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Petrography and Heavy Mineral analysis of the Dupi Tila sandstones from the Bijaipur area, northwest Sylhet Trough, Bengal Basin: Implication on Provenance Interpretations

MAJED BHUIYA, RUMANA YEASMIN* & MD. SAKIB HASAN

Abstract

This research investigates the Dupi Tila Formation, the youngest Tertiary stratigraphic unit in the Bengal Basin, focusing on its mineralogical composition and geological significance in the Bijaipur area of the Netrokona District, Bangladesh. Mineralogically, the sandstones are primarily composed of quartz (average 87.88%), with subordinate feldspar (average 1.34%) and lithic grains (average 0.57%), and therefore, categorize the sandstones mainly as quartzarenites, differentiating them from sandstones of this formations in other part of the Bengal Basin. The study suggests that the sediments originated from eroded cratonic rocks and were influenced by climatic conditions characterized by high temperatures and humidity, which facilitated significant weathering processes. Heavy mineral analysis indicates low overall concentrations with zircon, amphibole, and pyroxene being the most abundant, reflecting a range of igneous and metamorphic parent rocks. The high amount of quartz and ZTR indices in these sandstones reveal a relatively mature sediments, which probably the results of severe chemical weathering of parent rocks. In addition to framework mineralogy, the presence of diverse heavy mineral suites indicates complex geological histories involving collision orogen settings. Such observations help to find the link with the uplift history of the Shillong Plateau during late Pliocene–Pleistocene time which is the result of ongoing tectonic interactions among the Indian-Eurasian plates.

Keywords: Quartzarenites, heavy mineral assemblages, craton, Shillong Plateau

Introduction

The Dupi Tila Formation in Bijaipur area comprises mainly variegated colored sandstones like the type area of the formation, i.e., Dupigaon in Jaintiapur area of the northeastern Sylhet Trough, but the formation in Bijaipur area has thick deposits of economically significant kaolinite-rich clayey succession which is known as Bijaipur Clay (ISLAM 1985). In this area, this sedimentary sequence is exposed along a 14 km long stretch section which is diced by the Someshwari River (Fig. 1). Geologically, the area is located at the northwestern fringe of the Sylhet Trough while the formation is also well-exposed along the eastern and northern boundaries (Fig. 1).

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The exposed Dupi Tila Formation in the northeastern Sylhet Trough is a well-studied formation which have been widely studied in different aspects, for examples, inferred facies architecture and depositional environments (Gani & Alam 2004); provenance interpretation (Uddin & Lundberg 1998a; Uddin & Lundberg 1998b; Bhuiyan *et al*. 2004; Hossain *et al*. 2010; Rahman *et al*. 2014; Khanam *et al*. 2020); and as a part of tectonic evolution of the Bengal Basin (Alam 1989; Johnson & Alam 1991; Alam *et al*. 2003). The Dupi Tila Formation that exposed in the northwestern part of the Sylhet Trough is needed to study in detail to correlate with this formation exposed in the type area, although Islam (1985) and Gazi *et al*. (2021) both studied the Dupi Tila Formation in the Bijaipur area which are important for understanding the geology of the area, especially characterizing the white clay deposits. Therefore, this research project aims to apply sedimentological concepts to characterize the Dupi Tila sandstones from Bijaipur area in order to: (1) assess the mineralogical composition of the Dupi Tila Formation, (2) infer parent rock types and compositions, (3) elucidate the tectonic settings of the provenance areas, and (4) find out paleoclimate, weathering patterns and intensity in provenance areas. However, several researches are also conducted on this formation exposed in different structures of the Chittagong Tripura Fold Belt (CTFB) to figure out the provenance and depositional settings, e.g., the Lalmai (Yeasmin *et al*. 2024; Abdullah *et al*. 2021; Roy *et al*. 2012); the Sitapahar (Roy & Roser 2011; Rahman *et al*. 2020), the Bandarban (Uddin & Lundberg 1998a; Bhuiyan *et al*. 2004; Dina *et al*. 2016; Roy & Roser 2011; Rahman *et al*. 2020) and the Inani (Uddin & Lundberg 1998a; Bhuiyan *et al*. 2004; Roy & Roser 2011), and also studied the formation from Stable Shelf (Roy & Roser 2011; 2013) of the Bengal Basin.

Geological Settings

The Sylhet Trough is a sub-basin of Foredeep Basin (Geotectonic Province 2) of the Bengal Basin and located between the Eocene Hinge Zone to the west and the Barail-Imphal Ridge of Assam to the east (Hossain *et al*. 2019). The trough is bounded to the north by the striking Barail Range of the Shillong Plateau and to the south by the Madhupur-Tripura High (Hossain *et al*. 2019). The trough is known for approximately 18–20 km thick Cenozoic sedimentary sequence (Hiller & Elahi 1988; Curray 1994; Uddin & Lundberg 2004), which comprises mostly clastic sedimentary sequences of alternating sandstones and shales/mudstones with subordinate amount of carbonate rocks. They were deposited in a wide range of depositional settings from marine shelf through deltaic to fluvial environments (Alam 1989; Alam *et al*. 2003).

The Dupi Tila Formation is the youngest of the Tertiary successions of the Sylhet Trough which is deposited in meandering river-dominant fluvial systems during late Pliocene (Johnson & Alam 1991; Alam *et al*. 2003; Gani & Alam 2004). In Bijaipur area of the northwest Sylhet Trough, this formation is exposed in isolated hillocks surrounded by valleys which are covered by alluvial deposits. The Dupi Tila Formation consists of variegated colored, medium-to-very fine grain and poorly sorted sandstones, and variegated colored kaolinite-rich silty clay to mudstone. The stratigraphy of the Bijaipur area is given in Table 1.

