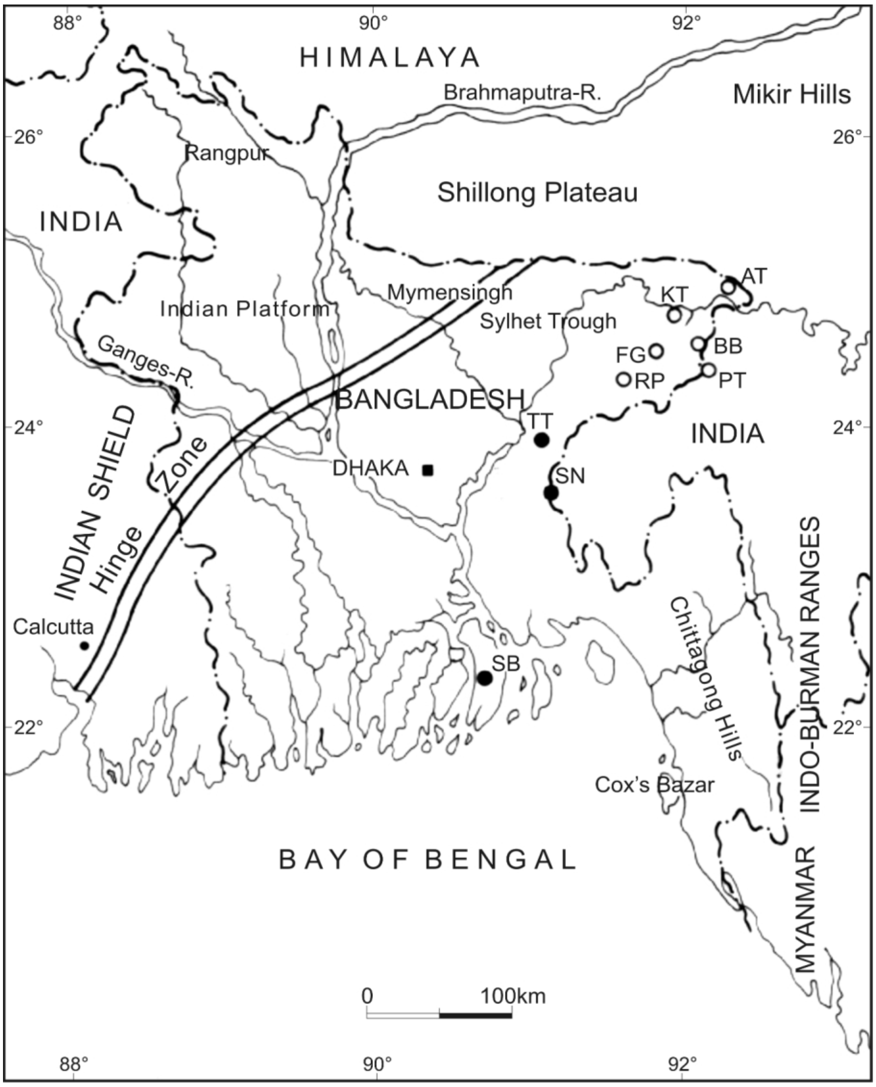

Figure 1: Major tectonic elements of the Bengal Basin (after Uddin and Lundberg, 1999); The map also shows the locations of petroleum exploration wells (●) from which cores of Neogene shales from the Surma Group were analyzed in this study. Symbol (○) shows the petroleum exploration wells in the Sylhet Trough (northeastern Bengal Basin).

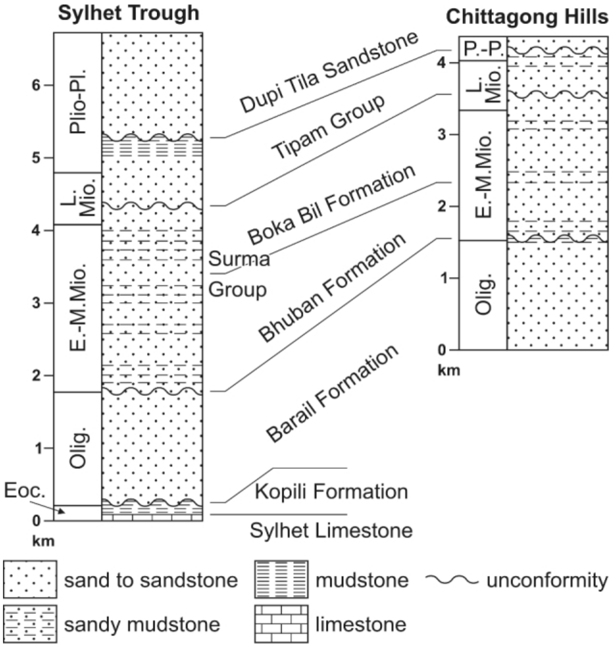

FIGURE 2: Stratigraphic framework of the north-east and south-east Bengal Basin (after Uddin and Lundberg,1999).

ocean basin” (Mitchell and Reading, 1986) at the juncture of the Indian plate and the Burma plate (Curray et al., 1982). The Bengal Basin lies on the north-eastern part of the Indian subcontinent, between the Indian Shield to the west and north, and the Indo-Burman Ranges to the east, occupies most of Bangladesh, parts of West Bengal and Tripura states of India and the Bay of Bengal (Alam et al., 2003).

Sedimentation in the Bengal Basin has been controlled by the movement of the Indian plate with the Burmese plate and Tibetan plates and by the uplift and erosion of the Himalayas and Indo-Burmese mountain ranges (Alam, 1989). The onshore part of the Bengal Basin has been divided into platform or shelf, slope or ‘hinge’, and basinal facies (Fig.1) (Evans, 1964; Salt et al., 1986). The Bengal Basin of Bangladesh includes one of the largest delta complexes in the world, covering an area of more than 200,000 km^2 and it is filled mainly by orogenic sediments derived from the eastern Himalayas to the north and the Indo-Burman ranges to the east (Uddin and Lundberg, 1999) (Fig.1). These deposits record uplift and exhumation of mountain belts formed by the ongoing India-Eurasia collision (Uddin and Lundberg, 1999). The bulk of the deltaic deposits are Miocene and younger (Fig. 2). Miocene sediments of the Surma Group comprises Early to Middle Miocene Bhuban Formation and the Middle to Late Miocene Boka Bil Formation making up thick accumulations of mudstone and quartzolithic sandstones derived from neighbouring orogenic belts and was deposited following repeated transgressions and regressions. The Neogene Surma Group sediments reach ≥4 km thick in the eastern fold belts and the deeper part of the basin (Uddin and Lundberg, 1999).

