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Thin-section Petrography and Heavy Mineral Study of sandstones of the Barail Group of rocks occuring around Sonapur area of Jaintia Hills, Meghalaya, India

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Abstract

The study area represents a part of the South Shillong Shelf, Meghalaya, where sandstones belonging to the Barail Group (Eocene-Oligocene) are well exposed. Thin section petrography and heavy mineral investigations have been undertaken to assess the geological significance of the sandstones. Framework grains of the Barail sediments comprise of quartz (56.98 to 71.91%), feldspar (1.87 to 7.35%), mica (1.07 to 9.72%), lithic fragments (2.20 to 8.41%) and matrix (9.20 to 20.43%). The detrital composition of the sandstones comprises primarily of quartz grains, angular to sub-rounded, fine to medium grained and moderately sorted in nature. The sandstones are classified as subarkose, feldspathic graywacke and lithic graywacke. Provenance discrimination triangular plots of QFL and Q_mFL_t reflect that the detritus were mostly derived from cratonic interior sources. The Diamond diagram indicates that the Barail sandstones were derived from middle and upper rank metamorphic source.

Heavy mineral study of these sandstones indicates the presence of zircon, tourmaline, rutile, sillimanite, kyanite, staurolite, garnet, epidote, sphene, hypersthene, hornblende, chlorite, chloritoid, andalusite, apatite and opaque minerals. The percentages of most stable heavy minerals zircon, tourmaline and rutile vary from 6.11to 21.61, 2.60 to 6.56 and 2.42 to 7.57 respectively. The ZTR maturity index varies from 15.15 to 34.37, which reflects that the sandstones are mineralogically immature. The petrographic and heavy mineral study of the sandstones suggest that the detritus was probably derived from Shillong Massif where Precambrian metamorphic rocks of pelitic and arenaceous composition with plutonic bodies were exposed around the shelf margin. As the Shillong Massif comprises of Precambrian metamorphic rocks of pelitic and semitic (arenaceous) composition with intrusive plutonic bodies.

Key words: feldspathic, heavy mineral assemblage and provenance, Oligocene Barail Group

Introduction

The present study area is an integral part of the South Shillong Basin which developed on the southern fringe of the Meghalaya Plateau. This basin evolved due to the subduction- collision tectonics between the Indian plate and Burmese (Myanmar) plate (Curray et al., 1979). The Tertiary sediments of the basin deposited over the Upper Cretaceous Mahadek Formation in the Precambrian rocks of Basement Complex in Meghalaya Plateau. Southern boundary of the basin is delineated by the Dauki fault (Johnson and Nur Alam, 1991; Dasgupta & Biswas, 2000). The sedimentation continued uninterruptedly during the Tertiary period in this peripheral foreland basin (Raju A.T.R., 1968; Ranga Rao, 1983; Dasgupta & Biswas, 2000 and Nandy, 2001). These sediments tend further to the east and NE in the contigurous parts of Karbi Anglong and North Cachar Hills of Assam and underneath of the Brahmaputra valley. Present study is confined fully to the Oligocene Barail Group of rocks which are well exposed in Lumshnong -Sonapur area along Jowai-Badarpur Road section, Jaintia Hills, Meghalaya (Fig. 1).

Pioneer geological works of Medlicot (1869) and Evans (1932, 1959) established the Tertiary stratigraphic succession of Assam and Meghalaya. Dasgupta et al. (1964) mapped the area along Jowai-Badarpur Road with a summarised description of various formations exposed along it. Subsequently, many workers like Sah and Dutta (1968), Saxena and Tripathi (1982) carried out geological investigations emphasising on palynostratigraphy. Das et al. (2001) studied the stratigraphic and sedimentation of the early Tertiary sediments from Sonapur-Lumshnong area, Jaintia Hills, Meghalaya. It is evident from the previous works that a data gap exist in the understanding the sedimentation history and provenance of the Eocene-Oligocene Barail Group of rocks of the region. The present study is an attempt to unreveal the provenance and tectonic settings based on petrography and heavy mineral analysis of the sandstones of the Barail Group.

