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RESEARCH ARTICLE

Heavy Mineral Studies of Miocene Bhuban Sandstone from Surma Basin, Mizoram, India

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Heavy mineral analysis is a valuable tool that helps to determine the source area of sediments and the transport history of sedimentary rock. The heavy mineral assemblage of Bhuban sandstones included non-opaque in the form of mainly zircon, rutile, tourmaline, apatite, staurolite, kyanite, garnet, epidote, augite and opaque minerals. The presence of zircon, tourmaline, rutile in the shape of euhedral to rounded and opaque minerals suggests the derivation of igneous rocks and metamorphic rock. The Bhuban sandstone is derived from mixed sources which includes high-grade metamorphic rocks as well as igneous and sedimentary sources with short to moderate distance of sediment transportation. The ZTR maturity index suggests that the sediment of Bhuban Formation is mineralogically immature in nature.

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Introduction

The analysis of heavy minerals and their properties in sediments is one of the oldest endeavors in sedimentary petrology. It is extensively used as a reference for source-rock characterization, assessments of lithological variation, heavy mineral zonation, and dispersal pattern, and it also aids in giving a mineralogical basis by which two source locations may be separated from one another.[1] Heavy minerals are accessory minerals with concentration of less than 1 percent and a specific gravity of greater than 2.89 g/cm3, as well as a volumetric weight of fewer than 1 percent of terrigenous rocks.[2] Heavy mineral composition of sandstones is commonly employed in provenance investigations in sedimentary petrology. The detrital sediments that contain accessory minerals are comprised of several distinct mineral species, each with its unique history. As a result of their deposition nature, transportation behaviors, and alteration of physical and chemical properties which could lead to revealing their provenance. The mineral assemblage can be a direct indication of the supply of sediments from their parent rocks such as igneous, metamorphic, or even sedimentary.[3] The heavy mineral assemblage in sediment is mainly governed by the provenance, source area weathering, transport mechanism, deposition and post-depositional modification.[4]

Materials and Methods

Retrieval and preparation of protein

Heavy mineral analysis was carried out on the selected 26 samples in the sedimentology laboratory, Department of Geology, Mizoram University. There are many ways to separate minerals, but Bromoform (sp. gr. 2.89), and Thoulet's solution are two heavy liquids that are frequently used to separate heavy minerals (sp.gr. 3.40). In this present study, heavy minerals were separated using Bromoform liquid. Due to the hard and compact nature of the rock samples, their breakdown for heavy mineral separation was not possible, hence, the method proposed by Folk[2] was used. In order to remove the authigenic clay, carbonate, and

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Table 1. Generalized stratigraphic succession of the Mizoram fold belt with detailed successions and depositional environments of various geological formations.[6,8,16,17,18]

Age	Group / Formation		Thickness	Gross lithology	Environment of Deposition
Recent	-		-	Gravel, silts and clays	Fluvial and alluvial
------------------Unconformity-------------------					
Early Pliocene to Late Miocene	Tipam		+ 900 m.	Friable sandstone with occasional clay bands	Fluvial
------------------Conformable and transitional contact -------------------					
Miocene To Upper Oligocene	SURMA	Bokabil	+ 950 m.	Shale, siltstone and sandstone	Shallow marine
		------------------Conformable and transitional contact -------------------			
		BHUBAN	Upper (+1100 m.)	Arenaceous predominating with sandstone, shale and siltstone	Shallow marine, near shore to lagoonal
			----------Conformable and transitional contact --------		
			Middle (+1000 m.)	Argillaceous predominating with shale alterations and sandstone	Deltaic
			--------Conformable and transitional contact --------		
			Lower (+900 m.)	Arenaceous predominating with sandstone, silty shale	Shallow marine
------------------Unconformity obtained by faults-------------------					
Oligocene	Barail		(+ 3000 m.)	Shale, siltstone and sandstone	Shallow marine
----------------- Lower contact not exposed -------------------					

