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Heavy Minerals as Provenance and Maturity Indicator of The Barail Group Exposed Between Khawzawl and Champhai, Mizoram, India

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Abstract

Objectives: To evaluate heavy mineral assemblages as reliable indicators of sediment provenance and mineralogical maturity in the Barail Group sandstones exposed between Khawzawl and Champhai, Mizoram. **Methods:** Heavy mineral analysis was performed to determine provenance and maturity using standard petrographic and mineral separation techniques. Twenty-eight representative sample portions were gently crushed and soaked to remove clay coatings, followed by chemical treatments to eliminate carbonate, iron oxides, and organic matter. After drying and sieving (80-mesh fraction), heavy minerals were separated using bromoform and mounted on glass slides with Canada balsam. Mineral identification and counting were carried out under a polarizing microscope, and the ZTR index was calculated to quantify sediment maturity. **Findings:** The heavy mineral suite includes zircon, tourmaline, rutile, sillimanite, kyanite, staurolite, garnet, epidote, hornblende, and opaque minerals, indicating mixed metamorphic, igneous, and recycled sedimentary sources from an orogenic hinterland. ZTR values range from 43.24 to 71.25, signifying mineralogically immature to submature sandstones. These results suggest moderate degrees of weathering, sediment recycling, and hydraulic sorting during transport and deposition. **Novelty**: This study provides the first detailed heavy-mineral-based assessment of Barail sandstones in Mizoram, establishing new insights into Oligocene sediment routing, provenance, and depositional maturity within the Indo-Myanmar foreland region.

Keywords: Heavy minerals; provenance; Barail Group; ZTR Index; Mizoram

1 Introduction

Sediment provenance studies are essential for reconstructing source-area lithology, tectonic history, and sediment dispersal pathways.[1–3] Heavy mineral analysis serves as a robust provenance tool because these minerals preserve primary source signatures through weathering, transport, and early diagenesis.[4–7] Variations in heavy mineral assemblages reflect differences in source rock composition, sediment recycling, and depositional environments, with minerals such as zircon, tourmaline, rutile, garnet, and opaque phases effectively discriminating between igneous, metamorphic, and sedimentary sources.[4–7] Recent studies demonstrate that integrating heavy mineral data with quantitative maturity indices like ZTR (zircon–tourmaline–rutile) enhances provenance resolution in foreland basin systems.[6,8]

Heavy mineral analysis has been increasingly applied to Tertiary sedimentary rocks of the Surma Basin and Indo-Myanmar foreland in Mizoram (NE India) to infer sediment sources and transport history.[1,9] For instance, Miocene Bhuban Formation sandstones in the region contain abundant zircon, rutile, tourmaline, staurolite, kyanite, garnet, and opaque minerals, indicating derivation from mixed metamorphic and igneous sources with moderate transport distances.[9] Earlier work on Barail Group equivalents identified complex heavy mineral suites reflecting input from igneous, metamorphic, and recycled sedimentary terrains linked to Himalayan and Indo-Burman orogens.[2] However, systematic heavy mineral studies with ZTR maturity assessment remain absent for Oligocene Barail sandstones exposed between Khawzawl and Champhai, Mizoram. This study addresses this gap by documenting heavy mineral assemblages and ZTR indices to constrain provenance, recycling, and sediment maturity in this low-dip foreland sector (Figure 1: Location map with GPS coordinates).[1,2,6]

2 Methodology

2.1 Study Area

The study area spans the Khawzawl–Champhai road section (23°32'10.68" N, 93°11'4.51" E to 23°28'44" N, 93°18'45.98" E) within the Oligocene Barail Group of the Indo-Myanmar foreland basin, Mizoram (Figure 1).[1–3] The succession dips gently at 10–15° and consists predominantly of very fine- to fine-grained sandstones interbedded with shale and siltstone, forming coarsening-upward cycles typical of shallow marine to paralic depositional settings.[1,10]

Sandstones occur as thick (1–3 m), laterally pinching beds suggestive of channelized deposition, with grey to brown coloration (Figure 2: Field photographs of sandstone beds). Shales are grey, often displaying exfoliation joints, while siltstones range from brown to reddish-brown. Diagnostic sedimentary structures include heterolithic bedding, tidal rhythmites, trace fossils, ripple marks, flute casts, and hummocky cross-stratification (HCS), collectively indicating tide- and wave-influenced shallow marine environments with periodic storm influence (Figures 3a– 3e: Photomosaics of sedimentary structures).[3,4] These features align with Barail Group depositional models from adjacent sectors of the Surma Basin and Indo-Burman Ranges.[1,2,4]