Geological setting

The Meghalaya Plateau is presumably considered as the northeastern prolongation of the Indian Peninsular Shield. The Shield areas of the Plateau constitute of Palaeo-Proterozoic tonalite gneisses, meta-gabbronorites and amphibolites (Nandy, 2001; Ghosh et al., 2005; Yin et al., 2010). These rocks form the basement of the younger sediments of the South Shillong Basin and adjoining parts of Upper Assam Basin underneath the Brahmaputra valley. The basement rocks are overlain by the Meso-Proterozoic metasedimentary cover rocks of the Shillong Group with metavolcanic Khasi Greenstone and volcaniclastics. Both the Basement rocks and Shillong Group of rocks were intruded by Neo-Proterozoic and early palaeozoic granites (Mitra and Mitra, 2001). After long period of quiescence during Permian time, Peninsular Lower Gondwana sediments deposited in the western margin of the Meghalaya Plateau in Garo Hills in Singrimari (25044/: 89044/) (Nandy, 2001). During Jurassic-early Cretaceous time, effusion of plateau basalt (Sylhet trap) took place along the southern margin of the plateau and closely associated with the Dauki Fault System (Nandy, 2001). The Sylhet trap at Therriaghat (25011/00//:91045/20//) section are in contact with the gneisses, granites or rocks of the Shillong Group at E-W trending Raibah Fault. The southern block along the Raibah fault subsided and the northern block uplifted. Soon after the cessation of the basaltic effusion the sinking of the southern block became intense, resulting into a marine transgression. In this downsinking basin Upper Cretaceous sediments represented by Mahadek Formation was deposited. Thereafter the rate of subsidence slowed down forming a stable platform with warm sea condition. The carbonate rocks of the Jaintia Group (Plaeocene- Eocene) were deposit (Nandy, 2001). All throughout the South Shillong Basin, the subsidence of the different blocks is not uniform over the southern fringe of the Meghalaya Plateau. The Garo Hills in the west and the Jaintia Hills in the East remain landmass till mid-Eocene and later it witnessed progressive subsidence. As a consequence, coal bearing sandstone followed by carbonate rocks equivalent to the upper Sylhet Limestone of the Khasi Hills were accumulated in these sectors of the basin. During late Eocene time, predominantly argillaceous lithofacies of the Kopili Formation were deposited under fluctuating shallow marine condition in the southern, southwestern and eastern margin of the Meghalaya Plateau. At the Oligocene-Miocene boundary due to terminal collision of the Indian plate with the Burmese plate, the Indo-Burmese Ranges (IBR) raised considerably forming high hills and ridges to the south and south of the south Shillong Basin. This resulted in the shallowing of the remnant sea and regressive deltaic to shallow marine deposition took place in the southern margin of the Shillong Plateau and in Upper Assam Basin. This lithosequence of platform facies has been variously named as Chokpotgiri Formation in the southern Khasi Hills, Simsang or Kherapara Formation in Garo Hills and as Barails in the East Khasi, Jaintia, North Cachar and Mikir Hills (Karbi Anglong) (Nandy, 2001). Stratigraphically a dual classification is followed for the Barail Group of rocks (Oligocene). In upper Assam and adjoining fold-thrust belt the Barails are subdivided into Nagaon, Baragolai and Tikak Parbat formations and their equivalents to the south of Naga Hills and in the south Shilling Basin are termed as Laisong, Jenam and Renji formations (Chakraborty, 1972; Ranga Rao, 1983; Nandy, 2001; Najman et al., 2019; Yin et al., 2010).

During Miocene, sedimentation continued uninterruptedly over the southern and western part of the Garo Hills and southern margin of the Khasi Hills. But the Jaintia Hills remained positive areas at that period. The major upliftment of the Meghalaya Plateau was at the end of Miocene resulting into the formation of continental fluvio-lacustrine basins along the southern margin of the Plateau. The Pliocene Dupi Tila sediments were deposited in these basins. The recent older and newer alluvium along the southern fringe of the Meghalaya Plateau represents fluvial deposits along old river valleys. The Tertiary stratigraphic succession of the south-eastern part of the Jaintia Hills (after Rangarao, 1983; Singh and Singh, 2000) is given in the Table 1.

Materials and Method

The Oligocene Barail sediments were collected systematically along Lubha River section, a part of Jowai-Badarpur Road in Sonapur village, Meghalaya. For thin-section petrographic investigations, ten numbers of representative sandstone samples of the Barail Group were taken from a continuous outcrop of larger and thicker major unit of sandstones. Modal analysis for detrital grains was done following the Gazzi–Dickinson method of point counting (Ingersoll et al., 1984). A total number of 400 framework grains were counted in each thin-section. The mineralogical classification of the sandstones was done following Dott (1964), while, the nature of the source rock was

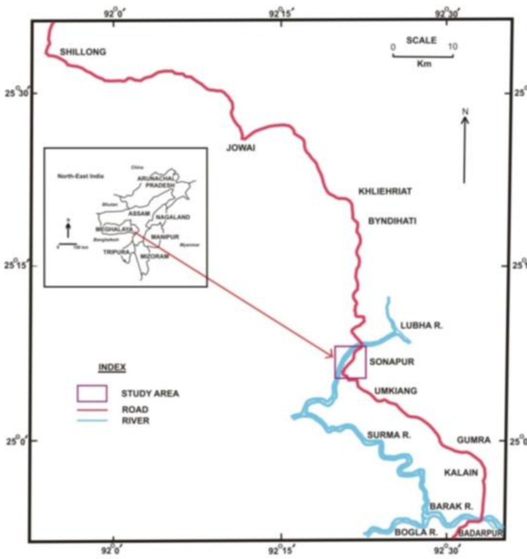

Fig. 1: Location map of the study area

determined following Basu et al. (1975). The tectonic set up of the source area was determined from QmFLt and QFL triangular plots of Dickinson et al. (1983).

Table 1. Tertiary stratigraphic succession of the study area (after Rangarao, 1983; Singh and Singh, 2000).