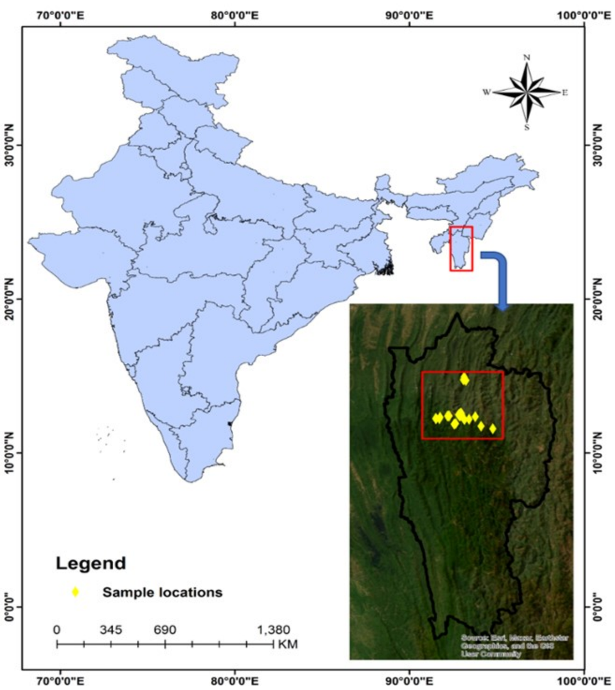

Figure 1. Location map of the study area in Aizawl, Mizoram (yellow rhombus indicating the sample location of the study area)

ferruginous coatings on the grains, approximately 50 gm of samples for heavy mineral separation were crushed gently, washed properly, and then alternately treated with Hydrogen Peroxide, distilled water, dilute Hydrochloric acid, and Stannous Chloride for 5 to 10 minutes. Then minerals were separated in funnel using Bromoform to extract heavy minerals. The extracted minerals were then mounted on slides with Canada Balsam for microscopic examination to determine the relative abundance of heavy minerals in each sample, by using Ribbon Counting Method.[5]

General Geology and Stratigraphy of the Study Area

The study area is within the Aizawl district, located in the northwestern part of Mizoram and is characterized by a thick succession of sedimentary rocks belonging to Bhuban Formation of Surma Group, which is well exposed along the road-cutting section in and around Aizawl (Figure 1). The study region falls in the Survey of India Toposheet No 84-A/10, 84-A/14, 84-A/15 and extends between 23°38 'to 23°46 'N latitude and 92°43 'to 92°49' E longitude with the maximum elevation of 1159 m MSL. The whole Miocene sedimentary sequence of Mizoram is made up of a

Table 2. Heavy mineral percentage and ZTR Index of Bhuban sandstones, Mizoram (where, Zr=Zircon, Tr=Tourmaline, Rt=Rutile, , Ky=Kyanite, Si=Sillimanite, Ep=Epidote, Cl=Chlorite, Hb=Hornblende, Bt=Biotite, Gr=Garnet Ap=Apatite, Au= Augite, Di=Diopside, St= Staurolite, Op=opaque mineral)