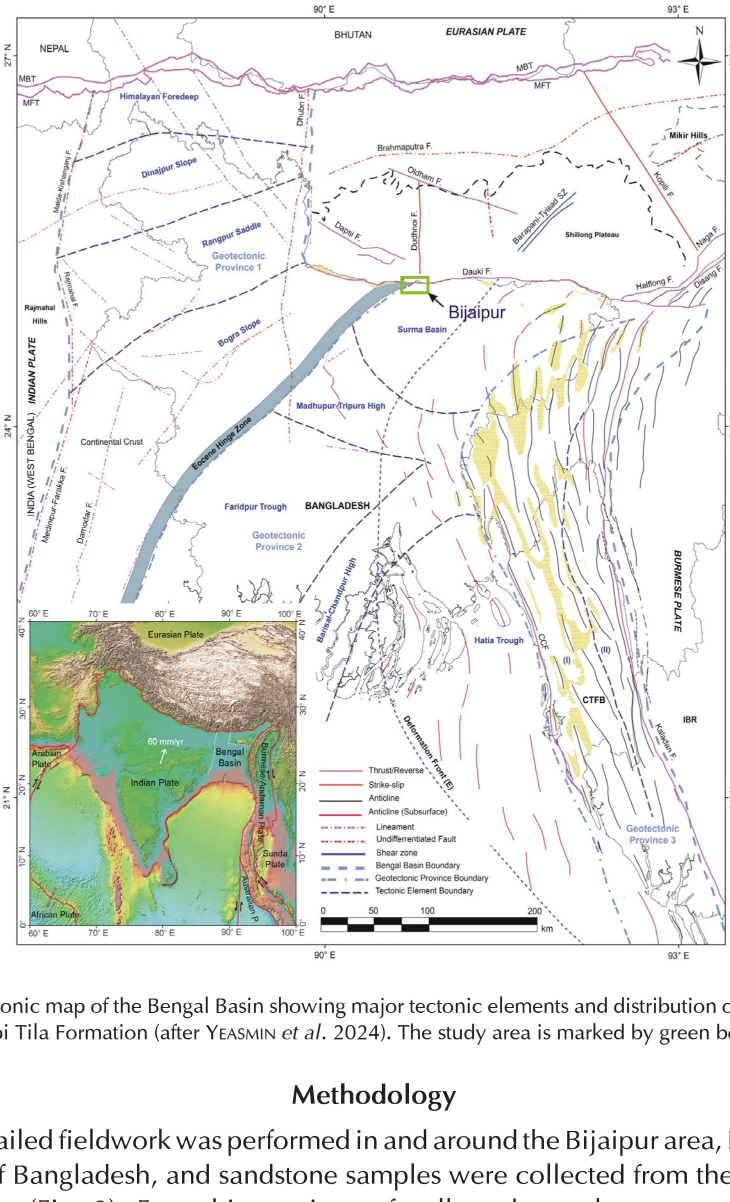

Fig. 1. Tectonic map of the Bengal Basin showing major tectonic elements and distribution of the exposed Dupi Tila Formation (after YEASMIN *et al*. 2024). The study area is marked by green box.

Methodology

Detailed fieldwork was performed in and around the Bijaipur area, Netrokona district of Bangladesh, and sandstone samples were collected from the Dupi Tila Formation (Fig. 2). Four thin sections of collected samples were prepared to determine mineralogical compositions. The framework minerals were identified

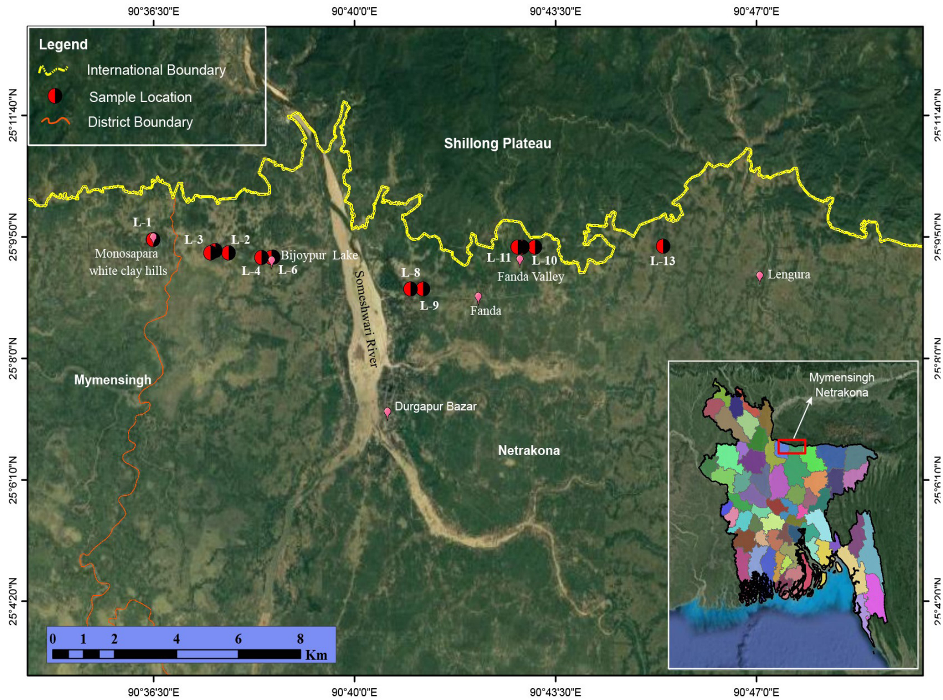

Fig. 2. The satellite image (Google Earth) of the study area showing the sampling locations (L-1 to L-13) along the foothills of the Shillong Plateau and on both side of the Someshwari River, Netrokona District, Bangladesh.

Table 1. Stratigraphic successions in Bijaipur area, northwest Sylhet Trough (modified from ISLAM 1985).

Age (approximately)	Formation	Thickness (m)	Lithology	Depositional Environment
Recent	Alluvium	-	Sand and clay	Piedmont and alluvial
---------- Unconformity ----------				
Pleistocene to late Pliocene	Dupi Tila	915	Variegated colored, ferruginous sandstones, pebbly sandstone with thick white and yellowish brown clay (kaolin) in upper part	Fluvial
---------- Unconformity ----------				
Mid Pliocene	Tipam	670	Sandstone and shale	Fluvial

under a polarizing microscope in the thin section laboratory of the Department of Geological Sciences, Jahangirnagar University and compositions were determined by point count method. At least, 600 grains per thin section had been counted in this method.

Eight Dupi Tila sandstone samples were chosen for heavy mineral analysis. 200 gm of each sample was treated with dilute HCl (10%) to remove carbonate materials. After washing and drying, the treated samples were sieved using 0.063 mm mesh. Then, heavy minerals were separated from 30 gm of samples using bromoform ($CHBR_3$). The analytical procedures of MANGE & MAURER (1992) were followed for heavy mineral separation. The grain slides of separated heavy minerals were prepared and were studied under a polarizing microscope in the thin section laboratory of the Department of Geological Sciences, Jahangirnagar University.

Results

Sandstone petrography and classification

The Dupi Tila sandstones of the Bijaipur area are very fine to medium grained, mainly poorly sorted and angular to subangular. The framework mineral compositions of these sandstones are shown in Table 2.

The main mineral in the Dupi Tila sandstones of Bijaipur is quartz (95.30–96.94%; average 95.85%). Monocrystalline quartz (Qm; Fig. 3A) makes up average 87.88% of total framework grains, whereas polycrystalline quartz (Qp) which consists of two or more crystals (Fig. 3B), accounts for around 7.97% (average Qm/Qt = 0.91). In contrast, concentrations of feldspar and lithic fragments in these sandstones are remarkably low (Table 2). Both K-feldspar and plagioclase feldspar are present (Fig. 3C, D), but their total contents range from 0.74 to 1.79% (average 1.34%; average K/F = 0.55). However, insignificant amount of lithic grains are found in the Dupi Tila sandstones of the study area and they make up average 1.14% of the total framework grains (Table 2). There are two main types of lithic grains recognized: (1) sedimentary lithic grains which include mainly chert (average 0.57%) and shale fragments (average 0.39%), and (2) metamorphic lithic grains (average 0.18%) which are mainly schists (Fig. 3D). Other than major framework grains in sandstones, only trace amount of phyllosilicate minerals such as chlorite, muscovite and biotite are found (0.62–1.71%; average 1.21%). However, the compositions of these sandstones differ greatly from the compositions of Dupi Tila sandstones from other parts of the Bengal Basin (Table 2).

The modal analysis of the Dupi Tila sandstones in Bijaipur area suggests that these are quartzose in composition, and classify as largely as quartzarenites (Fig. 4) as the abundance of total quartz (Qt) are exceptionally high relative to other principal framework grains of sandstone, i.e., feldspar and lithic fragments.