Age	Group	Formation	Thickness (m)	Lithology
Pliocene to Pleistocene	Dupi Tila	Dupi Tila	1200	Massive to cross bedded sandstone at the lower part with increasing mud units toward the top.
Unconformity (?)				
Upper Miocene to Pliocene	Tipam	Girujan Clay	1900	Not exposed in this area
		Tipam Sandstone Sanstone		Massive,thick-bedded sandstone
Lower Miocene	Surma	Boka Bil	2500	Fine-grained, laminated sandstone and shale.
		Bhuban		Fine-grained, indurated sandstone alternating with shale.
Unconformity (?)				
Oligocene .	Barail	Renji	577	Medium to fine-grained, hard massive sandstone.
		Jenum	814	Argillaceous sandstone
		Laisong	1658	Medium to fine sandstone with subordinate shale and conglomerate
Eocene	Jaintia	Kopili	500	Alternating sandstone & black shale
		Sylhet Limestone	500	Bluish, massive to thinly bedded limestone. Coarse to medium grained sandstone with bands of sandy limestone. Gray to pinkish gray limestone, sandy limestone, and calcareous sandstone. One member, known as Lakadong Sandstone, is made up of medium– grained arkosic sandstone with carbonaceous shale and coal seams.
		Therria	100	Medium to coarse sandstone with thin bands of pyrite-rich siltstone

Heavy minerals rarely constitute more than 1% of the total volume of the sediments. They provide valuable information concerning provenance which describe the character of the source terrain. Heavy minerals were separated from the more abundant light minerals following the "Funnel Separation Method" of Milner (1962) with the help of heavy liquid Bromoform (specific gravity 2.89). The separated heavy minerals were mounted on a glass slide and examined under a petrological microscope.

Petrographic Study

Thin section studies of the sandstone samples and their modal analysis shows that the detrital constituents include different types of quartz followed by feldspar, mica, rock fragments, cement and matrix (Table 2). Among the various framework constituents, quartz is the most dominant constituent. The detrital grains are mostly fine to medium grained, angular to sub angular and moderately sorted in nature. The interlocking grain shows point, line and concavo-convex contact. Concavo-convex contact is most dominant. A brief description of the mineralogical constituents is as follows.

Quartz: Quartz is the most abundant detrital component of the sandstones. The grains are mostly angular to subrounded, fine to medium grained and moderately sorted in nature. Both monocrystalline and polycrystalline variety of quartz are present. In the monocrystalline type both undulose and non-undulose varieties are present. In case of polycrystalline quartz type both "2-3 crystal units per grain type" (Fig. 2a) and ">3 crystal units per grain type" (Fig. 2b) are present. Different varieties of polycrystalline quartz are present like schistose metamorphic quartz, stretched metamorphic quartz and vein quartz. Among these the stretched metamorphic quartz is the dominant one. The total percentage of quartz in the sandstones varies from 56.98 to 71.92.

Feldspar: Feldspar is the second dominant mineral in the studied sandstones. Both K-feldspar and plagioclase feldspar are present in the sandstone of the Barail Group. Plagioclase grains are identified by its characteristic lamellar twinning. Orthoclase is identified by its characteristic carlsbad twinning whereas microcline is identified by its crosshatched twinning. Weathered feldspar grains (Fig. 2c) are also found in the sandstones. These grains are identified by its bending and displacement of twin lamellae within the broken grains, which may be due to the effect of deformation. The total percentage of feldspar in the sandstone varies from 1.87 to 7.35.

Mica: Both muscovite and biotite are present in the sandstone samples. They are also present in the argillaceous matrix as authigenic mica. Muscovite is dominant in comparison to biotite. Bending of mica (Fig. 2f) due to compaction has also been observed in the studied sandstone. The percentage of mica varies from 1.07 to 9.72 in the sandstone.

Lithic Fragments (Rock fragments): Rock fragments are very important in the study of provenance and tectonic setting of the source area as they are the disintegrated particles of source rocks. All the three types of rock fragments i.e. igneous, metamorphic and sedimentary (Fig. 2d) are present in studied samples. Metamorphic rock fragments show elongated and foliated minerals such as quartz and mica. Igneous rock fragments show intergrown crystal of quartz, feldspar and mica whereas sedimentary rock fragments show detrital texture and dull in appearance. The percentage of the rock fragments varies from 2.20 to 8.41.

Matrix: All the detrital grains which have 0.02 mm diameter or less in size are included in the group of matrix. Clayey matrix i.e. argillaceous matrix (Fig. 2d) is the most dominant one in the studied sandstones. The argillaceous matrix is identified by the presence of clay and recrystallized micas. The siliceous matrix is also present in the sandstones of the Barail Group. The percentage of matrix varies from 9.20 to 20.43 in the sandstone samples.

Cement: Siliceous, argillaceous and ferruginous cement are present in the intergranular spaces of the sandstone of the Barail Group under study. Argillaceous matrix when undergoes alteration to other clay and phyllosilicates minerals due to diagenetic processes can be treated as argillaceous cement (Fig. 2a). When grain margins of the quartz are cemented by secondary silica can be treated as siliceous cement (Fig. 2e) and ferruginous cement (Fig. 2a) are rich in iron oxide, deep brown to blackish in colour. The percentage of cement varies from 3.02 to 8.18 in the studied samples.