Sample No.	Zr	Tr	Rt	Ky	Si	Ep	Cl	Hb	Bt	Gr	Ap	Au	St	Di	Op	ZTR
AR#4	23.53	16.81	14.29	5.88	3.36	1.68	1.68	2.52	3.36	4.20	2.52	1.68	0.84	1.68	14.29	54.62
AR#5	23.01	16.81	13.27	5.31	7.08	2.65	0.00	0.88	2.65	3.54	1.77	0.00	2.65	1.77	18.58	53.10
AR#6	19.13	14.78	11.30	7.83	2.61	0.87	2.61	3.48	5.22	4.35	3.48	0.87	5.22	1.74	16.52	45.22
AR#7	20.65	11.96	15.22	7.61	6.52	5.43	0.00	2.17	2.17	1.09	2.17	2.17	3.26	2.17	17.39	47.83
ZT#3	22.12	15.38	12.50	8.65	6.73	1.92	0.96	2.88	0.96	3.85	1.92	0.96	0.96	1.92	17.31	50.00
ZT#6A	23.58	19.81	16.04	7.55	8.49	0.94	0.00	0.00	1.89	2.83	0.94	2.83	0.00	1.89	14.15	59.43
ZT#6B	23.20	15.20	17.60	8.00	6.40	0.00	2.40	1.60	2.40	4.00	1.60	0.00	1.60	1.60	15.20	56.00
ZT#7	21.52	13.92	11.39	6.33	7.59	3.80	2.53	0.00	2.53	3.80	0.00	1.27	2.53	2.53	18.99	46.84
ZT#10	25.24	17.48	12.62	6.80	4.85	0.97	2.91	0.97	0.00	4.85	1.94	1.94	2.91	1.94	16.50	55.34
PK#7A	22.86	18.10	13.33	8.57	6.67	0.00	1.90	2.86	2.86	0.95	2.86	0.00	2.86	1.90	14.29	54.29
PK#7C	16.50	10.68	12.62	5.83	5.83	1.94	4.85	0.97	3.88	4.85	2.91	1.94	1.94	1.94	20.39	39.81
PK#8A	22.50	11.67	15.00	6.67	3.33	3.33	2.50	0.00	1.67	0.00	1.67	3.33	2.50	1.67	22.50	49.17
SS#1A	21.25	18.75	13.75	8.75	3.75	1.25	0.00	3.75	1.25	2.50	0.00	3.75	5.00	2.50	13.75	53.75
SS#2A	19.81	15.09	12.26	8.49	6.60	2.83	0.94	1.89	1.89	3.77	0.94	3.77	0.00	1.89	18.87	47.17
SS#3A	16.05	12.35	13.58	4.94	9.88	0.00	2.47	0.00	3.70	3.70	1.23	2.47	3.70	2.47	25.93	41.98
AR#1	21.69	14.46	18.07	8.43	4.82	0.00	2.41	0.00	2.41	6.02	2.41	0.00	0.00	2.41	18.07	54.22
AR#2	25.22	14.78	12.17	7.83	6.09	2.61	0.87	1.74	2.61	2.61	0.87	0.00	2.61	1.74	19.13	52.17
AR#3	26.74	16.28	13.95	6.98	4.65	1.16	0.00	3.49	1.16	0.00	0.00	2.33	3.49	2.33	19.77	56.98
ZT#1	19.18	13.70	12.33	6.85	4.11	1.37	0.00	2.74	2.74	4.11	1.37	1.37	2.74	2.74	27.40	45.21
ZT#2	24.37	15.13	12.61	5.88	6.72	3.36	2.52	0.00	3.36	0.84	1.68	2.52	1.68	1.68	19.33	52.10
ZT#4	24.11	15.18	11.61	8.04	5.36	2.68	0.00	1.79	2.68	1.79	0.89	4.46	2.68	1.79	16.96	50.89
PK#1B	22.33	14.56	10.68	6.80	3.88	4.85	1.94	0.97	2.91	3.88	1.94	0.00	1.94	1.94	20.39	47.57
PK#1C	22.02	15.60	11.93	5.50	7.34	2.75	0.92	2.75	0.00	0.92	2.75	4.59	1.83	1.83	20.18	49.54
PK#2	13.98	18.28	13.98	7.53	4.30	2.15	5.38	0.00	3.23	2.15	1.08	2.15	1.08	2.15	24.73	46.24
PK#3	22.22	14.81	11.11	4.94	7.41	0.00	2.47	1.23	1.23	4.94	6.17	2.47	3.70	2.47	17.28	48.15
PK#4	24.35	20.00	16.52	2.61	6.09	0.00	0.87	1.74	0.00	0.87	1.74	3.48	0.87	1.74	18.26	60.87

rhythmic alternation of arenaceous and argillaceous rocks from the Palaeogene and Neogene Periods and have a total thickness of around 8000 meters.[6-10]

Results and Discussion

Heavy Minerals Description

The heavy mineral assemblages of Bhuban sandstone included Zircon, Tourmaline, Rutile, Garnet, Apatite, Chlorite, Epidote, Diopsite, Augite, Kyanite, Staurolite, Silliminite, and non-opaque minerals which are presented in the Table 2. The identified heavy minerals and their characteristics are discussed below:

Zircon

Zircon grains are the most stable non-opaque heavy mineral that has been observed in the studied sediments (Figure 2. D-E-F). These grains have subangular to subrounded edges, usually colourless with parallel extinction. Zircon is the most dominant heavy mineral which is followed by tourmaline and rutile. It constitutes an average of 29.93% of the total heavy mineral assemblage. According to Krumbein *et al.*[11] the sub-rounded edge Zircon mineral suggests that the mineral is originated from reworked sediments along with considerable amount of transportation through the depositional medium.

