Source Rock Characteristics And Depositional Environments Of The Basal Part Of Tura Formation In Parts Of Upper Assam Basin: Insights From Petrography And Whole Rock Geochemistry

Nishanta Sahariah Pramathesh Bhattacharyya

Abstract: The Tura Formation of Early Eocene age, is the oldest sedimentary sequence in the Assam shelf and unconformably overlies Precambrian granitic basement. Although sedimentological studies including reservoir properties of the Tura Formation have been carried out by some workers, very few reports on the detailed portray of source area and tectonic setting have been constrained. This paper deals with the petrography and geochemical characteristics of a few borehole samples of Tura Formation belonging to both North and South Assam Shelf of Upper Assam Basin to trace their nature of source rock and depositional setting. Based on the modal analysis, the Tura sandstones are classified as quartz arenite, sublitharenite and lithic greywacke types. Plots of the recalculated composition of detrital constituents of these sandstone samples in tectonic setting discrimination diagrams suggest derivation from recycled orogenic provenance. Geochemical classification of the sandstone samples shows mostly wacke type and provenance discrimination plots of sediments based on major oxides depict that the sandstone of Tura Formation was derived from quartzose sedimentary rock source. The tectonic discrimination diagrams suggest both passive and active continental marginal setting for the sandstone. The chondrite normalized REE pattern of the samples is equivalent to the upper continental crust, which reflects enriched LREE and depleted HREE with negative Eu anomaly. The Eu/Eu* (~ 0.73), La/Sc (~ 4.99), Th/Sc (~ 2.49), La/Co (~ 9.34), Th/Co (~ 4.55) and Cr/Th (~ 6.06) ratios indicate derivation of the Tura Sandstones from felsic rock source. Furthermore, K2O/Rb and TiO2/Zr binary plots also suggest felsic igneous source rock for the Tura Formation.The geochemical parameters such as U, authigenic U, U/Th, V/Cr, Ni/Co and Cu/Zn ratios support the deposition of these sandstones take place under an oxic environment.

Keywords : Tura Formation, Provenance, Depostional setting, Oxic environment, Whole rock geochemistry

1. INTRODUCTION :

Upper Assam Basin is essentially a Tertiary basin, although some pre – Tertiary sediments are reported from parts of Assam Shelf (Barpathar, Jamuguri, East Lakhibari, Furkating etc.). The basin formation was initiated in the Early to Late Cretaceous due to rifting and drifting of the Indian plate from the Indo – African – Antarctic Continent. Pre – Tertiary sediments were reported in the Assam – Arakan Basin as the Dergaon Group (Deshpande et al., 1993). During Palaeocene – Eocene, continued northward drifting of the Indian plate resulted in initiation of subduction of the oceanic part of the Indian plate below the Burmese plate in the east. This caused the formation of the Indo – Burmese trench system east of the Assam Shelf. The present day Upper Assam Shelf probably experienced continental set up (Naik et al., 2004).Lithology of Tura Formation has been described as coarse grained sandstone with shale and carbonaceous shale with some kaolinitic clay bands (Deshpande et al., 1993).

- *Nishanta Sahariah, Department of Applied Geology, Dibrugarh University, Dibrugarh – 786004, Email id : nishantasahariahns21@gmail.com*
- *Pramathesh Bhattacharyya, Department of Applied Geology, Dibrugarh University, Dibrugarh – 786004, Email id : pbappgeol@gmail.com*

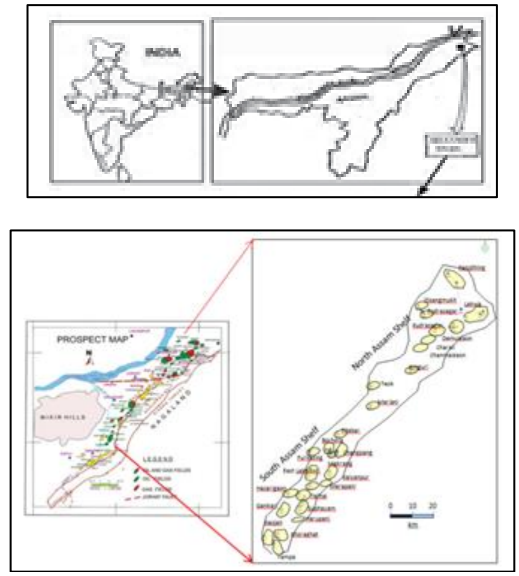
In general, the Tura sediments have been interpreted to be deposited under distal alluvial fan setting with subordinate downstream braided channel deposit to transgressive shallow marine beach/ littoral depositional environment (Deshpande et al., 1993 and kataki et al., 2003).The petrographic properties of sedimentary rocks provide a basic tool for sandstone classification. Sandstone compostion is influenced by the provenance characteristics, the nature of sedimentary processes within the basin and the dispersed path that connect the provenance and depositional basin (Dickinson & Suczek, 1979; Johnsson, 1993). Petrographic analyses, wherein the proportions of the detrital framework grains are plotted on different ternary diagrams, have demonstrated the intimate relationship between detrital sandstone compostion and tectonic setting (Ingersoll, 1978; Dickinson and Suczek, 1979; Dickinson et al., 1983; Decelles and Hertel, 1989). Recent developments in the field of sedimentary geochemistry highlight that chemical composition of the clastic sedimentary rocks is a function of complex interplay of several variables, including the nature of the source rocks, source area weathering and diagenesis (McLennan et al., 1993; McLennan et al., 2003). The study of the nature of source rock composition and tectonic setting of the Early Eocene rocks of Tura Formation is essential to understand the tectonic nature of the entire basin, but little is known. Therefore, the present study has been undertaken with an aim to identify the source rock characteristics, tectonic setting and the palaeo – oxygenation conditions of deposition of Tura Formation by using petrography and whole rock geochemistry.

2. GEOLOGY AND STRATIGRAPHY OF THE STUDY AREA :

The Upper Assam Basin is bounded by the Himalaya in the north, Indo – Burma Ranges to the east, the Mishmi block to the northeast, Naga Hills to the southeast and the Shillong plateau and Mikir Hills basement uplift to southwest (Rangarao, 1983). This basin, through which the Brahmaputra river flows, is covered by thick alluvium and is structurally less complex and tectonically less deformed than the thrust zone (Schuppen Belt) to the east (Mathur et al., 2001). It is divided into two distinct blocks viz North Assam shelf (NAS) and South Assam Shelf (SAS) on the basis of structural style, and hydrocarbon plays. The North Assam Shelf (NAS) is separated from the South Assam Shelf (SAS) by E –W trending Jorhat Fault System (fig 1). The Shillong Plateau upliftment has been a major influence on sedimentation and structural configuration of young stratigraphic strata of the Assam Shelf. Lower Cenozoic sediments in the shelf zone are 3.6 km to more than 7 km thick. Rocks with lithological affinities with the Shillong – Meghalaya Gneissic complex (SMGC) are believed to form the basement of the Assam Shelf (Clark and Bilham, 2008).Stratigraphically, the basal part of Tura Formation consists of poorly consolidated whitish grey, light brown to reddish brown, coarse to medium grained, friable sandstone with scour base intermixed with ferruginous clay clast. The generalized stratigraphy of Cenozoic sequences from the Assam and Assam – Arakan basin is presented in table 1.