3. METHODS

Fifteen shale samples from the Neogene Surma group encountered in three petroleum exploration wells (4 from Shahbazpur-1, 6 from Shalda Nadi-1, and 5 from Titas-11) in the Bengal Basin, Bangladesh were analyzed for major, trace and rare earth elements at the Activation Laboratories Ltd., (Code: 4Lithoresearch) Ontario, Canada. Major elements were analy-

Sample	Depth (m)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3(T)	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
SB-1	997-1006	57,95	0,94	17,18	8,8	0,06	3,34	0,61	1,46	3,32	0,13	5,94	99,73
SB-1(A)	997-1006	59,52	0,77	15,91	6,67	0,10	2,54	0,84	1,55	3,25	0,15	7,84	99,14
SB-3	2016	65,82	0,76	13,64	5,68	0,06	2,42	1,99	1,71	2,79	0,14	4,75	99,77
SB-5	3020-3021	69,42	0,70	12,64	5,49	0,04	2,42	0,96	1,7	2,62	0,13	4,02	99,93
SN-1	1277.5-1278.5	59,97	0,824	15,94	6,51	0,103	2,68	1,53	1,45	3,19	0,15	7,02	99,36
SN-1 A	1282.5-1283.5	59,6	0,78	16,28	6,52	0,10	2,66	1,32	1,5	3,11	0,15	7,01	99,01
SN-1 B	1285.5-1286.5	60,6	0,83	15,64	6,37	0,10	2,69	1,44	1,49	3,1	0,16	6,77	99,19
SN-2	1570.9-1571.9	59,42	0,814	16,09	6,44	0,09	2,64	2,09	1,39	3,12	0,14	7,5	99,72
SN- 2A	1575.9-1576.9	57,97	0,736	14,54	6,19	0,253	2,45	4,59	1,32	2,91	0,16	8,8	99,92
SN-5	2313-2314	59,8	0,91	16,28	7,84	0,07	2,56	0,93	1,56	2,98	0,13	5,69	98,77
TT-2	2318.3-2318.9	60,81	0,78	15	7,53	0,06	2,76	1,69	1,39	2,96	0,12	6,58	99,67
TT-3	2716.2-2716.8	63,21	0,88	15,82	6,38	0,08	2,19	0,56	1,47	2,94	0,13	6,17	99,82
TT-3A	2717-2718	60,7	0,88	17,04	6,76	0,07	2,37	0,49	1,48	3,19	0,12	6,74	99,83
TT-4	2736.9-2737.8	55,78	0,94	19,41	7,98	0,07	2,79	0,48	1,36	3,37	0,11	7,54	99,83
TT-5	2785.4-2786.3	63,35	0,83	15,51	6,47	0,08	2,43	0,98	1,46	2,95	0,13	5,89	100,1
	Average	**60,93**	**0,82**	**15,79**	**6,78**	**0,09**	**2,60**	**1,37**	**1,49**	**3,05**	**0,14**	**6,55**	**99,59**

	SB-1	SB-1(A)	SB-3	SB-5	SN-1	SN-1 A	SN-1 B	SN-2	SN- 2A	SN-5	TT-2	TT-3	TT-3A	TT-4	TT-5
K_2O/Na_2O	2,3	2,1	1,6	1,5	1,9	2,2	2,2	2,1	2,2	2,1	2,1	2,0	2,2	2,5	2,0
Na_2O/K_2O	0,4	0,5	0,6	0,6	0,5	0,5	0,4	0,5	0,5	0,5	0,5	0,5	0,5	0,4	0,5
Fe_2O_3+MgO	12,14	4,09	8,10	7,91	10,40	8,64	9,08	9,06	9,19	9,18	10,29	8,57	9,13	10,77	8,90
SiO_2/Al_2O_3	3,4	3,7	4,8	5,5	3,7	4,0	3,7	3,9	3,8	3,7	4,1	4,0	3,6	2,9	4,1
Al_2O_3/TiO_2	18,2	20,6	17,9	18,2	17,8	19,8	19,8	18,8	19,3	20,9	19,3	18,1	19,5	20,8	18,7

TABLE 1: Table1 Chemical composition of the Neogene shales from the Surma Group encountered in three petroleum exploration wells in the

zed by lithium metaborate/tetraborate fusion Inductively Coupled Plasma (ICP) and trace and rare earth elements (REE) by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

4. Results

The results of major, trace and rare earth elements of the Neogene shales from the Surma Group encountered in different wells are presented in Table 1.

4.1 Major elements

The SiO_2 content varies from 55.78 to 69.42 wt%, TiO_2 content from 0.70 to 0.94 wt%, the Al_2O_3 content from 14.54 to 19.41wt%, and the Fe2O3 content ranges from 5.49 to 8.80 wt%. The CaO content is low (0.48-4.59 wt%; av. 1.37 wt %).

