Journal of Nepal Geological Society, 2011, Vol. 43 (Special Issue), pp. 53–68

The Barail sandstones of Ukhrul area, Manipur, India: a study on provenance and tectonic environment based on petrographic, heavy mineral and geochemical data

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ABSTRACT

Petrographic, mineralogical and geochemical studies have been carried out for the Barail sandstones in Ukhrul area of Manipur in the Assam-Arakan Basin to determine the nature of sediments, their sources and tectono-sedimentary environment. The study is based on thin-section petrographic works on the Barail sandstones, heavy mineral identification and evaluation, and also determination of major oxides of the sandstones collected from the Barail Group using XRF technique.

The petrographic study shows that the sandstones are quartz arenite, quartzose arenite, sub-litharenite, sub-arkose, sublithic arenite in the eastern part (lower sequence) and quartzose arenite, arkose, sub-arkose, lithic arkose in the western part (upper sequence) of the study area following the classifications given by different workers. There is higher degree of diagenetic changes, with poor matrix due to dissolution of the fine mineral grains. Petrographic study and heavy mineral composition indicate that the sediments were mostly derived from plutonic acid igneous and quartzo-feldspathic gneissic rocks. The lower sequence of the Barail Group is mineralogically highly matured and the upper sequence is markedly immature. Contribution of sediments from the Indo-Burma Ophiolite belt is also evident. There was change in tectonic settings before the onset of deposition of the upper Barail sequence in the study area.

The chemical characteristics of the Barail sandstones indicate that these rocks are graywacke and Fe-shale which is not reflected in the petrographic classification. It appears from the analysis that the matrix of the sandstones contains higher concentration of Na_2O, Fe_2O_3 and Al_2O_3 compared to K_2O and SiO_2, and influence the chemical classification. Usually, in petrographic work, the fine-grained matrix components are counted together, but during chemical analysis the chemical component of the matrix are also picked up along with the coarse grains of the sandstones used for petrographic analysis. Chemical analysis indicates that the sediments were derived from metamorphic rocks of predominantly quartzose sedimentary and intermediate igneous provenances in oceanic and continental arc tectonic settings having some passive margin influence. Paleoclimatic condition during deposition of the sediments was mostly humid during deposition of the lower coarser sequence of the Barail sandstones and semi-humid to arid during deposition of the upper fine sandstone sequence, as evidenced by petrographic and geochemical data.

Keywords: Petrography, heavy mineral, geochemistry, barail sandstone, Assam-Arakan basin

Received: 14 November 2010 **revision accepted:** 10 February 2011

INTRODUCTION

The thick argillo-arenaceous sequence overlying a thick shale sequence of Disang Group (Upper Cretaceous to Upper Eocene) in part of Manipur and Nagaland is designated as Barail (Upper Eocene to Oligocene) in the Assam-Arakan sedimentary basin (Mathur and Evans 1964). The rocks of the Barails along with the underlying shale (Disang) are together folded (Saxena 1987) with the axial trace trending roughly in NNE- SSW direction. As a result of this folding the Disangs and the Barails occur in a number of roughly NE-SW trending belts throughout the major part of the state of Manipur and Nagaland. In the anticlinal zones, the Disang rocks are exposed with several smaller sized symmetrical folds. The younger Barail sandstones occur in the core of major synclines. In the present study, we have collected samples mainly from two such synclines of which the lower coarse sandstones are very prominent in the eastern syncline and upper finer sandstones in the western syncline in the stratigraphic sequence.

The eastern sandstones are generally hard and brown to reddish brown in colour. Occasionally intrusions of fine quartz veins in these massive to coarse bedded sandstones are observed in the field. Small pockets of coal and thin coal seams are encounted during fieldwork within the Barail sandstones. Poorly preserved silicified foraminifera fossil shells in broken form have been identified in petrographic thin sections at rare occasions. The western sandstones are generally fine grained, bedded, light grey coloured and are commonly associated with siltstones.

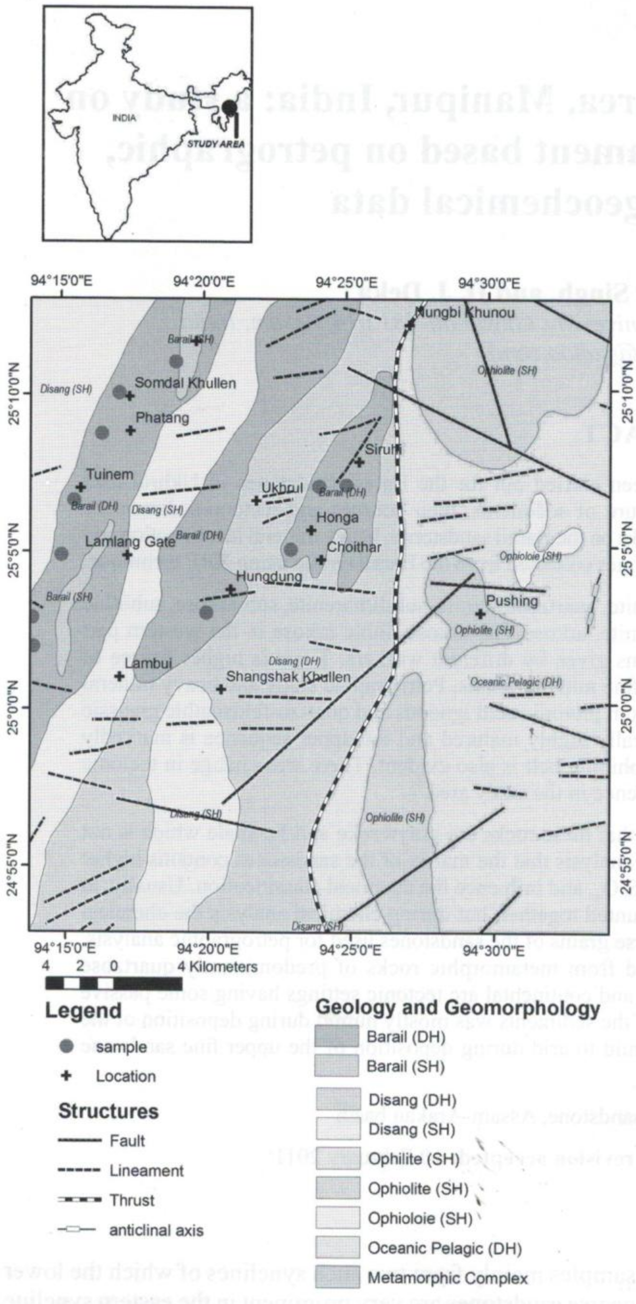

Fig. 1: Geological map of Ukhrul area. Red dots on the map are the sampling sites for the Barail sandstones. The thrust dips to the east. The abbreviations DH and SH stands for denudational and structural hills. Map has been prepared using Mitra et al. 1986 and our own field survey.

The location of the study area in the globe is $24^0 53'$ N – $25^0 12'$N and $94^0 14'$E – $94^0 33'$E and is covered by the Survey of India toposheet no. 83K/8 (Fig. 1). The article is based on the results obtained from petrographic works, heavy mineral study, and major oxides data derived from XRF machine.

Table 1: Stratigraphic succession of the study area

Age	Unit	Lithology
Upper Eocene to Oligocene	Barail Group	Massive sandstone, alternation of shale and sandstone, and bedded structure.
	Gradational contact	
Cretaceous to Upper Eocene	Disang Group	Arenaceous rocks, dark grey splintery shale interbeded with sandy-shale and siltstone in upper part. Argillacious grey shale inter-bedded with mudstones and minor amount of silt in lower part
	Tectonic contact	
Cretaceous to Middle Eocene	Ophiolite-Melange Suite	Basic and ultrabasic intrusives and extrusives of peridotite, gabbro, serpentinite, chert, limestone, shale, sandstone, conglomerate, etc.
	Unconformity	
Pre- Mesozoic or older	Metamorphic Complex	Low to medium grade metamorphic rocks of various composition, phyllitic schists, quartzites, micaceous quartzite, quartz, chlorite, mica schists, marble, etc.

GEOLOGICAL SETTING

The study area is the eastern part of mountainous regions which surrounded the central Imphal Valley of Manipur, India. The study area lies in the inner Palaeogene fold belt of Manipur-Nagaland-Upper Assam-Arunachal Pradesh. A large spread of the Disang Group with isolated covers of Barail Group characterizes the geological setting of this area. A simplified geological succession of the study area is given in Table 1.

METHODOLOGY

Petrographic studies has been carried out in thin section using petrological microscope (Fig. 2) in the Department of Geological Sciences, Gauhati University taking 16 samples from the western part and 34 samples from the eastern part. The study includes description of mineral constituents and other petrographic properties. For the purpose of convenience the rock constituents have been subdivided into four major groups. They are - (i) primary detrital constituents (ii) miscellaneous detrital constituents including heavy minerals (iii) cement, and (iv) matrix. All the major minerals are included in the primary detrital constituents. The accessory minerals are included in the miscellaneous detrital constituents. The cements include ferruginous and siliceous cementing materials. Detrital grains smaller than 0.03 mm in size is included in the matrix group. Among detrital constituents, quartz is the main constituents mineral of the sandstones under study, and hence, different types of quartz have been studied. Volumetric count of clastic grains and cements has been carried out using Swift point counting machine.