2.2 Fieldwork

Fieldwork was conducted using standard geological tools including topographic sheets (1:50,000 scale), handheld GPS devices, Brunton compasses, geological hammers, chisels, field notebooks, permanent markers, and sample bags.[2] The primary objectives were to:

- Map outcrop distribution and document sedimentary structures in their stratigraphic context (heterolithic bedding, tidal rhythmites, trace fossils, ripple marks, flute casts, hummocky cross-stratification).[1,2]
- Systematically collect representative sandstone samples with precise GPS coordinates for heavy mineral and petrographic analysis.[2,3]

A total of 28 fresh sandstone samples (coded KTC 1-12, TKZ-2 to TKZ-15) were collected at regular stratigraphic intervals (20-30 m vertically) and from laterally continuous, unweathered beds to ensure comprehensive coverage of lithofacies variations.[1,2] Sample locations span the full Khawzawl-Champhai road section (23°32′10.68″N, 93°11′04.51″E to 23°28′44″N, 93°18′45.98″E), with GPS data, lithologic descriptions, bed thickness, and structural orientations recorded in the field logbook.[1,2] All observations were cross verified against regional Barail Group mapping to maintain stratigraphic consistency.[1,3]

2.3 Laboratory Analysis

Heavy mineral separation and identification followed established protocols optimized for fine-grained sandstones, as applied in recent regional provenance studies.[2,3,6]