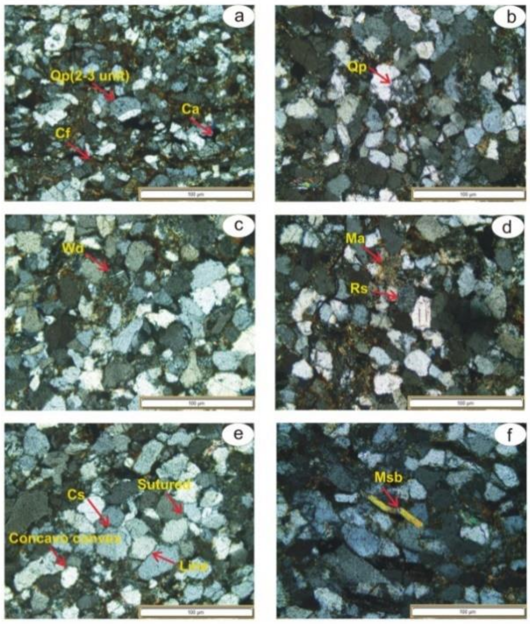

Fig. 2: Representative photomicrographs of the constituents of Barail sandstones of the study area showing (a) Qp(2-3 unit)- Polycrystalline quartz (2-3 unit), Ca- Argillaceous cement, Cf- Ferruginous cement (b) Qp- polycrystalline quartz (c) Wd- Weathered feldspar grain (d) Ma- Argillaceous matrix, Rs- Sedimentary rock fragment (e) Cs- Siliceous cement and diagenetic features like line, concavo-convex and sutured contact (d) Msb-bent muscovite flake.

Sandstone Classification

The sandstones under study have been classified on the basis of Dott's (1964) scheme of classification. For this classification the percentage of Quartz (Q), Feldspar (F) and Rock fragments(R) (Table 2) of the studied sandstones are plotted on the QFR triangular plot (Fig.3). In this classification, two groups of sandstone are recognized i.e. arenite group having less than 15% matrix and wacke group having more than 15% matrix. The plot shows that the sandstones are mainly subarkose type. Few of them are classified as arkosic wacke and lithic graywacke. Subarkose sandstones are arenite sandstones having less than 25% feldspar. Arkosic wacke and lithic greywacke sandstones are wacke sandstones. Arkosic wacke sandstones have more feldspar than rock fragments as compared to lithic greywacke sandstones.

Provenance and Tectonic Setting

Sandstone petrography of the Barail sandstones has been used to constrained provenance

Table 2: Results of Modal Analysis of the sandstones of the Barail Group.

Sample No.	Qm		Qp		Qt	F	Lt	Mica	Chert	C	M
	Un	Non	2-3 unit	>3 unit							
S-1	27.66	24.67	1.87	12.15	66.35	1.87	8.41	1.87	1.87	3.74	15.89
S-2	6.86	31.86	6.86	19.60	65.18	7.35	4.9 0	1.23	2.48	5.39	13.47
S-3	10.06	28.17	11.07	15.09	64.32	5.03	4.02	3.42	5.03	3.02	15.09
S-4	10.75	26.88	6.45	12.90	56.98	3.23	7.52	1.07	3.23	7.53	20.43
S-5	15.34	42.94	3.07	10.22	71.57	4.50	4.08	4.11	1.02	5.52	9.20
S-6	6.12	50.00	2.04	8.16	66.32	6.12	3.07	2.04	3.06	4.08	15.31
S-7	8.64	30.24	9.72	12.96	61.56	3.24	3.23	9.72	2.16	6.05	14.04
S-8	11.32	23.58	11.33	18.86	65.09	5.66	3.77	8.49	0.94	2.83	13.21
S-9	14.85	24.75	7.92	17.82	65.34	3.96	3.97	4.94	0.00	6.93	14.86
S-10	11.06	50.88	2.23	7.74	71.91	4.42	2.20	1.11	2.22	8.18	9.95

Qm= Monocrystalline quartz; Un= Undulatory monocrystalline quartz; Non= Non-undulatory monocrystalline quartz; Qp= Polycrystalline quartz; Qt= Total quartz; F= Total feldspar; Lt= Total lithic fragments; C= Cement; M=Matrix.

and tectonic settings of study area. Information on the nature of the source of the sediments was derived through the use of the Diamond diagram of Basu et al. (1975). The plot indicates the sediments of the Barail Group of rocks to have been derived from iddle and upper rank metamorphic sources (Fig. 4). For determination of the tectonic setting of the area under study, the QFL and Q_mFL_t triangular plots of Dickinson et al. (1983), were considered. For these QFL and Q_mFL_t triangular plot the recalculated percentage values of total quartz, monocrystalline quartz, feldspar and lithic fragments are considered (Table 2 & 3). QFL triangular plot reflects that the Barail sediments were mostly derived from cratonic interior source and few samples showing recycled orogenic source (Fig. 5a). Q_mFL_t triangular plot also reflects that Barail sediments were mostly derived from cratonic interior source and few samples showing recycled orogenic source (Fig. 5b).

Heavy Mineral Study

Heavy minerals can be classified as opaques and non-opaques. The opaque iron minerals are most abundant in the studied sandstones of the Barail Group. The percentage of the opaque minerals vary from 45.46 to 72.73. The non-opaque minerals of the sandstones are zircon, tourmaline, rutile, sillimanite, kyanite, staurolite, garnet, epidote, sphene, hypersthenes, hornblende, chlorite, chloritoid, andalusite, and apatite (Table 4) (Fig.7). The characteristic salient features and percentage of heavy minerals are described below.

Zircon: Zircon is the most abundant heavy mineral present in the studied sandstones. Grains are colourless and occur as prismatic, euhedral slender and elongated in shape. Rounded grains (Fig. 6c) are also observed. Under cross nicols the grains show parallel extinction, strong birefringence, high refractive index and well defined zoning (Fig. 6a). Percentage of zircon in the sandstones of the Barail Group varies from 6.11 to 21.61.

Tourmaline: Tourmaline grains are pale brown to dark brown in colour. The grains display a variety of shapes such as irregular, prismatic, sub rounded and rounded (Fig. 6f). Tourmaline grains are strongly pleochroic and have no cleavage. They have strong birefringence and high-order interference colours. The percentage of tourmaline varies from 2.60 to 6.56.