Trace element (ppm)

		Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Sn	Sb	Cs	Ba	La
SB-1	997-1006	21	3	135	110	21	50	20	80	24	161	124	32,2	252	17,1	4	1	12,6	486	49,3
SB-1(A)	997-1006	17	3	111	110	16	80	30	90	21	161	117	31,4	160	14,3	4	1,2	11,4	453	40,9
SB-3	2016	14	2	93	80	13	20	20	80	18	126	131	29,8	240	13,9	3	1,5	7,8	438	40
SB-5	3020-3021	12	2	81	100	13	30	20	70	17	124	120	29,9	222	13,4	3	1,4	8,1	417	39,1
SN-1	1277.5-1278.5	17	3	109	90	20	40	30	90	22	157	131	33,3	176	16,2	4	1,4	11,1	478	45,8
SN-1 A	1282.5-1283.5	18	3	114	100	16	40	30	80	23	161	135	32,9	248	17,7	3	1	9,4	476	49,3
SN-1 B	1285.5-1286.5	16	3	110	100	16	30	30	260	22	154	132	34	188	16,7	5	1,4	10,8	513	46,3
SN-2	1570.9-1571.9	17	3	110	90	17	40	30	80	22	157	118	31,1	176	16,2	4	1,4	11,1	478	45,8
SN- 2A	1575.9-1576.9	15	3	96	90	15	40	30	70	20	147	137	30,7	168	16,1	4	1,5	11,4	581	43,9
SN-5	2313-2314	20	3	122	100	17	40	20	70	24	146	114	39,4	248	17,7	3	1	9,4	476	49,3
TT-2	2318.3-2318.9	17	3	106	90	16	40	460	550	21	143	106	33,4	216	15,8	3	1,9	9,5	456	47,2
TT-3	2716.2-2716.8	17	2	108	110	15	40	70	140	20	141	128	33,5	247	16,3	4	1,2	10,1	456	45,2
TT-3A	2717-2718	18	3	118	110	17	50	30	90	23	162	132	33,5	203	17	4	1,3	12,2	539	47
TT-4	2736.9-2737.8	21	3	137	120	20	50	40	110	27	182	142	32	160	17,8	4	1,5	15,5	497	45,9
TT-5	2785.4-2786.3	16	3	103	90	17	40	30	100	21	148	132	33,5	203	16,1	4	1,8	10,6	495	44,2
	Average	**17**	**3**	**110**	**99**	**17**	**42**	**59**	**131**	**22**	**151**	**127**	**33**	**207**	**16**	**4**	**1**	**11**	**483**	**45**

Trace element (ppm) (cont.)

		Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Tl	Pb	Th	U
SB-1	997-1006	96,7	11	36,6	7,08	1,33	5,56	1	5,54	1,13	3,56	0,56	3,46	0,5	7,1	1,46	0,72	18	19	3,56
SB-1(A)	997-1006	84,2	9,74	33,6	6,8	1,37	5,69	1,01	5,44	1,1	3,35	0,5	3	0,42	4,8	1,28	0,89	28	18,8	3,16
SB-3	2016	83	9,52	32,9	6,74	1,34	5,39	0,96	5,06	1,03	3,17	0,46	2,86	0,41	6,8	1,22	0,71	18	16,4	3,06
SB-5	3020-3021	80,4	9,45	31,9	6,54	1,33	5,37	0,95	5,1	1,03	3,14	0,46	2,76	0,41	6,5	1,14	0,66	22	15,5	2,65
SN-1	1277.5-1278.5	90	10,5	36,3	7,38	1,51	6,3	1,1	5,83	1,16	3,34	0,51	3,2	0,45	5,5	1,28	0,84	27	18,1	3,04
SN-1 A	1282.5-1283.5	95	11	38,2	7,74	1,57	6,61	1,19	6,63	1,34	4,04	0,63	3,97	0,55	7,5	1,42	0,66	16	18,4	3,23
SN-1 B	1285.5-1286.5	93,1	10,8	37,5	7,51	1,55	6,36	1,14	5,9	1,16	3,39	0,51	3,21	0,45	5,9	1,32	0,85	28	19,4	3,29
SN-2	1570.9-1571.9	90	10,5	36,3	7,38	1,51	6,3	1,1	5,83	1,16	3,34	0,51	3,2	0,45	5,5	1,28	0,84	27	18,1	3,04
SN- 2A	1575.9-1576.9	87,3	10,2	35,2	7,2	1,52	6,19	1,09	5,63	1,11	3,2	0,49	3,06	0,43	5,2	1,24	0,87	27	17,6	2,92
SN-5	2313-2314	95	11	38,2	7,74	1,57	6,61	1,19	6,63	1,34	4,04	0,63	3,97	0,55	7,5	1,42	0,66	16	18,4	3,23
TT-2	2318.3-2318.9	93,5	11	37,9	7,66	1,49	6,54	1,14	5,91	1,17	3,42	0,52	3,26	0,46	6,6	1,26	0,85	72	18	3,18
TT-3	2716.2-2716.8	90,5	10,7	37,3	7,49	1,59	6,46	1,1	5,91	1,16	3,36	0,51	3,15	0,44	7	1,24	0,76	28	17,4	2,97
TT-3A	2717-2718	93,6	10,9	38,2	7,88	1,64	6,52	1,13	5,96	1,14	3,38	0,51	3,2	0,45	6,1	1,29	0,84	27	17,8	2,91
TT-4	2736.9-2737.8	89,9	10,6	36,9	7,21	1,56	6,08	1,06	5,43	1,09	3,21	0,52	3,17	0,45	4,9	1,33	0,92	35	19,2	2,89
TT-5	2785.4-2786.3	89,2	10,5	36,4	7,37	1,56	6,45	1,13	5,94	1,18	3,39	0,51	3,13	0,43	6,2	1,3	0,85	28	17,5	2,99
	Average	**90**	**10**	**36**	**7**	**1**	**6**	**1**	**6**	**1**	**3**	**1**	**3**	**0**	**6**	**1**	**1**	**28**	**18**	**3**