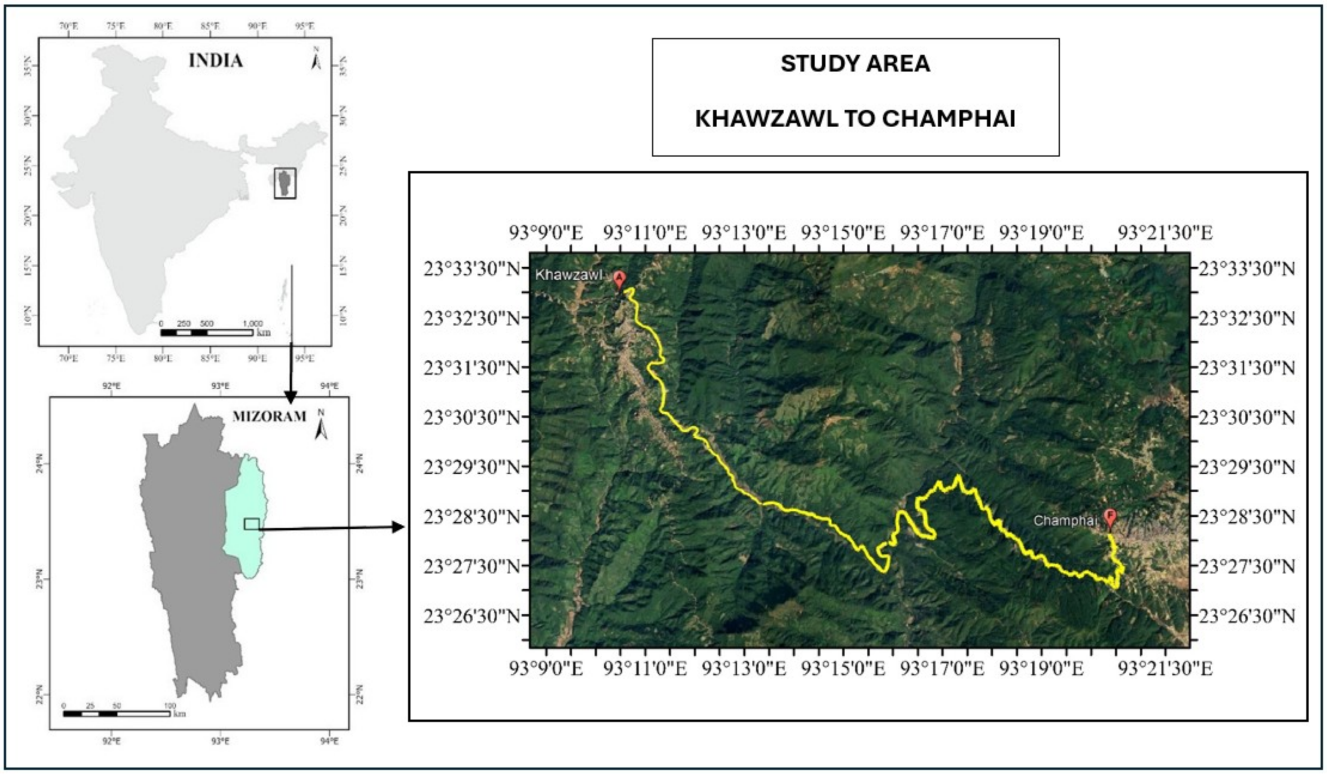

Fig 1. Study area

Fig 2. Sandstone bed pinching out and tidal bundle

2.4 Sample preparation

1. Representative portions (200 g) of each sandstone sample (KTC 1-12 and TKZ 2-15) were gently crushed using porcelain mortar to avoid artificial grain breakage. [2,3]
2. Crushed material was soaked in distilled water for 2-3 days to disaggregate clay-rich matrix and friable aggregates. [2]
3. Samples were treated with dilute hydrochloric acid (10% HCl) for 10 minutes at room temperature to dissolve carbonate cements and iron oxide coatings, followed by thorough rinsing with distilled water until neutral pH. [2,6]
4. Organic matter and residual clay were removed by treatment with 30% hydrogen peroxide (H_2O_2) for 36 hours, with periodic agitation. [2,3]
5. Samples were oven-dried at 60°C and gently disaggregated to powder. [2]