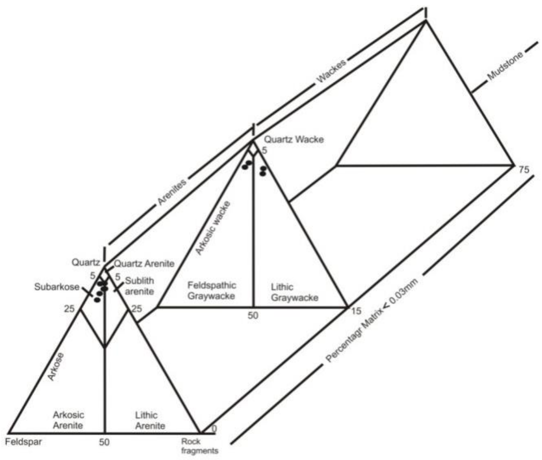

Fig. 3: Mineralogical Classification of the sandstones of Barail Group of the study area (after Dott, 1964).

Table 3: Recalculated percentage data for QFR triangular plot, Diamond diagram and QmFLt triangular plot.									
Sample No.	QFR triangular plot			Data for Diamond diagram			Data for QmFLt triangular plot		
	Q	F	R(Lt)	Qp (>3 unit)	Qm (Un)	Qm (Non)	Qm	F	Lt
S-1	86.58	2.44	10.97	18.84	42.90	38.26	83.58	2.99	13.43
S-2	84.18	9.49	6.33	33.61	11.76	54.63	75.97	14.42	9.61
S-3	87.66	6.85	5.48	28.30	18.87	52.83	80.86	10.64	8.50
S-4	84.13	4.77	11.10	25.53	21.27	53.19	77.78	6.68	15.54
S-5	89.30	5.61	5.09	14.92	22.39	62.69	87.17	6.73	6.10
S-6	87.83	8.10	4.07	12.69	9.52	77.78	85.93	9.37	4.70
S-7	90.49	4.76	4.75	25.00	16.67	58.33	85.73	7.14	7.12
S-8	87.34	7.60	5.06	35.08	21.06	43.86	78.73	12.77	8.50
S-9	89.18	5.40	5.42	31.03	25.86	43.10	83.32	8.33	8.35
S-10	91.57	5.63	2.80	11.11	15.87	73.02	90.34	6.45	3.21

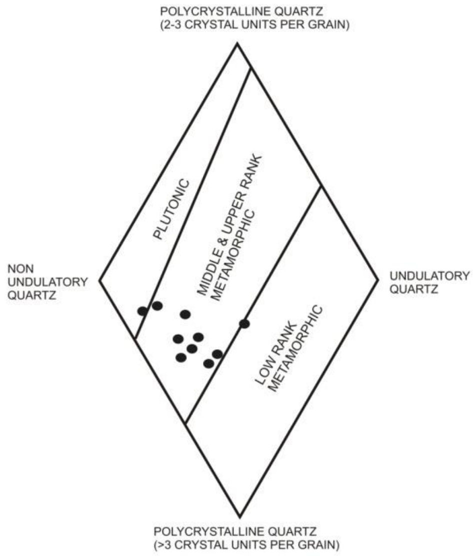

Fig. 4: Diamond diagram of sandstones of the Barail Group (after Basu et al., 1975).

Rutile: Rutile grains are identified by its characteristic blood red (Fig. 6b, d) and brownish red colour. Grains are rounded to sub rounded and prismatic in shape. They show slight pleochroism. Rutile grain shows the same colour under cross nicols as in ordinary light owing to its strong birefringence. They have extremely high refractive indices. The percentage of rutile varies from 2.42 to 9.20.

Sillimanite: Grains are mostly colourless and pale brown variety is also present. Grains occur in elongated prismatic and fibrous forms. The grains show parallel extinction, moderate to fairly strong birefringence. The percentage of sillimanite in the sandstones of the Barail Group varies from 3.09 to 7.36.

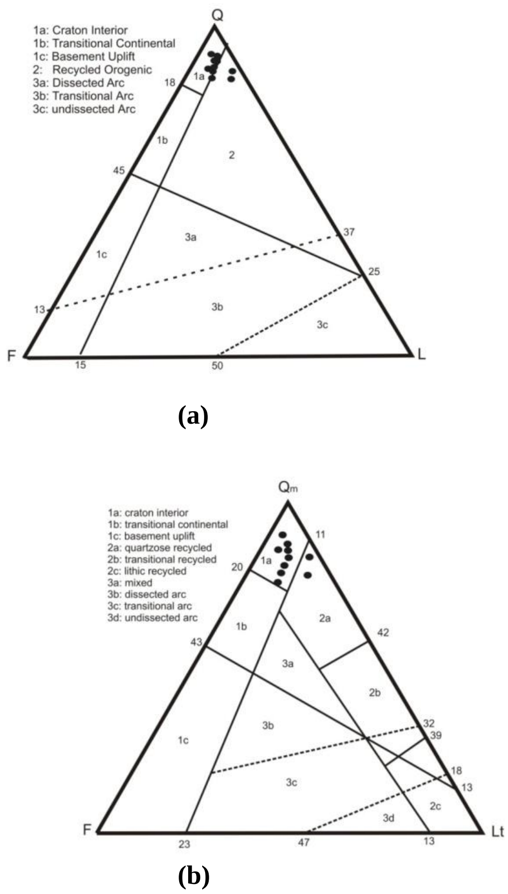

Fig.5: (a) QFL and (b) Q_mFL_t triangular plot of sandstones of the Barail Group (after Dickinson et al., 1983)

Kyanite: kyanite grains are dominantly colourless or rarely blue (Fig. 6g). Grains are elongated, bladed and angular. It exhibits weak pleochroism, perfect cleavage and show inclined extinction and a step like change in the order of interference colour. The percentage of kyanite varies from 0.78 to 3.12.