Tourmaline

The grains are pleochroic, prismatic, pale green to grayish in color and are about averages 15.34% of the total heavy mineral assemblage. Grains are subhedral to sub rounded in shape. Some grains are also rounded. Extinction is generally parallel (Figure 2. A-B-C).

Rutile

Rutile is easily distinguished from other types of heavy minerals because of its rich blood-red, brownish-red, or yellowish-brown hue. They have a high refractive index, no cleavage and display both euhedral and subhedral forms, as well as a short prismatic form. It constitutes an average of 10.84% of the total heavy mineral assemblage (Figure 2. H-I-J).

Garnet

In the heavy mineral assemblage, detrital Garnets display as euhedral, sharp irregular fragments and sub-rounded to rounded grains. They are generally colorless, light pale pink or pale brown. The mineral is easy to identify due to its high relief and isotropic nature. They constitute about an average of 6.22% among the heavy mineral assemblages (Figure 2O).

Kyanite

Kyanite exhibits angular to bladed or even

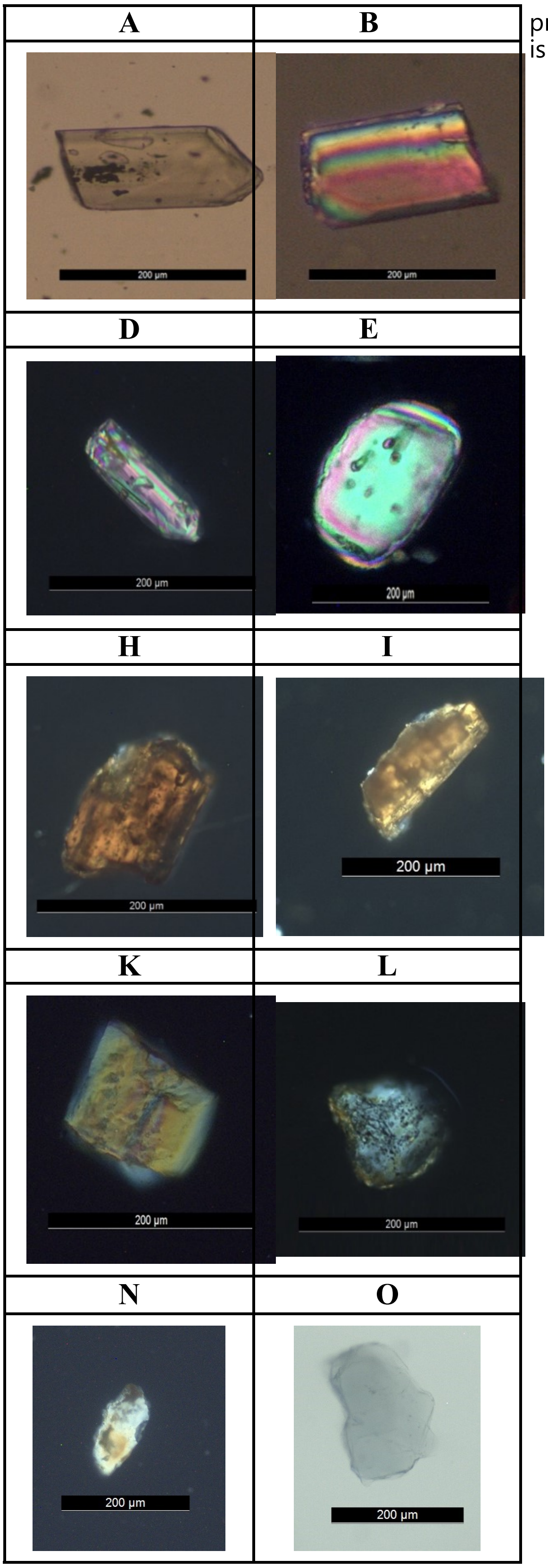

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Figure 2. Photomicrographs of heavy minerals from Bhuban sandstone showing, Tourmaline (A-B-C); Zircon (D-E-F); Rutile (H-I-J); Sillimanite (K); Chlorite (L); Epidote (M); Kyanite (N); Garnet (O)