Heavy mineral analysis is an important and useful tool as it bears characters of the source rocks from which the sediments are derived. Heavy minerals include both chemically stable and unstable varieties. The most stable heavy minerals such as tourmaline, zircon, and rutile can survive multiple recycling episodes and occur in the older sandstones, whereas much less stable minerals, epidote, zoisite, chlorite, hornblende etc. are less likely to survive recycling. They generally represent first cycle sediments that reflect the composition of proximate source rocks and are often found in the younger sandstones. This difference is also resulted from intrastratal solutional activity for longer time in older sediments than in the younger sediments. Heavy minerals are useful indicators of sediment source rocks (provenance) because different types of source rocks yield different suites of heavy minerals (Van Andel 1959; Hurbert 1962; Morton 1985). The "funnel separation method" of Krumbein and Pettijohn (1938) was used to separate heavy mineral with the help of bromoform (Sp. Gr. 2.89). The heavy minerals have been studied under binocular petrological microscope.

Geochemical studies have been carried out in the Barail sandstones to determine the nature of sediments, their sources and depositional environment. This study is based on determination of major oxides and synthesizing these data for 15 Barail sandstone samples (six from the east and nine from the west) using XRF technique. More number of samples from the west have been selected since they are relatively fine-grained than that of the eastern part. XRF spectroscopy techniques of analysis were carried out for major oxides. The XRF spectroscopy is widely used for the qualitative and quantitative elemental analysis of powdered samples. In the present study, the samples were analyzed at SAIF (Sophisticated Advance Instrumentation Facility) in the USIC Department of the Gauhati University using XRF machine (PAN analytical make, Model-Axios) using beads prepared from the powdered sediment samples. The bead is prepared by 4g Lithium tetra-borate, 1g Lithium carbonate, 1g sample (powder). The beads were fused in an Au-Pt crucible at 1100^{0}C. All the analyses were done by using X40 software.

RESULTS

Petrography of sandstone

The petrographic constituent of the sandstones are discussed below. Model analysis of the sandstones was done with the help of point counter and the volumetric percentages of different constituents determined (Table 2). The clastic constituents of the Barail sandstones show that the eastern sandstones are composed mostly of sub-rounded to sub-angular grains whereas the western sandstones are composed of sub-angular to angular grains. The constituent mineral grains, lithic fragments and diagenetic features are given in Fig. 2.

Quartz

Quartz is the principal constituent of arenaceous rocks, and forms the major mineralogical entity of the present sandstones. The quartz grains (Conolly 1965; Blatt 1967 a, b) of the sandstones consist of a single crystal (monocrystalline) or aggregate of crystals (polycrystalline). Monocrystalline quartz can be further classified into Unit (identified by their unit extinction within a range 1^0 to 3^0), Undulose (characterized by their sweeping extinction feature), and Vein quartz (grain having sub- parallel planes of weakness along which fluid or gas bubbles present). The vein quartz are found as unit and undulose type, but due to their genetic distinction are excluded from the later two classes. Polycrystalline quartz can be classified into Composite (presence of three or more quartz units), Pressure (mosaic like appearance with sutured grain boundary) and Schistose (number of smaller interlocking quartz grains with smooth grain boundary). The average quartz percentage in the sandstones of the eastern part and the western part are 62.92 and 45.47 respectively.

Feldspar

Feldspars is one of the important constituent of the present sandstone. Feldspar of both types i.e., K-feldspars, such as microcline and orthoclase and Na-feldspars such as plagioclase are found. Among the feldspar group of minerals sodic plagioclase is the most common. Less amount of feldspars are identified from the samples collected from Ukhrul East (Lower sequence) whereas good amount of feldspar are identified from the samples collected from Ukhrul West (Upper sequence). The average feldspar percentage in the sandstones of the eastern part and the western part are 3.66 and 16.66 respectively.

Chert

Chert is a chemically precipitated sedimentary rock formed in the sedimentation basin. It may also enter the basin as clastic grains derived from sedimentary provenance. In the present sandstones, the average chert percentages from the eastern part and the western part are 3.03 and 3.28 respectively.

Mica

Both muscovite and biotite constitute the mica population. The muscovite grains are elongated slender and flaky in character. They are colourless in polarized light and show distinct cleavage. They are pleochroic and show high order interference colour. The elongated flaky muscovite grains show kink bending as well as crumpling along the grain boundaries. Biotites are brownish in colour with one set of cleavage, pleochroic and show parallel extinction. The average mica percentage in the sandstones of the eastern part and the western part are 1.92 and 6.69 respectively.

Accessory minerals

Accessory minerals mostly include the heavy minerals. Detrital grains of calcite, though very rare are found in two thin sections analysed from the western part of the study area [Fig.3(a)]. The average accessory minerals percentage in the sandstones of the eastern part and the western part are 2.51 and 3.11 respectively.

Rock fragments

A rock fragment is defined as a composite unit more than one mineral species (Blatt 1967b). They have, in general, recognizable characteristics of their parent rocks. The rock fragments in the sandstones belong to granite, schist and quartzite. Quartzites are identified by inclusions of minerals such as micas and other accessory minerals or otherwise are considered as polycrystalline quartz. The average percentages of igneous, sedimentary and metamorphic rock fragments in the sandstones are 2.83, 0.16 and 1.85 respectively in the eastern part, and 4.98, 0.41 and 1.25 respectively in the western part. The average rock fragments percentage in the east and west are 4.84 and 6.58 respectively.

Matrix and Cement

Relatively fine, cryptocrystalline grains are considered as matrix. The average matrix percentage in the sandstone is 11.96 in the eastern part samples and 12.97 in the western part samples of the area. They are mostly composed of quartz and clay. The cementing materials are mostly ferruginous and found as iron coatings in the clastic grains. The cementing materials vary from 1.47% to 25.15% (average 9.44%) in the eastern sandstones, whereas they vary from 2.53% to 11.16% (average 5.20%) in the western sandstones. Authigenic growth of quartz grains also act as siliceous cement. Iron oxide coating are distributed within the large grains as well as the fine grains of the matrix. So matrix percentage calculation using point counter also includes some amount of iron cement. As a result, matrix in the sandstones might have overestimated.

SANDSTONE CLASSIFICATION

The quantitative mineralogical classifications of the sandstones have been made in triangular diagrams and the rocks are classified as quartz arenite (Pettijohn et al. 1972; Folk 1980; James et al. 1986), quartzose arenite (James et al. 1986), sublitharenite (Folk 1980), sub-arkose (Pettijohn et al. 1972), sublithic arenite (Pettijohn et al. 1972) in the easternpart of the area. The western part sandstones are classified as quartzose arenite James et al. 1986), arkose (Folk 1980), sub-arkose (Pettijohn et al. 1972),lithic arkose (Folk 1980) as per various scheme of sandstone classifications (Fig. 3). In general, it may be interpreted that the sandstones of the eastern part are dominantly quartz arenite and quartzose arenite, whereas of the western part are sub-arkose and arkose.

About 25% of the sandstones are marginally falling in the wacke field which has very large domain from 15% to 75% matrix (Dott 1964; Pettijohn 1984). We have carried out Student-t test (one-tailed) at 5% significance level on the 15% boundary of matrix and wacke, and found that the samples exceeding 15% matrix in the present case cannot be claimed as distinctly different from the arenite fields.

Tectonic Setting

Dickinson and Suczek (1979) and Dickinson (1983, 1985) have emphasized the role of plate tectonics in determination of the composition of sandstones on a regional scale. Plate tectonics control the distribution of different sandstones, being governed by the key relationships between provenance and basins (Dickinson and Suczek 1979). The composition of sandstone, however, is also affected by factors other than tectonic setting, viz, transportation history (Suttner 1974; Franzinelli and Potter 1983), sedimentary processes within the depositional basin (Davis and Ethride 1975), and paleoclimate (Basu 1985; Suttner and Dutta 1986).

Classification of sandstones according to Dickinson (1985) was attempted, and detrital modes were recalculated (Table 2). Two triangular plots namely Q_tFL_t and $QmFL_t$ show compositional field characteristics of different provenance. Q_tFL_t with emphasis on maturity and $QmFL_t$ with emphsis on source rock. where, Qm = Monocrystalline quartz, Qt = Total quartz, F= Total feldspar, Lt = Total lithic fragments. Such compositional plots for the Barail sandstones show that they were derived from stable frame work continental-block provenance and recycled orogen provenance for the eastern sandstones and continental block to mixed provenance for the western sandstones (Fig. 3).

An attempt has been made to relate the framework composition of the sandstones to climatic control, following Suttner and Dutta (1986). A bivariant log-log plot indicates a humid climate during the deposition of the eastern sediments and sub-humid climate for the western sediments (Fig. 4).

Heavy Minerals

In the present study area heavy mineral consists of Tourmaline, Zircon, Rutile, Epidote, Zoisite, Chlorite, Chloritoid, Hornblende and opaque minerals (Table 3; Fig. 5) The heavy minerals have been studied under binocular polarizing microscope and their brief descriptions are given below.

Tourmaline

Tourmaline is one of the most dominant of all the heavy minerals found in the sandstones apart from the opaque minerals. The grains are prismatic, rounded, sub-rounded and elongated. They are light brown, yellowish brown, deep brown and greenish in colour. The grains are strongly pleochroic. Tourmaline population percentage varies from 2.56 to 25.95 averaging 10.73 in the eastern part and from 1.14 to 9.52 averaging 4.35 in the western part.