3. MATERIALS AND METHODS :

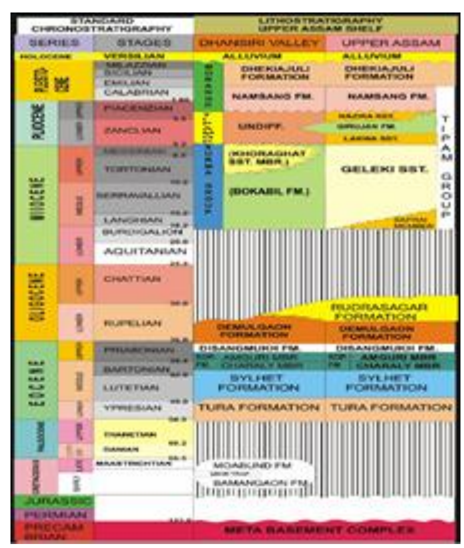
For the present study, ten borehole samples (both cuttings and cores) belonging to both North and South Assam Shelf along with depth were collected from ONGCL, Sibasagar for laboratory investigations. The representative samples have been selected and thin sections were prepared for detailed petrographic study using standard techniques. Point counting of these slides has been done following the Gazzi – Dickinson method and atleast 500 grains were counted in each thin section. Recalculated modal analysis data, from point counting of the framework grains of Tura sandstones, are listed in Table 2(a). For whole rock geochemistry, samples were crushed and grinded and were powdered to 200 mesh size using a morter. X – ray fluorescence (XRF) analysis for major oxides were carried out at Sophisticated Analytical Instrument Facility (SAIF), Department of Instrumentation & USIC, Gauhati University, Guwahati and Wadia Institute of Himalayan Geology, Dehadun. Quantitative analysis of trace and rare earth elements were done by Inductively Coupled Plasma Mass Spectrometry (ICPMS) at Shiva Analyticals Private Limited, Banglore and Wadia Institute of Himalayan Geology, Dehadun. The major, trace and REE concentrations of different wells from study area are presented in table 3 and 4 respectively.



Operational Areas :
North Assam Shelf : Panidihing, Disangmukh, Lakwa, Rudrasagar
South Assam Shelf : Furkating, Merapani

Fig 1 : *location map of North and South Assam Shelf, Basin showing Different fields (After ONGCL)*

Table 1 : *Stratigraphic succession of the area under study (Deshpande et al., 1993)*



4. RESULTS :

4.1: Petrography :

Petrographic study of the Tura sandstones reveals that they are mainly composed of variable amounts of quartz (both monocrystalline and polycrystalline), potash and plagioclase feldspars with minor amounts of micas, chert and igneous rock fragments. Quartz is the most dominant constituent of the studied Tura sandstones (Table 2a). Monocrystalline quartz is more abundant than the polycrystalline quartz. The constituent mineral grains are mostly medium to coarse grained and subangular to subrounded. Cements are mostly carbonate and silica (plate 1). Some of the sandstone samples also contain clayey matrix. The recalculated values of quartz(Q), feldspar(F) and rock fragments(R) are plotted in the QFR triangular diagram by Dott, 1964 (in Pettijohn, 1984) for petrographical classification of the Tura sandstones. The ternary QFR plot shows that the investigated Tura samples fall in the quartz arenite, sublitharenite and lithic greywacke field (fig 2).

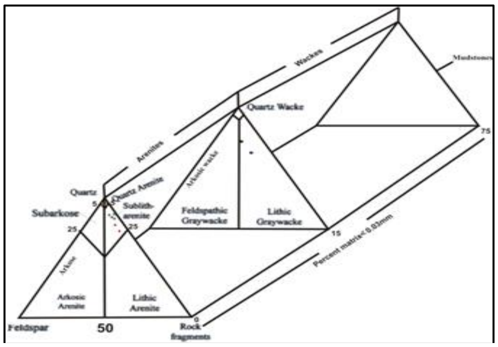


Fig 2: *Classification of the Tura Formation (After Dott, 1964 in Pettijohn, 1984)*

4.2 : Major Elements :

The samples from different wells of the study area shows variable major oxide compositions. The results show that SiO2 (47.32 – 82.29 % ; average 60.59 %) constitute the major portion of the oxides followed by Al2O3 (10.64 – 21.61 % ; average 14.73 %), Fe2O3 (2.57 - 7.97 % ; average 4.92), CaO (0.52 – 7.77 % ; average 4.83) and K2O (0.17 – 2.93% ; average 1.97). The Na2O and MgO content range from 0.35 –2.19 % (average 1.73%) and 0.06 – 2.71% (average 1.58%) respectively. The concentration of TiO2, P2O5 and MnO are found in minor amounts and their concentration are 0.4 – 1.12%, 0.06 – 0.14% and 0.009 – 0.19% respectively.

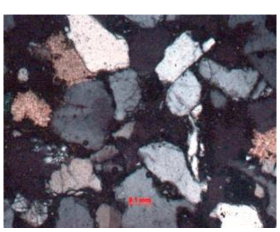
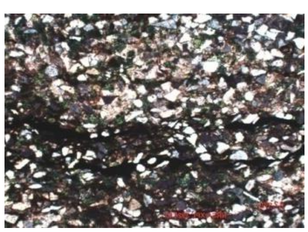
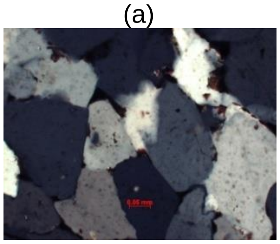
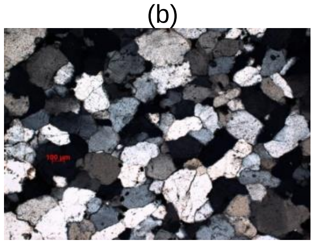

(a)

(b)

(c)

(d)

Plate 1: *a. Patchy carbonate cement in quartz arenite, b. Calcite cemented , fine grained glauconite rich sandstone, c. Quartz arenite showing iron cement and d. Quartz arenite showing tight packing. Traces of silica cement can be seen.*

Values of Al2O3/TiO2 of the studied samples are relatively high (10.64-29.85; average 20.06) and it suggests derivation of the detrital material from a continental source (Fyffe and Pickerill, 1993). Low values of Al2O3/SiO2 ratio (0.13 – 0.46) gives an indication of quartz enrichment in the sandstones (Potter, 1978). The higher value of K_2O/Na_2O ratio (0.08 – 6.25) than the Na2O/K2O ratio (0.15 – 12.7) indicates the dominance of K- feldspar over the plagioclase feldspar in the sandstone samples (Crook, 1974). In addition, Na2O/K2O ratio is more than 1 representing immature sediments near to the source (Table 3). A SiO2/Al2O3 ratio of more than 5 represents mineralogical immaturity of the sediments (Roser et al., 1996). The SiO2/Al2O3 ratio for the studied samples is relatively high (2.19 – 7.73, average 4.47) suggesting low maturity of the sandstone samples. Though SiO2/Al2O3 ratio for samples RDS-80 (5.58), St-4 (7.73), B-1 (5.58) and B-6 (5.36) indicates that there were a part of matured sedimentary rocks involved in the source area. Besides, relatively higher values of Al2O3 and K2O indicates dominance of clay minerals. Thus, The K2O/Al2O3 ratio of sediments can be used as an indicator of the original composition of ancient sediments. The K2O/Al2O3 ratios for clay minerals and feldspar are different (0.0 – 0.3, 0.3 – 0.9 respectively ; Cox et.al., 1995). In the studied rock samples the K2O/Al2O3 ratio for ranges from 0.02 to 0.24 (average 0.14). These values indicate prevalence of clay minerals over K- bearing minerals such as K- feldspar and mica in source rock. Harkar variation of major elements with respect to SiO2 content is shown in Fig 3. In the Harkar diagram, the behaviour of the most major oxides (e.g Al2O3, MgO, CaO, K2O, TiO_2 and P2O5) show strong linear negative trends with SiO2 and only Na_2O shows scattered distribution due to the mobility of sodium during diagenesis and metamorphism and hence formed sodium or calcium rich clay minerals. The negative correlation of SiO2 with most major elements is due to most of the silica is being sequestered in quartz as indicated by Osman (1996). However, Mgo, CaO, K2O, TiO_2 and P_2O_5 exhibit positive correlations with Al2O3 (Fig 4). A marked increase in the abundance of these elements indicates enrichment of clay minerals (Nagarajan et al., 2007 a,b). In the present samples TiO2 increases with Al2O3 indicates that TiO2 may be associated with phyllosilicates especially with illite (Dabard, 1990).Based on the geochemical classification diagram of Herron (1988), it is found that most of the analysed samples of Tura Formation fall in the wacke field (Fig 5 a) whereas the Na2O-K2O diagram after Crook (1974) shows that samples fall both in the quartz rich and quartz intermediate field (Fig 5 b). According to Roser and Korsch (1986), quartz-rich sandstones are associated with passive continental margin, whereas sandstones with quartz-intermediate composition are characterized by an active continental margin. Therefore, our samples could be associated with both active and passive continental margins. However, The plot of Na2O-K2O discrimination diagram established by Roser and Korsch (1986) shows that the investigated samples of Tura Formation fall in the active continental margin field (Fig 6a). On the other hand, the tectonic setting discrimination diagram by Kroonenberg(1994) indicates that sediments of Tura formation were deposited within a passive marginal setting (Fig 6b). The present study also shows that CaO, K2O and Ti02 are high in the Tura sediments. This might indicate intrusion of felsic components in the later part of the sedimentation under active continental setting which was before remained as passive setting. This perhaps influence the change of rock chemistry which is reflected in the palaeoclimate data (Fig.6 c) and probably interpretation of arid climate during Tura sedimentation will be largely a mistake.