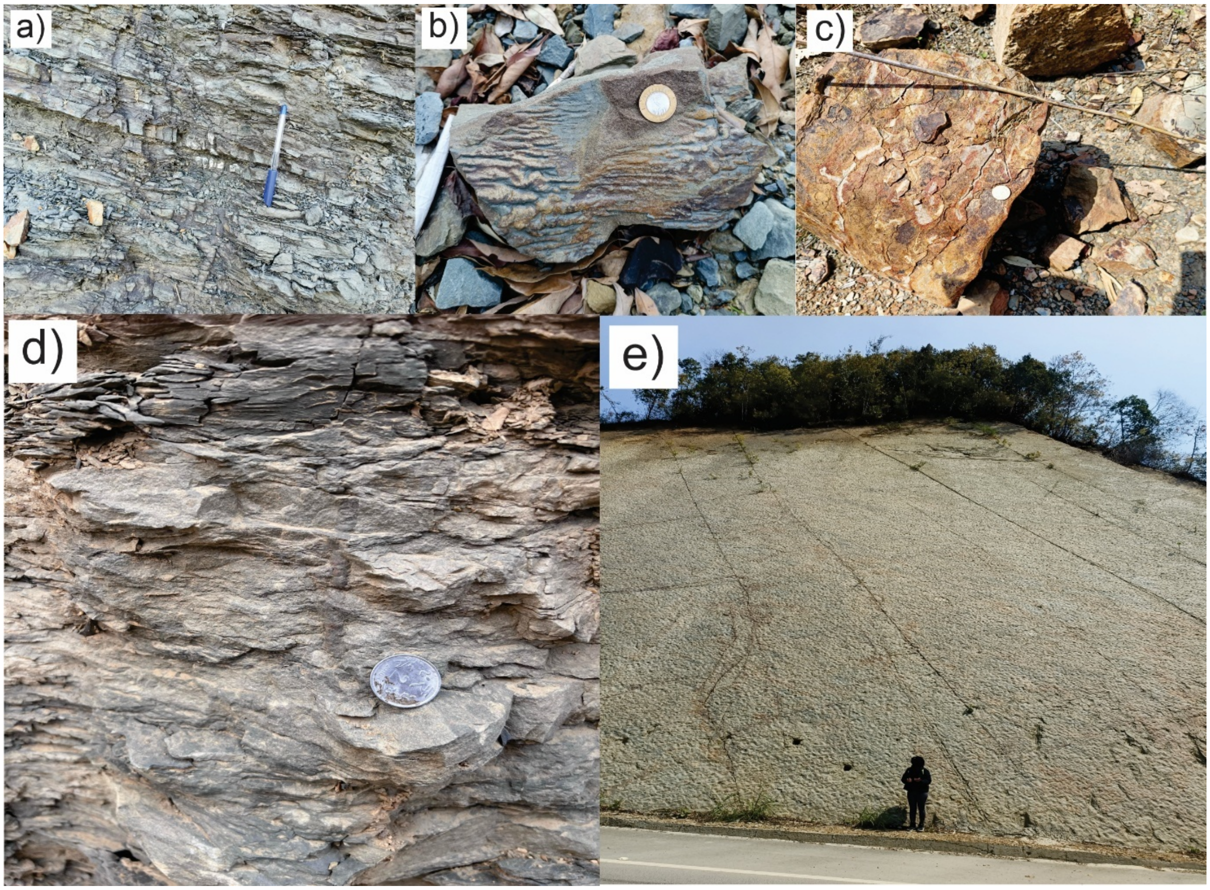

Fig 3. a) Heterolithic bedding b) Flute marks c) Hummocky Cross Stratification d) Trace fossils (Ophiomorpha nodosa) e) Ripple marks

2.5 Sieving and heavy mineral separation

1. Dried powder was dry-sieved through a stack of ASTM sieves; the 80-mesh fraction (177 μm) was selected for heavy mineral analysis as it represents the optimal grain size for provenance work in fine sandstones. [2,8]
2. Approximately 25 g (not 50 g; standardized weight for statistical reliability) of the 80-mesh fraction from each sample was weighed out for heavy liquid separation. [2,3]
3. Heavy minerals were separated using the stopcock funnel method with bromoform ($CHBr_3$; specific gravity 2.89 g/cm^3) following standard density fractionation procedures. [2,6] The heavy fraction (>2.89 g/cm^3) was recovered through repeated settling and decantation cycles.
4. The heavy mineral concentrate was washed multiple times with acetone to remove bromoform residues, then air-dried and stored in labeled glass vials. [2,3]

2.6 Microscopic identification and quantification

1. Heavy mineral separates were mounted on glass slides using Canadian balsam (refractive index 1.54) as the embedding medium, following routine petrographic practice. [2,3]
2. Identification and point-counting were performed under a polarizing microscope (10$\times$ objective, 400$\times$ total magnification) using standard optical criteria (relief, birefringence, pleochroism, extinction angles, interference colors). [2,6]
3. Minimum 300 non-opaque grains were counted per sample using the ribbon-counting method to achieve statistically robust percentages ($\pm$5% error at 95% confidence). [2,3,6] Opaque minerals were noted separately but excluded from ZTR calculations.

4. The ZTR maturity index was calculated as: ZTR (%) = [Zircon + Tourmaline + Rutile / Total non-opaque heavy minerals] $\times$ 100 [4,6,7]

Representative photomicrographs of identified heavy minerals (zircon, tourmaline, rutile, amphiboles, metamorphic indices) are presented in Figures 4a– 4j. Detailed grain-count data, ZTR values, and analytical reproducibility are summarized in Table 2. [2,3]

3 Results and Discussion

3.1 Heavy Mineral Descriptions and Interpretations

Heavy mineral assemblages in the Barail sandstones comprise zircon, tourmaline, rutile, garnet, augite, staurolite, sillimanite, kyanite, hypersthene, hornblende, chlorite, apatite, and magnetite (Figures 4a– 4o; Table 2). [2–4] Detailed optical characteristics and provenance implications for each mineral are summarized below.

3.2 Ultrastable minerals (ZTR)

Zircon (Fig. 4n, o): It is colorless to pale gray prismatic grains (subangular to subrounded) having high relief, parallel extinction, high-order interference colors, zoning common, no cleavage. It indicates igneous (granite, pegmatite) and high-grade metamorphic (gneiss) sources and extreme durability survives multiple recycling cycles. [2,3,7]

Tourmaline (Fig. 4m): Elongated prismatic grains (brown to pale green, pleochroic) showing moderate-high relief, striations, parallel extinction and high birefringence. It derives from granites, pegmatites, and schists and shows resistance to weathering and transport. [3,4]

Rutile (Fig. 4j): It is blood-red to brownish-yellow, short prismatic/platy (angular to subangular) showing high relief, no cleavage and fractures is common. It is accessory in granites, gneisses, amphibolites; abundant in all samples, with rounded grains suggesting sedimentary recycling. [2,6]