Table 2: Model analysis of the Barail sandstones in and around Ukhrul District, Manipur

Sample Nos.	Quartz type: Monocrystalline: Unit	Monocrystalline: Undulose	Monocrystalline: Vein	Polycrystalline: Composite	Polycrystalline: Pressure	Polycrystalline: Schistose	Total	Feldspar	Chert	Mica	Accessory minerals	Rock fragments: Igneous	Rock fragments: Sedimentary	Rock fragments: Metamorphic	Rock fragments: Total	Cement
E/1	3.87	50.97	2.58	4.52	3.87	2.58	68.39	1.94	1.94	1.94	2.58	1.94	0.65	1.94	4.52	3.23
E/2(a)	6.45	41.48	0.92	5.07	1.84	0.92	56.68	3.69	2.76	1.38	4.15	17.97	0	2.30	20.27	4.15
E/3	7.29	52.60	1.04	7.81	4.17	5.21	78.13	0.52	1.56	1.04	1.56	1.56	0	1.04	2.60	8.33
E/4	5.02	43.38	1.37	1.83	1.83	2.74	56.16	8.68	1.83	4.57	2.28	8.23	0	1.37	9.59	9.59
E/5	3.72	45.04	1.24	5.79	4.13	3.72	63.64	0.83	2.48	1.65	1.24	0.83	0	3.72	4.55	14.88
E/6	1.41	40.38	0.94	4.23	1.41	1.41	49.77	9.86	6.10	2.82	1.41	2.82	0	2.35	5.16	9.86
E/7	2.45	36.20	1.23	3.68	1.84	1.84	47.24	1.23	3.68	1.23	1.84	0.61	0	1.84	2.45	25.15
E/8	1.54	44.62	1.03	3.08	2.05	3.59	55.90	1.03	3.59	0.51	2.05	1.03	0	1.03	2.05	15.90
E/9	2.70	49.32	1.35	4.73	2.70	5.41	66.22	2.03	4.05	2.03	1.35	1.35	0	2.70	4.05	10.81
E/10	2.47	37.04	0.62	4.32	2.47	3.70	50.62	3.70	3.70	1.85	2.47	1.23	0	2.47	3.70	13.58
E/11	1.12	32.58	0.56	1.69	1.12	1.12	38.20	14.61	3.37	7.30	2.25	1.12	0	1.12	2.25	12.92
E/12	3.03	65.91	2.27	1.52	2.27	2.27	77.27	2.27	3.03	1.52	1.52	0.76	0	2.27	3.03	4.55
E/13	0.55	27.87	1.09	15.30	15.30	4.37	64.48	6.56	1.09	0.55	1.09	2.19	0	1.64	3.83	8.74
E/14(a)	1.99	69.54	1.32	3.97	2.65	1.99	81.46	1.32	1.99	1.32	0.66	1.32	0	1.99	3.31	4.64
E/14(b)	6.75	54.60	1.84	3.07	1.23	1.23	68.71	2.45	3.07	1.84	5.52	1.84	0	0.61	2.45	4.91
E/15	3.78	45.41	2.16	8.65	2.70	1.08	63.78	1.08	0.54	0.54	0.54	1.62	0.54	0.54	2.70	11.35
E/16	2.92	48.18	1.46	3.65	2.19	3.65	62.04	2.19	1.46	1.46	2.19	4.38	0.73	2.19	7.30	10.22
E/17	2.01	46.31	0.67	7.38	4.03	2.02	62.42	1.34	3.36	0.67	1.34	2.68	0.67	4.03	7.38	8.72
E/19	6.37	43.14	1.47	5.39	4.90	5.88	67.16	1.47	4.41	2.94	1.96	10.78	0	0.49	11.27	1.47
E/20	2.31	51.45	1.73	5.78	4.62	2.31	68.21	1.16	4.05	2.31	2.89	1.73	0	2.89	4.62	8.09
E/23	2.22	60.74	2.22	2.96	2.22	2.22	72.59	1.48	3.70	1.48	2.22	1.48	0	1.48	2.96	6.67
E/25	1.34	44.30	2.01	1.34	2.68	2.01	53.69	2.68	5.37	2.01	2.01	4.70	0	3.36	8.05	10.07
E/26	2.44	23.78	1.22	3.05	2.44	1.83	34.76	9.15	9.76	3.05	4.27	2.44	0	1.83	4.27	7.32
E/27	1.31	29.41	1.96	1.31	1.31	0.65	35.95	11.76	8.50	3.92	3.27	1.96	0	1.31	3.27	9.80
E/28	6.53	49.75	2.01	7.04	4.52	4.02	73.87	1.01	1.01	1.01	1.51	2.01	1.51	1.51	5.03	11.56
E/28(b)	7.18	51.93	2.21	7.18	2.76	4.97	76.24	1.66	1.66	1.10	1.66	2.21	0	1.10	3.31	9.94
E/41	4.84	53.23	2.69	3.76	1.08	1.08	66.67	3.23	1.08	1.61	4.84	2.15	0	1.61	3.76	9.14
E/42	3.19	54.79	2.13	1.60	3.72	4.26	69.68	1.06	1.06	1.60	2.66	1.60	0	2.66	4.26	11.17
E/44	4.83	51.69	1.45	2.90	2.42	2.90	66.18	1.45	2.42	1.45	2.90	1.45	0.48	0.97	2.90	10.63
E/45	5.24	56.77	1.31	4.37	3.93	6.99	78.60	1.31	0.44	0.87	1.31	0.44	0	0.44	0.87	7.86
E/46	6.84	61.05	4.21	3.68	2.63	3.16	81.58	1.58	0.53	1.05	2.63	1.05	0	0.53	1.58	5.26
E/47	3.74	46.73	1.40	5.14	5.61	4.67	67.29	4.21	2.34	0.93	2.80	4.21	0.93	2.80	7.94	9.35
E/48	1.52	48.73	1.01	2.54	2.03	1.52	57.36	8.12	4.06	3.05	1.52	3.05	0	2.54	5.58	10.15
E/49	1.06	51.32	1.06	2.12	1.59	1.06	58.20	7.94	3.17	2.65	1.06	1.59	0	2.12	3.70	11.11
Average	3.53	47.36	1.58	4.43	3.13	2.89	62.92	3.66	3.03	1.92	2.22	2.83	0.16	1.85	4.84	9.44

Sample Nos.	Quartz type: Monocrystalline: Unit	Monocrystalline: Undulose	Monocrystalline: Vein	Polycrystalline: Composite	Polycrystalline: Pressure	Polycrystalline: Schistose	Total	Feldspar	Chert	Mica	Accessory minerals	Rock fragments: Igneous	Rock fragments: Sedimentary	Rock fragments: Metamorphic	Rock fragments: Total	Cement
W/1	3.43	29.61	0.86	8.58	2.15	3.00	47.63	13.73	3.43	4.72	1.72	4.72	0	1.72	6.44	11.16
W/3	2.76	34.81	1.10	1.10	1.10	0.55	41.44	14.92	1.66	8.29	3.31	7.73	0.55	1.10	9.39	5.52
W/5	0.99	37.30	0.99	0.99	1.49	2.48	44.06	17.33	1.49	4.46	2.48	7.92	1.99	0.99	9.90	7.43
W/7	2.44	46.34	0.97	0.49	1.46	0.98	52.68	12.19	1.95	5.85	3.41	5.37	0	0.98	6.34	4.88
W/8	2.55	33.71	1.69	1.12	1.68	1.69	42.13	16.85	2.81	10.67	3.37	5.62	0.56	1.12	7.30	3.37
W/13	2.33	40.46	1.39	0.47	1.39	1.39	47.44	13.49	1.86	6.05	2.79	8.37	0.93	2.33	11.63	5.58
W/14	2.45	31.37	1.47	0.98	2.45	1.96	40.69	17.16	2.45	4.90	5.88	4.90	0.49	2.94	8.33	6.37
W/15	2.67	45.45	1.07	1.07	1.07	1.07	52.41	17.11	4.81	1.60	3.21	4.81	1.07	1.07	6.95	3.74
W/16	2.23	44.19	0.89	1.34	1.34	0.89	50.89	22.32	6.69	1.79	1.79	2.68	0.45	1.34	4.46	3.57
W/17	1.69	33.75	1.27	1.27	1.69	1.27	40.93	18.99	2.11	12.67	1.27	8.02	0	1.69	9.70	2.53
W/18	1.72	37.50	0.86	1.29	1.72	1.29	44.39	16.81	2.59	11.21	2.16	1.72	0	2.16	3.88	3.45
W/20	1.74	32.61	0.43	0.87	0.87	1.30	37.83	15.65	4.35	11.30	4.78	4.35	0	0.87	5.22	2.61
W/23	3.61	26.80	1.03	1.03	2.58	2.06	37.11	16.49	4.64	6.19	5.15	2.58	0.52	0.52	3.61	4.12
W/24	1.90	36.19	0.95	2.38	1.90	2.38	45.11	21.43	3.81	6.19	1.43	4.29	0	0.48	4.76	3.33
W/27	3.61	38.26	0.72	1.81	3.97	1.08	49.46	16.61	3.25	7.22	4.69	4.33	0	0.36	4.69	9.39
W/28	3.86	42.47	0.77	0.77	1.93	3.47	53.28	15.44	4.63	3.86	2.32	2.32	0	0.39	2.70	6.18
Average	2.28	36.92	1.03	1.60	1.80	1.68	45.47	16.66	3.28	6.69	3.11	4.98	0.41	1.25	6.58	5.20

N.B. Sample name begins with 'E' represents the eastern samples and 'W' the western samples.