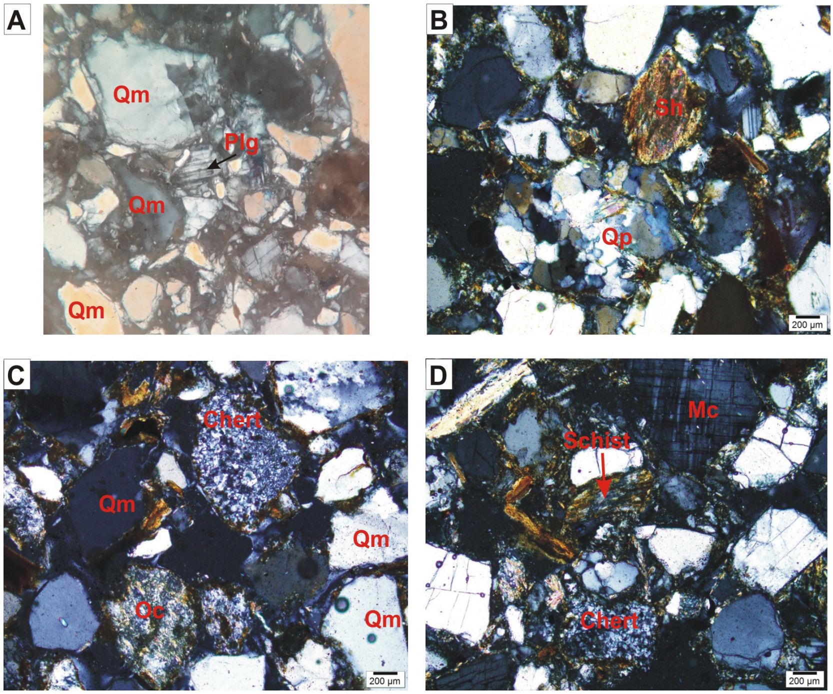

Fig. 3. Thin section photomicrographs of different framework grains in the Dupi Tila sandstones of the Bijaipur area. (A) monocrystalline quartz (Qm) and plagioclase (Plg) in sample no. DT-B-6-1 (cross-polarized light, xpl), (B) polycrystalline quartz (Qp) and shale fragment (Sh) in sample no. DT-B-11-1 (xpl), (C) monocrystalline quartz (Qm), chert and orthoclase (Oc) in sample no. DT-B-6-1 (xpl), and (D) schist, chert and microcline (Mc) in sample no. DT-B-5-1 (xpl).

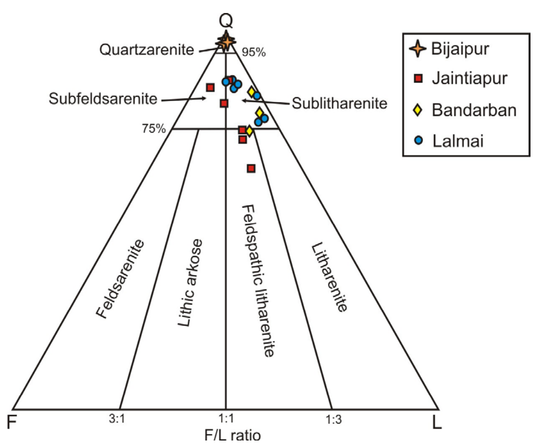

Fig. 4. Classification of the Dupi Tila sandstones of the Bengal basin based on FOLK (1980) classification scheme. The modal compositions of the Dupi Tila sandstones from Jaintiapur after BHUIYAN *et al*. (2004) and JOHNSON & ALAM (1991), Bandarban after DINA *et al*. (2016), and Lalmai after YEASMIN *et al*. (2024).

Table 2. Framework mineral composition of the Dupi Tila sandstones of Bijaipur, northwest Sylhet Trough and other areas of the Bengal Basin.

<table>
<tr><th colspan="9">Sylhet Trough</th><th colspan="2">CTFB</th></tr>
<tr><th colspan="2" rowspan="3"></th><th colspan="5">This study</th><th>BHUIYAN et al. 2004</th><th>JOHNSON & ALAM 1991</th><th>YEASMIN et al. 2024</th><th>DINA et al. 2016</th></tr>
<tr><th colspan="5">Bijaipur</th><th colspan="2">Jaintiapur</th><th>Lalmai</th><th>Bandarban</th></tr>
<tr><th>L-5*
DT-B-5-1</th><th>L-6*
DT-B-6-1</th><th>L-11*
DT-B-11-1</th><th>L-12*
DT-B-12-1</th><th>Mean</th><th>Mean (n = 5)</th><th>Mean (n = 7)</th><th>Mean (n = 7)</th><th>Mean (n = 2)</th></tr>
<tr><td rowspan="2">Quartz</td><td>Monocrystalline</td><td>80.03</td><td>92.36</td><td>89.25</td><td>89.88</td><td>87.88</td><td>69.10</td><td>62.90</td><td>66.60</td><td>61.00</td></tr>
<tr><td>Polycrystalline</td><td>14.98</td><td>3.79</td><td>6.05</td><td>7.06</td><td>7.97</td><td>7.60</td><td>5.30</td><td>10.00</td><td>3.40</td></tr>
<tr><td colspan="2">Chert</td><td>0.64</td><td>0.62</td><td>0.66</td><td>0.37</td><td>0.57</td><td>2.70</td><td>0.40</td><td>1.30</td><td>6.40</td></tr>
<tr><td rowspan="2">K-feldspar</td><td>Orthoclase</td><td rowspan="2">0.90</td><td rowspan="2">1.24</td><td rowspan="2">0.52</td><td rowspan="2">0.37</td><td rowspan="2">0.76</td><td rowspan="2">7.80</td><td rowspan="2">5.30</td><td>1.60</td><td rowspan="2">1.40</td></tr>
<tr><td>Microcline</td><td>0.90</td></tr>
<tr><td colspan="2">Plagioclase</td><td>0.90</td><td>0.41</td><td>0.66</td><td>0.37</td><td>0.58</td><td>1.70</td><td>2.90</td><td>1.40</td><td>0.40</td></tr>
<tr><td colspan="2">Chlorite</td><td>0.08</td><td>0.10</td><td>0.25</td><td>0.00</td><td>0.11</td><td>0.20</td><td>-</td><td>0.10</td><td>0.70</td></tr>
<tr><td colspan="2">Biotite</td><td>0.70</td><td>0.52</td><td>0.80</td><td>0.37</td><td>0.60</td><td>0.70</td><td rowspan="2">7.40</td><td>5.10</td><td>5.20</td></tr>
<tr><td colspan="2">Muscovite</td><td>0.51</td><td>0.00</td><td>0.66</td><td>0.86</td><td>0.51</td><td>0.70</td><td>1.30</td><td>0.50</td></tr>
<tr><td rowspan="3">Unstable lithic grains</td><td>Sedimentary</td><td>0.51</td><td>0.00</td><td>0.79</td><td>0.25</td><td>0.39</td><td>2.40</td><td>14.30</td><td>3.30</td><td>3.40</td></tr>
<tr><td>Metamorphic</td><td>0.26</td><td>0.21</td><td>0.13</td><td>0.12</td><td>0.18</td><td>7.30</td><td>0.70</td><td>7.10</td><td>3.60</td></tr>
<tr><td>Volcanic</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.20</td><td>0.00</td><td>0.00</td></tr>
<tr><td colspan="2">Others</td><td>0.50</td><td>0.75</td><td>0.24</td><td>0.35</td><td>0.46</td><td>-</td><td>-</td><td>1.30</td><td>-</td></tr>
</table>

