Part-1
Survey Report including Feasibility Study

Survey Report (Series 2 of 2)

Geological Study of the Ne Tong-Chandrakilla Hill & Identification of the Geological Hazard Zones of that Area for the Construction of Cable Car in the Naf Tourism Park, Teknaf

Bangladesh Economic Zones Authority (BEZA)

December 2020

Prepared by
Department of Geology
University of Dhaka

In Support of
Chittagong University of
Engineering and Technology

Part-1

Survey Report including Feasibility Study

Survey Report (Series 2 of 2)

Geological Study of the Ne Tong-Chandrakilla Hill & Identification of the Geological Hazard Zones of that Area for the Construction of Cable Car in the Naf Tourism Park, Teknaf

Bangladesh Economic Zones Authority (BEZA)

December 2020

Prepared by
Department of Geology
University of Dhaka

In Support of
Chittagong University of
Engineering and Technology

CONTRIBUTORS TO THE REPORT

Lead Authors

[1] Dr. Md. Mahfuzur Rahman Khan [a]
[2] Md. Jahangir Alam [a]
[3] Md. Al Amin Mishu [b]

Field investigation

[1] Md. Jahangir Alam

[2] Dr. Md. Mahfuzur Rahman Khan

[3] Dr. Md. Bodruddoza Mia [c]

[4] Md. Al Amin Mishu

[5] Mohtasim Shahajad [d]

[6] Tareq Chowdhury [e]

Authors Affiliations

[a] Assistant Professor, Department of Geology, University of Dhaka, Dhaka-1000.

[b] M.Phil. Student, Department of Geology, University of Dhaka, Dhaka-1000.

[c] Professor, Department of Geology, University of Dhaka, Dhaka-1000.

[d] M.S Student, Department of Geology, University of Dhaka, Dhaka-1000.

[e] Field Hydrogeologist, UNICEF Project, Department of Geology, University of Dhaka, Dhaka-1000.

Executive Summary

The investigated area for the proposed cable car network is located on the southernmost part of the Dakshin Nhila anticline, Teknaf, Cox's Bazar. The area belongs to a hilly region that shows irregular topography consisting mainly of hills, valleys, vertical cliffs, plain lands, and beaches. The average elevation of the study area varies from 105 m to 120 m and the highest elevation is about 260 m. Several NE-SW trending inflowing and seasonal streams and stream valleys are present in the investigated area. These drainage streams are continuously eroding the terrain. Landslides, especially in the monsoon season along the sides of stream valleys are common. One of the proposed cable car pillars (No 7, according to our map) is located on a steep slope of a stream valley.

The Dakshin Nhila anticline is characterized by a double plunging box type, asymmetrical fold with a low angle axial region. In our study area, the dip amount gradually increases away from the axial region in both flanks. The western flank is relatively steeper than the eastern flank due to the N-S trending Teknaf fault in the west. The attitude of beds in the southern part of the study area suggests that this is the displaced southern plunging zone of the anticline that moved northward along a E-W trending thrust fault. This thrust fault is outlined along the Keruntoli chara based on the sudden change of topography, structural discontinuities, and lithological dissimilarities.

Stratigraphically, the study area is classified into Bhuban and Bokabil formations of the Miocene age (5.33 Ma to 23.03 Ma years old). The exposed rock sequences in these formations are further divided in this study into five rock units based on lithological characteristics. The oldest rock unit in the study area is Unit 1 which is characterized by hard and compacted highly jointed silty shale/shale, very fine sandstone and siltstone. Unit 2 is composed of very hard and compacted fine grained N-S trending canyon filled thinly to thickly bedded sandy turbidites. Unit 3 consists of alternation of yellowish brown colored hard thickly bedded sandstone and occasionally jointed grey colored laminated shale. Unit 4 is predominantly composed of moderately compacted fine-grained sandstone and unit 5 is moderately hard silty shale/shale, very fine-grained sandstone and siltstone. The youngest rock unit in our study area is unconsolidated beach sands on western part and recent tidal sediments on the eastern side.