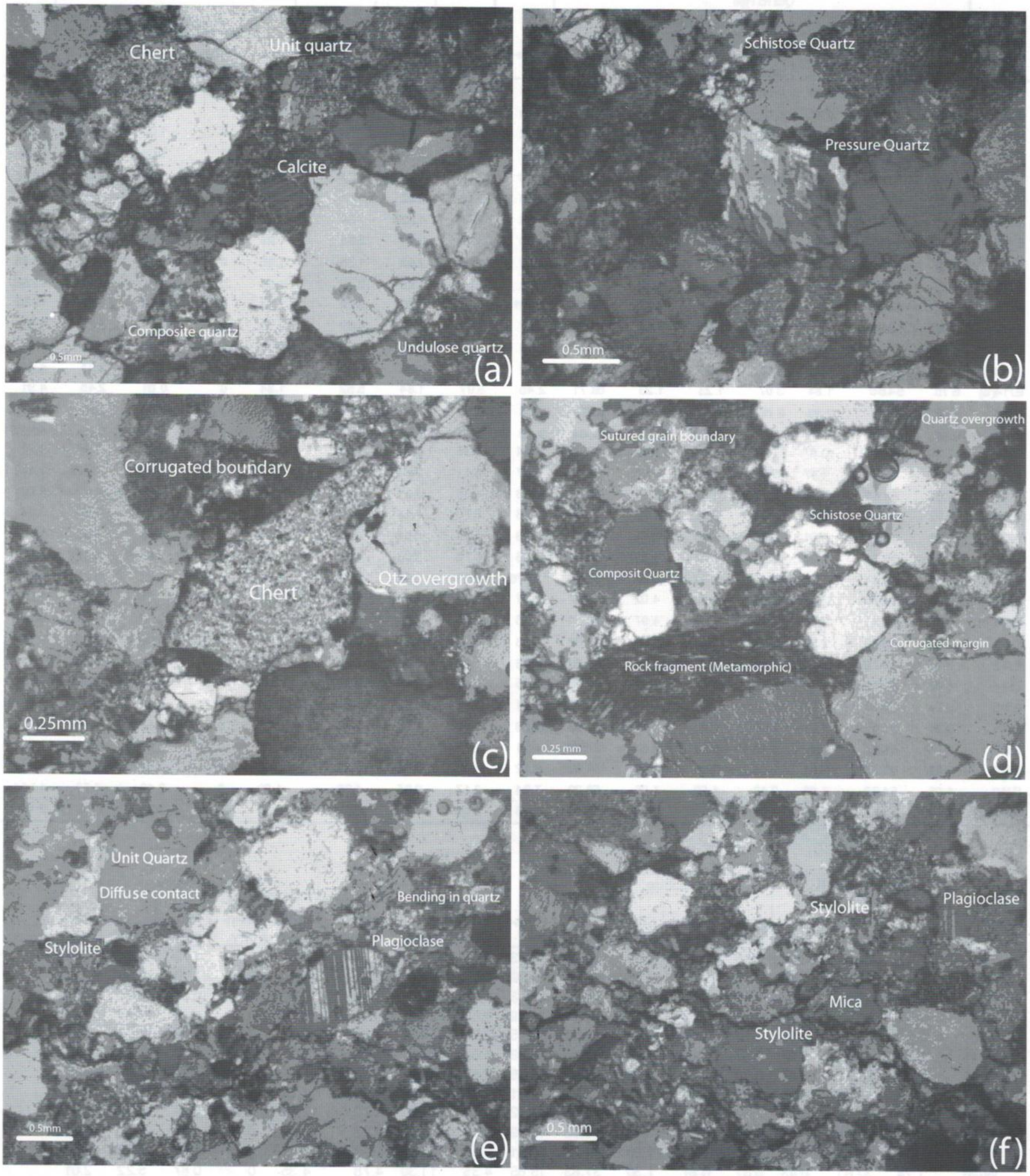

Fig. 2: Photomicrographs of petrographic sections of the Barail Sandstones, Ukhrul district, Manipur, showing the mineral grains and their diagenetic features; (a) and (c) are from the western part and (b), (d), (e) and (f) are from the eastern part of the study area. Qtz- quartz.

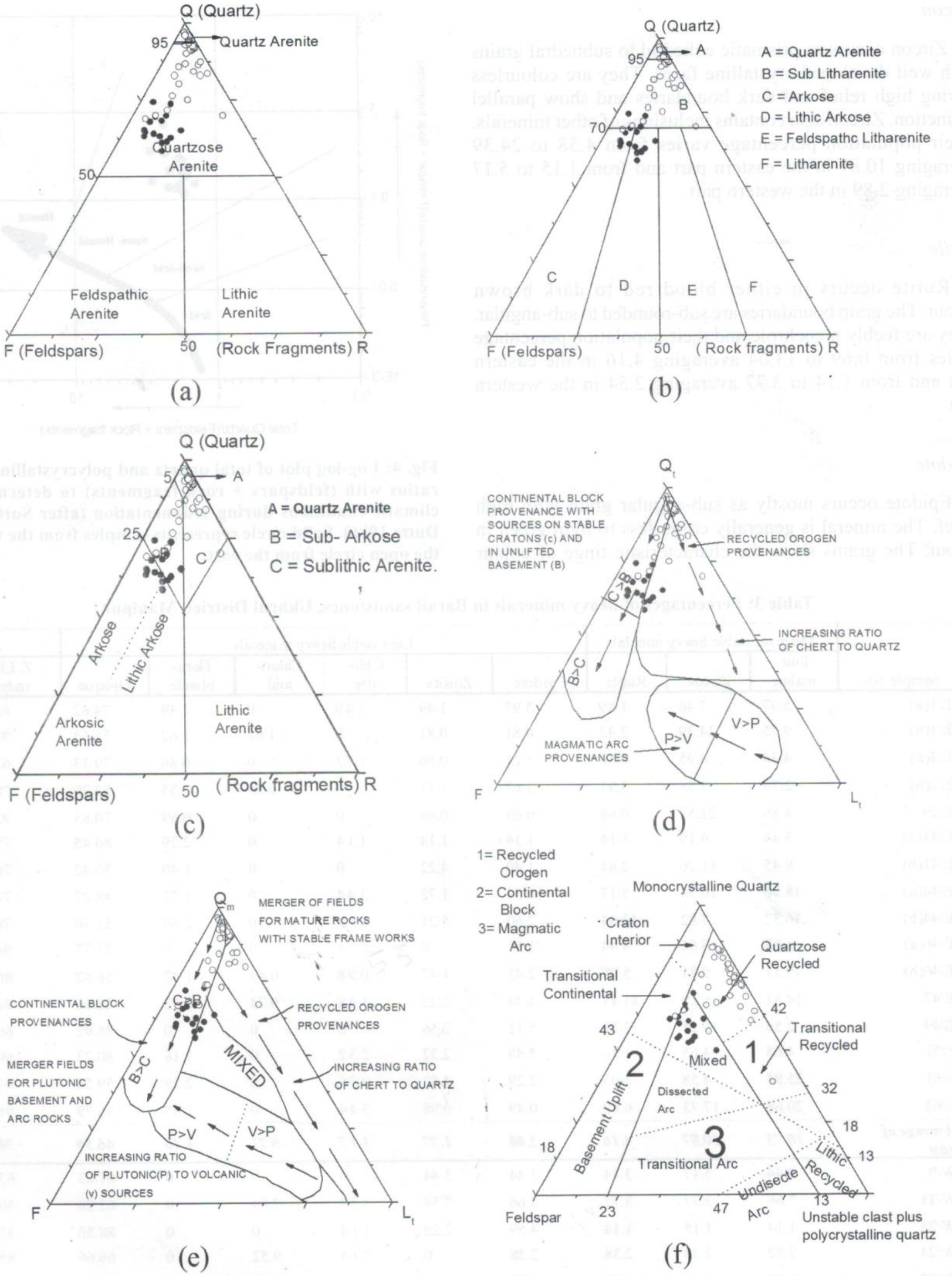

Fig. 3: Triangular plots of petrographic data of the Barail sandstones, Ukhrul district, Manipur. Classification of the sandstones: (a) after James et al. 1986; (b) after Folk 1980; (c) after Pettijohn et al. 1972. Provenance and tectonic setting; (d) Q_tFL_t after Dickinson 1985; (e) Q_mFL_t after Dickinson 1985; and (f) Dickinson et al. 1983. Solid circle represents samples from the west and the open circle from the east.

Zircon

Zircon occurs as prismatic euhedral to subhedral grains with well developed crystalline faces. They are colourless having high relief and dark boundaries and show parallel extinction. Zircon also contains inclusions of other minerals. Their population percentage varies from 4.58 to 24.39 averaging 10.87 in the eastern part and from 1.15 to 5.17 averaging 2.89 in the western part.

Rutile

Rutile occurs in either blood red to dark brown colour. The grain boundaries are sub-rounded to sub-angular. They are feebly pleochroic and their population percentage varies from 0.69 to 13.04 averaging 4.16 in the eastern part and from 1.14 to 3.77 averaging 2.54 in the western part.