* sample locations in Fig. 2

Heavy Minerals Contents

The total heavy mineral concentrations in the Dupi Tila sandstones of Bijaipur area are very low (< 1%), but these sandstones are diverse in heavy mineral concentrations (Table 3). The predominant heavy minerals in these sandstones are zircon (8.26-24.38%; average 16.49%), kyanite (4.62–22.37%; average 13.53%), amphibole (9.38–21.05%; average 15.96%), pyroxene (3.30–11.76%; average 8.26%), and opaque minerals (7.69–15.31%; average 11.87%) (Fig. 5). The sandstones are also characterized by lesser amounts of rutile, epidote, tourmaline, garnet, sillimanite, apatite, staurolite and traces of andalusite, blue amphibole and chloritoid (Table 3). The ZTR indices which are calculated based on the relative abundance of zircon (Z), tourmaline (T) and rutile (R), are relatively high with values ranging from 17.99% to 33.44% (average 25.89%).

Based on the relative abundances of different heavy minerals in the Dupi Tila sandstones, three main assemblages are identified (Cluster: A, B and C). Cluster A

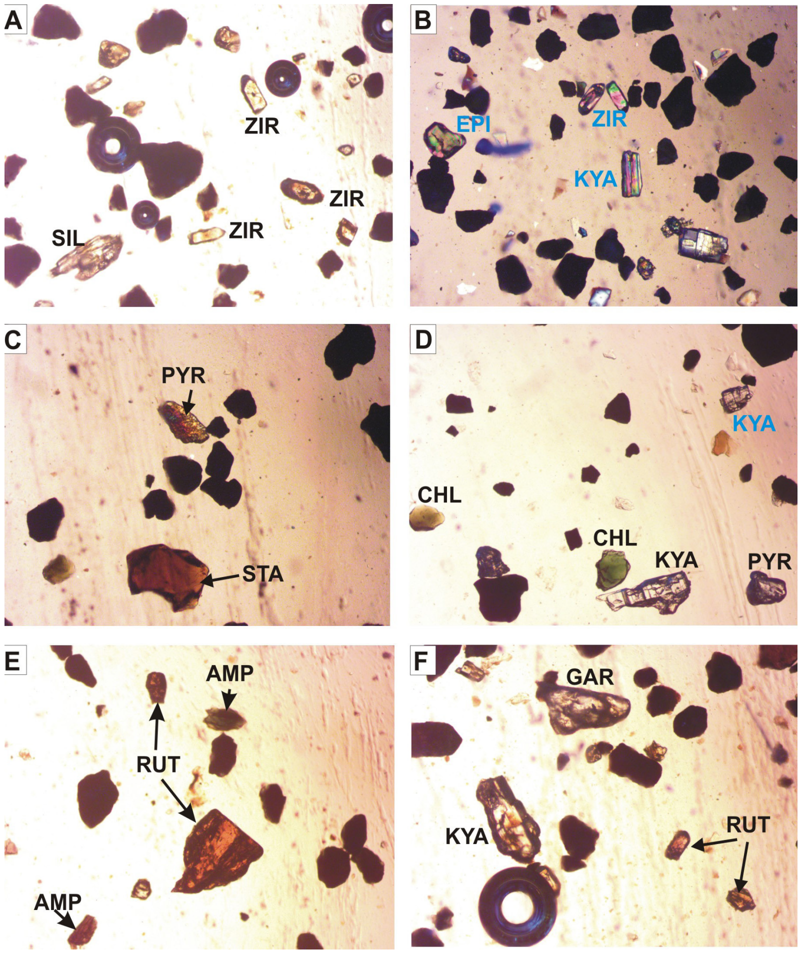

Fig. 5. Photomicrographs of different types of heavy minerals found in the Dupi Tila sandstones of the Bijaipur area. (A) zircon (ZIR) and sillimanite (SIL) in sample no. DT-B-1-4 (plane-polarized light, ppl), (B) zircon (ZIR), epidote (EPI) and kyanite (KYA) in sample no. DT-B-1-5 (cross-polarized light, xpl), (C) pyroxene (PYR) and staurolite (STA) in sample no. DT-B-13-3 (xpl), (D) kyanite (KYA), chloritoid (CHL) and pyroxene (PYR) in sample no. DT-B-1-6 (ppl), (E) rutile (RUT) and amphibole (AMP) in sample no. DT-B-1-5 (ppl), and (F) garnet (GAR), kyanite (KYA) and rutile (RUT) in sample no. DT-B-11-1 (ppl).

(Fig. 6A) is represented by three samples (DT-B-1-4, DT-B-1-6, and DT-B-11-5) which show a clear predominance of zircon (average 22.93%), followed by amphibole (average 13.37%), opaque minerals (average 12.55%), kyanite (average 11.90%) and epidote (average 7.36%). The ZTR index for cluster A is the highest among the three clusters (average 32.50%). On the other hand, Cluster B (Fig. 6B) is also represented by three samples (DT-B-5-1, DT-B-5-2, and DT-B-11-1). This cluster is also rich in zircon (average 15.22%), amphibole (average 16.75%), and kyanite (average 9.89), but contains a reasonable amount of pyroxene (average 11.24%). The ZTR index is also high in cluster B (average 23.96%). However, Cluster C (Fig. 6C) is represented by two samples (DT-B-13-3 and DT-B-1-5). This cluster contains a high amount of kyanite (average 21.45%) and amphibole (average 18.66%), followed by zircon (average 8.74%), pyroxene (average 7.51%), rutile (average 7.21%) and sillimanite (average 5.76%). The ZTR index is low (average 18.86%).

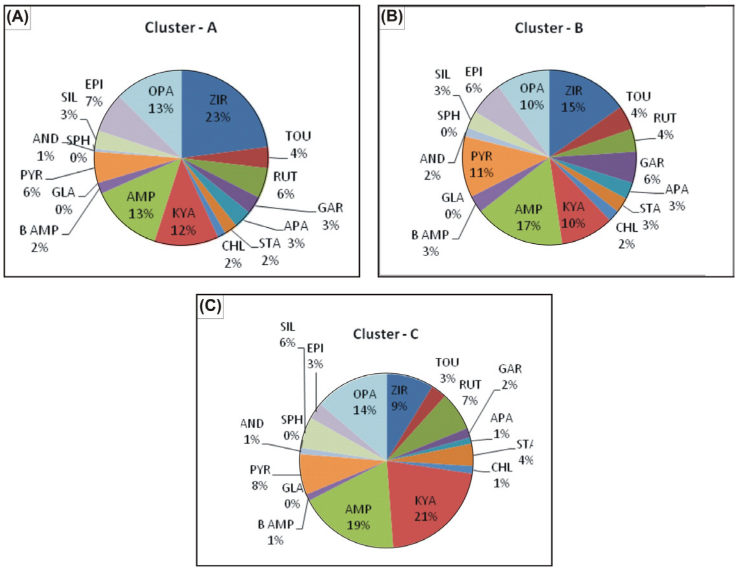

Fig. 6. Heavy mineral assemblages of the Dupi Tila sandstones from Bijaipur.