	SB-1	**SB-1(A)**	**SB-3**	**SB-5**	**SN-1**	**SN-1 A**	**SN-1 B**	**SN-2**	**SN- 2A**	**SN-5**	**TT-2**	**TT-3**	**TT-3A**	**TT-4**	**TT-5**
Eu/Eu*	0,65	0,67	0,68	0,69	0,67	0,68	0,69	0,69	0,68	0,70	0,64	0,70	0,70	0,72	0,69
(La/Lu)cn	10,30	10,04	10,03	10,02	9,39	10,43	10,95	10,68	10,54	10,67	10,58	10,57	10,82	10,64	10,80
La/Sc	2,35	2,41	2,86	3,26	2,47	2,64	2,61	2,89	2,69	2,44	2,78	2,66	2,61	2,19	2,76
Th/Sc	0,90	1,11	1,17	1,29	0,92	1,05	1,06	1,21	1,06	0,98	1,06	1,02	0,99	0,91	1,09
La/Co	2,35	2,56	3,08	3,01	2,90	2,64	2,61	2,89	2,29	2,74	2,95	3,01	2,76	2,30	2,60
Th/Co	0,90	1,18	1,26	1,19	1,08	1,05	1,06	1,21	0,91	1,10	1,13	1,16	1,05	0,96	1,03
Cr/Th	5,79	5,85	4,88	6,45	5,43	5,70	4,97	5,15	4,97	5,68	5,00	6,32	6,18	6,25	5,14
La/Th	2,59	2,18	2,44	2,52	2,68	2,51	2,45	2,39	2,53	2,49	2,62	2,60	2,64	2,39	2,53
Cr/Ni	2,2	1,4	4,0	3,3	2,5	2,3	2,3	3,3	2,3	2,5	2,3	2,8	2,2	2,4	2,3
La_N/Yb_N	9,63	9,21	9,45	9,57	8,39	9,49	9,87	9,75	9,67	9,69	9,78	9,70	9,93	9,78	9,54
ΣREE	**223**	**197**	**193**	**188**	**228**	**186**	**211**	**219**	**213**	**207**	**221**	**215**	**222**	**213**	**211**

Bengal Basin (For well locations see Fig.1). SB=Shahbazpur-1, SN=Shalda Nadi-1, TT=Titas-11; 1,2,3,4, 5….= core1, core2, core3, core4, core5

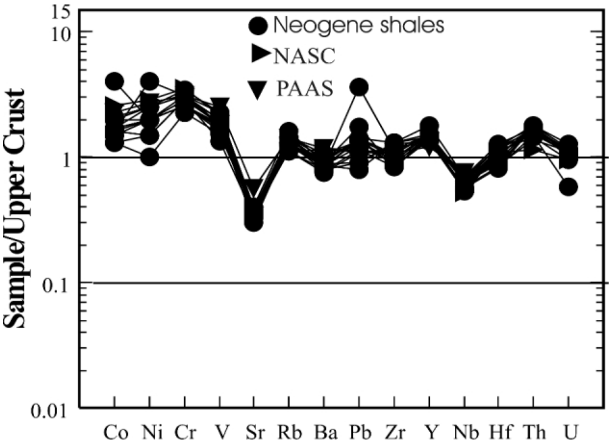

Figure 3: Multi-element normalized diagram for the Neogene shales against upper continental crust (Taylor and McLennan, 1985).

Mean major elemental composition of the Neogene shales of the Surma Group is in fair concurrence with that of the average shale described by Wedepohl (1971), NASC (North American Shale Composite, Gromer et al., 1984), UC (the upper crust, Taylor and McLennan, 1985) with the exception of the low content of CaO (Table 2) but compared with PASS (Post-Archaean Shale, Taylor and McLennan, 1985), the Neogene shales are little depleted in Al_2O_3 content. The SiO_2/Al_2O_3 ratios (~3.9) of the Neogene shales which is similar to that of PASS and NASC. But K_2O/Na_2O ratios for the Neogene shales are slightly lower than those of NASC (Gromer et al., 1984), PASS (Taylor and McLennan, 1985) but close to UC (Taylor and McLennan, 1985). The CaO depletion of the Neogene shales is related to the scarcity of calcic minerals (after Dabard, 1990) which is reflected partly in the low carbonate content (average 1.7 %) in the Neogene shales in the northeastern Bengal Basin (Sylhet Trough) (Rahman and Faupl, 2003). The Neogene shale samples show no clear difference in major chemical composition with burial depth. The negative correlation of SiO_2 with most major and trace elements is due to size sorting and quartz dilution during transport of these sediments. In the present samples, TiO_2 concentrations increase with Al_2O_3, suggesting that TiO_2 is probably associated with phyllosilicates especially with illite (after Dabard, 1990); Fe_2O_3+MgO are also well correlated with Al_2O_3. The latter correlation implies that these oxides are associated with phyllosilicates, particularly in matrix chlorites (after Dabard, 1990). X-ray diffraction patterns also reveal that Neogene shales of the Surma Group comprise illite-chlorite rich clay minerals.

4.2 TRACE ELEMENTS

Trace element concentrations of the Neogene shales of the Surma Group are compared with average upper continental crust (UCC), PASS and NASC. The Neogene shales are enriched in V (~110), Cr (~99), Co (~17), Ni (~42) and depleted in Sr in compared to UC but are in good agreement with those of the PASS and the NASC (Fig. 3). The trace element data of the Neogene shales show variations. The Neogene shales from the Sylhet Trough (northeastern Bengal Basin) are relatively rich in V (~136 ppm), Cr (~136 ppm) and Ni (~61ppm) content than those of the eastern, central and southern parts of the Bengal Basin. The behavior of trace elements during sedimentary processes is variable because of weathering, sorting, adsorption, provenance, diagenesis and metamorphism (review by Nyakairu and Koeberl, 2001).

Strontium and barium mostly reside in plagioclase and k-feldspar respectively (Puchett, 1972). Clear positive correlations between K contents and the abundances of Al, Cs, Ba, total REE, Th and U in the Neogene Surma Group shales suggest that concentrations of these trace elements are controlled by clay minerals and mica (after McLennan et al., 1983). A significant correlation between Ba and K_2O suggests that Ba is mainly associated with a feldspar component. High field strength elements (e.g., Zr, Nb, Hf, Y) generally show consistent inter-relationships. Also, ferromagnesian trace elements (Cr, Ni, V, Co, and Sc) in the Neogene Surma Group shales show strong inter-relationships. These trace element relationships illustrate the chemical coherence and uniformity of the sediments. The Co and Sc in the Neogene Surma group shales show significant positive correlation with Ni, V and Al_2O_3 inferring that for the Surma Group shales Co and Sc are partly controlled by chlorite and other accessory non-aluminous silicate minerals.