Epidote

Epidote occurs mostly as sub-angular grain with high relief. The mineral is generally colourless to light green in colour. The grains show the characteristic tinge of colour

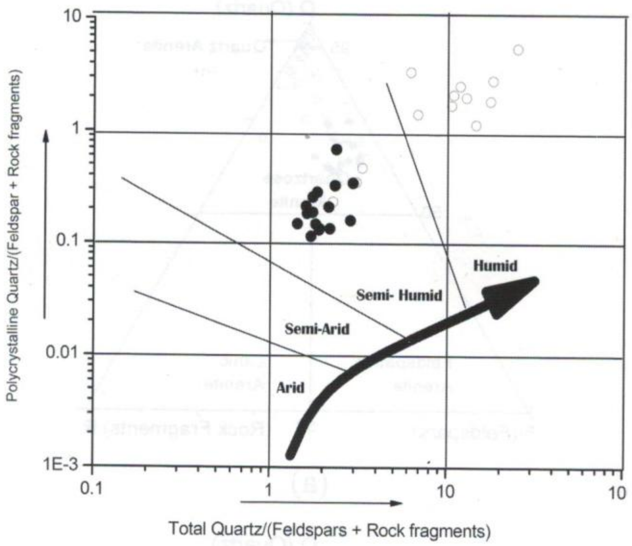

Fig. 4: Log-log plot of total quartz and polycrystalline quartz ratios with (feldspars + rock fragments) to determine the climatic conditions during sedimentation (after Suttner and Dutta 1986). Solid circle represents samples from the west and the open circle from the east.

Table 3: Percentages of heavy minerals in Barail sandstones, Ukhrul District, Manipur

	The most stable heavy minerals			Less stable heavy minerals						
Sample No.	Tour-maline	Zircon	Rutile	Epidote	Zoisite	Chlo-rite	Chlori-toid	Horn-blande	Opaque	Z.T.R. index
E/1(a)	5.97	7.46	1.49	5.97	1.49	1.49	0	1.49	74.62	62.50
E/1(b)	9.75	24.39	2.43	0.81	0.81	0	1.62	1.62	58.53	91.83
E/2(a)	4.34	6.95	0.86	5.21	0.86	1.73	0	0.86	79.13	63.63
E/2(b)	2.79	5.58	3.91	1.67	1.11	0	0.55	0.55	83.79	78.57
E/29	4.86	21.52	0.69	0.69	0.69	0	0	0.69	70.83	92.85
E/41(a)	3.44	9.19	1.14	1.14	1.14	1.14	0	2.29	80.45	75.00
E/41(b)	8.45	11.26	2.81	1.40	4.22	0	0	1.40	70.42	76.19
E/44(a)	18.96	10.34	5.17	10.34	1.72	3.44	0	1.72	48.27	71.42
E/44(b)	16.52	7.82	13.04	2.60	5.21	0.86	0	2.60	51.30	78.18
E/46(a)	8.88	6.66	4.44	1.11	0	1.11	0	0	77.77	94.73
E/46(b)	19.11	9.31	5.88	2.45	1.47	0.98	0.49	1.47	58.82	86.42
E/47	14.81	16.29	11.11	4.44	2.22	1.48	0.74	2.22	46.66	82.60
E/49	2.56	10.25	2.56	5.12	2.56	0	0	0	76.92	66.66
E/51	4.65	4.65	1.16	3.48	2.32	2.32	0	1.16	80.23	60.00
E/61	25.95	4.58	3.05	2.29	1.52	0.76	0	2.29	59.54	84.61
E/62	20.68	17.73	6.89	0.49	0.98	3.44	0	2.95	46.79	91.08
Average of east	***10.73***	***10.87***	***4.16***	***3.08***	***1.77***	***1.17***	***0.21***	***1.46***	***66.50***	***78.52***
W/9	3.44	5.17	3.44	3.44	3.44	0	0	0	81.03	63.63
W/11	5.66	3.77	3.77	5.66	7.54	3.77	7.54	0	62.26	50.00
W/23	1.14	1.15	1.14	4.59	2.29	1.14	0	0	88.50	33.33
W/24	9.52	2.38	2.38	2.38	0	7.14	9.52	0	66.66	85.71
W/27	1.98	1.98	1.98	3.96	6.93	6.93	0.99	0	75.24	35.29
Average of west	***4.35***	***2.89***	***2.54***	***4.01***	***4.04***	***3.80***	***3.61***	***0***	***74.74***	***53.59***
Total Average	**9.21**	**8.97**	**3.77**	**3.29**	**2.31**	**1.79**	**1.02**	**1.11**	**68.46**	**72.58**

N.B. Sample name begins with 'E' represents the eastern samples and 'W' the western samples.

marked by brilliant greenish purple and red colours under crossed nicols. The percentage of the epidote varies from 0.49 to 10.34 averaging 3.08 in the eastern part and from 2.38 to 5.66 averaging 4.01 in the western part.

Zoisite

Zoisite occurs sub-angular grain with parallel extinction of grey, green brown colour under the crossed nicols. Zoisite crystallized in the environment of medium grade regional metamorphism and is particularly common in rocks of argillaceous and calcareous sandstone composition. Its population percentage varies from 0 to 5.21 averaging 1.77 in the eastern part and from 0 to 7.54 averaging 4.04 in the western part.

Chlorite

Chlorite grains are sub-angular to sub-rounded. Pleochroism is from green to yellow green and relief is low to moderate. Interference colour is very low. Chlorite percentage varies from 0 to 3.44 averaging 1.17 in the eastern part and from 0 to 7.14 averaging 3.80 in the western part.

Chloritoid

Chloritoid occurs as irregular to sub-rounded grains. The mineral is pale greenish brown and greenish grey in colour and possess high relief. It shows white colour banding under the crossed nicols. Chloritoid is relatively common constituent of to medium grade regionally metamorphosed pelitic sediments, rich in aluminum and ferric iron. The percentage varies from 0 to 1.62 averaging 0.21 in the eastern part and from 0 to 9.52 averaging 3.61 in the western part.

Hornblende

Hornblende occurs as sub-rounded to elongate in outline. They show green to greenish brown colour. Pleochroism is strong while the prismatic grains show one set of cleavages. Green coloured hornblende is found in granite. The population percentage varies from 0 to 2.95 averaging 1.46 in the eastern part. In the western part no hornblende has been obtained.

Opaques

Opaque minerals are the dominant heavy minerals in the sandstones. The opaque mineral grains, in general, are irregular in shape and size with broken surface. They are usually black to brownish in colour. They are mostly oxide of iron. Though rare, a few chromite grains with cubic and octahedral shape are identified under ore microscope. Octahedral magnetite is also found in substantial number. The nearest sources for the euheral and subhedral chromites and magnetite in all probability the Nagaland-Manipur Ophiolite belt (Indo-Burma Ophiolite belt). The population percentage of the opaques varies from 46.66 to 83.79 averaging 66.50

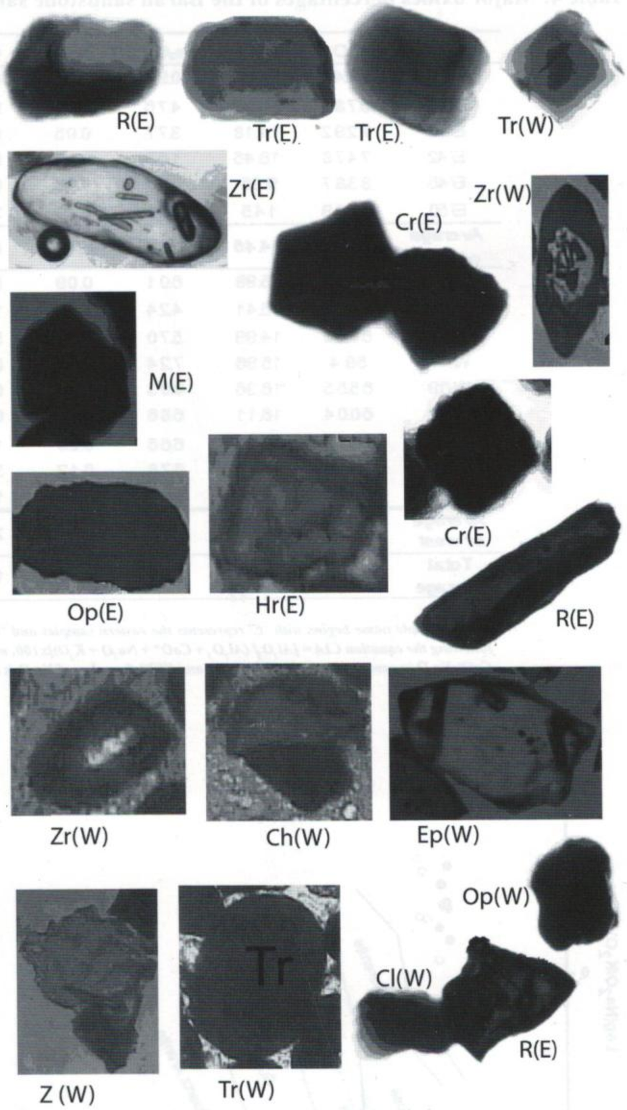

Fig. 5: Photomicrograph of heavy mineral of the Barail sandstones, Ukhrul district, Manipur. R- Rutile, Tr- Tourmaline, Zr- Zircon, Cr- Chromite, M- magnetite, Op- Opaque, Hb- Hornblande, Ch-Chloritoid, Ep- Epidote, Z- Zoisite Cl-Chlorite. The bracketed letter 'E' represents samples from the eastern part, and 'W' represents samples from the western part of the study area.

in the eastern part and from 62.26 to 88.50 averaging 74.74 in the western part.