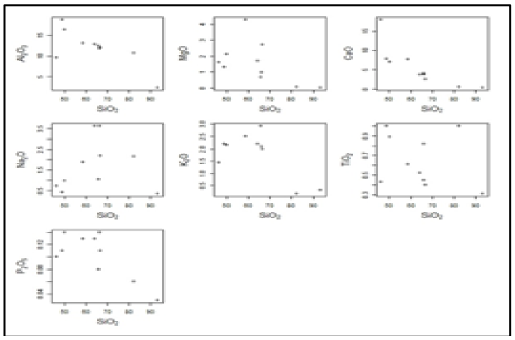


Fig 3: *Harker variation diagram of Tura Formation major oxides against SiO_2*

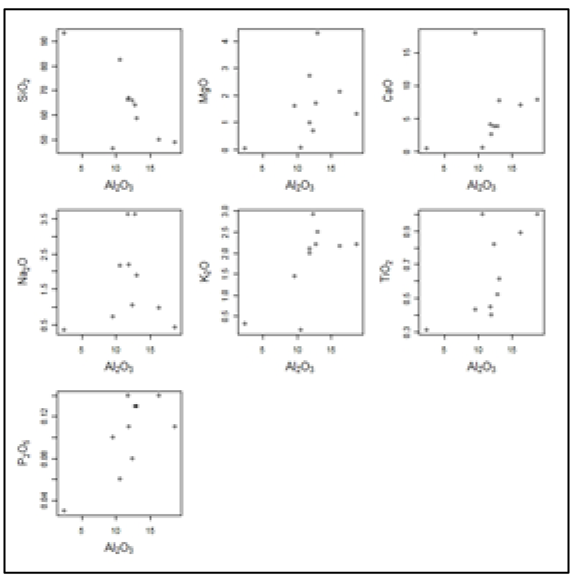
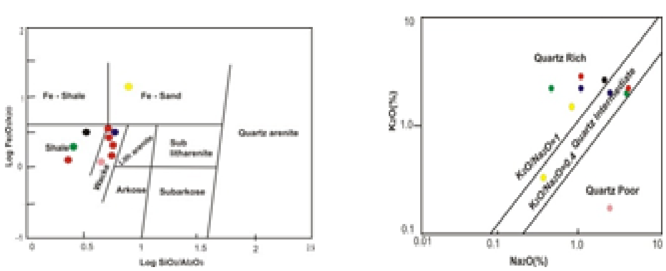
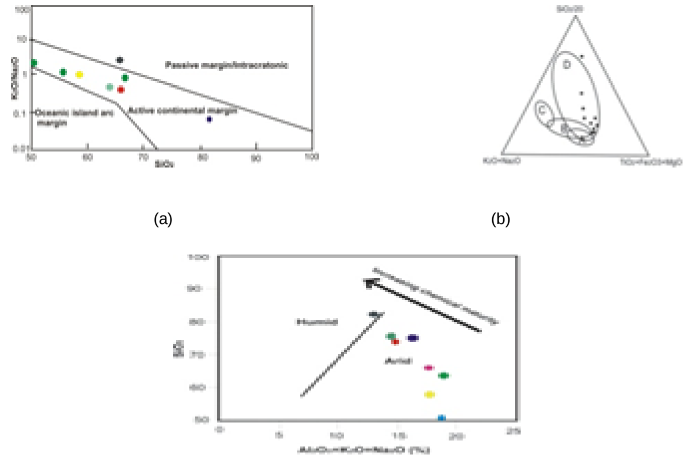


Fig 4: *Harker variation diagram of Tura Formation major oxides against Al_2O_3*



(a) (b)

Fig 5 : *Geochemical classification of Tura Formation based on a. Log SiO2/Al2O3-Log Fe2O3/K2O diagram by Herron(1988) b. Na2O-K2O diagram by Crook(1974).*



(a) (b)

(c)

Fig 6 : *a. K2O/Na2O versus SiO2 plot of Tura Formation by Roser and Korsch (1986) b: Plot of the major element composition on the tectonic setting discrimination diagram by Kroonenberg (1994) A: oceanic island arc, B: continental island arc, C: active continental margin, D: passive margin and c. SiO2 versus Al2O3+K2O+Na2O bivariant plot for Tura Formation (Suttner & Dutta, 1986)*

Table 2(a): *Results of the modal analysis of Formation*

Sample	*Quartz*				*Total quartz*	*Feldspar*	*Rock fragments*	*Mica*	*Matrix*	*Cement*	*Chert*
	Monocrystalline		*polycrystalline*								
	undulose	*Non undulose*	*2-3 units*	*>3 units*							
B1	*11.29*	*12.99*	*7.34*	*16.24*	*47.88*	*9.60*	*6.77*	*3.25*	*10.87*	*21.61*	*1.6*
B6	*2.63*	*19.51*	*1.23*	*4.39*	*27.76*	*10.19*	*28.12*	*3.51*	*2.64*	*27.77*	*0.9*
Bag-1	*2.99*	*11.38*	*0.99*	*11.38*	*26.74*	*4.99*	*11.38*	*1.79*	*39.92*	*16.97*	*1.7*
RDS-80	*5.88*	*59.15*	*1.31*	*3.59*	*69.93*	*4.90*	*2.61*	*2.28*	*10.45*	*9.80*	*1.3*
Mer-1	*10.30*	*20.40*	*2.18*	*13.07*	*45.95*	*8.63*	*9.79*	*4.95*	*19.80*	*8.91*	*0.8*
For-1	*3.75*	*29.21*	*4.31*	*5.99*	*43.26*	*4.12*	*16.85*	*2.62*	*12.17*	*13.67*	*1.5*
B3	*5.2*	*58.3*	*5.5*	*9.6*	*78.6*	*1.7*	*2.6*	*3.5*	*8.5*	*4.3*	*2.2*
A10	*10.1*	*41.3*	*3.4*	*11.7*	*66.5*	*1.4*	*12.6*	*2.8*	*10.3*	*14.5*	*1.7*
A11	*9.3*	*29.4*	*2.6*	*5.2*	*46.5*	*3.9*	*8.1*	*1.3*	*13.8*	*23.6*	*1.4*
A2	*10.9*	*21.4*	*1.5*	*17.8*	*51.6*	*1.7*	*13.3*	*6.1*	*12.2*	*13.4*	*2.1*

Table 2b : *Recalculated framework grain parameters used in this study (after Dott, 1964; Basu et al., 1975; Folk, 1980;*

Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Dickinson et al., 1983 and Suttner and Dutta, 1986)

QFR
Q= total quartz grains (Qm+Qp) where
Qm = undulose monocrystalline quartz (Qum)+non undulose
Qm= monocrystalline quartz Qp= polycrystalline quartz
monocrystalline quartz (Qnum)
F= Total feldspar (K+P), where
Qp = polycrystalline quartz with 2-3 units+polycrystalline quartz
K= K-feldspar P= plagioclase
with >3 unit
R= Rock fragments

QtFL
Q= total quartz grains (Qm+Qp) where
Qm= monocrystalline quartz Qp= polycrystalline quartz
F= Total feldspar
L= total rock fragments including mica and chert

