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Petrography and heavy minerals as tools for reconstruction of provenance and depositional environment of Bhuban sandstones in Aizawl, Mizoram

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Abstract

Mizoram is entirely covered by sedimentary successions of variable sand-silt-shale ratio. The predominating bed comprises of Surma Group of rocks, and Bhuban Formation being the dominating strata. The present study area of eastern anticlinal limbs of the Aizawl city are made up of thick succession of Bhuban Formation of Surma Group dipping towards east with strike of approximately N-S direction. The present research aims to find out the nature of provenance and the environment of deposition of the sediments on the bases of petrography of the sandstones and heavy minerals present. The petrography indicate presence of quartz, lithic fragments, feldspar, micas, opaque minerals bind together by siliceous, ferruginous and carbonate cements. The heavy minerals comprises of garnet, augite, zircon, rutile, staurolite, sillimanite, kyanite, hypersthene, hornblende, chlorite, tourmaline and apatite. It is found that the sediments of sandstones are derived most probably from the Himalayan Orogenic fold belt and the Indo-Burmese Collision Zones, and the sediments being transported by turbidity current and deposited in deltaic to shallow marine environment.

Key words: Aizawl; Bhuban sandstone; heavy minerals; petrography; provenance.

Introduction

In sedimentary research, the reconstruction of provenance and depositional environment of the sediments that make up the rock forms the main objectives. Since sediments forming sedimentary rocks are derived from the pre-existing rocks, the various detrital grains preserved certain characteristic features having various significances, structurally in the sedimentary strata, mineralogically, or chemically. Among the various useful tools, petrographic analyses and heavy mineral studies are successfully used by different authors around the globe for recon-

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struction of provenance and depositional environment of the sandstone in different areas.[1-14] The heavy minerals are those having specific gravity greater than 2.85 and their occurrences in the sandstones are largely controlled by weathering and diagenesis, as well as their degree of stability in various stages of sedimentary processes. The various heavy minerals found in sandstones are properly classified into different groups on the basis of their stability and source rocks from where they are believed to be derived.[15]

In Mizoram, the analyses of heavy minerals are successfully carried out in the sedimentary successions of Kolasib District.[16,17] However, none have reported combined analyses of petrography and heavy minerals as tools for reconstruction of provenance and depositional environment of Bhuban sandstones exposed in Aizawl, which forms the main objective of the present study.

Geological settings

The first geologist who traversed Mizoram noticed a huge succession of sandstone and shale and claimed it belonging to flysch facies deposited in deltaic or estuary of large river system.[18] Geologically, Mizoram comprises entirely of sedimentary rocks of Tertiary age (65 Ma) with general strike of north-south trend which are constituted by differential ratios of sandstones, siltstones and shale in different areas. These rocks are divided into Barail, Surma and Tipam Groups based on their stratigraphic ages which are characterized by different ratios of grain size of sediments. These rocks are thrown into fold, faulted and fractured due to tectonic activities in the geological past.[19-22] The Surma Group is divided into a lower Bhuban Formation comprising Lower, Middle and Upper Bhuban Unit, and an upper Bokabil Formation of Miocene to Upper Oligocene age.

The city of Aizawl lies upon the eastern and western anticlinal limbs of folded and faulted thick beds of sandstones, and intercalation of sandstone-shale, sandstone-siltstone-shale, etc. of Bhuban Formation. The study area falls in the eastern anticlinal limb of Aizawl anticline which comprises of the Upper Bhuban Unit (arenaceous) and Middle Bhuban Units (argillaceous) of the Bhuban Formation.[20]

Materials and Methods

The study area is falling within the Survey of India Toposheet No 84A/9 and 84A/14, located within the GPS coordinates of 92°40’ to 92°49’ E longitude and 23°40’ to 23°50’ N latitude for Upper Bhuban Unit and 92°43’ to 92°44’ E longitude and 23°45’ to 23°46’ N latitude for Middle Bhuban Unit.