Staurolite: The grains are golden yellow in colour and occur as sub angular to irregular in forms. It shows marked pleochroism, moderate birefringence and exhibits conchoidal fractures. The percentage of staurolite varies from 1.71 to 4.68.

Garnet: Grains are mostly colourless. They are isotropic under cross nicols. Grains are occurs in the form of irregular fragments as well as subrounded to rounded grains which are bounded by conchoidal fracture surface (Fig. 6c). The Percentage of garnet varies from 0.00 to 2.93.

Epidote: grains are mostly pale greenish in colour (Fig. 6i). They are subrounded to rounded in form. It shows moderate birefringence, weak pleocroism and appears almost same under cross nicols as in ordinary light due to its high order interference colour. The percentage of epidote varies from 0.73 to 2.86.

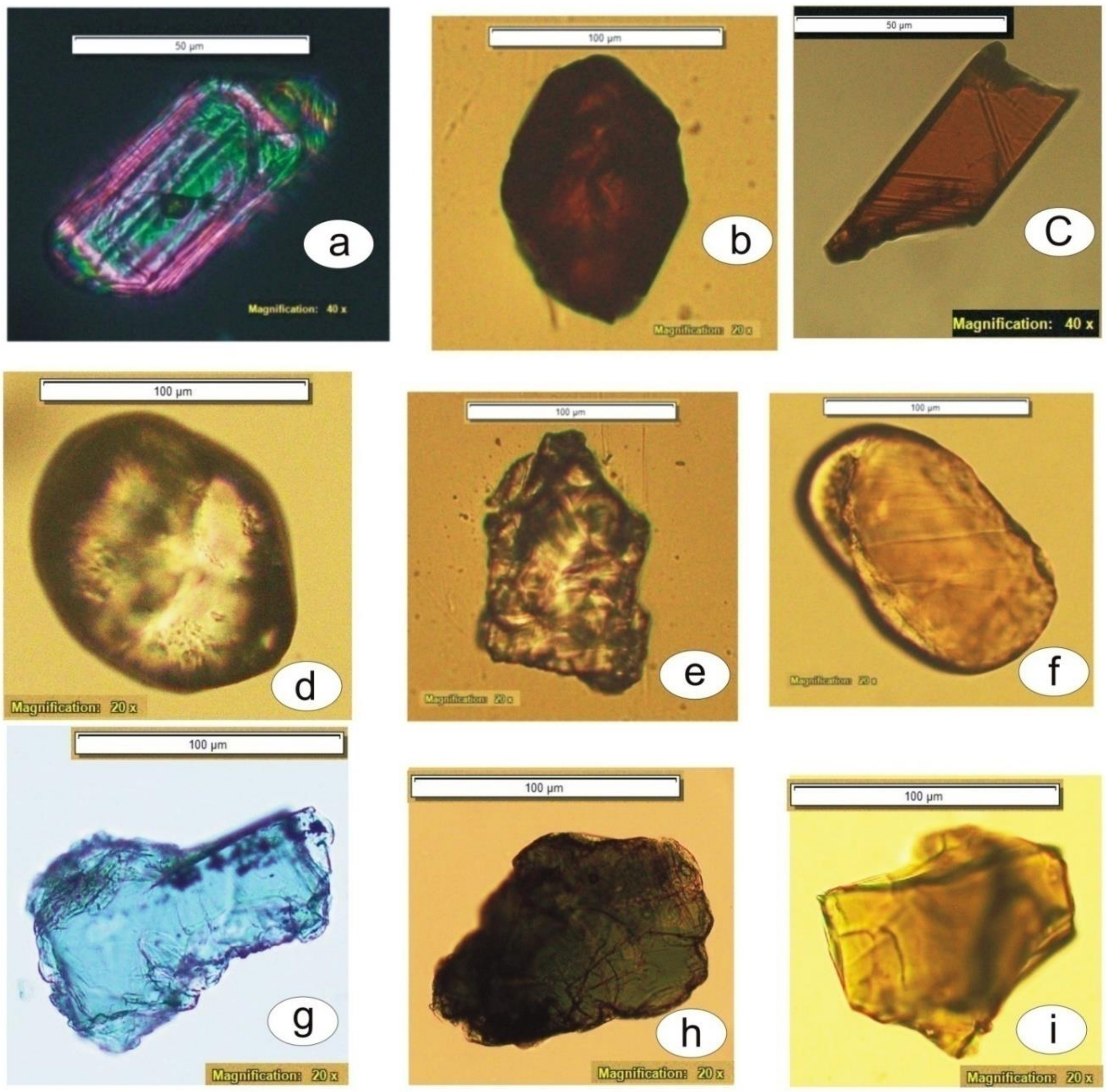

Fig. 6: Representative photomicrographs of Heavy minerals showing (a) a prismatic zircon grain (b) a rounded rutile grain (c) a prismatic rutile grain (d) a rounded zircon grain (e) garnet (f) oval shaped tourmaline (g) kyanite (h) chlorite and (i) epidote

Sphene: Sphene are colourless and sometimes green in colour. They are sub angular in shape and are marked by conchoidal fractures. Coloured grains exhibits weak pleochroism and show same colour under cross nicols as in ordinary light owing to its birefringence. The percentage of sphene in the sandstones of the Barail Group varies from 0.24 to 1.30.