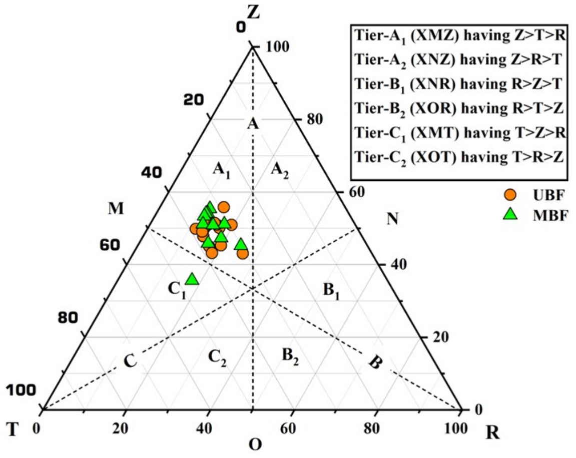

Figure 3. ZTR maturity index for Bhuban sandstones of Surma Basin, Aizawl, Mizoram (After Hubert[12])

matic grain texture, is mostly colorless, weakly pleochroic and possesses cross-fractures and step-like characteristics. The Kyanite constitutes an average of 4.77% of total heavy minerals

assemblages (Figure 2N).

Sillimanite

Sillimanite develops as a thin, elongated prismatic habit. Mineral grains are colorless. They display parallel extinction and cleavage is very distinct. Minerals comprise an average of 3.38% of total heavy mineral assemblages (Figure 2K).

Epidote

The mineral grains of Epidote are typically greenish-yellow and pleochroic. Their shape is generally described as subrounded to rounded. The extinction angle of epidote minerals is low. Epidote minerals make up approximately 2.19% of the total heavy mineral assemblage (Figure 2M).

Chlorite

Detrital Chlorite displays greenish in color and appears in the form of thin, flaky, oval or irregular shapes and it does not show any pleochroism. On average, they make up about 1.74% of total heavy mineral assemblages (Figure 2L).

Zircon

The opaque minerals cannot be adequately described due to their absence of distinct optical properties. The opaque minerals show diverse habits but they are commonly cubic or rhombohedral. However, some are distinct as hematite and magnetite. On average, opaque minerals make up about 20.61% of total heavy mineral assemblages.

ZTR Maturity Index

According to Hubert[12] Zircon-Tourmaline-Rutile (ZTR) index was established to assess the mineralogical maturity of sedimentary rocks. Sediments are considered to be mineralogically immature or sub-mature if the ZTR index is less than 75%.[13] In this study, the ZTR index of the Bhuban Formation ranges from 39.81% to 60.81%, with an average of about 50.71%. This suggests that the Bhuban sediments are mineralogically immature. Additionally, in the ZTR triangular diagram (Figure 3), it has been observed that all the samples fall within the A1 tier of the A block. This finding indicates that the proportion of zircon is the highest and followed by tourmaline and rutile. According to Ramamoorthy *et al.*[14] presence of kyanite, staurolite, sillimanite, tourmaline etc. indicates their derivation from acid igneous and crystalline metamorphic rocks, as well as igneous source is also indicated by the presence of prismatic and angular zircon grains and the high percentage of opaque minerals. Subhedral and rounded zircon grains indicate their derivation from reworked sedimentary sources (Figure 3). The presence of kyanite in the studied samples indicates that the sediments originated from a metamorphic source and may have undergone a higher degree of metamorphism. The kyanite grade of metamorphism are generally found in the Higher Himalayas.[15] Therefore, it could be an indication of the derivation of sediments from the Himalayan terrain.

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Conclusions

The abundance of zircon and rutile in the form of euhedral suggests that these rocks originated from acidic igneous and crystalline metamorphic rocks as well as short to moderate distances of sediment transportation. In addition to this, prismatic and angular zircon grains and a significant proportion of opaque minerals also signs that the sediments were sourced from igneous rock. However, rounded zircons, tourmalines and rutile are also often found, which shows that sedimentary rock may have been recycled and transported over a considerable distance. Zircon fragments suggest a short to moderate distance of transportation as well while the ZTR index for Bhuban sediments displays a low value which suggests that the sediments are mineralogically immature. The presence of kyanite, staurolite, sillimanite, tourmaline and rutile in examined Bhuban sandstones indicates that they originated from a metamorphic source of high rank.

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