Field study

Field study is carried out with the help of toposheet, GPS, Brunton Compass, hammer and chisel, notebook, marker and sample bags, etc. The field studies aimed at identification of sedimentary structures and their field occurrences, and systematic collection of samples with their GPS location for detailed laboratory analyses.

Laboratory analyses

Laboratory analyses comprises of preparing samples for thin sections, and separations and identification of heavy minerals. The rock samples collected for petrography are cut into thin slabs and send to Hindustan Minerals & Natural History Specimens Supply Co., Kolkata for thin section preparation. Microscopic identification are carried out with the help of CNOEC make Trinocular polarizing petrological microscope with transmitted light illumination for rock thin section study with Mechanical stage attachment for point counting. The rock samples for heavy mineral separation are crushed gently and soaked with water for about 2-3 days, and then boiled with dil. HCl for about 10 minutes to remove unnecessary coatings on the grains. After washing with water, samples are treated with

H_2O_2 for about 36 hours, then, dried again in oven. The samples are then crushed, undergo sieving and 80 mesh (ASTM) fractions are collected, then about 25 g of each sample are weighted out for separation of heavy minerals using stop-coke funnel separation method with the help of bromoform (specific gravity 2.89). The separated heavy minerals having specific gravity greater than 2.89 are then washed with acetone and then after drying, mounted on glass slide with epoxy for identification under the microscope.

RESULTS AND DISCUSSION

Field geology, sedimentary structures and depositional environment

The study areas around Aizawl exposed thick succession of Upper Bhuban Unit along Zemabawk-Tuirial road section and Middle Bhuban Unit along Durtlang-Mualpui road section. The Upper Bhuban Unit exposed along Zemabawk-Tuirial road section comprises of thick succession of sandstones-siltstones-shale intercalation. The sedimentary beds are dipping approximately towards east with dip amount 15° to 45°. The sandstones are grey, bluish-grey or brown in colour and fine to medium-grained. The sandstones are sometimes thick and massive, but brown sandstones are comparatively friable comparing other variety which may be due to weak iron-oxide cementation, supplemented by intensive weathering by water seepage. In parts of the area where there are interbedding of fine siltstone with brittle and crumpled shale, instability is very high. Sedimentary structures observed in the area include ripple marks and load structures, which are characteristic to the sedimentary process of turbidity current, tidal flats and deltaic environment, and further, as observed by previous worker who stated the coarsening upward pattern in the area,[23] a progradation process in deltaic environment may be suggested.

The Middle Bhuban Unit exposed along Durtlang road section comprise of intercalation of shales, siltstones and sandstones. The sandstones and siltstones are sometimes thickly bedded in spite of their occurrence as thin beds alternating with shale and silty shale. The siltstone -shale components are highly micaceous and mud clasts are also observed in the sand bodies. Sedimentary structures observed in the area like interference ripples, ripple drift lamination, planar cross bedding, flame structure, flaser bedding, and wavy and lenticular bedding are characteristic to upper tidal flats while lamellar bedding indicate lower tidal flat deposited under low-density turbidity current.[24] The ripple drift also indicate rapid sedimentation and flaser structure support the view of this ripple drift under which condition streak of mud gets deposited between the cross lamination. The presence of load casts at the sole of sandstone body are the result of squeezing of underlying mud up into the sand due to density contrast between the two beds, and the ball-and-pillow structures overlying more plastic and weaker shale bed are the result of fluidization and liquefaction.[24] These sedimentary features indicate that the depositional environment might be deltaic to shallow marine environment. Further, as observed by previous worker,[25] sandstones of the area are bioturbated with ripple laminated fine sand. These combined features could be indicative of deposition in the transition zone between offshore and shoreface of marine shoreline environment.[24]

Petrographic indication of provenance and depositional environment

Microscopic studies indicated that the Bhuban sandstones of Upper and Middle Bhuban Unit ranges from fine- to medium-grained, moderate to poorly sorted and angular to subangular grains. The detrital grains comprises of quartz, lithic fragments, feldspars, micas, opaque minerals, fossil fragments and other accessory components. The cementing materials are mostly of silica and iron oxides, but in the sandstones where fossil fragments are observed, the cement-