Discussion

The Dupi Tila sandstones from the Bijaipur area have extremely high quartz contents compare to other structures representing different tectonic provinces of the Bengal Basin, e.g., Lalmai (average 76.60%, YEASMIN *et al*. 2024) and Bandarban (average 64.40, DINA *et al*. 2016) of the Chittagong Tripura Fold Belt and Jaintiapur area of the northeastern Sylhet Trough (average 68.20%, JOHNSON & ALAM 1991; average 76.70%, BHUIYAN *et al*. 2004) of the Bengal Basin (Table 2). In addition to Bijaipur, the total feldspar contents in the Dupi Tila sandstones are reasonably low in the Lalmai Anticline (average 3.81%; after YEASMIN *et al*. 2024) in contrast to the feldspar concentrations from the Sylhet Trough and other anticlinal structures of the fold belt (JOHNSON & ALAM 1991; BHUIYAN *et al*. 2004). Additional important framework grains are lithic grains which are much less in concentrations in the sandstones of the Bijaipur area (Table 2). Therefore, the Dupi Tila sandstones are classify widely from sublitharenite to subfeldsarenite–feldspathic litharenite in different tectonic provinces of the Bengal Basin, except Bijaipur area where these sandstones are quartzarenite in composition (Fig. 4).

Table 3. Heavy mineral concentrations of the Dupi Tila sandstones of Bijaipur, northwest Sylhet Trough and other areas of the Bengal Basin.

				Sample No.	ZIR	TOU	RUT	ZTR index	GAR	APA	STA	CHL	KYA	AMP	B AMP	GLA	PYR	AND	SPH	SIL	EPI	OPA
Sylhet Trough	This study	Bijaipur	L-1*	DT-B-1-4	24.38	2.19	6.88	33.44	4.38	2.19	4.06	0.94	9.06	9.38	1.56	0.00	8.44	1.56	0.00	1.56	8.13	15.31
				DT-B-1-5	9.21	2.63	7.89	19.74	1.32	1.32	3.95	1.32	22.37	21.05	1.32	0.00	5.26	1.32	0.00	5.26	2.63	13.16
				DT-B-1-6	24.18	4.40	3.30	31.87	2.20	4.40	1.10	2.20	14.29	16.48	3.30	0.00	3.30	0.00	0.00	3.30	6.59	10.99
			L-5*	DT-B-5-1	16.67	1.96	2.94	21.57	4.90	2.94	1.96	0.98	9.80	20.59	6.86	0.00	11.76	0.98	0.00	2.94	4.90	9.80
				DT-B-5-2	15.91	2.22	1.42	19.55	3.24	1.75	2.63	1.55	15.24	17.35	1.21	0.00	10.43	0.85	0.00	5.28	8.57	12.35
			L-11*	DT-B-11-1	13.08	9.23	8.46	30.77	9.23	4.62	3.85	3.85	4.62	12.31	1.54	0.00	11.54	3.08	0.00	1.54	5.38	7.69
				DT-B-11-5	20.24	5.25	6.71	32.20	3.25	3.54	2.10	1.42	12.35	14.25	1.28	0.00	5.57	0.00	0.00	5.35	7.35	11.34
			L-13*	DT-B-13-3	8.26	3.21	6.52	17.99	2.22	1.05	4.35	1.52	20.54	16.27	1.13	0.00	9.76	1.05	0.00	6.25	3.54	14.33
				Mean	16.49	3.89	5.51	25.89	3.84	2.72	3.00	1.72	13.53	15.96	2.27	0.00	8.26	1.10	0.00	3.94	5.89	11.87
	Bhuiyan *et al.* 2004	Jaintapur		Mean (n = 8)	21.60	3.90	6.90	32.40	1.30	2.40	16.70	3.00	7.50	3.60	0.10	-	2.20	0.00	0.10	1.60	17.50	11.30
	Uddin & Lundberg 1998b			Mean (n = 6)	5.00	11.70	5.00	21.70	9.00	2.90	3.10	2.20	10.00	4.60	-	1.40	5.40	2.70	-	8.10	11.10	11.40
Chittagong Tripura Fold Belt (CTFB)	Bhuiyan *et al.* 2004	Bandarban		Mean (n = 3)	2.70	3.90	6.10	12.70	1.00	0.60	26.00	0.80	14.70	0.00	0.00	-	4.20	0.00	0.10	11.50	19.80	8.50
	Bhuiyan *et al.* 2004	Inani		Mean (n = 4)	8.30	3.60	3.10	15.00	2.10	0.20	18.00	2.50	9.40	6.10	0.00	-	2.90	0.20	0.10	4.60	29.10	8.20
	Yeasmin *et al.* 2024	Lalmai		Mean (n= 4)	2.45	1.95	2.02	6.42	1.58	0.21	1.54	1.09	14.15	23.71	0.96	0.22	7.92	2.38	1.70	5.48	21.85	10.79

ZIR = Zircon, TOU = Tourmaline, RUT = Rutile, GAR = Garnet, APA = Apatite, STA = Staurolite, CHL = Chloritoid, KYA = Kyanite, AMP = Amphibole, B AMP = Blue amphibole, GLA = Glaucophane, PYR = Pyroxene, AND = Andalusite, SPH = Sphene, SIL = Sillimanite, EPI = Epidote, OPA = Opaque minerals

* sample locations in Fig. 2

The total heavy mineral concentrations in the Dupi Tila sandstones of the Bengal Basin are relatively high (2–8 wt.%) (UDDIN & LUNDBERG 1998b; RAHMAN *et al.* 2008), although these sandstones in the Bijaipur area have relatively low heavy mineral contents (0.1%). Nevertheless, the concentrations of different types of heavy minerals in the different structures are highly variable. For example, the Dupi Tila sandstones in the Lalmai anticline are characterized by the predominance of amphibole (average 23.71%) and epidote (average 21.85%) with a reasonable amount of kyanite, opaque minerals, pyroxene and sillimanite (YEASMIN *et al*. 2024), whereas these sandstones from the Bandarban and Inani anticlines in the fold belt show predominance of epidote and staurolite followed by kyanite, opaque minerals and sillimanite (BHUIYAN *et al.* 2004). On the other hand, the Dupi Tila sandstones in the Jaintiapur area (average 21.60%) of the Sylhet Trough and the Inani Anticline (average 8.30%) of the CTFB show the high concentration of zircon (BHUIYAN *et al.* 2004) like the Bijaipur area (average 16.49%). Therefore, the ZTR index in these areas are relatively high (Table 3). However, UDDIN & LUNDBERG (1998b) documented relatively less amount of zircon (average 5.00%) in the Dupi Tila sandstones of Jaintiapur area.