Heavy mineral study shows that among these minerals, zircons are found as euhedral to sub-rounded grains, tourmalines and rutiles as sub-rounded elongated grains, and chromites and magnetites as euhedral to subhedral cubic to octahedral grains in the eastern part (Fig. 5) along with other unstable heavies (Table 3). The western sandstones have abundant unstable heavies as compared to the eastern part, some of which are substantially angular. These sandstones possess some highly rounded stable minerals like tourmaline and zircon derived from recycled sediments.

Table 4: Major oxides percentages of the Barail sandstone samples, Ukhrul district, Manipur

Sp. No.	SiO_2	Al_2O_3	Fe_2O_3(t)	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	CIA
E/15	74.42	14.81	0.94	0.01	0.01	0.24	2.18	1.18	0.89	0.15	81.46
E/16	67.83	16.89	4.76	0.03	0.01	0.25	2.2	1.89	0.47	0.29	80.47
E/18	72.92	14.18	3.77	0.05	0.01	0.19	2.23	0.64	0.74	0.09	83.12
E/42	74.78	16.45	1.53	0.03	0.01	0.24	2.32	1.29	0.3	0.2	81.96
E/45	83.87	9.86	0.29	0.06	0.01	0.06	2.17	0.28	0.23	0.03	80.03
E/50	69.89	14.5	3.01	0.13	3.01	0.34	2.34	0.77	0.72	0.11	72.68
Average of east	***73.95***	***14.45***	***2.38***	***0.05***	***0.51***	***0.22***	***2.24***	***1.01***	***0.56***	***0.15***	***79.95***
W/4	58.87	15.98	6.01	0.09	5.85	5.76	2.45	0.76	0.59	0.22	73.84
W/7	66.15	16.41	4.24	0.02	1.27	0.69	2.47	1.49	0.68	0.13	75.83
W/14	58.26	14.99	5.70	0.11	5.23	5.2	2.37	1.12	0.73	0.18	71.89
W/17	59.4	15.96	7.24	0.22	0.59	4.23	2.37	1.09	0.82	0.18	79.76
W/19	65.55	16.36	6.03	0.08	0.07	3.44	2.41	0.91	0.93	0.13	82.84
W/20	60.04	16.11	6.86	0.13	0.38	5.88	2.34	1.08	0.85	0.2	80.91
W/23	63.75	16.21	6.66	0.29	1.62	5.25	2.4	0.91	0.66	0.17	76.68
W/30	59.49	16.45	6.75	0.12	3.29	5.08	2.38	1.64	0.77	0.22	71.99
W/31	60.30	16.42	6.53	0.09	1.51	5.8	2.34	1.14	0.99	0.22	76.69
Average of west	***61.31***	***16.10***	***6.22***	***0.13***	***2.20***	***4.59***	***2.39***	***1.13***	***0.78***	***0.18***	***76.71***
Total average	66.37	15.44	4.69	0.10	1.52	2.84	2.33	1.08	0.69	0.17	78.01

NB. 1. Sample name begins with 'E' represents the eastern samples and 'W' the western samples.2. The CIA index is calculated using molar proportions following the equation CIA = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)]x100$, where CaO represents the amount of CaO incorporated in the silicate phases. As, $CaO>Na_2O$ in sample nos. E/50, W/4, W/14 and W/30 the value of Na_2O is assumed as CaO* in the CIA calculation (McLennan 1993).*

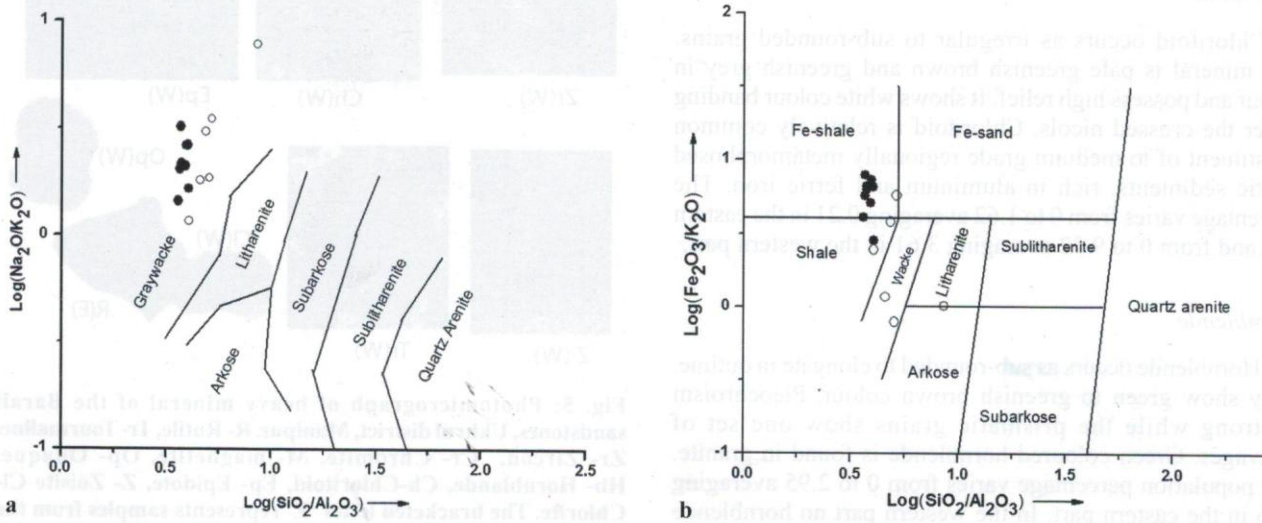

Fig. 6: Chemical classification of the Barail sandstones, Ukhrul district, Manipur following (a) Pettijohn et al. 1972, and (b) Herron 1988. Solid circle represents samples from the west and the open circle from the east.

ZTR maturity index

The mineralogical maturity of the heavy mineral assemblages of the sediments is quantitatively defined by the ZTR maturity index. It is the percentage of the combined zircon (Z), tourmaline (T) and rutile (R) grains among the transparent, non-micaceous, detrital heavy minerals (Hubert 1962). The ZTR maturity index is a dominant factor in the study of heavy mineral, because these three minerals have high mechanical and chemical stability to wear and tear. In most arkoses and graywackes the average ZTR index is low, but in case of orthoquartzite (quartz arenite) it is high (Hubert 1962). The less resistant, unstable minerals are dissolved down when the maturity of the sediments increases. The more resistant mineral remain almost unchanged and their relative abundance to their counterparts in sediment increases. This is the reason why the percentage of these resistant minerals can express the maturity of sediment. Among the three constituents of the maturity index population, tourmaline present the highest percentage followed by zircon and rutile. In the present study, the maturity index varies from 60.00