3.3 Metamorphic index minerals

Garnet (Fig. 4e): Subangular to irregular, colorless (isotropic, remains dark in XPL) having conchoidal fractures and inclusions common. It is the most abundant non-opaque mineral which derives from contact metamorphics, granitic pegmatites, and regional metamorphics. The high stability permits long transport. [3,4]

Kyanite (Fig. 4h): It is colorless to pale yellow, bladed rectangular grains showing excellent cleavage, inclined/straight extinction and step-like interference colors. It indicates medium-high grade schists/gneisses. Relative instability suggests proximal metamorphic sources. [2]

Sillimanite (Fig. 4k): It is slender fibrous/elongated crystals; colorless, straight extinction, 2nd order greenish/blue birefringence, containing fractures and inclusions. It is diagnostic of high-grade metamorphics ($\geq$500°C). [2,3]

Staurolite (Fig. 41): Bright yellowish, hackly fractures and no cleavage showing strong pleochroism (yellow-golden), straight extinction, low birefringence. It originated from medium grade pelitic schists and proximal derivation due to moderate stability. [3,4]

3.4 Mafic/igneous minerals

Augite (Fig. 4b): Colorless, weak pleochroism; high relief, subhedral-anhedral prismatic, 30-40° inclined extinction to cleavage. It indicates mafic/volcanic sources and are unstable during transport, suggesting proximity to basic igneous terrains. [2,6]

Hornblende (Fig. 4f): Anhedral-elongated, green-pale green pleochroism; prominent cleavage, inclined extinction, 2nd order green interference, fractures. It derives from amphibolites, mafic-intermediate intrusives, and medium-high grade metamorphic and short transport indicators. [3,4]

Hypersthene (Fig. 4g): It is subhedral to anhedral having 1st order colors, undulatory extinction, weak pleochroism. It shows mafic-intermediate igneous provenance (norites, gabbros). [2]

3.5 Accessory and unstable minerals

Apatite (Fig. 4a): It is colorless under plane polarized light and shows low interference color under cross polar, moderately high relief under plane polarized light; low interference color (first order gray/light bluish gray) under crossed nicol and are subrounded to sub angular shape or irregular grains. Inclusion is commonly seen, and cleavage is not prominent. Igneous/metamorphic accessory; rounded grains indicate sedimentary recycling.[2,6]

Chlorite (Fig. 4c): Chlorites are observed as light green in color under plane polarized light and are non-pleochroic. They are usually anhedral in shape. It is observed that some shows deformed structure 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. Its presence in heavy mineral assemblages generally indicates proximal source areas, limited chemical weathering, and short transport distance, as chlorite is unstable under intense weathering and prolonged transport.[3]

Epidote (Fig. 4d): epidote shows pale yellowish color and have moderate relief and some show pleochroism. In XPL, they are low to moderate birefringence that is first order grey to yellowish and show fractures in it. Its presence, along with other heavy minerals such as garnet, zircon, and hornblende, indicates a derivation from low- to medium-grade metamorphic rocks and locally exposed igneous terrains.[3,4] Epidote grains in these sandstones are typically moderately stable under weathering, suggesting short to moderate transport distances from the source area.[3,9]

Opaque minerals: The only opaque minerals which can be identified in the present study are magnetite since other opaque minerals could not be named under the petrological microscope. Identification and separation of magnetite was done by using bar magnet because of its magnetic property.

This analysis of heavy minerals is conducted to investigate the nature of source rock lithology, and tectonic history of the source area and maturity of the study area during this research work. The presence of apatite, hornblende, rutile and elongated zircon and tourmaline might indicate their derivation from acidic igneous rocks[11] The presence of rounded apatite and rutile are, however, indicative of its derivation from reworked sediments[12–14]. The occurrence of augite, magnetite and hypersthene is an indicator of basic igneous rock source. The presence of garnet could be indicative of three provenances such as contact metamorphic rocks, granite pegmatite, and dyno thermal metamorphic rocks. The presence of staurolite can be inferred as contact metamorphic source. The presence of sillimanite, staurolite, kyanite and chlorite is also an indicator of a provenance of dyno thermal metamorphic rocks. The euhedral and irregular shaped grains generally indicate short transportation while the presence of sub rounded to rounded zircon and rutile may indicate sedimentary source. Therefore, the study shows that the sandstones of The Barail group are believed to be derived from mixed provenance formed of basic to acidic igneous rock and low grade to high grade metamorphic rocks with short transportation. Thus, this may also indicate the quick deposition of sediments derived from nearby recycled orogenic belt of extraordinarily complex lithology.