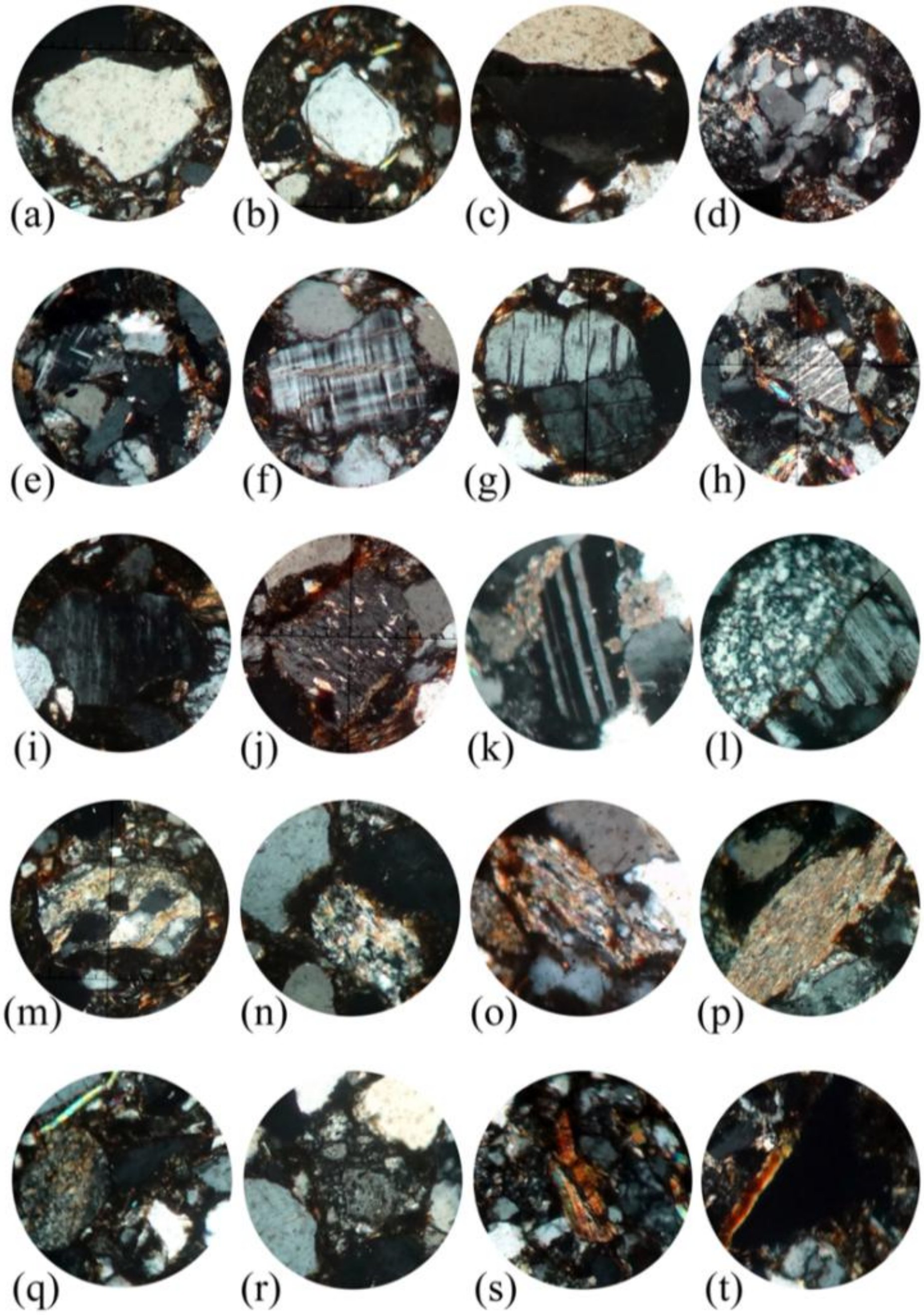

Figure 1. Crossed Nicol microphotographs of detrital grains of the Upper and Middle Bhuban Unit of Bhuban Formation in the study area of Aizawl. The grains comprises of non-undulatory monocrystalline quartz (a), non-undulatory monocrystalline quartz with silica overgrowth (b), undulatory monocrystalline quartz (c), polycrystalline quartz (d), plagioclase (e), microcline (f), plagioclase-orthoclase (g), perthite (h-i), altered feldspar (j), fresh plagioclase (k-l), chert (l), gneiss fragment (m), schists fragments (n-o), shale fragments (p-q), reworked sandstone (r), greenish, elongated thin muscovite (r), biotite (s-t) and opaque mineral (t).

ing materials are observed to be of carbonate in composition as indicated by their high birefringence. The occurrences and characters of important detrital components are briefly explained below:

Quartz: Quartz is the most predominating mineral in the studied sandstones which constitute about 67.03 to 87.61% of the total sediments in Upper Bhuban Unit while 54.8 to 82.46% in the Middle Bhuban Unit. It is commonly occurred as non-undulose monocrystalline quartz and strained monocrystalline and/or polycrystalline quartz. The quartz grains are generally poorly sorted, angular to sub angular in shape which indicate short transportation and immature sediments.