4.3 RARE EARTH ELEMENTS

REE concentrations of the Neogene shales from the Surma Group are shown as chondrite-normalized patterns in Figure 4. The Neogene shales show REE content ranging between 186-228 with an average of 208 which is above than of average UC (143, Tayler and McLenan,

Wt%	Bengal Basin(central, eastern and southern most part) (n=15)	Sylhet Trough (northeastern Bengal Basin) (n=20) (Rahman and Faupl, 2003)	NASC	PASS	Wedepohl	UC
SiO_2	60.93	60.01	64.80	62.80	58.9	66.00
TiO_2	0.82	0.88	0.70	1.00	0.78	0.50
Al_2O_3	15.79	17.14	16.90	18.90	16.7	15.20
Fe_2O_3	6.78	7.09	5.65	7.22	6.91	5.00
MnO	0.09	0.09	0.06	0.11	0.09	0.08
MgO	2.60	2.79	2.86	2.20	2.6	2.20
CaO	1.37	1.19	3.63	1.30	2.2	4.20
Na_2O	1.49	1.53	1.14	1.20	1.6	3.90
K_2O	3.05	3.24	3.97	3.70	3.6	3.40
P_2O_5	0.14	0.14	0.13	0.16	0.16	-
LOI	6.55	6.39		6.00	6.3	

Table 2: Average composition of the Neogene shales from the Surma Group in the Bengal basin and compared with those of PASS (Post-Archaean Shale, Taylor and McLennan, 1985), NASC (North American Shale Composite, Gromer et al., 1984), UC (Upper Crust, Taylor and McLennan, 1985) and Wedepohl (1971).

1985). Compared to UC and NASC, the REE concentrations of the samples are enriched but are in accordance with those of PASS. The Neogene shales have similar values of La_N/Yb_N (~9.6) and Eu/Eu*(~0.68) as compared to PASS (Taylor and McLennan, 1985) and UC. Despite the differences in the abundance, the samples show similar REE pattern as UC. The Neogene shales show slight LREE-enriched and relatively flat HREE patterns with negative Eu anomaly. The negative Eu anomalies are pronounced with Eu/Eu*=0.62-0.72.Eu anomalies are chiefly controlled by feldspars, particularly in felsic magmas (Rollinson, 1993; p. 138). The Eu anomaly parallels the depletion in Na_2O and CaO, suggesting that it developed at least partially in response to plagioclase weathering, where most of the Eu is hosted (Nyakairu and Koeberl, 2001).

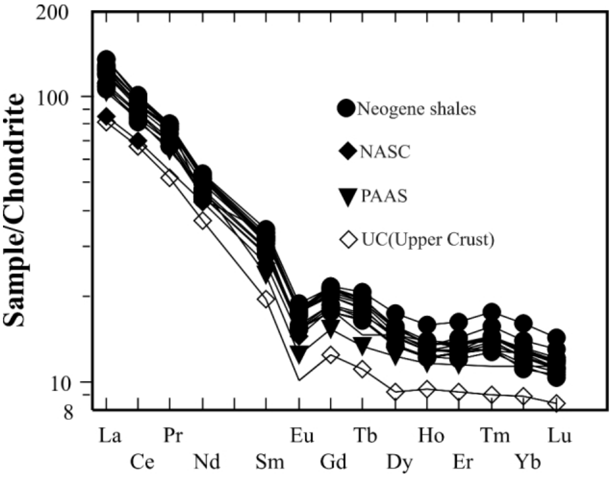

Figure 4: Chondrite-normalized rare earth element plots for the Neogene shales.

5. Discussion

5.1 Provenance and tectonic Setting

Several classification schemes have been proposed to discriminate from various origins and tectonic settings (Maynard et al., 1982; Bhatia, 1983, 1986; Roser and Korsch, 1986, 1988). The classification of Roser and Korsch (1988) is based on major element discriminant functions. Four provenance groups can be distinguished: mafic (P1: first-cycle basaltic and minor andesitic detritus); intermediate (P2: dominantly andesitic detritus); felsic (P3: acid plutonic and volcanic detritus); and recycled (P4: mature polycilic quartzose detritus. To infer provenance, unstandardised discriminant function scores of the samples (F1 and F2) for major elements (after Roser and Korsch, 1988) were plotted following the boundaries between fields (P1-P4), as proposed by Roser and Korsch (1988) (Fig. 5). Most of the shales of the Surma Group of the Bengal Basin are located within the P4 field, which represents a recycled mature polycyclic quartzose detritus. Recycled sources represent quartzose sediments of mature continental provenance and the derivation of the sediments could be from a highly weathered granite-gneiss terrain and/or from a preexisting sedimentary terrane as in the case of the Greenland Group of New Zealand (Roser and Korsch, 1988). SiO_2 content and the ratio of K_2O/Na_2O of the samples (Fig. 6) were used to decipher their tectonic setting (Roser and Korsch, 1986). All the data points plot into the active continental margin field.

The shales of the Surma Group of the Bengal Basin were derived from an active margin setting related to recycled sources (after Roser and Korsch, 1986, 1988). The recycled nature of the provenance area of the Neogene Surma Group is also reflected in the sandstone composition.

Bhatia (1985) suggested that immobile trace elements (e.g. La, Th, Nb, Y, Zr, Sc) preserve the signatures of source rocks and tectonic setting in mudrocks. He differentiated four major tectonic provenances on the basis of Th, U, Nb, La, Cr, Ni concentrations and on the ratio of Th/U, Zr/Th, Zr/Nb, Nb/Y, La/Sc, Sc/Ni, Rb/Sr and Ba/Sr. Based on Bhatia's (1985) model, the trace elements of the samples suggest diverse tectonic setting ranging from continental island arc to active continental margin to passive margin (Table 3). The content of Nb and La concentrations and the ratio of Zr/Nb, La/Sc can be approximately compared with that of an active margin setting. The Cr and Ni concentrations seem to be more comparable with those of passive margin, whereas the ratios of Rb/Sr and Ba/Sr are closer to a continental island arc. McCann (1991) found that the specified trace elements pertaining to tectonic settings of Bhatia (1985) were not definitive for all four tectonic settings. According to Bhatia (1985), the active continental and passive margin mudrocks are discriminated from other mudrocks by their significantly higher Th, Nb and Nb/Y, and lower Zr/Th and Zr/Nb ratio. The active continental