During our field investigation in the study area, mainly two types of geologic hazards are identified; 1) Faults and Earthquake zone, 2) Mass wasting area. The study area is located in the tectonically active Chittagong-Tripura Fold Belt (CTFB), which is an earthquake prone area. Several earthquakes occurred in this tectonic area in the past. However, there is no evidence of recent earthquakes in the Dakshin Nhila anticline. If any earthquake with magnitude 5.5 or higher occurs in and around this area, it could be a vulnerable zone for any infrastructures. Proper guidelines and necessary measures as per Standard Code(s) must be taken for any constructions in the study area.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1. Background

Teknaf is the southernmost Upazila of Bangladesh. It is located at the southern part of the Chittagong Hill tracts on an anticlinal structure namely 'the Dashkin Nhila Anticline'. The Teknaf town is located about 80km south of Bangladesh's main tourist location, Cox's Bazar. The hilly terrain of the Teknaf region is bordered by the Bay of Bengal to the west and south and the Naf river in the east. The area is famous for its natural beauty and it is one of the main tourist attractions in Bangladesh. Bangladesh Economic Zones Authority (BEZA) has taken an initiative to set up a 9.5 kilometers long cable car network in the proposed Naf Tourism Park between the Jaliardwip in the east to the Teknaf Beach in the west. Currently, Chittagong University of Engineering and Technology (CUET) is conducting a feasibility study in this hilly area for the establishment of this cable car network. To complete the feasibility study, CUET has requested the Department of Geology, University of Dhaka to carry out a detailed geological investigation in the study area. In this context, the Department of Geology, University of Dhaka has carried out a detailed geological fieldwork in the study area between November 10 to November 23, 2020. This report presents the geological map prepared based on the field observations.

1.2. Objectives

The main objectives of this study is to assess the geology of the Ne Tong – Chandrakilla hilly area for the establishment of the cable car network. The specific purposes of the field investigation were -

a. To collect geomorphological information of the study area
b. Identify and assess all water bodies (springs, creek, stream both seasonal and perennial, seepages, rivers, etc) that have impacts on the study area
c. Identify and assess the structural information (faults, joints, etc.)
d. Identify and assess the rock formation, rocky types, and lithological characteristics of the area

After completion of the field data, the study aims to -

e. Prepare cross-sections based on the lithology of the study area
f. To assess the mineralogical study of the rock samples in the laboratory
g. Identify and assess possible geological hazards zone within the study area

h. Prepare a geological map of the study area
i. Finally, prepare a report detailing the observations made in this study