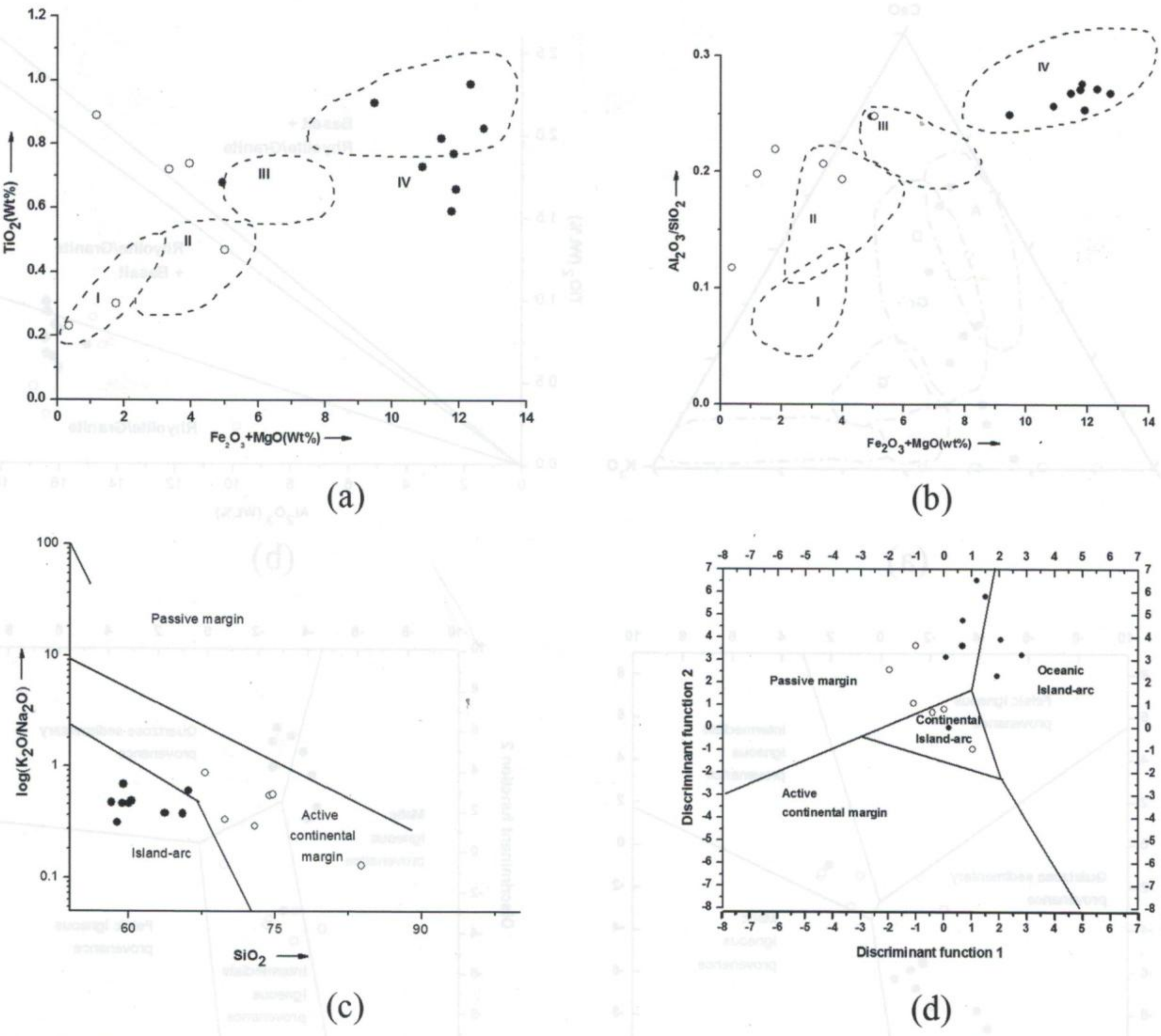

Fig. 7: (a) Discriminant diagram for sandstones (after Bhatia 1983), based upon a bivarient plot of $Fe_2O_{3(total)}$+MgO vs TiO_2. (b) Discriminant diagram for sandstones (after Bhatia 1983), based upon a bivarient plot of ($Fe_2O_{3(total)}$+MgO) vs Al_2O_3/SiO_2. (*The fields re - (I) passive margin, (II) active continental margin, (III) continental arc, and (IV) oceanic island-arc.*) (c) The SiO_2 vs log (K_2O/Na_2O) discrimination diagram of Roser and Korsch (1986) for sandstone-mudstone suites and showing the fields for a passive continental margin, an active continental margin and an island-arc. (d) Discriminant function diagram for sandstones tectonic settings (after Bhatia 1983). Solid circle represents samples from the west and the open circle from the east.

to 94.73, average being 78.52 in the eastern part and from 33.33 to 85.71, average being 53.59 in the western part | (Table 3). The sandstones of the eastern part shows higher maturity index than the sandstones of the western part. This difference in maturity indices has been induced by – (i) climatic condition during deposition, which was humid in the eastern part (older sediments) and thereby the chemical weathering was faster than in the western part (younger sediments) which suffered from sub-humid climatic condition during deposition; (ii) textural parameter, viz., roundness, matrix component, mineralogical composition indicate that eastern sediments were deposited in a relatively stable depositional environment as compared to the western part; (iii) diagenetic changes in the eastern part are more than in the western part and the intrastratal solution appeared to be more active in the eastern part, thus removing the chemically unstable minerals faster. The higher values of ZTR index of the sandstones indicate that the Barail sediments are chemically matured.

GEOCHEMISTRY

Geochemical composition of terrigenous sedimentary rocks is a function of the complex interplay of various variables, such as provenance, weathering, transportation and diagenesis (Bhatia 1983). Recent investigations on geochemical characteristics of ancient and modern detritus have been carried out in order to infer the source rocks, provenance and tectonic setting (Potter 1978; Bhatia 1983; Hiscott 1984; Bhatia and Crook 1986; Roser and Korsch 1986, 1988; Rollinson 1993; McLennan et al. 1993; Garver et al. 1996; Nesbitt and Young 1996).

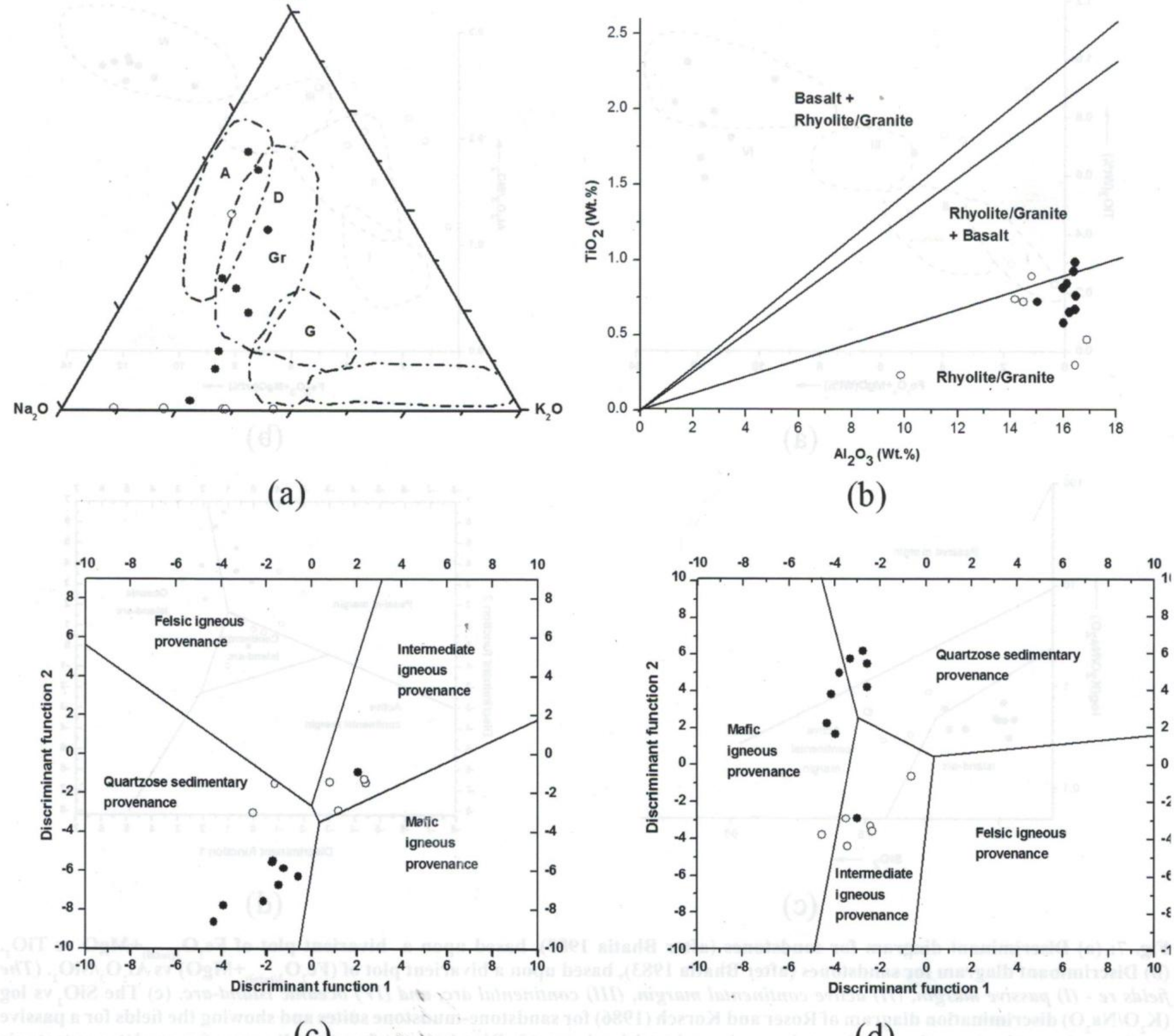

Fig. 8: Diagram to determine the provenance of the studied sandstones. (a) CaO-Na_2O-K_2O plot of sandstones (*after* Bhatia 1983). Also shown are the averages of Granites (G), Granodiorites (Gr.), Dacites (D) and Andesite (A). (b) TiO_2 – Al_2O_3 binary diagram of the sandstones (*after* Ekosse 2001). Discriminant function diagrams for the provonence signatures of sandstone- mudstone suites using major element ratios (Roser and Korsch,1988) considering seven oxides TiO_2, Al_2O_3, $Fe_2O_{3(total)}$, MgO, CaO, Na_2O and K_2O (Fig.8c) and six oxides TiO_2, Al_2O_3, $Fe_2O_{3(total)}$, MgO, Na_2O and K_2O (Fig.8d). Solid circle represents samples from the west and the open circle from the east.

Chemical classification of the sandstones

Various workers (Crook 1974; Pettijohn et al. 1972; Blatt et al. 1980; Herron 1988) have devised plots to chemically classify sedimentary rocks. In the present study the oxides percentages derived from XRF analysis are given in Table 4. The chemical classifications of the sandstones have been carried out following Pettijohn et al. (1972) and Herron (1988) which shows that the Barail sandstones are classified as graywacke and Fe-shale (Fig. 6). This contradicts the results obtained from the classification derived from the petrographic data. This problem is encountered most commonly in sandstones (Herron 1988) because in petrographic analysis, the mineral composition of the matrix is not considered. Variety of classification schemes, the compositional ambiguity of the matrix and lithic fragment components, and differences in size range of matrix, among other factors, preclude an exact relationship between chemical composition and sandstone type, but attempts

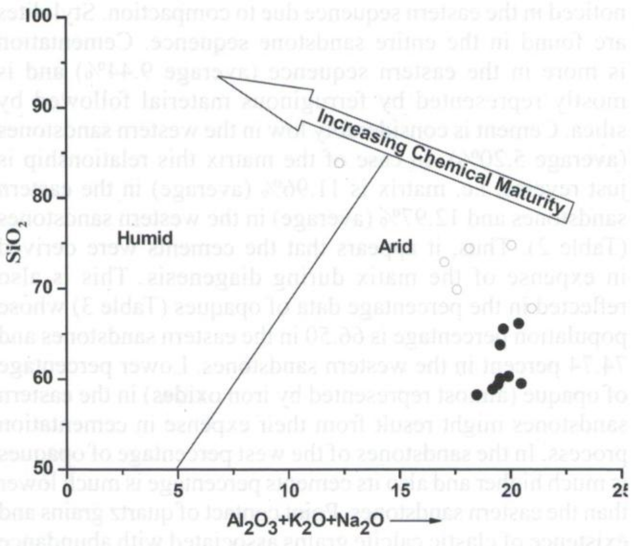

Fig. 9: Scatter plot of SiO_2 (wt %) vs $Al_2O_3+K_2O+Na_2O$ (wt %) for climatic settings (*after* Suttner and Dutta, 1986). Solid circle represents samples from the west and the open circle from the east.

have been made to derive useful, if inexact, relationships (Herron 1988). Generally, chemical classification of sedimentary rocks is suitable for fine grained rocks like shale and mudstones where petrographic classification impracticable.