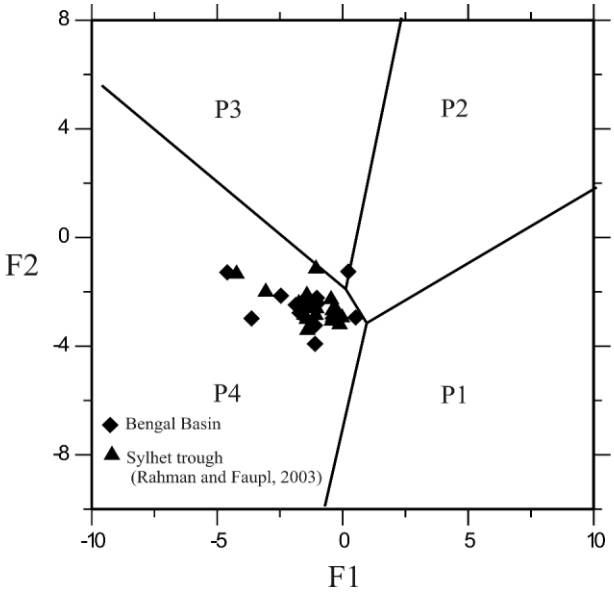

Figure 5: Plot of discriminant functions F1 and F2 for the shales from the Neogene Surma Group of the Bengal Basin. Provenance fields are after Roser and Korsch (1988). P1 = mafic and lesser intermediate igneous provenance; P2 = intermediate igneous provenance; P3 = felsic igneous provenance and P4 = recycled-mature polycyclic quartzose detritus.

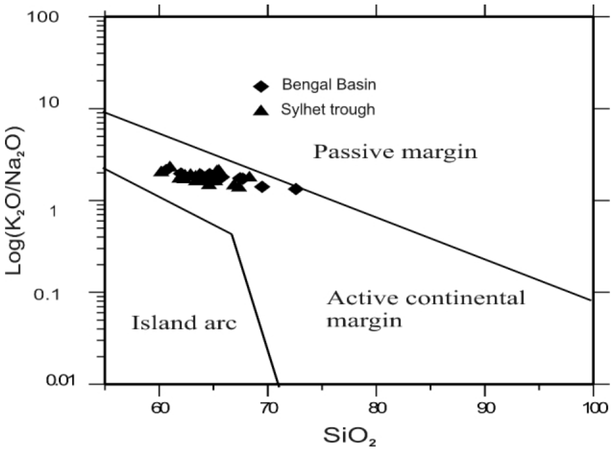

Figure 6: Tectonic discrimination diagram for shales from the Neogene Surma Group of the Bengal Basin. Boundaries are after Roser and Korsch (1986).

and passive margin mudrocks are similar in most immobile trace elements, and may be distinguished from each other by higher Rb/Sr, Ba/Sr and higher Cr and Ni abundance for the passive margin setting. The increase in the Cr and Ni abundance for passive margin mudrocks is due to the enrichment and adsorption of these elements with the increased phyllosilicate content. Decreasing in Rb/Sr and Ba/Sr is due to the loss of Sr and feldspar with increasing weathering and recycling (Bhatia, 1985).

The concentrations of Rb (mean ~151 ppm), Sr (~127), Sm (~7.0) and Nd (~36) of the Neogene Surma Group shales in the Bengal Basin are in accordance with those of High Himalaya sedimentary series (France-Lanord, 1993).

The high-field-strength elements (HFSE) such as Zr, Nb, Hf, Y, Th, and U are preferentially portioned into melts during crystallization (Feng and Kerrich, 1990), and as a result these elements are enriched in felsic rather than mafic sources. These elements are thought to reflect provenance compositions as a consequence of their generally immobile behavior (Taylor and McLennan, 1985). REE, Th and Sc are quite useful for inferring crustal compositions, because their distribution is not significantly affected by diagenesis and metamorphism and is less affected by heavy mineral fractionation than that for elements such as Zr, Hf, and Sn (Review by Armstrong-altrin, J.S. et al., 2004). REE and Th abundances are higher in felsic than in mafic igneous source rocks and in their weathered products, whereas Co, Sc, and Cr are more concentrated in mafic than in felsic igneous rocks and in their weathered products. The ratios such as Eu/Eu*, (La/Lu)cn, La/Sc, Th/Sc, La/Co, Th/Co, and Cr/Th are significantly different in mafic and felsic source rocks and can therefore provide information about the provenance of sedimentary rocks (Review by Armstrong-altrin, J.S. et al., 2004). In this study, Eu/Eu*, (La/Lu)cn, La/Sc, Th/Sc, La/Co, Th/Co, and Cr/Th values of the Neogene Surma Group shales are similar to the values for sediments derived from felsic source rocks than those for mafic source rocks (Table 4), suggesting that these shales were likely derived from felsic source rocks. On Sc-Th scatter diagram (Fig. 7), most of the shale samples plot in the field of felsic composition although few samples occupy a field that bears the characteristics of intermediate composition. The higher LREE/HREE ratios and negative Eu anomalies of the Surma Group shales also bears the characteristics of felsic source rocks (after Taylor and McLennan 1985; Wronkiewicz and Condie, 1989). The ferromagnesian trace elements Cr, Ni, Co, and V show generally similar behavior in magmatic processes, but they may be fractionated during weathering (Feng and Kerrich, 1990). In the studied samples, Cr and Ni are enriched with respect to the average composition of the Upper continental crust (UCC). This enrichment in Cr and Ni may suggest some basic input from the source terrane.