Lithic fragments: The most common lithic fragments are schists and gneiss fragments of metamorphic origin, and grains of rework sandstone, chert and shale are also observed. The lithic fragments constitute about 5.31 to 23.36% in the Upper Bhuban Unit while 10.96 to 34.23% in the Middle Bhuban Unit, and are the second abundant constituents of the investigated sandstones.

Feldspars: Feldspar minerals, like plagioclase and alkali feldspars, constitute about 4.65 to 14.29% in the Upper Bhuban Unit while 6.58 to 16.03% in the Middle Bhuban Unit, and are the least mineral among quartz-feldspar-lithic

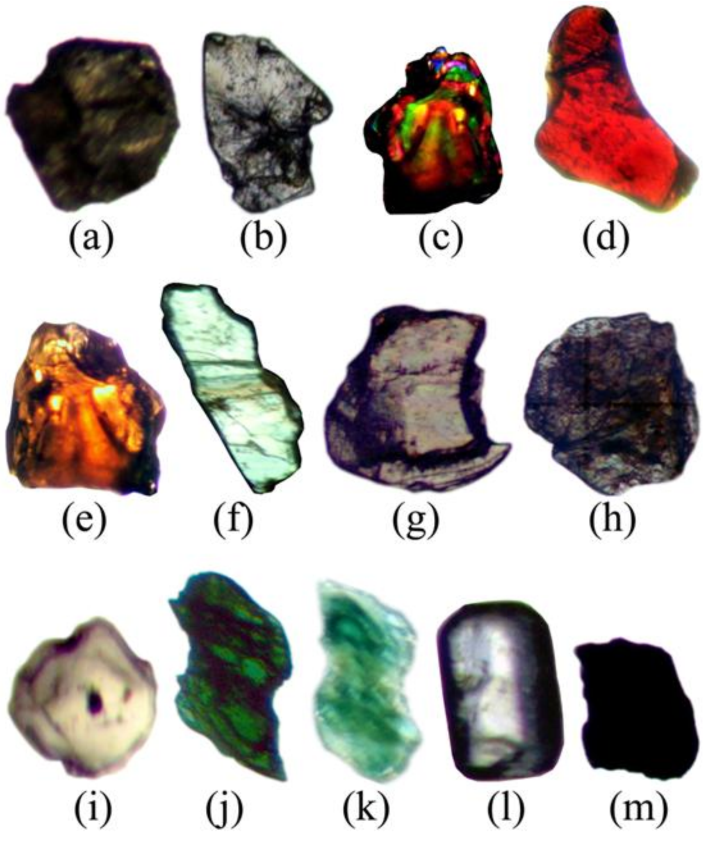

Figure 2. Different types of heavy minerals (80 mesh size) observed in the Upper and Middle Bhuban Units of Bhuban Formation in the study area of Aizawl. (a) Garnet, (b) Augite, (c) Zircon (under crossed nicol), (d) Rutile, (e) Staurolite, (f) Sillimanite (under crossed nicol), (g) Kyanite, (h) Hypersthene, (i) Apatite, (j) Hornblende, (k) Chlorite, (l) Tourmaline and (m) Magnetite.

fragment group, and are found as subhedral to anhedral form. Perthites are also observed which probably indicates alkaline igneous source rock while the alterations of orthoclase and other feldspar minerals might suggests metamorphic origin.