Studies have taken up only some parts of Mizoram in which heavy mineral analysis is conducted only in about two to three areas where the minerals alone are used to derive the provenance of their respective study areas, whereas this study includes ZTR maturity index providing not only the provenance of the study area but also the maturity of the study area respectively.

3.6 ZTR Maturity Index

The ZTR (Zircon-Tourmaline-Rutile) maturity index, proposed by Hubert (1962) and widely applied in modern provenance studies, quantifies mineralogical maturity as the percentage of the three most chemically and mechanically stable heavy minerals within the total non-opaque heavy mineral assemblage: ZTR (%) = [Zircon + Tourmaline + Rutile / Total non-opaque heavy minerals] $\times$ 100[2,3,7]

In the studied Barail sandstones, ZTR values range from 43.24% to 71.25% (average 57.24%; Table 2; Fig. 5). This plot predominantly in Hubert's A1 and A2 fields of the ZTR triangular diagram (Fig. 5), characterized by zircon-tourmaline dominance with subordinate rutile, indicating derivation from mixed metamorphic and igneous sources.[3,4] The relatively low ZTR values (<75%) classify these sediments as mineralogically immature to sub mature, reflecting limited mineral attrition, moderate weathering, and proximal deposition in a tectonically active foreland basin.[2,6,7]

Mineral abundance trends (Table 1):

- Zircon (most dominant, 10-33.3%): Acidic igneous (granite/pegmatite) and high-grade metamorphic sources; prismatic/angular grains indicate first-cycle input, subrounded forms suggest recycling.[1,3]
- Tourmaline (2.73-13.51%): Granite, schist; brown varieties diagnostic of metamorphic provenance.[4]
- Rutile (3.44-13.39%): Accessory in granites, gneisses, amphibolites; rounded grains confirm sedimentary reworking.[1,2]

Non-opaque minerals (tourmaline, zircon, rutile, kyanite, sillimanite, staurolite) significantly outnumber opaques, with zircon consistently dominant and staurolite rare/absent in some samples. The presence of metamorphic index minerals (kyanite, sillimanite, staurolite, brown tourmaline) alongside prismatic zircon and high opaque percentages confirms acidic igneous + crystalline metamorphic provenance.[3,4]

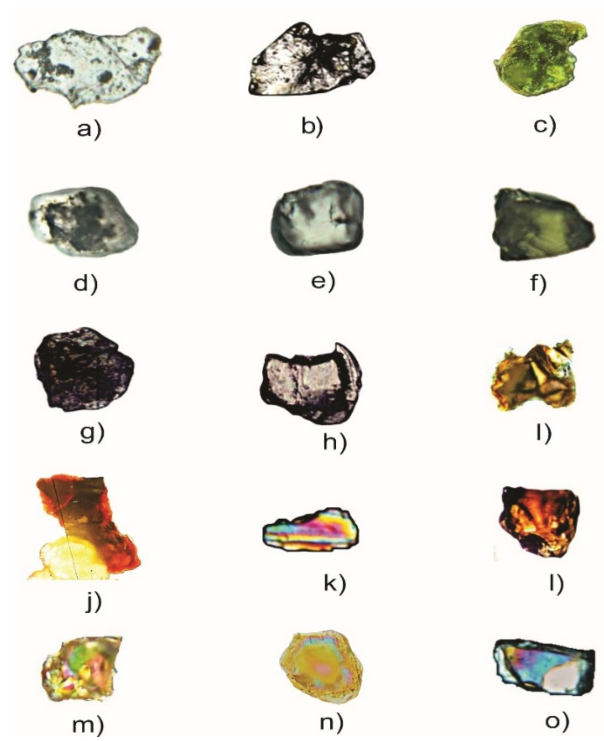

Fig 4. a) apatite b) augite c)chlorite d)epidote e)garnet f)hornblende g)hypersthene h) kyanite i)magnetite j)rutile k)sillimanite l)staurolite m)tourmaline n)zircon o)zircon