Garver et al. (1996) suggested that elevated Cr (>150 ppm) and Ni (>100 ppm) and a ratio of Cr/Ni between 1.3 - 1.5 are diagnostic of ultramafic rocks in the source region. In comparison, Cr concentrations ranges from 80 to 120 ppm (average 99 ppm) and Ni concentrations ranges from 20 to 80 ppm (average 42 ppm) and Cr/Ni ratios range from 1.3 to 4.0, but mostly above 2.0. This comparison suggests that the existence of huge complexes of mafic/ultramafic rocks were most unlikely in the source region. The occurrence of lower amounts of detrital chrome spinel within the sandstones of the Surma Group, as revealed from heavy mineral data, is in good agreement with this finding. The derivation from the Indo-Burman Ranges could also be possible in part, e.g. ophiolitic detritus could

Element	Bengal Basin	Sylhet Trough	OIA	CIA	ACM	PM
Nb	16	13	3.7	9	16.5	15.8
Zr/Nb	14.7	15	38	21	11	10
Nb/Y	0.5	0.43	0.17	0.35	0.5	0.54
Rb/Sr	1.3	1.29	0.29	1.31	2.9	5.8
Th	18	-	5.5	16.2	28.0	22.0
Zr/Th	13.3	-	28.0	12.0	7.0	7.0
Ba/Sr	3.9	4.3	2.5	6.3	8.7	17.6
Cr	99	137	39	55	58	100
Ni	42	62	15	18	26	36
La	45	47	18	24	42	34
La/Sc	2.3	2.2	1	1.8	2.5	1.9
Sc/Ni	0.4	0.34	1.7	0.96	0.75	0.45

Table 3: Trace element geochemical parameters for the Neogene shales (n = 15) from the Bengal Basin; (n = 19) from the Sylhet Trough (north-eastern Bengal Basin (Rahman and Faupl, 2003) and values for trace element characters of mudrocks from OIA (Oceanic Island Arc), CIA (Continental Island Arc), ACM (Active Continental Margin) and PM (Passive Margin) after Bhatia (1985).

be derived from the suture zone of the Indo-Burman Ranges as it was suggested by Uddin and Lundberg (1998).

5.2 Weathering in the Source Area

In deciphering the weathering history of sedimentary rocks, Nesbitt and Young (1982) proposed the CIA value (Chemical Index of Alteration) using molecular proportion of some bulk elements. The chemical index of alteration (CIA) monitors the progressive alteration of plagioclase and potassium feldspars to clay minerals. The CIA value was calculated using the equation CIA= $[Al_2O_3/ (Al_2O_3+CaO^*+Na_2O+K_2O)]*100$, where CaO* represents the amount of CaO incorporated in the silicate phases. High values (i.e.76-100) indicate intensive chemical weathering in the source areas whereas low values (i.e., 50 or less) indicate unweathered source areas. CIA values for the Neogene Surma Group shales vary from 52 to 78 with an average 68 indicating significant weathering at the source areas. The obtained average CIA value (~68) is higher than that of the CIA value (50) of upper continental crust. The calculated CIA values for the Neogene Surma Group shales are very much similar to the CIA values of the Yamuna River System sediments in the Himalaya (~51 to 69; average ~60) (Dalai et al., 2002a). The CIA values are also plotted in Al_2O_3-(CaO^*+Na_2O)-K_2O (A-CN-K) diagram (Fig. 8). The obtained CIA values are indicative of the weathered nature of some of the minerals incorporated in shales. From the relation, $Na_2O/K_2O<1$, the shales seem to be mature.

Th/U in sedimentary rocks is of interest as weathering and recycling typically result in loss of U, leading to an elevation in the Th/U ratio. The Th/U ratio in most upper crustal rocks is typically between 3.5 and 4.0 (McLennan et al., 1993). In sedimentary rocks, Th/U values higher than 4.0 may indicate intense weathering in source areas or sediment recycling. The Th/U ratios in the Neogene Surma Group shales range from 5.3 to 6.6, with an average of 5.9, indicating the derivation of these sediments from the recycling of the crust. The Th/U versus Th plot for the Neogene Surma group shales (Fig. 9) shows a typical distribution similar to the average values of fine-grained sedimentary rocks reported by Taylor and McLennan (1985) and follows the normal weathering trend (McLennan et al., 1993). It is most likely that the sources for the Neogene Surma Group sediments were recycled sediments and have undergone significant weathering. The presence of plagioclase (~9%) in the shales (Rahman and Faupl, 2003) may indicate insignificant chemical weathering during sedimentation in the basin (Einsele, 1992, p. 364), whereas the CIA values of shales are indicative of the significant weathering in their source. The occurrence of high quartz, little amounts of feldspar of the sandstones as well as illite and chlorite rich clay assemblages of the shales (Rahman and Faupl, 2003) indicates that minerals are predominantly detrital and reflect their source material character (after Weaver, 1958). The huge pile up of interbedded sandstones and mudrocks could have been result from rapid erosion of fast rising Himalayas and Indo-Burman Ranges. The presence of granitic plutons, Mesozoic flysch deposits, ophiolite rocks, and Tertiary molasse sediments are common in the Eastern Himalayan structural belt (Gansser, 1964). In the Indo-Burman Ranges, thick Eocene to Oligocene turbidite successions and Upper Miocene to Pleistocene molasse sediments (Uddin and Lundberg, 1998) are the significant rocks successions. The low temperature Ar-Ar ages of detrital white mica from the Neogene sandstones of Surma Group are diagnostic of the youngest cooling events which can be corelated with early cooling ages from High Himalayan Crystalline rocks (Rahman and Faupl, 2003). Based on sand petrography and lithofacies maps, it is suggested that the Miocene sediments were transported from the immediate east, inclu-

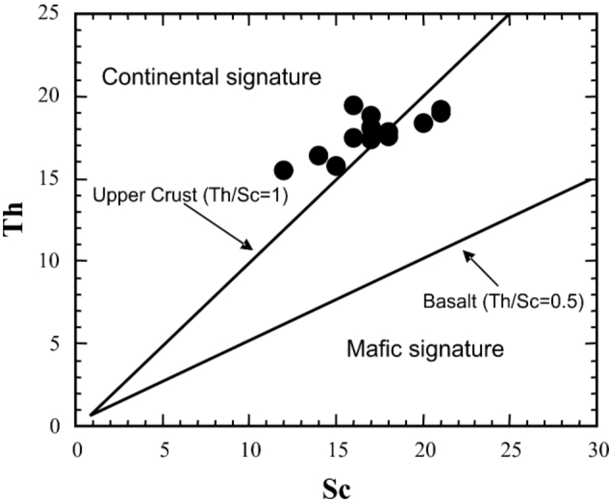

Figure 7: Sc-Th plot for Neogene shales of the Surma Group.