Hypersthene: The grains exhibit various shades of pink and also found pale reddish brown, green in colour variety. The grains are prismatic, elongated and irregular in shape. They show distinct pleochroism and moderate to strong birefringence. Prismatic grains show parallel extinction. The percentage of hypersthene in the sandstones of the Barail Group varies from 0.00 to 0.52.

Hornblende: Hornblende grains are bluish green and brownish green in colour. The grains are prismatic, elongated and irregular in shape and also occur in the form of long thin flakes. They are strongly pleochroic, moderate to strong birefringence and show inclined extinction. Extinction angle measured in longitudinal sections varies from about 12^0 to about 30^0. The percentage of hornblende varies from 0.00 to 0.76.

Chlorite and Chloritoid: Chlorite grains exhibit various shades of green and occurred as flaky and rounded with irregular grain boundary (Fig. 6h). Pleochroism is not distinct in chlorite grains but deep coloured varieties are strongly pleochroic. Extinction is almost parallel in chlorite. Chloritoid grains are distinguished by its greyish blue or slightly greenish to yellowish blue colour. They show distinct pleochroism in shades of grey and blue. Birefringence is weak to moderate and extinction angle varies from almost parallel to 18^0. The percentage of chlorite varies from 0.26 to 1.76 and chloritoid varies from 0.00 to 3.03.

Andalusite: Andalusite grains are colourless and few of them have pinkish tinge. They are occurred as angular, irregular, occasionally prismatic, subrounded and rarely rounded. Some grains are non-pleochroic and others display a distinct pleochroism. Birefringence is weak in andalusite. The percentage of andalusite varies from 0.60 to 2.18.

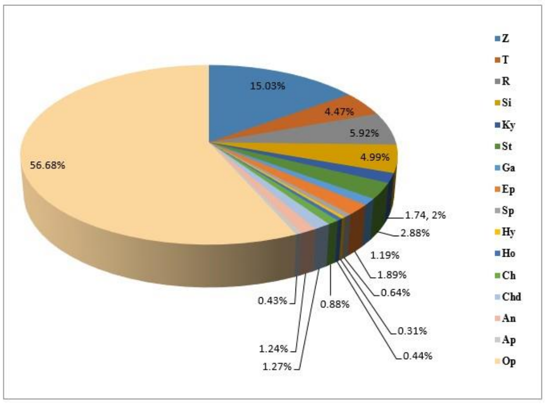

Fig. 7: Distribution of heavy minerals in the sandstones of the Barail Group.

Apatite: Grains are usually colourless and sometimes they show greyish-green colour. The grains are prismatic, subrounded to rounded form. They show weak to moderate birefringence. Prismatic grains show parallel extinction. The percentage of apatite varies from 0.00 to 0.92.

ZTR maturity index

ZTR index is the combined percentage value of zircon, tourmaline and rutile (Hubert, 1962) and is used to express the mineralogical maturity of sedimentary rock. The ZTR maturity index of the studied sandstone varies from 15.15 to 34.37. Low percentage value of ZTR index of the present sediments indicates that the sandstones are mineralogically immature. The recalculated percentage values of zircon, tourmaline and rulite (Table 5) are plotted in ZTR triangular plot and it shows that most of the samples fall in the A2 tier of field A (Fig.8) indicating Z>R>T.

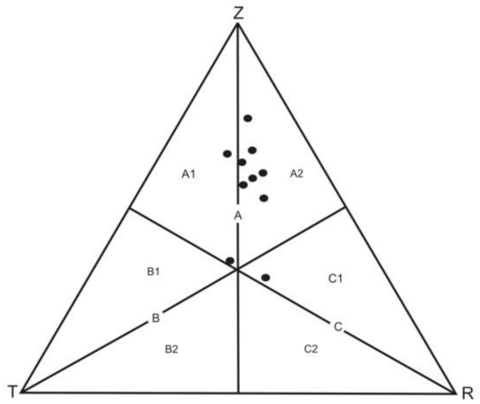

Fig. 8: ZTR triangular plot of the sandstones of the Barail Group.

Discussion and Conclusions

The petrographic study reveals that the studied Barail sandstones of the Barail Group comprises primarily of quartz grains which are angular to sub-rounded, fine to medium grained and moderately sorted in nature. According to Folk (1980), the textural maturity of sandstone is characterized by the decrease in clay matrix, improvement of sorting and increase in roundness value. So, the studied sandstones belong to sub-mature to immature classes of Folk (1980). High proportion of monocrystalline quartz indicates the plutonic source (Conolly, 1965). According to Basu et al. (1975), the presence of both unit and undulose monocrystalline quartzs gives an evidence for low rank metamorphic source. Presence of detrital mica minerals like muscovite and biotite gives an evidence for metamorphic source (Pettijohn, 1975) but some of the mica grains are of diagenetic origin. The sandstones are classified as subarkose, arkosic wacke and lithic graywacke type on the basis of mineralogical classification (after Dott, 1964).