QmFLt
Qm= monocrystalline quartz
F = Total feldspar
L_t = Lithic fragments + polycrystalline quartz (Qp)

Table 2c: *Recalculated composition of Tura Formation*

sample	Q	F	R	Qt	F	L	Qm	F	Lt	UM	NUM	Qp (2-3 unit)	Qp (>3unit)
B1	74.45	14.95	10.59	69.18	13.89	16.93	35.17	13.89	50.94	23.64	27.2	15.27	33.89
B6	42.03	15.33	42.64	39.4	14.37	46.23	31.44	14.37	54.19	9.39	70.4	4.33	15.88
B3	94.81	2.05	3.14	88.71	1.92	9.37	71.67	1.92	26.41	6.62	74.17	6.88	12.31
Mer-1	71.54	13.37	15.09	65.62	12.27	22.11	43.79	12.27	43.94	22.39	44.35	4.78	28.48
For-1	67.44	6.39	26.17	63.4	6	30.6	48.32	6	45.68	8.78	68.05	9.31	13.86
Bag-1	61.86	11.63	26.51	57.21	10.75	32.04	30.76	10.75	58.49	10.9	42.86	3.37	42.85
RDS-80	90.31	6.33	3.36	86.3	6.05	7.65	80.25	6.05	13.7	8.44	84.55	1.86	5.15
A10	82.61	1.74	15.65	78.24	1.65	20.11	60.47	1.65	37.88	15.19	62.11	5.11	17.59
A11	79.49	6.67	13.84	75.98	6.37	17.65	63.24	6.37	30.39	20	63.23	5.59	11.18
A2	77.48	2.55	19.97	68.98	2.28	28.74	43.18	2.28	54.54	21.12	41.47	2.91	34.5

4.3: Trace Elements:
Trace element concentrations of Tura Formation sandstones are shown in Table 4. All the trace element values were normalized using upper continental crust (UCC) values of Taylor and McLennan, 1985 and are plotted in fig 7. The contents of Cr, Ni, Co, Sc and V show a wide range from 11-411 ppm, 3-67ppm, 0.9-18ppm, 1.1-18ppm and 8-149ppm respectively. The lower values may suggest felsic rock source for the Tura Formation. Only a few samples (samples A2, A5, A7 and A8) have relativlely high contents, suggesting a contribution from mafic components. The Rb (~53.2ppm), Nb (~17.9) and Sr (~134.8ppm) values are distinctly depleted whereas the values of Th (~22.01ppm) and Ba (~1619.5ppm) are strongly enriched as compared to UCC. The enrichment of Ba may be due to the presence of K-fedspar and barite occurrence of which was established by petrographic observations. The highly variability of Sr values is caused by many influences on Sr in low temperature depositional environments (Fairbridge, 1972). The distribution of Sr can be affected by the presence of Ca and fractionation of Sr may result from the weathering of plagioclase feldspars.

4.4: Rare Earth Elements:
Rare earth element concentration of Tura Formation (Table 4) are shown as chondrite normalized patterns in fig 8. The REE patterns are used to infer the source of sedimentary rocks. The sandstones have REE contents ranging between 28.6-523 ppm with an average of 192.06 ppm which is higher than the average UCC (143, Taylor and McLennan, 1985). The sandstones have high LREE/HREE ratio ranging from 5.69-44.88ppm (~20.51ppm) with negative Eu anomaly considering their origin derived from felsic rock sources, which is similar to UCC (fig 8).

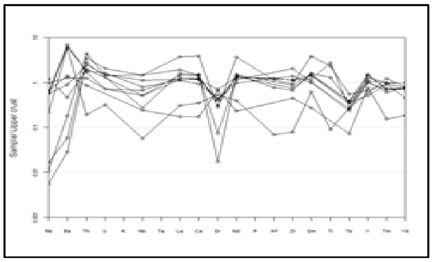


Fig 7: *Multi - element normalized diagram for the Tura Formation,*

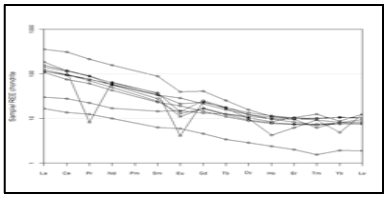


Fig 8: *Chondrite - normalized rare earth element plots for the Tura Formation normalized against upper continental crust (Taylor and McLennan, 1985) chondrite values from Sun and McDonough (1989)*

Table 3: *Major oxides compositions (wt%) of Formation*

Major Oxides	RDS-80	A2	A5	A7	A8	ST-4	For-1	Mer-1	B1	B6
SiO2	66.16	50.06	48.84	47.32	55.73	82.29	58.64	64.16	66.74	65.93
Al2O3	11.85	16.35	18.76	21.61	17.8	10.64	13.11	12.85	11.94	12.41
Fe2O3 (T)	6.6	7.97	4.37	3.35	4.58	2.57	3.4	7.82	4.28	4.34
MnO	0.1	0.1	0.06	0.07	0.09	0.009	0.19	0.15	0.08	0.03
MgO	0.99	2.11	1.31	0.91	1.04	0.06	4.30	1.69	2.71	0.68
CaO	4.12	7	7.77	8.21	2.96	0.52	7.72	3.72	2.63	3.74
Na2O	3.64	0.97	0.42	0.35	1	2.16	1.89	3.64	2.19	1.04
K2O	2.09	2.17	2.21	2.19	1.27	0.17	2.50	2.20	1.99	2.93
TiO2	0.45	0.89	1	1.12	1.11	1	0.61	0.52	0.4	0.82
P2O5	0.14	0.14	0.11	0.07	0.12	0.06	0.13	0.13	0.11	0.08
Total	96.14	87.76	84.45	85.2	85.7	99.48	92.49	96.88	93.07	92
SiO2/Al2O3	5.58	3.06	2.60	2.19	3.13	7.73	4.47	4.99	5.59	5.31
Al2O3/SiO2	0.17	0.33	0.38	0.46	0.32	0.13	0.22	0.20	0.18	0.19
K2O/Na2O	0.57	2.24	5.26	6.26	1.27	0.08	1.32	0.60	0.91	2.82
Na2O/K2O	1.74	0.45	0.19	0.16	0.79	12.7	0.76	1.65	1.10	0.35
Al2O3/TiO2	26.33	18.37	18.76	19.29	16.03	10.64	21.49	24.71	29.85	15.13

5. DISCUSSION:

5.1: Nature of source rock :

The mineralogical composition of the detrital constituents of siliciclastic sedimentary rocks provides a basic tool for lithology of the parent rocks in the source area. Petrographic composition also provides important clues in interpreting tectonic setting since source rock lithology is connected essentially to the tectonic setting. For the determination of the nature of the source rock, Diamond diagram by Basu et al. (1975) has been considered and recalculated petrographic values of different types of quartz have been plotted. The diamond diagram thus obtained indicates that the sediments of Tura Formation have been derived from plutonic and middle and upper rank metamorphic sources (fig 9). The QFL and QmFLt triangular plots of Dickinson et al. (1983) have been considered to decipher the tectonic setting of the Tura Formation. In QFL diagram these sandstones were derived from recycled orogenic provenance (Fig. 10a). Dickinson et al. (1983) pointed out that sandstones plotted in the recycled orogenic provenance field are commonly derived from sedimentary and meta-sedimentary sources, which were originally deposited in passive continental margins. On the other hand, in the QmFLt diagram, the Tura sandstone samples dominantly fall in the transitional recycled field, only four samples fall in the quartzose recycled field.