Micas: Mica group of minerals like muscovite and biotite are other common detrital mineral, which occur as thin flakes, usually in deformed lamellar structures.

Opaque minerals: Opaque minerals are also commonly observed which might be of Fe-oxide minerals.

The approximate percentages of three important detrital grains such as quartz, feldspar and lithic fragments indicated that the sandstones of Upper Bhuban Units are of subarkose, lithic subarkose to sublitharenite while those of the Middle Bhuban Units are sublitharenite, lithic subarkose, litharenite and feldspathic litharenite as is already carried out by previous workers.[26] The petrographic characters indicated that the provenance of the sandstones might be of slow cooling, acidic to basic igneous rocks, alkali-rich granites, and low- to high-grade metamorphic terrain like gneiss or mica schists. Further, Fe-rich minerals like biotite which might have experienced oxidation resulting in the release of Fe -ions which further reacts with aqueous fluids to forms oxides of iron during diagenetic processes to form cementing material to the detrital grains. This feature might be indicative of a well oxygenated environment of depositional basin under shoreline areas or shallow marine. The patchy cementation of carbonate cements might reflect the initially patchy carbonate precipitation, or it might be due to subsequent partial removal of more or less evenly distributed cement owing to dissolution during burial or outcrop exposure. The sediments might be derived from moderate to short distant source area and quickly deposited as indicated by their angular to subangular forms. The transport process might be of turbidity current and deposition might take place in deltaic environment to shallow marine environment where well oxygenation of the medium prevails.

Heavy mineral analyses and provenance

The heavy minerals observed in the investigated Bhuban sandstones comprises of garnet, augite, zircon, rutile, staurolite, sillimanite, kyanite, hypersthene, hornblende, chlorite, tourmaline and apatite as non-opaque varieties and magnetite as the only opaque variety. Garnet is the most commonly observed non-opaque heavy mineral assemblage in the present Bhuban sandstones of Upper and Middle Bhuban Unit. They are usually subhedral, sub-rounded to irregular in shape and colourless under plane polarized light. They remain dark under cross polar and commonly contain inclusions of small opaque minerals. It is more commonly seen in the Middle Bhuban Unit than the Upper Bhuban Unit. Augites are colourless to tinge of very pale yellow under plane polarized light and light grey under cross polar. They are found as small prismatic irregular grain, commonly fractured and contain common inclusions of opaque minerals. Cleavages are hardly observed but a somewhat short straight outlines are seen making the mineral observed as short prismatic form. Zircon constitutes one of the most common heavy minerals in the present investigated sandstones. It usually occurs as a prismatic form and euhedral to subhedral shape. They are colourless under plane polarized light but show high order interference colour under cross polar. Rutiles are fairly abundant in all the samples and are characterized by their blood red to brownish yellow colours under plane polarized light. Absence of cleavage is one of the distinguishing features seen in the minerals. Most of the rutiles are short prismatic to platy forms, angular to sub-angular or irregular forms. Cleavages are hardly observed but fractures are clearly visible. There are no inclusions in the minerals. Staurolites are identified by their typical bright yellowish colour under plane polarized light, showing no cleavages but exhibit conchoidal fractures. There are no inclusions in the minerals. Sillimanite is also rather common. They are observed as slender and elongated forms, colourless under crossed polar and showing cleavage. They also exhibit fracture and contain small speckles of inclusions. Kyanite is relatively equal in abundance to that of sillimanite in the sandstones. They are colourless to tinge of light yellow under plane polarized light but light bluish grey under cross polar. They occur as short and bladed grain with subhedral forms. Hypersthenes occur as either subhedral to anhedral forms, sub-rounded to irregular shape. They show slightly pale-green colour under plane polarized light. They show their characteristic pale pink to pale green pleochroism. They are showing fractures but no cleavages are observed. Hornblende occurs as anhedral to subhedral form or elongated to irregular shape. They are green in colour under plane polarized light, pleochroic and clearly show cleavages. The mineral shown in Fig. 2 shows a rhombohedral shaped hornblende which might indicate that it is a fragmented piece broken in the rhombohedral cleavages. They also exhibit fractures. Chlorites observed in the sandstones are light green in colour under plane polarized light and non-pleochroic. They are usually anhedral in shape. Some of the minerals are deformed which might be inherent possibly from the source rock that might undergo deformation during orogenic and tectonic activities under high pressure, probably of high pressure metamorphic belt. Tourmaline shows brown color under plane polarized light with pleochroism from brown to pale brown colour. The minerals are usually observed as elongated prismatic form with straight extinction. A variety of forms are observed, from elongated to short prismatic forms. Apatite shows subrounded to sub-angular shape, colourless under plane polarized light and show low interference colour under cross polar, cleavage is not prominent and inclusion is commonly seen. The opaque mineral that can be identified in the present study is magnetite. Identification and separation of magnetite is done by using bar magnet because of its magnetic property. They are found as short prismatic grain, subhedral to euhedral, cubic form.