Provenance of the Dupi Tila sandstones

Despite the fact that the sedimentation processes such as weathering, transportation, deposition, and post-depositional diagenesis subsequently affect the composition of the sedimentary rocks, the main controlling factor of the mineralogical contents in the sandstone is the parent rocks (ROSER & KORSCH 1986; MCLENNAN *et al.* 1993; CULLERS *et al.* 1997; HOFMANN 2005; RODDAZ *et al.* 2006). Therefore, modal analysis is one of the most widely used methods to determine the provenance and the ternary discrimination plots based on framework mineral compositions of sandstones provide substantial information about the nature of their provenance area (DICKINSON & SUCZEK 1979; INGERSOLL & SUCZEK 1979; DICKINSON *et al.* 1983; DICKINSON 1985; SUCZEK & INGERSOLL 1985). In this context, the mostly used QtFL and QmFLt triangular diagrams after DICKINSON *et al.* (1983) are used to specify the tectonic settings of the provenance areas. These diagrams exhibit three main provenance terranes: continental blocks, magmatic arcs, and recycled orogens (Fig. 7), which are further divided into several sub-types (DICKINSON & SUCZEK 1979; DICKINSON 1985). All of the Dupi Tila sandstones samples of Bijaipur fall in the continental block provenance, specifically the craton interior provenance (Fig. 7A). The sediments from this tectonic setting are derived either from igneous and metamorphic rocks of stable shields and platforms or uplifted plate boundaries and highly deformed areas within plate where the continental blocks are transected (DICKINSON *et al*. 1983). These sandstones are quartz-rich in composition (Fig. 7B) that persuasively indicates erosion from exposed

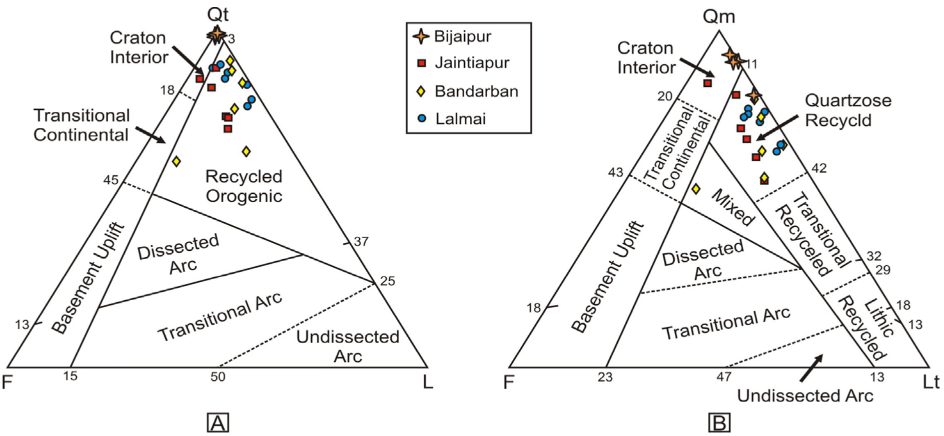

Fig. 7. (A) QFL and (B) QmFLt plots after DICKINSON *et al*. (1983) for modal data of the Dupi Tila sandstones of different areas of the Bengal Basin. Abbreviations: Q = total quartz; F = total feldspar; L = total unstable lithic fragments; Qm = monocrystalline quartz; Lt = total unstable lithic fragments + polycrystalline quartz.

stable cratons with low relief (DICKINSON *et al*. 1983). On the other hand, the QtFL plot of the Dupi Tila sandstones from different parts of the Bengal Basin is characterized by slightly lower quartz contents than those of Bijaipur area, low to moderate amounts of unstable lithic fragments, and low feldspar which are indicative of recycled orogen provenance (Fig. 7A). The QmFLt plot of these sandstones indicates abundance of monocrystalline quartz, moderate to high total lithic grains and low feldspar which falls into the field of quartzose recycled orogen (Fig. 7B).

In addition to modal compositions, suites of heavy minerals in sandstones are extensively used in tracing provenance (MANGE & MAURER 1992; FAUPL *et al*. 1998; DILL 2007; GARZANTI & ANDÒ 2007). A diverse suites of heavy minerals in the Dupi Tila sandstones of the Bijaipur area are recognized and categorized in three main heavy mineral assemblages (Fig. 6), which suggests predominant sediment source of igneous and metamorphic rocks. The high values of the ZTR index (Table 3), especially enrichments of zircon point out that a significant portion of sediments are eroded from crystalline sources (HURBERT 1962). The possible sources of stable minerals such as zircon, tourmaline, rutile, and apatite are acid igneous rocks (FEO-CODECIDO 1956). However, the significant presence of opaque minerals in these sandstones suggests additional contribution of basic igneous rocks. On the other hand, the presence of significant amounts of kyanite, amphibole, epidote, pyroxene, and staurolite point out a diverse assemblage of metamorphic source rocks (FEO-CODEOCIDE 1956). Although it is very difficult to define the exact grade of metamorphism without studying chemical composition, the assemblage of kyanite, epidote, staurolite, garnet, sillimanite, andalusite, and chloritoid is pointing the dynamo-thermal metamorphic source rock (FEO-CODEOCIDE 1956; KHARKWAL 1969). Whereas low-grade metamorphic source rocks are identified by chloritoid, epidote, and chlorite (RAHMAN 1999). However, the presence of trace amounts of blue amphibole suggests minor but additional sources from high-pressure metamorphic source rock.

The ternary plots based on the concentrations of heavy minerals after GARZANTI & ANDÒ (2007) are applied to deciphering the nature of the source rocks and tectonic settings such as collision orogen, obduction orogen, subduction continental margins and thrust belts, etc. The &-A-POS and &-Hb-(Gt+HgM) triangular diagrams of heavy minerals concentration in the Dupi Tila sandstones show an extensive and intricate tectonic settings of collision orogen – thrust belts – subduction related passive continental margin, and the sediments are eroded mainly from low-grade to medium-grade parent rocks (Fig. 8).

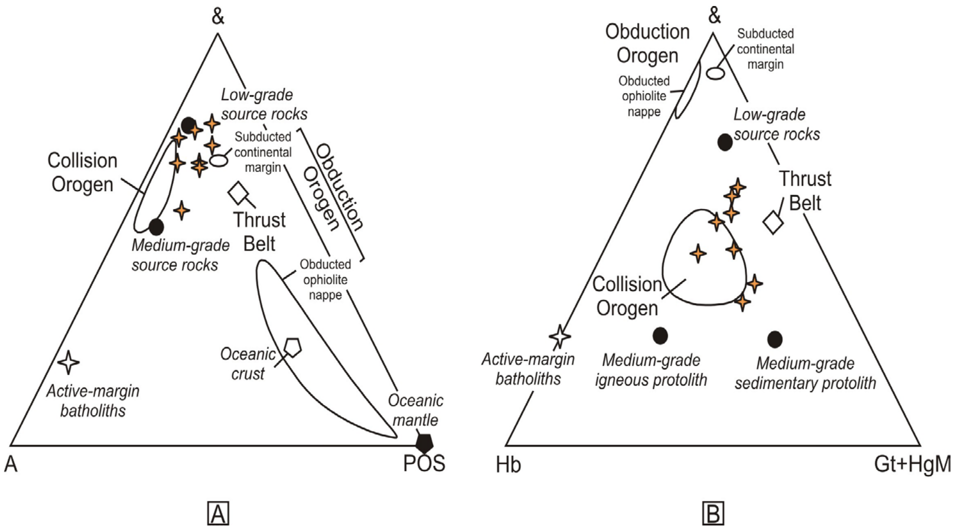

Fig. 8. (A) &-A-POS and (B) &-Hb-Gt+HgM triangular plots for heavy mineral suits of the Dupi Tila sandstones showing the classification of the orogenic provenance after GARZANTI & ANDÒ (2007). Abbreviations: & = all transparent heavy minerals not included in the other two poles; A = Hb + &A = total amphiboles; Hb = hornblende; &A = other amphiboles (including glaucophane, tremolite, actinolite); POS = CPX + OPX + OS = pyroxenes (clinopyroxenes and orthopyroxenes), olivine, and spinel; Gt = garnet; HgM = high-grade metasedimentary minerals (staurolite, andalusite, kyanite, sillimanite).