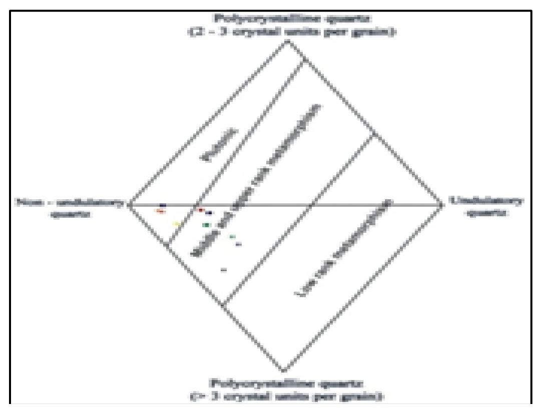
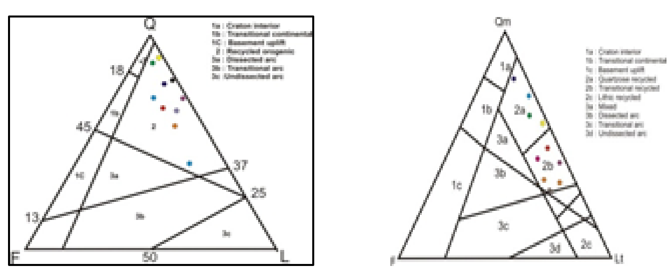


Fig 9: *Diamond diagram showing distribution of quartz grain (After Basu et al. 1975)*



(a) (b)

Fig 10 : *a. QFL triangular plot of Tura Formation (after Dickinson et al.1983) b. QmFLt triangular plot of Tura Formation (after Dickinson et al.1983)*

Several attempts have been made to use major elements as provenance indicators although major elements are prone to change in concentrations and ratios due to weathering, diagenesis and other metamorphic processes. Discriminant function diagram for provenance characteristics of the sediments based on major elements provides quartzose sedimentary provenance for most of the analysed samples (Roser and Korsch, 1988) (Fig 11). Sediments recycled from felsic sources plot progressively away from the igneous source line into the quartzose field Roser (2000).

Table 4: *Trace element and rare earth element concentrations in ppm for Tura Formation*

Trace and Rare Earth Elements	RDS-80	A-2	A-5	A-7	A-8	St-4	For-1	Mer-1	B-1	B-6
Sc	7	18	15	16	16	4.5	1.1	12.9	10	10
Co	3.8	18	10	10	13	2.8	0.9	3.2	16	12
Ga	17.8	19	18	20	23	6.3	3.4	41.3	14	14
Rb	1.8	108	65	62	61	0.6	23.9	1.2	73	135
Y	12.5	28	24	22	32	11	23.3	14.8	17	34
Zr	269.5	178	276	334	493	161.1	19	225.9	107	209
Nb	36.5	13	17	20	28	6.8	1.4	36.8	6	13
Th	36.5	13	18	19	26	29.6	2	46	9	21
U	5.1	1.8	1.8	4.1	3.8	3.3	0.8	3.6	0	0
Pb	661	35	20	19	17	3	102	126	17	15
Zn	53	100	62	65	99	29	22	113	118	67
Cr	66	119	139	108	411	16	11	61	86	73
Cu	85	27	24	16	31	14	32	122	23	30
Ni	20	67	30	23	36	3	3	28	62	26
Ba	41	884	4832	4264	629	20	4075	127	997	326
Sr	26	245	151	149	140	6	188	100	236	107
V	51	149	118	107	111	35	8	81	77	75
La	58	35.51	38.67	33.75	35.04	48.3	9.3	110.9	5.17	44.32
Ce	94.4	74.82	77.83	59.96	76.87	96.5	22.3	249.3	11	92.06
Pr	10.7	9.17	9.24	7.41	8.59	11	2.7	26.1	1.5	1
Nd	33.7	35.11	34.58	25.6	29.86	38	10.2	94.7	5.97	39.07
Sm	5.4	6.64	6.51	4.46	4.68	7.2	2.8	17.1	1.23	7.1
Eu	0.8	1.56	2.09	1.41	0.94	0.3	1.1	2.9	0.43	1.03
Gd	4.4	5.93	5.52	3.76	4.28	6.1	3.4	10.6	1.17	6.51
Tb	0.6	0.82	0.74	0.52	0.57	0.8	0.6	1.2	0.16	0.84
Dy	3.3	4.29	3.94	2.84	2.97	3.2	3.6	5	0.91	3.93
Ho	0.6	0.82	0.76	0.55	0.58	0.3	0.7	0.8	0.17	0.69
Er	2.2	2.16	2.06	1.53	1.56	1.3	2	2.1	0.42	1.73
Tm	0.4	0.33	0.32	0.23	0.24	0.3	0.2	0.3	0.05	0.23
Yb	1.8	2.17	2.2	1.65	1.64	1	1.7	1.7	0.4	1.55
Lu	0.4	0.33	0.33	0.27	0.25	0.4	0.3	0.3	0.06	0.24
$\sum$REE	216.7	179.6	184.8	143.9	168.1	214.7	60.9	523	28.6	200.3

The Tura sandstones have high K2O and Rb concentrations and most of the samples maintain a uniform ratio that lie close to the main trend with a ratio of 230 (Shaw, 1968; fig 12a). The figure emphasizes on the derivation mainly from the acid to intermediate magmatic rocks. Moreover, the concentration of zircon is used to characterize the nature and composition of source rock (Hayashi et al., 1997; Paikaray et al., 2008). The low TiO_2/Zr ratios of the sediments indicate felsic source rocks (Keskin, 2011). As demonstrated by Hayashi et al., (1997) the TiO_2/Zr ratios are much supportive indicator to distinguish among three different source rock types, i.e., felsic, intermediate and mafic. Based on Hayashi et al., (1997), the TiO_2 versus Zr plot of the studied sediments characterize felsic source rocks (fig 12 b). Furthermore, rare earth elements, Th and Sc are more abundant in felsic rocks and their weathering products than in mafic igneous source rocks whereas Co, Sc and Cr are more common in mafic rocks and their weathering products than in felsic rocks (Cullers et al.1979; Bhatia and Crook, 1986; Wronkiewiez and Condie, 1987; Cox et al.,1995). In this study, the higher abundances of Th and REE indicate felsic igneous source (Table 4). Also, Eu/Eu* (~ 0.73), La/Sc (~ 4.99), Th/Sc (~ 2.49), La/Co (~ 9.34), Th/Co (~ 4.55) and Cr/Th (~ 6.06) ratios indicate derivation of the Tura Formation from felsic rock source (table 6).

***Table 5 :** Elemental ratios of Tura Formation*

Elemental ratios	*RDS-80*	*A2*	*A5*	*A7*	*A8*	*St-4*	*For-1*	*Mer-1*	*B-1*	*B-6*
U/Th	*0.13*	*0.14*	*0.1*	*0.22*	*0.15*	*0.11*	*0.4*	*0.08*	*0*	*0*
V/Cr	*0.77*	*1.3*	*0.85*	*0.99*	*0.27*	*2.2*	*0.73*	*1.3*	*0.9*	*1.02*
Ni/Co	*5.3*	*3.7*	*3.0*	*2.3*	*2.8*	*1.1*	*3.3*	*8.8*	*3.9*	*2.2*
Cu/Zn	*1.6*	*0.27*	*0.39*	*0.25*	*0.31*	*0.48*	*1.5*	*1.1*	*0.20*	*0.45*
V/Sc	*7.3*	*8.3*	*7.9*	*6.7*	*6.9*	*7.8*	*7.3*	*6.3*	*7.7*	*7.5*
V/(Ni + V)	*0.72*	*0.69*	*0.8*	*0.82*	*0.6*	*0.92*	*0.73*	*0.74*	*0.55*	*0.74*
Zr/Sc	*38.5*	*9.9*	*18.4*	*20.9*	*30.8*	*35.8*	*17.3*	*17.5*	*10.7*	*20.9*
Th/Sc	*5.2*	*0.72*	*1.2*	*1.2*	*1.6*	*6.6*	*1.8*	*3.6*	*0.9*	*2.1*
La/Sc	*8.3*	*2.0*	*2.6*	*2.1*	*2.2*	*10.7*	*8.5*	*8.6*	*0.5*	*4.4*
Th/Co	*9.6*	*0.72*	*1.8*	*1.9*	*2.0*	*10.6*	*2.2*	*14.4*	*0.5*	*1.8*
Th/U	*7.2*	*7.2*	*10*	*4.6*	*6.8*	*9*	*2.5*	*12.8*	*-*	*-*
La/Co	*15.3*	*2.0*	*3.8*	*3.4*	*2.7*	*17.3*	*10.3*	*34.7*	*0.3*	*3.7*
Cr/Th	*1.8*	*9.2*	*7.7*	*5.7*	*15.8*	*0.5*	*5.5*	*1.3*	*9.6*	*3.5*
LREE/HREE	*22.3*	*15.5*	*16.9*	*18.0*	*20.5*	*28.4*	*5.7*	*44.9*	*12.2*	*20.8*
*Eu/Eu**	*0.48*	*0.75*	*1.04*	*1.03*	*0.63*	*0.14*	*1.08*	*0.61*	*1.08*	*0.46*