Table 4: Heavy mineral distribution in sandstones of the Barail Group.

Sample no.	Z	T	R	Si	Ky	St	Ga	Ep	Sp	Hy	Ho	Ch	Chd	An	Ap	Op
S-1	14.67	4.40	6.36	3.91	1.22	1.71	2.93	0.73	0.24	0.49	0.49	1.71	1.71	0.98	0.49	57.95
S-3	18.43	6.56	7.57	5.05	1.51	3.04	1.78	1.77	0.76	0.51	0.50	1.76	3.03	2.02	0.25	45.46
S-4	15.25	3.63	6.78	6.05	2.18	3.39	0.73	2.66	0.74	0.24	0.48	1.21	1.69	2.18	0.24	52.54
S-5	15.86	5.29	9.20	7.36	1.38	3.91	0.92	2.53	0.46	0.45	0.47	0.91	0.68	1.38	0.92	48.27
S-6	6.11	5.86	5.34	6.10	2.80	2.03	1.03	1.27	0.51	0.25	0.76	0.50	0.77	1.02	0.26	65.39
S-7	9.70	3.03	2.42	4.54	1.82	2.12	0.00	1.51	0.61	0.30	0.31	0.30	0.00	0.60	0.00	72.73
S-8	19.22	2.60	4.15	5.45	3.12	2.86	1.04	2.34	0.26	0.52	0.00	0.26	1.82	1.30	0.52	54.54
S-9	21.61	5.99	6.77	3.38	0.78	4.68	1.82	2.86	1.30	0.00	0.53	0.78	1.32	0.79	0.52	46.87
S-10	14.38	2.88	4.65	3.09	0.87	2.21	0.46	1.33	0.89	0.00	0.43	0.45	0.44	0.88	0.66	66.37

Z= Zircon; T= Tourmaline; R= Rutile; Si= Sillimanite; Ky= Kyanite; St= Staurolite; Ga= Garnet; Ep= Epidote; Sp= Sphene; Hy= Hypersthene; Ho= Hornblende; Ch= Chlorite; Chd= Chloritoid; An= Andalusite; Ap= Apatite; Op= Opaque.

Table 5: Tabulated data for the determination of ZTR Maturity Index of sandstones of the Barail Group.

Sample No.	Actual ZTR percentage				Recalculated ZTR percentage			
	Z	T	R	ZTR Maturity Index	Z	T	R	Total
S-1	14.67	4.40	6.36	25.43	57.69	17.30	25.01	100
S-3	18.43	6.56	7.57	32.56	56.60	20.15	23.25	100
S-4	15.25	3.63	6.78	25.66	59.43	14.15	26.42	100
S-5	15.86	5.29	9.20	30.35	52.26	17.43	30.31	100
S-6	6.11	5.86	5.34	17.31	35.30	33.85	30.85	100
S-7	9.70	3.03	2.42	15.15	64.03	20.00	15.97	100
S-8	19.22	2.60	4.15	25.97	74.01	10.01	15.98	100
S-9	21.61	5.99	6.77	34.37	62.87	17.43	19.70	100
S-10	14.38	2.88	4.65	21.91	65.64	13.14	21.22	100

Diamond diagram (after Basu et al., 1975) shows that the sediments of the Barail Group were derived from the middle and upper rank metamorphic source. QFL and QmFLt triangular plot (after Dickinson et al., 1983) reflects that the sediments were mostly derived from the cratonic interior source and few of them showing recycled orogenic source. Progressive compaction and deep burial stage of diagenesis is indicated by the presence of concavo-convex and sutured grain contacts (Blatt, 1980). Quartz overgrowth may be formed from the pressure solution of quartz (Pettijohn et al., 1987).

The heavy mineral study of the sandstones shows that zircon is the most abundant heavy mineral. Occurrence of Prismatic and slender grains of zircon indicate their derivations from igneous source (Poldervarrt, 1950). The presence of prismatic rutile grains with sharp boundaries may be attributed to high grade metamorphic as well as acid igneous source (Force, 1980; Milner, 1962). Presence of rounded and sub-rounded grains of zircon and tourmaline indicate their derivation from reworked sediments while the occurrence of heavy minerals like sillimanite, kyanite, andalusite and staurolite indicates high rank metamorphic source (Pettijohn, 1975). Presence of pale brown tourmaline indicates the source of the sandstones is metamorphic (Blatt et al., 1980). Low percentage of ZTR maturity index (15.15 to 34.37) indicates that the sandstones of the Barail Group are mineralogically immature.

Thus, from the above petrographic and heavy mineral study it can be interpreted that the studied sandstones of the Barail Group were mainly derived from the plutonic and metamorphic sources and are mineralogically sub-mature to immature. The sediments show a mixed source of cratonic interior and recycled orogenic source. Najman et al. (2019) observed that the inner folded belt of the Indo-Burmese Ranges (IBR) became positive landmass and uplifted considerably at the end of the Oligocene period. There is also a positivity of contribution of detritus during Barail sedimentation from the uplifted parts of the IBR (Uddin and Lundberg, 1998). So, we can conclude that the sediments were probably derived from raised Shillong Massif where Precambrian metamorphic rocks of pelitic and arenaceous composition with plutonic bodies were exposed around the shelf margin and also from the uplifted parts of the Indo-Burmese Ranges.

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