Intense humid weathering in the source area depleted unstable minerals (hornblende, epidote, chlorite, andalusite), while stable ZTR phases were preferentially transported to the basin.[5,6] This selective enrichment follows established maturity trends where chemical breakdown under humid conditions destroys mafic silicates and feldspars before deposition.[7,15]

Fig. 5: ZTR triangular diagram (after Hubert, 1962)[3] showing Barail sandstone samples plotting in A1 (zircon-dominant) and A2 (zircon-tourmaline) fields, diagnostic of igneous-metamorphic provenance with immature-submature maturity (ZTR 43-71%)

Table 1. Hubert's ZTR Fields

Field	Zircon	Tourmaline	Rutile	Maturity	Provenance
A1	Dominant	Moderate	Minor	Immature-Submature	Igneous + Metamorphic
A2	High	High	Low	Submature	Metamorphic dominant
B	Moderate	Dominant	Minor	Mature	Metasedimentary
C	Low	Moderate	Dominant	Supermature	Heavily recycled

Key interpretations for Barail sandstones:

- A1 field (zircon > tourmaline > rutile): First-cycle input from acidic igneous (granite/pegmatite) + high-grade metamorphic sources; prismatic zircon diagnostic.[3,4]
- A2 field (zircon ≈ tourmaline > rutile): Metamorphic provenance (schist/gnéiss) with subordinate igneous contribution; brown tourmaline + kyanite common.[2,16]
- ZTR <75% overall: Confirms mineralogical immaturity; unstable minerals (hornblende, augite) preserved due to short transport.[5,6]

The presence of a few euhedral (i.e., first generation) colorless zircons not only suggests an acidic igneous source[17] but possibly short-distance transportation. Presence of perfect euhedral and angular shaped tourmaline may also suggest a silicic igneous source with short transportation of the sediments. Blood red as well as orange color elongated/prismatic and sub-angular to sub-rounded rutile supports derivation of sediments not only from the sedimentary source but also from acid igneous rocks and high grade crystalline metamorphic rocks [12]. Presence of staurolite, elongated sillimanite, fibrous kyanite, colorless subangular garnet grains and irregular shaped hornblende may indicate a provenance comprising of metamorphic source dominated by green schist and amphibolites. Occurrence of few irregular hornblende grains may also reflect an acid igneous source too. Abundance of magnetite and other opaque varieties (iron oxides) may also suggest mafic igneous sources [12]

Considering the variety of grain shapes among the heavy minerals in the study area, it can be inferred that there is a significant contribution from sources other than purely sedimentary origins as euhedral, sub-euhedral and irregular grains dominate over those having sub-angular, sub-rounded to rounded ones. Euhedral and irregular shape grains generally reflect less transportation as well as non-sedimentary. Supply of sediments from the reworked sediments, however, could not be completely ruled out, as some mineral grains like zircon and staurolite are found to have sub-rounded to rounded shapes.

The overall heavy mineral assemblage, which is characterized by the abundance of zircon, tourmaline, rutile, sillimanite, staurolite, kyanite, garnet, epidote, and apatite thus suggests that the sediments were primarily derived from high-grade metamorphic source rocks [18,19]