5.2: Redox condition :

Palaeo – redox conditions during sedimentation of siliciclastic rocks can be evaluated based on their chemical analyses data. The accumulation of certain trace metals in sediments is directly or indirectly controlled by redox conditions through either a change in redox state and/or speciation (McKay et al., 2007). Element ratios such as U/Th, Ni/Co, Cu/Zn, V/Cr, V/Sc and V/(Ni+V) have been used to evaluate paleo redox conditions. U/Th ratios below 1.25 suggest oxic conditions of deposition; values above 1.25 indicate suboxic and anoxic conditions ((Jones and Manning, 1994; Hallberg, 1976). Low uranium content and low U/Th ratio (0 – 0..4; average 0.13), indicate that the Tura sandstones were deposited in an oxic environment. A number of authors have used the Ni/Co ratios as a redox indicator (Bjorlykke, 1974; Dypvik, 1984; Dill, 1986; Brumsack, 2006; Nagarajan, 2007). The Ni/Co ratios below 5 indicate oxic environments, while ratios above 5 indicate suboxic and anoxic environments (Jones and Manning, 1994). For the studied samples, the Ni/Co ratios vary between 1.1 and 8.8 (average 3.63), which indicate that these sediments were deposited in an oxic environment. According to Hallberg (1976), Cu/Zn ratio can be used as a redox parameter. He mentioned that high Cu/Zn ratios indicate reducing depositional conditions, while low Cu/Zn ratios suggest oxidising conditions. For this present investigation the Cu/Zn ratios range from 0.20-1.6, indicating Tura sandstones were deposited under well oxygenated conditions. V/Cr ratio has been utilized as an index of paleooxygenation (Bjorlykke, 1974; Shaw et al,. 1990; Nagarajan, 2007) due to the incorporation of Cr in the detrital fraction of sediments and its possible substitution for Al in the clay structure (Kimura and Watanabe, 2001). Bellanca et al (1996) stated that vanadium solubility in natural waters, its extraction from seawater and absorption onto sediments are mainly influenced by redox conditions. The V/Cr ratios above 2 indicate anoxic conditions, whereas values below 2 suggest more oxidizing conditions (Jones

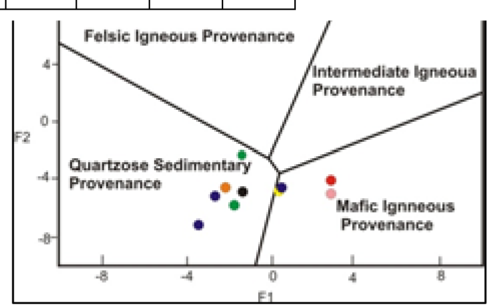
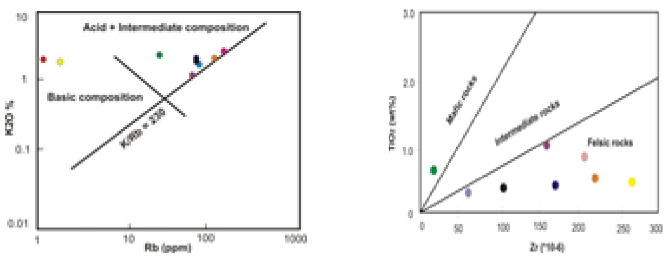


***Fig 11:** Tectonic discrimination diagram for Tura Sandstone Formation after Roser and Korsch (1988)*

Elemental ratio	*Tura sandstones*	*Ranges in sediments from felsic sources*[1]	*Ranges in sediments from mafic sources*[1]	*Upper Continental Crust*[2]
*Eu/Eu**	*0.14-1.08*	*0.40-0.94*	*0.71-0.95*	*0.63*
La/Sc	*0.5 - 10.7*	*2.50-16.3*	*0.43-0.86*	*2.21*
Th/Sc	*0.72-6.6*	*0.84-20.5*	*0.05-0.22*	*0.79*
La/Co	*0.3-34.7*	*1.80-13.8*	*0.14-0.38*	*1.76*
Th/Co	*0.5-14.4*	*0.04-3.25*	*0.04-1.40*	*0.63*
Cr/Th	*0.5-15.8*	*4.00-15.0*	*25-500*	*7.76*



(a) (b)

***Fig 12:** a. Distribution of K and Rb in Tura Formation relative to K/Rb ratio of 230 (= main trend of Shaw, 1968) b. TiO_2 vs Zr plot for the Tura Formation (Hayashi et al., 1997)*

And Manning, 1994). The V/Cr ratios of the studied samples range between 0.27 and 2.2 which indicates that sediments were deposited in suboxic to oxic environment. According to Hetzel et al. (2009), the V/Sc ratios below 9.1 indicate oxic depositional environment. V/Sc ratio for the studied samples is between 6.3 and 8.3, which indicates oxic depositional environment. Furthermore, the V/(Ni+V) ratios below 0.46 indicate oxic environments, but ratios above 0.54 to 0.82 suggest suboxic and anoxic environments (Hatch and Leventhal, 1992). The V/(Ni + V) ratios for the Tura sandstones range from 0.55 to 0.92 (~ 0.75), which indicate suboxic to anoxic environment of deposition. The Mn* value is a significant palaeochemical indicator of the redox conditions of the depositional environment (Bellanca et al., 1996; Cullers, 2002; Machhour et al., 1994). For calculating Mn* value, the applicable basic formula is $Mn^* = \log[(Mn_{sample}/Mn_{shales})/(Fe_{sample}/Fe_{shales})]$, where the values used for the Mn_{shales} and Fe_{shales} are $600*10^{-6}$ and $46150*10^{-6}$ respectively (Wedepohl, 1978). The Tura sandstones have mainly negative Mn* values (except one sample with value of 0.20) ranging from -1.14 to 0.20 with an average of -0.49. This suggests that the sandstones may have been deposited in suboxic and anoxic conditions. The authigenic uranium content is also considered as an index of bottom water condition in ancient sedimentary sequences (Wignall and Myers, 1988). The authigenic uranium content is calculated as –

(Authigenic U) = (total U) – Th/3

Values of authigenic U below 5 are thought to represent oxic depositional conditions, while values above 5 are indicator of suboxic and anoxic conditions. In the present study, authigenic U content ranges from -11.7 - 0.13 indicating an oxic condition for the Tura Formation.