Tectonic settings

Tectonic setting of the depositional basin can be assessed using petrographic data (Dickinsion 1985) as well as geochemical data (Bhatia 1983; Roser and Korsch 1986; Zhengjun et al. 2005). In the present study geochemical study has been carried out to understand the tectonic setting of the depositional environment. From this discriminant study following Bhatia (1983) and Roser and Korsch (1986) (Fig.7), it is observed that the tectonic setting of the depositional basin is oceanic arc / island arc for the western sandstones and active continental margin to passive margin for the eastern sediments. Prominently, the eastern sediments were formed under passive margin condition followed subsequently by the western sediments under ocean arc condition.

CHEMICAL DISCRIMINATION OF PROVENANCE

In the present study, the CaO-Na_2O-K_2O ternary diagram of Bhatia (1983) shows that the sediments are derived from a mixed provenance of granodiorites, dacites and andesite [Fig.8(a)]. The TiO_2 - Al_2O_3 binary diagram of the sandstones of Ekosse (2001) also indicate rhyolite/granite provenance of the sediments [Fig. 8(b)].

Based on chemistry of sedimentary detritus rocks under given tectonic settings and multi-variables, seven oxides in Fig.8(c) and six oxides in Fig.8(d) operations of discriminatory function analyses carried out following Roser and Korsch (1988). On seven variable discriminatory functions plot [Fig.8(c)] for provenance the Barail sandstone occupy quartzose sedimentary and intermediate igneous provenance for the eastern and western part of the study area respectively. On six variable discriminatory function plot [Fig.8(d)] for provenance the Barail sandstone occupy intermediate igneous provenance for the older lower sandstones (eastern part) and quartzose sedimentary and mafic provenance of the younger upper sandstones (western part).

Paleoclimate

The Barail sandstones are studied from chemical data after Suttner and Dutta (1986) to determine the climatic control on sedimentation process. The bivariant log-log plot indicates arid climate during the deposition of the Barail sediments (Fig. 9). The contradicting results are due to methodological approaches already discussed on chemical vis-a-vis mineralogical data.

Weathering in the source area

The Chemical Index of Alteration (CIA) gives an indication of the degree of weathering in the source region (Nesbitt and Young 1982). CIA records the progressive alteration of plagioclase and potassium feldspars to clay minerals. The CIA index is calculated using molar proportions following the equation $CIA = [Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)]x100$, where CaO^* represents the amount of CaO incorporated in the silicate phases. Nesbitt and Young (1982) suggested a CIA value of nearly 100 for kaolinite and chlorite, and 70 - 75 for average shales. High values (>76) indicate intensive chemical weathering in the source areas whereas low values (< 50) indicate unweathered source areas. Average CIA values for the Barail sandstones of the east is 79.95 and for the west is 76.71 indicating intense chemical weathering in the source area, however, the intensity of weathering was more in the source area of the eastern sediments.

DISCUSSIONS

The Barail sandstones of Ukhrul area, Manipur have been examined in the present study in terms of their physical appearances, mineralogy, clastic as well as chemical composition, provenance, tectonic settings, paleoclimate, diagenesis and weathering intensity in the source rocks.

In the field, the appearance of the eastern sandstones is brown to reddish brown in colour indicating an oxidising depositional environment, whereas the grey coloured sandstones of the west indicate their deposition in oxygen deficient environment. Presences of thin coal seams, coal pockets, silicified foraminifer shells, coarse texture, massive to coarse bedded sandstones with occasional current bedding and ripple marks indicate their deposition under shallow continental shelf environment.

Petrographic study of the sandstones indicates that the rocks are most commonly arenaceous. Higher percentage of quartz, lower amount of feldspars, mica, accessory minerals, rock fragments, lower matrix percentage in the sandstones of the eastern part contrary to their lower values in the western part (Table 2) indicate that eastern sandstones are more matured than the fine sandstones of the west. Tectonic settings study shows that tectono-sedimentary basin performed as a stable environment during deposition of the lower Barail sandstones which subsequently transformed into a tectonically disturbed, rejuvenated depositional basin. Angular clastic grains indicate that the sediments were not transported from long distances. Large population of quartz is represented by undulose quartz, average 47.36% in the eastern sandstones and 36.92% in the western sandstones, indicated there derivation from a tectonically disturbed area.

Heavy mineral study indicates abundance of stable heavy minerals in the eastern part and relatively unstable heavies in the western part. They were derived from different distinct rock types. Presence of epidote shows that the sediments were partly derived from acid igneous and /or altered metamorphic rocks. The presence of brown to yellow brown variety of tourmaline suggests metamorphic source. Presence of rutile is characteristic of a provenance of metamorphosed argillaceous sediments of high grade schist (Force, 1980). The zircon grains in the sediments indicate their derivation from acid igneous rock. Rounded zircon and tourmaline indicate their derivation from sedimentary provenance (Fig.5). It is seen that the eastern Barails (lower sequence) do not possess rounded tourmaline, zircon and also detrital calcite (Fig.2a), unlike their existence in the western Barails (upper sequence). Thus, there might be tectonic activities between the lower and upper sequences and a tectonically rejuvenated terrain containing sedimentary rocks became a part of the source area for the upper sequence. The Z.T.R. maturity index indicates that the eastern sediments are mineralogically highly matured and the western sediments are immatured. The paleoclimate of the sediments, as evidenced by the petrographic data was dominantly humid during the deposition of eastern sediments and sub humid during the deposition of the western sediments. Opaque minerals are mainly derived from crystalline rocks, both acidic and basic. Euhedral to subhedral cubic and octahedral chromite grains, and octahedral magnetite grains are found in the lower sandstone sequence of the east abundantly. These are also found among the heavy minerals of the western upper sequence of the sandstones. They appear to be contributed by the Indo-Burma Ophiolite Belt (Joshi and Vidyadharan 2008) of Cretaceous age located along the eastern border of the study area.

Diagenetic activities are well discernable in thin sections. Concavo-convex contact between grains indicates action of pressure solution along the grain boundary during diagenesis. Bending of micas is common in the entire sandstone sequence, however, bending of quartz have been noticed in the eastern sequence due to compaction. Stylolites are found in the entire sandstone sequence. Cementation is more in the eastern sequence (average 9.44%) and is mostly represented by ferruginous material followed by silica. Cement is considerably low in the western sandstones (average 5.20%). In case of the matrix this relationship is just reverse, i.e. matrix is 11.96% (average) in the eastern sandstones and 12.97% (average) in the western sandstones (Table 2). Thus, it appears that the cements were derived in expense of the matix during diagenesis. This is also reflected in the percentage data of opaques (Table 3) whose population percentage is 66.50 in the eastern sandstones and 74.74 percent in the western sandstones. Lower percentage of opaque (almost represented by iron oxides) in the eastern sandstones might result from their expense in cementation process. In the sandstones of the west percentage of opaques is much higher and also its cements percentage is much lower than the eastern sandstones. Point contact of quartz grains and existence of clastic calcite grains associated with abundance of rock fragments, micas, zoisite indicate poor diagenesis in the sandstones of the western side.

The chemical study shows that the Barail sediments were deposited under active continental margin to passive margin tectonic setting for the older eastern sedimentary basin with some passive margin influence and oceanic arc / island arc setting for the western younger sedimentary basin. The sediments were derived from rocks of granodiorite, dacite and andesitic composition, i.e. intermediate igneous provenance. The discriminant function plots for determination of provenance indicates their derivation from quartzose sedimentary, intermediate igneous and mafic igneous provenances. Also paleoclimatic condition during deposition of the sediments was mostly humid during deposition of the lower coarser sequence of the Barail sandstones and semi-humid to arid during deposition of the upper fine sandstone sequence, as evidenced by petrographic and geochemical data. The paleoclimate study indicates that during the deposition of the Barail sediments, the climate was largely arid, the eastern being somewhat of humid climatic deposition. High values of CIA indicating intense chemical weathering in the source areas in general, which was more pronounced during deposition of the eastern sediments.

CONCLUSIONS

The Barail Sandstones in Ukhrul area were deposited initially in humid climatic condition which gradually transformed into arid climatic condition. The diagenetic activity in the lower/older sequence (eastern sediments) was more than in the upper/younger sequence (western sediments) of the Barail Sandstones. Tectonic framework also changed from the lower to upper sequence during deposition. Presence of chromite, magnetite and clastic calcite grains in the sandstones possibly refer to their nearby provenance where the Indo-Burma Ophiolite Belt and olistrostromal Ukhrul limestones of Cretaceous age exist.

ACKNOWLEDGEMENTS

The authors are thankful to N. K. Tamrakar for his fruitful comments and suggestions to improve this manuscript.

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