Paleoclimate and Weathering Intensity of the Provenance

The climatic conditions of the source areas greatly influence the sediment generation processes such as weathering and erosion (JOHNSSON 1993; WELTJE *et al.* 1998). Therefore, the siliciclastic rocks bear the imprint of paleoclimate of the provenance areas (POTTER 1978; NESBITT *et al*. 1984; BASU 1985; SUTTNER & DUTTA 1986; MCLENNAN *et al*. 1993). The silica-rich mineralogically mature sandstones are produced due to severe chemical weathering of parent rocks in increased temperature and high rate of precipitation (Nesbitt & Young 1982; Nesbitt *et al.* 1997) that promote alteration of less stable minerals and rock fragments (Franzinelli & Potter 1983; Johnsson *et al.* 1991). Additionally, physiographic conditions of the provenance areas also influence the intensity of chemical weathering, for example, chemical weathering processes are intensified in areas of low relief and gentle slopes due to increase of residence time of detritus to alteration (Basu 1985; Weltje *et al*. 1998). In contrast, arid or cold climatic conditions inhibit chemical weathering processes due to lack of precipitation and help to preserve these less-stable constituents (Slatt & Eyles 1981; Weltje *et al.* 1998).

The framework mineralogy of sandstones are commonly used to interpret such paleo-conditions of provenance areas (Potter 1978; Basu 1985; Suttner & Dutta 1986). Notably, the bivariant plot of the relative abundances of quartz, feldspar, and lithic grains after Suttner & Dutta (1986) is one of the most sensitive and widely-used approaches to interpreting source-area climate, which reveals mostly tropical humid climatic condition in provenance areas during formation of the Dupi Tila sediments (Fig. 9A, B). This observation is also supported by the values of ZTR index in these sandstones (Table 3) as higher ZTR index generally indicates more mature sediment, meaning it has undergone more weathering and sorting. Moreover, the ln(Q/R)–ln(Q/F) plot after Weltje *et al*. (1998) shows that the weathering indices for these sandstones fall into 'zone 4' (Fig. 10), therefore, signifying sediment supply from low relief, gentle slope, and hot humid climatic conditions where intense weathering of the parent rocks as well as heavy rainfall cause complete alteration and leach down of unstable minerals and rock fragments and enrichment of high-resistance minerals like quartz.

Regional Tectonic Implications

The Bijaipur area is located at the south foothill of the Shillong Plateau which is a 1600 m high fault-bounded basement uplift in the Himalayan foreland (Govin *et al.* 2018). The plateau has been uplifted as a continental basement pop-up structure that was exhumed due to two seismically active steep reverse faults: the E-W trending Dauki Fault in the south and the WNW-ESE trending Oldham Fault in the north (Bilham & England 2001; Biswas & Grasemann 2005; Kayal *et al.* 2006; Kayal 2008). The Dauki fault is acting as a north-dipping thrust connected to the Himalayan orogen (Seeber & Armbruster 1981). The Shillong Plateau was a part of Himalayan foreland basin during early Miocene, therefore, Cenozoic sedimentary sequences originated from Himalayan orogen, covered Proterozoic-Paleozoic basement of the Shillong Plateau (Mitra & Mitra 2001). The exhumation of the plateau began between ca. 9 and 15 Ma (Biswas *et al.* 2007), but the topographic growth balanced

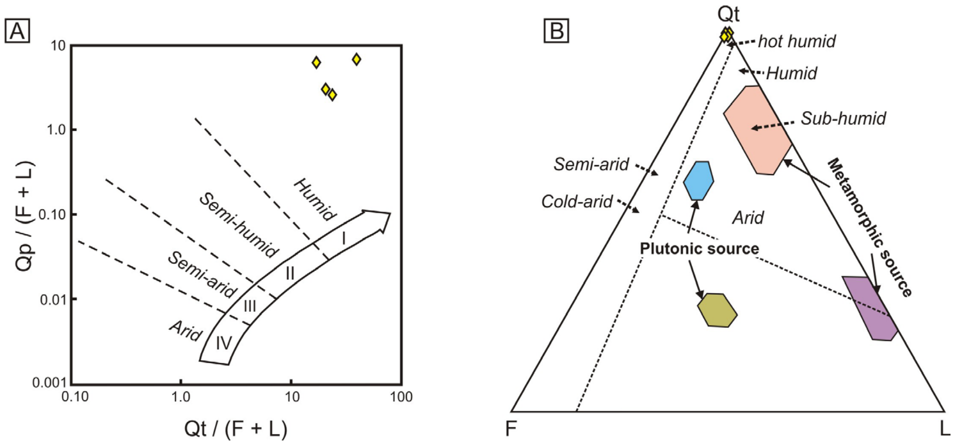

Fig. 9. (A) Bivariate plot and (B) QtFL triangular diagram for paleoclimate interpretation of the provenance of the Dupi Tila sandstones after SUTTNER & DUTTA (1986). Q: quartz, Qp: polycrystalline quartz, Qt: total quartz, F: Feldspar, L: lithic grains.

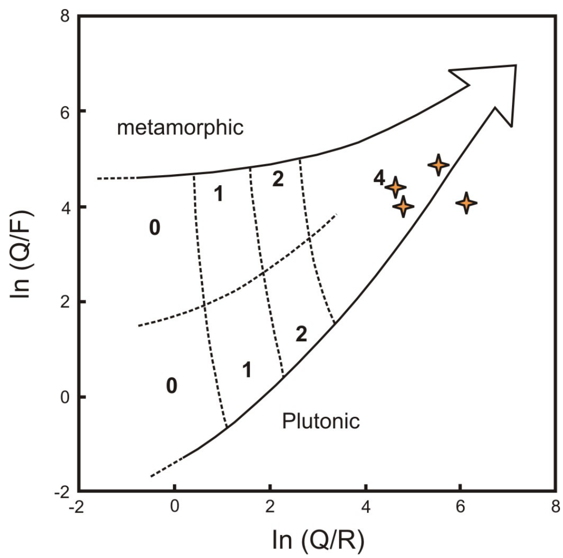

Fig. 10. Bivariate plots of the Dupi Tila sandstones of the Bijaipur area showing the climate-physiographic conditions based on mineralogical compositions (after WELTJE *et al.* 1998). Q : quartz, F : Feldspar, and R: lithic grains. Fields 0 to 4 refer to the semi-quantitative weathering indices (weathering index, Iw = climate, C x relief, R) where 0 = unweathered, 1 = slightly weathered, 2 = moderately weathered, and 4 = intensely weathered rocks.

by erosion (GOVIN *et al.* 2018). The topographic relief of the Shillong Plateau was started to visible between 4.9 and 5.2 Ma (GOVIN *et al.* 2018) and plateau uplift to significant magnitude is shown by ca. 2–3.5 Ma (NAJMAN *et al*. 2016).