***Table 6:** Range of elemental ratios of Tura Formation in this study compared to elemental ratios in sediments derived from felsic rocks, mafic rocks and in the upper continental crust*

[1]Cullers et al (1988); Cullers (1994, 2000); Cullers and Podkovyrov (2000).
[2]McLennan (2001); Taylor and McLennan (1985)

6. CONCLUSION :

1. Based on the petrographic results, these Tura sandstones are quartz arenite, sub-litharenite and lithic greywacke in composition and are derived from recycled orogenic provenances.
2. Diamond diagram indicates that sediments of Tura Formation were derived from plutonic as well as middle and upper rank metamorphic sources.
3. Based on major element geochemistry, the sandstone samples are classified as wacke type with moderate SiO_2 contents.
4. Tectonic discrimination diagram shows the continental signature derivatives, which are chiefly consisted of quartzose sedimentary provenance, comparable fields with the Tertiary sedimentary rocks of West Garo Hills, Meghalaya. Whole rock geochemistry data suggest felsic provenance types for the Tura Formation. Therefore, the sediments might have been derived from the felsic as well as from quartzose sedimentary provenance.
5. Similarly, the distribution pattern of REE along with specific geochemical parameters such as K2O/Rb and TiO2/Zr binary diagrams also represents a dominantly granitic source for the Tura Formation.
6. The felsic provenance of Tura Formation can be attributed to Higher Himalayan crystallines of Eastern Himalayas where acidic rocks are abundantly exposed in Arunachal Pradesh and Lohit plutonic complex in Mishmi Hills is thought to be the source of acidic as well as intermediate composition.
7. The present study also shows both passive and active marginal setting for the Tura Formation. This inconsistent result may be due to high CaO, K2O and low Na2O values and therefore it can be attributed that there might be felsic intrusion in the later part of the sedimentation under active continental setting which was before remained as passive setting.
8. Geochemical indices such as U, authigenic U, U/Th, V/Cr, Ni/Co, Cu/Zn and V/Sc ratios strongly suggest that these sandstones were deposited in an oxic environment while the Mn* and V/(Ni+V) values imply that sediments were deposited under suboxic and oxic environments. Therefore, these results show that the sediments were deposited in mostly oxic environments.

7. ACKNOWLEDGEMENTS :

The authors are thankful to RGL, ONGCL, Sibasagar for providing borehole samples and DST (INSPIRE Fellowship) for the financial support to carry out the work. The authors also acknowledge USIC, Gauhati University, Wadia Institute of Himalayan Geology, Dehradun and Shiva Analytical Private Limited, Banglore for giving permission to carry out the XRF and ICPMS analyses of the rock samples in their laboratories respectively.

8. REFERENCES:

[1] Basu A., Young W. S., Suttner J. L., James C. W., and Mack H. G. (1975) Re – evaluation of the use of Undulatory Extinction and Polycrystallinity in Detrital Quartz for Provenance Interpretation , Journal of Sedimentary Petrology, 45 (4) : 873 – 882.

[2] Bellanca A., Claps M., Erba E., Masetti D., Neri R., Premolisilva I., and Venezia F. (1996) Orbitally induced limestone/marlstone rhythms in the Albian-Cenomanian Cismon section (Venetian region, northern Italy): Sedimentology, calcareous and siliceous plankton distribution, elemental and isotope geochemistry, Paleogeography, Paleoclimatology and Paleoecology, 126: 227–260.

[3] Bhatia M.R. & Crook KAW (1986) Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins, Contrib Mineral Petrol, 92: 181–193

[4] Bjorlykke K. (1974) Geochemical and mineralogical influence of Ordovician island arcs on epicontinental clastic sedimentation: a study of Lower Palaeozoic sedimentation in the Oslo region, Norway, Sedimentology, 21(2): 251-272.

[5] Brumsack H. J. (2006) The trace metal content of recent organic carbon-rich sediments: implications for Cretaceous black shale formation, Palaeogeography, Palaeoceanography, Palaeoecology, 232 (2–4): 344–361.

[6] Clark M. K. and Bilham R. (2008) Miocene rise of the Shillong Plateau and the beginning of the end for the Eastern Himalaya, Earth and Planetary Science Letters, 269 : 337-351.

[7] Cox R., Lowe D.R. & Cullers R.L. (1995) The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States, Geochimica et Cosmochimica Acta, 59(14): 2919-2940

[8] Crook KAW (1974) Lithogenesis & Geotectonics: The significance of compositional variation in Flyscharenites (greywackes), Society of Economical, Palaeontological and Mineralogical Special Publications, 19:304-310

[9] Cullers R.L., Chaudhuri S., Kilbane N., and Koch R.J. (1979) The rare earth contents in different size fractions and whole rocks from Pennsylvanian and Permian platform sediments from the mid – continent of the USA, Geochimica Cosmochimica Acta, 43: 1285 – 1302.

[10] Cullers R.L., Basu A. & Suttner L.J. (1988) Geochemical signature of provenance in sand-size material in soils and stream sediments near the Tobacco Root batholith, Montana, USA, Chem Geol., 70: 335–348

[11] Cullers R.L (1994) The controls on the major and trace element variation of shales, siltstones and sandstones of Pennsylvanian–Permian age from uplifted continental blocks in Colorado to platform sediment in Kansas, USA, Geochim. Cosmochim. Acta, 58(22):4955–4972.

[12] Cullers R.L. (2000) The geochemistry of shales, siltstones and sandstones of Pennsylvanian–Permian age, Colorado, USA: Implications for provenance and metamorphic studies, Lithos, 51: 181–203

[13] Cullers R.L. & Podkovyrov V.N. (2000) Geochemistry of the Mesoproterozoic Lakhanda shales in southeastern Yakutia, Russia: Implications for mineralogical and provenance control and recycling, Precamb Res., 104: 77–93

[14] Cullers R.L. (2002) Implications of elemental concentrations for provenance, redox conditions and metamorphic studies of shales and limestones near Pueblo, CO, USA, Chemical Geology, 191(4): 305-327

[15] Dabard M.P. (1990) : Lower Brioverian formations (Upper Proterozoic) of the Armorican Massif (France): Geodynamic evolution of source areas revealed by sandstone petrography and geochemistry. Sed. Geol. 69, 45—58.

[16] Deshpande S.V., Goel S.M., Bhandari A., Baruah R.M., Despande J., Kumar A., Rana K.S., Chitrao A.M., Giridhar M., Chaudhuri D., and Phor L. (1993) Lithostratigraphy of Indian Petroliferous Basin, Document – X, Assam – Arakan Basin, ONGC Vol – 1 & 11

[17] Decelles P.G and Hertel F. (1989) Petrology of fluvial sands from the Amazonian Foreland Basin, Peru and Bolivia, Geological society of America Bulletin, 101(12) : 1552-1562

[18] Dickinson W.R. and Suczek C.A. (1979) Plate tectonics and sandstone compositions, Amer. Assoc. Petrol. Geol., Bull. 63, 12 : 2164 - 2182

[19] Dickinson W. R., Bread L. S., Brakenrideg G. R., Erjavec J.L., Ferguson R.C., Inmam K. F., Knepp R. A., Linberg F. A., and Ryberg P. T. (1983) Provenance of North American Phanerozoic Sandstonesin Relation to Tectonic Setting, Geol.Soc. America Bull., 94: 222 – 235.

[20] Dill H. (1986) Metallogenesis of early Paleozoic graptolite shales from the Graefenthal Horst northern Bavaria Federal Republic of Germany, Economic Geology, 81: 889-903.

[21] Dott R. L., JR. (1964) Wacke, Greywacke and Matrix – What Approach to Immature Sandstone Classification? Journal Sedimentary Petrology, 34: 625 – 632.

[22] Dypvik H. (1984) Geochemical compositions and depositional conditions of Upper Jurassic and Lower Cretaceous Yorkshire clays, England, Geological Magazine, 121(5): 489-504.

[23] Fairbridge R.W. (Ed.) (1972) The Encyclopedia of geochemistry and environmental sciences. Van Nostrand Reinhold Co., New York, 1—1344.