Table 2. Heavy Minerals and ZTR%

Sample No.	Zircon	Tourmaline	Rutile	Kyanite	Sillimanite	staurolite	epidote	Opaque	Garnet	ZTR%
KTC 1	17.07317	9.7560976	11.38211	1.626016	4.8780488	1.62601626	1.626016	42.2764228	9.756098	66.19718
KTC 2	17.85714	8.0357143	9.821429	4.464286	7.1428571	2.67857143	0.892857	37.5	11.60714	57.14286
KTC 3	10.71429	6.25	13.39286	3.571429	8.0357143	0.89285714	4.464286	40.1785714	12.5	50.74627
KTC 4	12.64368	9.1954023	13.7931	3.448276	8.045977	2.29885057	4.597701	28.7356322	17.24138	50
KTC 5	23.59551	10.674157	12.92135	4.494382	6.741573	0	1.685393	28.6516854	11.23596	66.14173
KTC 6	20.43796	8.7591241	15.32847	6.569343	8.0291971	1.45985401	1.459854	30.6569343	7.29927	64.21053
KTC 7	30.40541	13.513514	6.081081	3.378378	5.4054054	0.67567568	3.378378	26.3513514	10.81081	67.88991
KTC 8	20.51282	12.820513	5.128205	1.709402	5.1282051	2.56410256	3.418803	32.4786325	16.23932	56.96203
KTC 9	13.27434	10.619469	10.61947	3.539823	5.3097345	1.7699115	2.654867	36.2831858	15.9292	54.16667
KTC 10	22.95082	4.9180328	9.016393	4.918033	5.7377049	2.45901639	2.459016	37.704918	9.836066	59.21053
KTC 11	21.69811	6.6037736	7.54717	7.54717	8.490566	0	0.943396	33.0188679	14.15094	53.52113
KTC 12	20	6.6666667	7.777778	4.444444	6.6666667	1.11111111	0	35.5555556	17.77778	53.44828
TKZ 2	19.17808	2.739726	9.589041	0	5.4794521	0	5.479452	28.7671233	28.76712	44.23077
TKZ 3	17.64706	7.3529412	5.882353	5.882353	8.8235294	2.94117647	2.941176	30.8823529	17.64706	44.68085
TKZ 5	15.51724	8.6206897	5.172414	1.724138	8.6206897	5.17241379	5.172414	34.4827586	15.51724	44.73684
TKZ 6	21.21212	9.0909091	11.11111	3.030303	9.0909091	2.02020202	2.020202	30.3030303	12.12121	59.42029
TKZ 7	15.18987	7.5949367	7.594937	2.531646	6.3291139	1.26582278	1.265823	44.3037975	13.92405	54.54545
TKZ 8	20	5.7142857	7.142857	4.285714	5.7142857	0	8.571429	37.1428571	11.42857	52.27273
TKZ 9	18.96552	5.1724138	3.448276	6.896552	3.4482759	0	3.448276	36.2068966	22.41379	43.24324
TKZ 10	17.64706	7.3529412	11.76471	0	2.9411765	0	5.882353	36.7647059	17.64706	58.13953
TKZ 11	23.15789	9.4736842	9.473684	2.105263	3.1578947	2.10526316	3.157895	33.6842105	13.68421	63.49206
TKZ 14	33.33333	11.111111	8.333333	5.555556	8.3333333	0.69444444	1.388889	24.3055556	6.944444	69.72477
TKZ 15	27.58621	12.068966	9.482759	2.586207	6.0344828	1.72413793	1.724138	31.0344828	7.758621	71.25

4 Conclusions

The heavy mineral assemblage of the Barail Group sandstones indicates a mixed igneous, metamorphic and sedimentary recycled provenance. Zircon and tourmaline, both highly stable minerals, suggest derivation from felsic igneous and high-grade metamorphic rocks, reflecting sedimentary recycling and high sediment maturity. Rutile similarly indicates metamorphic sources, particularly high-grade metamorphic rocks. Garnet, kyanite, sillimanite, and staurolite are characteristic of medium-to high-grade metamorphic rocks, pointing to proximal metamorphic source terrains. Hornblende, augite, and hypersthene are less stable and derive from igneous and amphibolite-facies metamorphic rocks, suggesting relatively short transport distances and low chemical weathering. Epidote and chlorite indicate contributions from low- to medium-grade metamorphic or hydrothermally altered igneous rocks. Apatite reflects igneous and metamorphic parent rocks and provides additional provenance information. Magnetite as an opaque mineral indicates igneous and metamorphic sources but is less diagnostic for precise provenance. The overall assemblage demonstrates a mixed provenance with varying transport distances and sedimentary maturity, consistent with deposition in a low-dip, channel-influenced foreland basin setting.

The heavy mineral study of the sandstones also shows that the occurrence of Prismatic and slender grains of zircon indicate their derivation from igneous source. The presence of prismatic rutile grains with sharp boundaries may be attributed to high grade metamorphic as well as acid igneous source. 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. Presence of pale brown tourmaline indicates the source of the sandstones is metamorphic

The ZTR maturity index suggests that the sediments are mineralogically immature, reflecting relatively short to moderate transport and rapid deposition in the basin setting. The ZTR index shows us that the Barail Group of rocks exposed between Khawzawl and Champhai are thus immature to sub-mature.

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