The Dupi Tila Formation in the Sylhet Trough has been believed to accumulate the recycled sediments from the Cenozoic sedimentary cover of the Shillong Plateau (BISWAS 1961; HILLER & ELAHI 1984). However, the present study reveals that the Dupi Tila sandstones of the Bijaipur area originated from felsic igneous and metamorphic rocks which undergo severe chemical weathering due to hot and humid climatic conditions. The tectonic setting of the source area was probably in the domain of collision orogen where igneous craton was exposed due to uplift. From these observations, it can be said that the upliftment history of the Shillong Plateau coincides with the sedimentation of the Dupi Tila Formation in the Bijaipur area during late Pliocene – Pleistocene time. At that time, the Shillong Plateau was uplifted significantly to develop topographic highland and, the Proterozoic-Paleozoic basement rocks were exposed to weathering and erosion processes. The basement of the plateau is mainly composed of Precambrian to Early Paleozoic metamorphic and intrusive rocks which overlain by the Cretaceous to Cenozoic sedimentary rocks, especially in the south, east and west of the plateau (NAJMAN *et al.* 2016). At that time, topographic relief was probably such that prompt severe chemical weathering of the basement rocks. The heavy rainfalls and high surface temperature might be intensified the chemical weathering and resulted in quartz-rich sand of the Dupi Tila Formation.

Conclusion

This research presents an in-depth analysis of the Dupi Tila Formation, a significant stratigraphic unit in the Bengal Basin, specifically focusing on the Bijaipur area of the northwestern Sylhet Trough. The following conclusions can be drawn from this study:

1. Detailed mineralogical analysis of the Dupi Tila sandstones of this area reveals that the sandstones are predominantly composed of quartz, with lesser amounts of feldspar and lithic grains. The high quartz content, particularly in the form of monocrystalline quartz, indicates mineralogical maturity of these sandstones. The QFL classification framework shows that the sandstones are predominantly quartzarenites, underscoring their provenance from stable craton regions.

2. Among the heavy minerals in the Dupi Tila sandstones, the concentration of zircon is very high, consequently high ZTR index that also indicates mature sandstones which experiences significant weathering and sorting processes. The presence of diverse heavy mineral assemblages grouped into three clusters reflects the influences of both igneous and metamorphic source rocks.

3. The extreme enrichment of quartz suggests a tropical humid climate conducive to intense chemical weathering. The weathering indices, as indicated by the ln(Q/R)–ln(Q/F) plot, reveal that sediment originated from low-relief areas

where climatic conditions were characterized by high temperatures and significant rainfall. Such environmental factors facilitated the alteration of unstable minerals, resulting in the predominance of quartz.

4. Situated at the southern foothills of the Shillong Plateau which underwent significant uplift during the Pliocene epoch, the Dupi Tila Formation of the Bijaipur area was influenced by tectonic activities related to this geological event. The interplay between uplift and weathering led to the deposition of quartz-rich sandstones that derived mainly from its basement of felsic igneous and metamorphic rocks. The exhumation of the Shillong Plateau is closely related to complex tectonic settings and rise of Himalayan collision orogen.

The study significantly enhances our understanding about the characteristics of the Dupi Tila sandstones and the factors influencing the formation of these sediments in the potential provenance areas which could also be implied in comprehend the regional geology as well as the formation of economically significant deposits of kaolinite-rich clay layers in the Bijaipur area.

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দক্ষিণ-পশ্চিম সিলেট খাদ এর বিজয়পুর ডুপি টিলা বেলেপাথরের শীলাবীক্ষণ এবং ভারী মনিক বিশ্লেষণ ঃ উৎস অঞ্চলের অন্তর্নিহিত ব্যাখ্যা

মাজেদ ভূইয়া, রুমানা ইয়াছমিন ও মোঃ সাকিব হাসান

সারসংক্ষেপ

ডুপি টিলা স্তরসমষ্টি বেঙ্গল বেসিনের টারশিয়ারি যুগের সবচেয়ে নবীন স্তরসমষ্টি। এই গবেষণায় নেত্রকোনা জেলার বিজয়পুর এলাকার ডুপি টিলা স্তরসমষ্টির মনিক সমূহের প্রাচুর্য এবং এর ভূতাত্ত্বিক গুরুত্ব অনুসন্ধান করা হয়েছে। মনিক প্রাচুর্যে/উপস্থিতিতে দেখা যায়, বেলে পাথরগুলো মূলত কোয়ার্টজ দ্বারা গঠিত (গড় ৮৭.৮৮%), যেখানে কিছু পরিমাণ ফেল্ডস্পার (গড় ১.৩৪%) এবং লিথিক কণা (গড় ০.৫৭%) আছে এবং সে কারণে এই বেলে পাথরগুলো কোয়ার্টজ অ্যারেনাইট এ শ্রেণিবদ্ধ করা হয়েছে, যা বেঙ্গল বেসিনের অন্য এলাকার ডুপি টিলা স্তরসমষ্টির বেলে পাথর থেকে আলাদা। এই গবেষণা ইঙ্গিত দেয় যে, এই পললগুলো ক্ষয়প্রাপ্ত ক্রেটনিক শিলা থেকে উৎপন্ন হয়েছে এবং উচ্চ তাপমাত্রা এবং আর্দ্রতা সমৃদ্ধ জলবায়ু দ্বারা প্রভাবিত হয়েছে; যা ক্ষয় প্রক্রিয়াকে উল্লেখযোগ্যভাবে সহায়তা করেছে। ভারী মনিকসমূহের বিশ্লেষণ সামগ্রিকভাবে কমঘনত্ব নির্দেশ করে, তার মধ্যে জিকরন, অ্যাম্ফিবোল এবং পাইরোক্সিন এর পরিমাণ সবচেয়ে বেশী, যা উৎস শিলা হিসেবে বিভিন্ন আগ্নেয় এবং রুপান্তরিত শিলাকে নির্দেশ করে। এই বেলে পাথরে উচ্চ পরিমাণ কোয়ার্টজ এবং জেড-টি-আর সূচকগুলি তুলানামূলকভাবে পরিপক্ক পললকে নির্দেশ করে, যা সম্ভবত মূল শিলার তীব্র রাসায়নিক ক্ষয়ের ফলাফল। মৌলিক কাঠামোর মনিকসমূহের পাশাপাশি বিভিন্ন ভারী মনিকসমূহের সমাবেশ জটিল ভূতাত্ত্বিক ইতিহাস, যেমন কলিসন অরোজেনিক অবস্থাকে নির্দেশ করে। এই পর্যবেক্ষণ শিলং মালভূমির উৎপত্তি ইতিহাসের সাথে সংযোগ পেতে সহায়তা করে যা লেট প্লাইওসিন-প্লাইওস্টোসিন সময়কালের ভারত-ইউরোশিয়া প্লেটের চলমান টেকটনিক সক্রিয়তার ফলাফল।