[24] Folk, R.L. (1980) Petrology of Sedimentary Rocks, Austin, Tex: Hemphill pub.Co.
[25] Fyffe L.R., Pickerill R.K. (1993) Geochemistry of Upper Cambrian – Lower Ordovician black shale along a northeastern Appalachian transect, Bull. Geol. Soc. Am, 105 : 897 - 910
[26] Hallberg R.O., and Халлберг, P.O. (1976) A Geochemical Method for Investigation of Paleoredox Conditions in Sediments / Геохимический метод исследований условий палеоредокса в осадках, Ambio Special Report, 4: 139-147.
[27] Hatch J. R. and Leventhal J. S. (1992) Relationship between inferred redox potential of the depositional environment and geochemistry of the Upper Pennsylvanian (Missourian) Stark Shale Member of the Dennis Limestone, Wabaunsee County, Kansas, U.S.A, Chemical Geology, 99: 65–82.
[28] Hayashi Ken-IH., Fujisawa H.D., Holland & Ohmoto H. (1997) Geochemistry of 1.9 Ga sedimentary rocks from northeastern Labrador, Canada, GeochimCosmochimActa, 61 : 4115–4137.
[29] Herron M.M. (1988) Geochemical classification of terrigenous sands and shales from core or log data, J Sediment Petrol, 58:820–829
[30] Hetzel A., Böttcher M. E., Wortmann U. G., Brumsack, H. (2009) Paleo-redox conditions during OAE 2 reflected in Demerara Rise sediment geochemistry (ODP Leg 207), Palaeogeography, Palaeoclimatology, Palaeoecology 273: 302–328.
[31] Ingersoll R.V. (1978) Petrofacies and petrologic evolution of the Late Cretaceous fore-arc basin, northern and central California, Journal of Geology, 86 : 335-352
[32] Ingersoll R.V., Suczek C.A (1979) Petrology and provenance of Neogene sand from Nicobar and Bangal Fans, DSDP sites 211 and218, Journal of Sedimentary Petrology, 45 : 103-116
[33] Johnsson M.J. (1993) The system controlling the composition of clastic sediments, In Johnsson, M.J., and Basu, A., eds., processes controlling the compostion of clastic sediments: Boulder, Colorado, Geological Society of America Special Paper 284 : 1-19
[34] Jones B. and Manning D. A. C. (1994) Comparison of geological indices used for the interpretation of palaeoredox conditions in ancient mudstones, Chemical Geology, 111: 111-129.
[35] Kataki P.S., Saikia H.C., Pundir B.S., Begum J., Vushum A.T. (2003) Prospect analysis of Palaeogene sequence in the area between Panidihing – Disangmukh and Rudrasagar through integration of Panidihing – Disangmukh and OIL's nearby area.
[36] Keskin S. (2011) Geochemistry of Camardi Formation sediments, central Anatolia (Turkey): Implication of source area weathering, provenance and tectonic setting, Geosciences Journal, 15: 185 – 195.
[37] Kimura H. and Watanabe Y. (2001) Oceanic anoxia at the Precambrian-Cambrian boundary Geology, 21: 995-998.
[38] Kroonenberg S.B. (1994) Effects of provenance, sorting and weathering on the geochemistry of fluvial sands from different tectonic and climatic environments, Proc. 29th Int. Geol. Cong. A, 69 – 81.
[39] Machhour L., Philip J., and Oudin J.L. (1994) Formation of laminate deposits in anaerobic-dysaerobic marine environments, Marine Geology, 117: 287–302.
[40] Mathur N., Raju S. V and Kulkarni T. G. (2001) Improved identification of pay zones through integration of geochemical and log data: A case study from upper Assam basin: American Association of Petroleum Geologists Bulletin, 85: 309-323.
[41] McDonough W.C. and Sun S. (1989) Chemical and isotopic systematic of oceanic basalts : implications for mantle composition and processes
[42] McKay J.L., Pedersen T.F., and Mucci A. (2007) Sedimentary redox conditions in continental margin sediments (N.E. Pacific)—Influence on the accumulation of redox-sensitive trace metals, Chemical Geology, 238: 180–196.
[43] McLennan S.M., Hemming S., McDaniel D.K., and Hanson G.N. (1993) Geochemical approaches to sedimentation, provenance and tectonics, Geological Society of America(Special Paper), 285: 21–40.
[44] McLennan S. M., Barbara B., Hemming S. R., Hurowitz J. A., lev S. M and McDaniel D. K. (2003) The role of provenance and sedimentary processes in the geochemistry of sedimentary rocks. In Geochemistry of sediments and sedimentary rocks: Evolutionary considerations to mineral deposit-forming environments, Geological Association of Canada, 4 : 7-38.
[45] McLennan S.M. (2001) Relationships between the trace element composition of sedimentary rocks and upper continental crust, Geochemistry, Geophysics and Geosystems, vol 2, paper number 2000GC000109
[46] Nagarajan R., Madhavaraju J., Nagendral, R., Armstrong-Altrin J.S., Moutte, J. (2007) Geochemistry of Neoproterozoic shales of the Rabanpalli Formation, Bhima Basin, Northern Karnataka, southern India: implications for provenance and paleoredox conditions, Revista Mexicana de Ciencias Geológicas, 24(2): 150-160.
[47] Nagarajan R., Madhavaraju J., Nagenra R., Armstrong-Altrin J.S. and Moutte J. (2007a) Geochemistry of Neoproterozoic shales of the Rababnpalli Formation, Bhima basin, Northern Karnataka, southern India: Implications for provenance and palaeoredox conditions, Revista Mexicana de Ciencias Geologicas, 24: 150–160.
[48] Nagarajan R., Madhavaraju J., Armstrong-Altrin J. S. and Nagendra R. (2007b) Geochemistry of Neoproterozoic limestones of the Shahabad Formation, Bhima basin, Karnataka, southern India, Geosci. J, 15: 9–25.
[49] Naik G.C., Kumar R., and Soren M.N. (2004) Tectonic Setting and Petroleum System Significance of Pre -Tertiary Sediments, Assam

Basi, Northeast India, 5th Conference & Exposition on Petroleum Geophysics, Hyderabad – India, 365 – 371

[50] Osman M.(1996) Recent to quaternary River Nil e sediments:A sedimentological characterizaton o n samples from Aswan toNagaHammadi, Egypt,Un pub. Ph.D. Thesis, Univ. of Vienna Vienna, 1—162.

[51] Paikaray S., Banerjee S., and Mukherji S. (2008) Geochemistry of shales from Paleoproterozoic to Neoprotzoic Vindhyan Super-group: Implications on provenance, tectonic and paleoweathering, Journal of Asia Earth Science, 32:34–48.

[52] Pettijohn F.J. (1984) Sedimentary rocks, third edition, The John Hopkins University, Baltimore, Chapter 7, 195 – 246

[53] Potter P.E. (1978) Petrology and chemistry of big river sands [J]. Journal of Geology, 86: 423 – 449.

[54] Rangarao A. (1983) Geology and Hydrocarbon Potential of a part of Assam – Arakan Basin and its adjacent area, Petroleum Asia Journal, 127-158

[55] Roser B.P. & Korsch R.J. (1986) Determination of tectonic setting of sandstone-mudstone suites using SiO2 content and K2O/Na2O ratio, J. Geol., 94 (5) : 635—650.

[56] Roser B.P. and Korsch R.J. (1988) Provenance signatures of sandstone-mudstone suites determined using discriminant function analysis of major-element data,Chemical Geology, 67:119–139

[57] Roser B.P., Cooper R.A., Nathan S., Tulloch A.J (1996) Reconnaissance sandstone geochemistry, provenance, and tectonic setting of the lower Paleozoic terranes of the West Coast and Nelson, New Zealand, New Zealand Journal of Geology and Geophysics, 39:1– 16.

[58] Roser B. P. (2000) Whole-rock geochemical studies of clastic sedimentary suites, Mem. Geol. Soc. Japan, 57: 73–89.

[59] Suttner L.J. and Dutta P.K. (1986) Alluvial sandstone composition and paleoclimate 1. Framework mineralogy, Journal of Sedimentary Petrology, 56: 326-345

[60] Shaw D.M. (1968) A review of K–Rb fractionation trends by covariance analysis, Geochim Cosmochim Acta, 32: 573–602

[61] Shaw, T. J., Geiskes J. M., Jahnke R. A. (1990) Early diagénesis in differing depositional environments: the response of transition metals in pore water, Geochimica et Cosmochimica Acta 54(5): 1233-1246.

[62] Taylor S.R. & McLennan S.M. (1985) The Continental Crust; Its Composition and Evolution Blackwell, London

[63] Wignall P. B. and Myers K. J. (1988) Interpreting benthic oxygen levels in mudrocks: A new approach, Geology,16;452-455.

[64] Wronkiewicz D.J. and Condie K.C. (1987) Geochemistry of Archean shales from the Witwatersrand Supergroup, South Africa: Source-area weathering and provenance, Geochimica et Cosmochimica Acta, 51: 2401–2416