The analyses of heavy minerals are carried out in order to know the nature of sources rock lithology and tectonic history of the source area during this research work. The presence of apatite, hornblende, rutile and elongated zircon and tourmaline might indicate their derivation from acidic igneous rocks. The presence of rounded apatite and rutile are, however, indicative of its derivation from reworked sediments.[15,16,17,27] The occurrence of augite, hypersthene and magnetite might indicate source rock of basic igneous rock. The presence of staurolite can be inferred as contact metamorphic source. The presence of garnet could be indicative of three provenances such as granite pegmatite, contact metamorphic rocks and dynamothermal metamorphic rocks. The presence of staurolite, sillimanite, kyanite and chlorite might also indicate a provenance of dynamothermal metamorphic rocks. All the identified grains of heavy minerals show different shapes like euhedral to anhedral, angular to sub angular and rounded to sub-rounded shape. The euhedral and irregular shaped grains generally indicate short transportation while the presence of sub-rounded to rounded shape of zircon and rutile may indicate sedimentary source. Therefore, the studies revealed that the sandstones of Upper and Middle Bhuban Units of Bhuban Formation are believed to be derived from a mixed provenance comprising of basic to acidic igneous rocks and low- to high-grade metamorphic rocks, with probably short transportation. This may further indicated the quick deposition of sediments derived from the nearby recycled orogenic belt of highly complex lithology.

Conclusion

The study area as a whole comprises of thick turbidite succession of sandstones-siltstones-siltyshale-shale intercalation. The sedimentary structures, though not included in the main objective of the present paper, are mention in brief context as a supporting evidence of the objectives of present study. The observed structures probably indicate upper tidal flats to lower tidal flats deposited under low-density turbidity current. The sediments might be deposited rapidly with short transportation. There is operation of post depositional processes like squeezing of underlying mud, fluidization and liquefaction which also conform to the depositional environment of deltaic to shallow marine environment. Further, one of the proofs on deposition under these environments is bioturbation of the sandstones in certain sandstone beds. Thus, these combined features are suggestive of deposition in the transition zone between offshore and shoreface of marine shoreline environment.

The combined petrographic analyses and the heavy minerals present in the investigated sandstones suggested that the sediments of Upper and Middle Bhuban Units might be derived from nearby recycled orogenic belt of highly complex lithology, most probably of the Himalayan Orogenic fold belt and the Indo-Burmese Collision Zones comprising of reworked sedimentary rock, acid to basic igneous rocks and low- to high-grade metamorphic rocks, with short distance of transportation by turbidity current and deposited quickly in deltaic to shallow marine environments.

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