Elemental Ratio	Range of the Neogene shales from the Surma Group, Bengal Basin	Range of sediment from felsic sources[2]	Range of sediment from mafic sources[2]	Upper Continental Crust[3]
Eu/Eu*	0.62-0.72	0.40-0.94	0.71-0.95	0.63
La/Lu)cn	9.39-10.95	3.00-27.0	1.10-7.00	9.73
La/Sc	2.19-3.26	2.50-16.3	0.43-0.86	2.21
Th/Sc	0.90-1.29	0.84-20.5	0.05-0.22	0.79
La/Co	2.29-3.08	1.80-13.8	0.14-0.38	1.76
Th/Co	0.90-1.26	0.04-3.25	0.04-1.40	0.63
Cr/Th	4.88-6.45	4.00-15.0	25-500	7.76

[2] Cullers (1994, 2000); Cullers and Podkovyrov (2000); Cullers et al. (1998)
[3] McLennan (2001); Taylor and McLennan (1985)

Table 4: Range of elemental ratios of the Neogene shales of the Surma Group in this study compared to the similar elemental ratios derived from felsic rocks, mafic rocks, and upper continental crust.

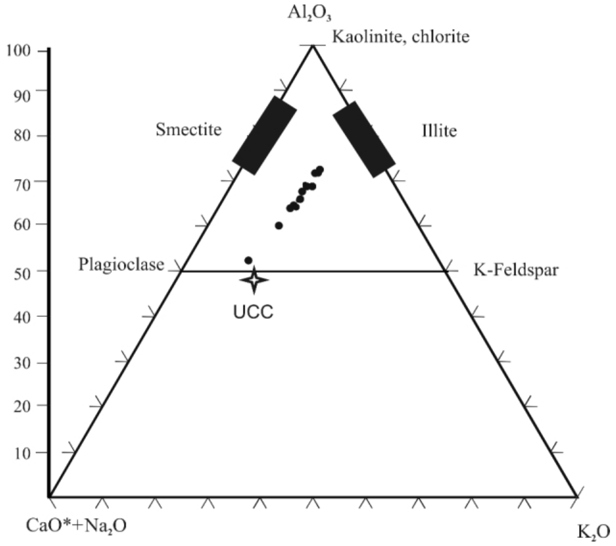

Figure 8: CIA ternary diagram, Al_2O_3-CaO^*+Na_2O-K_2O (after Nesbit and Young, 1982); CaO* = CaO in silicate phase.

ding the Indo-Burman Ranges as well and yield a clear record of unroofing of the eastern Himalaya/Indo-Burman Ranges (Uddin and Lundberg, 1998, 1999).

It is most likely that Himalayan terrain, particularly Eastern Himalaya could be recognized as the principal source area of the Neogene Surma Group sediments of the Bengal Basin. Recycled sediment material from the flysch successions of the Indo-Burman Ranges could also be mixed with the sediments of Himalayan origin within the deltaic system.

6. Conclusions

Mean major elemental composition of the Neogene shales of the Surma Group is consistent with that of the average shale described by Wedepohl (1971), NASC (North American Shale Composite, Gromer et al., 1984), UC (the upper crust, Taylor and McLennan, 1985) with the exception of the low content of CaO (1.37 wt%) but compared with PASS (Post-Archaean Shale, Taylor and McLennan, 1985), the Neogene shales are little depleted with Al_2O_3 content. The Neogene shales are enriched with V, Cr, Co, Ni and are depleted in Sr in compared to UC but are in agreement with those of PASS and NASC. Eu/Eu*, (La/Lu)cn, La/Sc, Th/Sc, La/Co, Th/Co and Cr/Th ratios and the higher concentrations of the REE and REE patterns indicate the derivation of these shaless from felsic source rocks. The existence of huge complexes of mafic/ultramafic rocks was most unlikely in the source region. The CIA values for the Neogene shales from the Surma Group vary from 52 to 78 with an average 68 indicating significant weathering at the source areas.

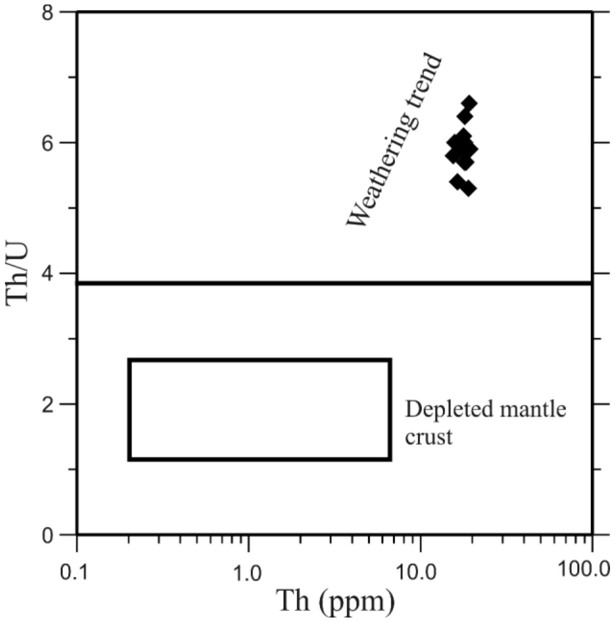

Figure 9: Plots of Th/U versus Th (after McLennan et al., 1993).

The geochemical characteristics suggest the active continental margin setting for the Neogene Surma Group shales and preserve the signatures of recycled provenance field that have undergone significant degrees of weathering. Having identified the sources as recycled detritus, the source region such as the most of the Himalayan rocks are made of recycled material and hence it could be a dominant supplier. Recycled sediment material from the flysch successions of the Indo-Burman Ranges could also be mixed with the sediments of Himalayan origin within the deltaic system.

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