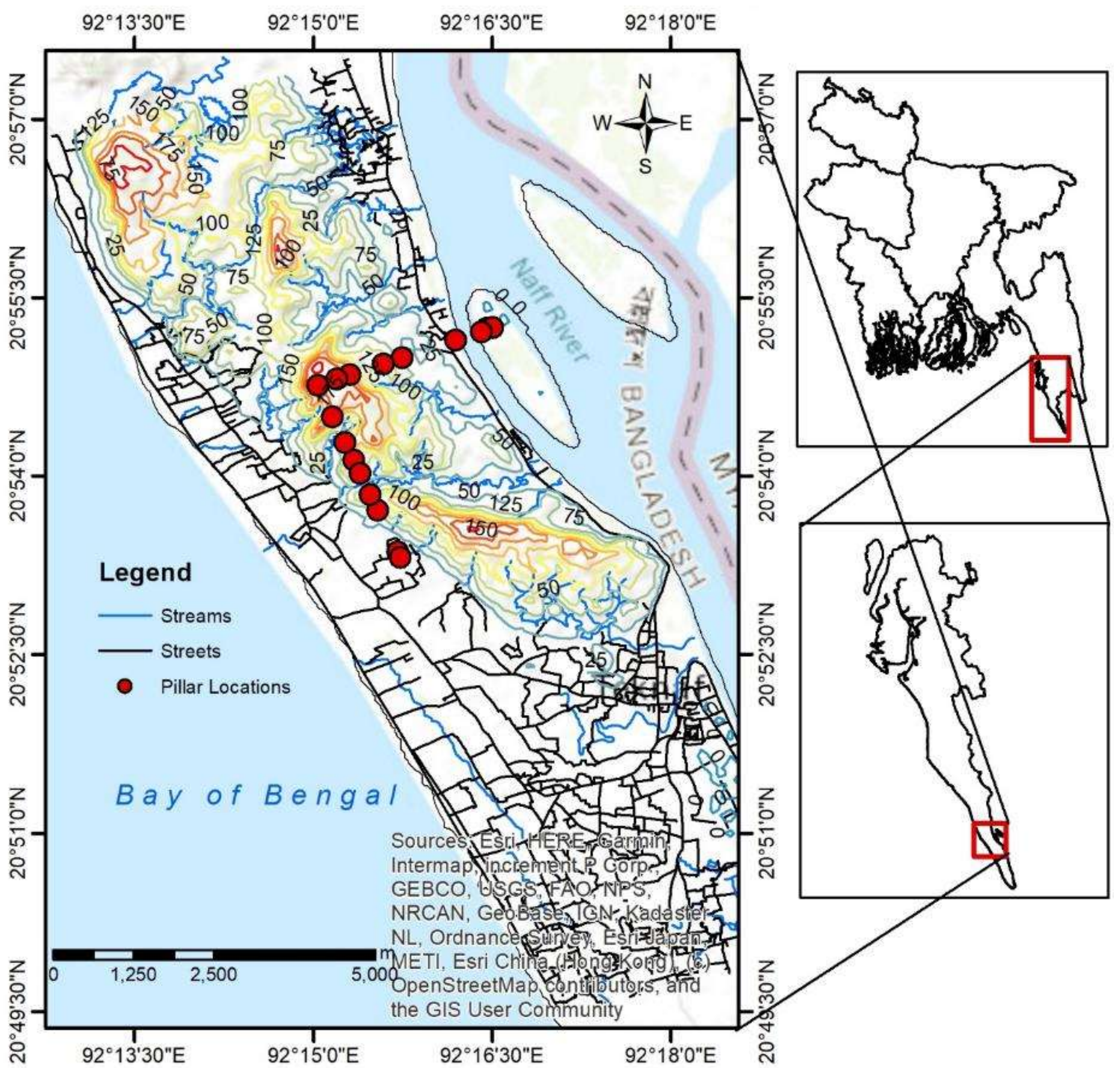


Figure 1: Location map of the study area

1.3. Study area

The study area belongs to the southern part of Teknaf Upazila of Cox's Bazar district. It lies between 20^{0}52'42"N and 20^{0}55'39"N latitude and 92^{0}13'30"E and 92^{0}18'0"E longitude. The investigated area is a hilly terrain bounded by the Naf River to the east, the Bay of Bengal to the west, Teknaf Pourashava to the south and Baharchara union in the north (Figure 1). It is about 9 km long and 5.5 km wide. The area is about 75 km south of Cox's Bazar town and about 400 km SE of Dhaka city, and is well connected with Dhaka, Chittagong and Cox's Bazar by a regional highway. The Cox's Bazar-Teknaf road runs along the syncline between Inani and Olatang anticline and the Marine drive road goes along the sea beach which connects Cox's Bazar from Teknaf. Both the eastern and western side of the hilly terrain are easily accessible from the roads. However, it is quite challenging to cross the hilly terrain in the study area, there is no path or roads across the hills in this area.

1.4. Topography and Relief

The investigated area is characterized by high topographic relief (Figure 3a). In all three sides of the study area land surface elevation rises rapidly upto an elevation of above 200m from a few meters high (amsl) plain land areas. The average elevation of the hills varies from about 105 meters to 120 m. The highest elevation in this hill range is about 266 meters. The current plain land areas represent erosional surfaces cut by the waves of the Bay of Bengal in the west & south and by the currents of the Naf river in the east. The hilly terrain is characterized by irregular topographic features such as NNW-SSE to NW-SE trending ridges, valleys, NE-SW trending inflowing and seasonal streams and stream valleys (Figure 1).

In the northern portion of the study area, the western side of the hills are generally higher than the eastern side and these ridges are frequently marked by vertical cliffs that rise more than 50 m above surrounding land areas and about 200 m above mean sea level. On the other hand, in the southern portion of the study area the eastern side is characterized by abruptly elevated high heels that reach an elevation above 200 meters, whereas the southwestern side is gently sloping (Figure 1).

1.5. Drainage and Streams

The study area is drained by a number of streams and streamlets showing trellis to dendritic drainage patterns. The streamlets are locally known as "Chara". The major chara's are Dak chara, Noakhali chara, Raja chara, Habib Chara, Bahar chara, Boro chara, Kachhopya chara etc (Figure 2). The longest chara in this investigated area is "Keruntoli Chara" which runs through the E-W trending thrust fault. These charas are mostly of "intermittent" type, i.e. these are rain fed and thus have much higher discharge during the monsoon. Some charas become dry during the dry periods and some maintain their discharge at smaller rates fed by springs (Figure 3b, 3c). The charas on the western side of the hill range flow through the sandy beach to the Bay of Bengal; whereas the streamlets on the eastern side merge with the Naf River.

The prominent river of the studied area, Naf River, makes the boundary between Bangladesh and Myanmar. It rises in the Arakan hills on the southeastern borders of the district and flows into the Bay of Bengal. Its width varies from 1.61 km to 3.22 km and average depth is 39 m. The river is influenced by the tide.

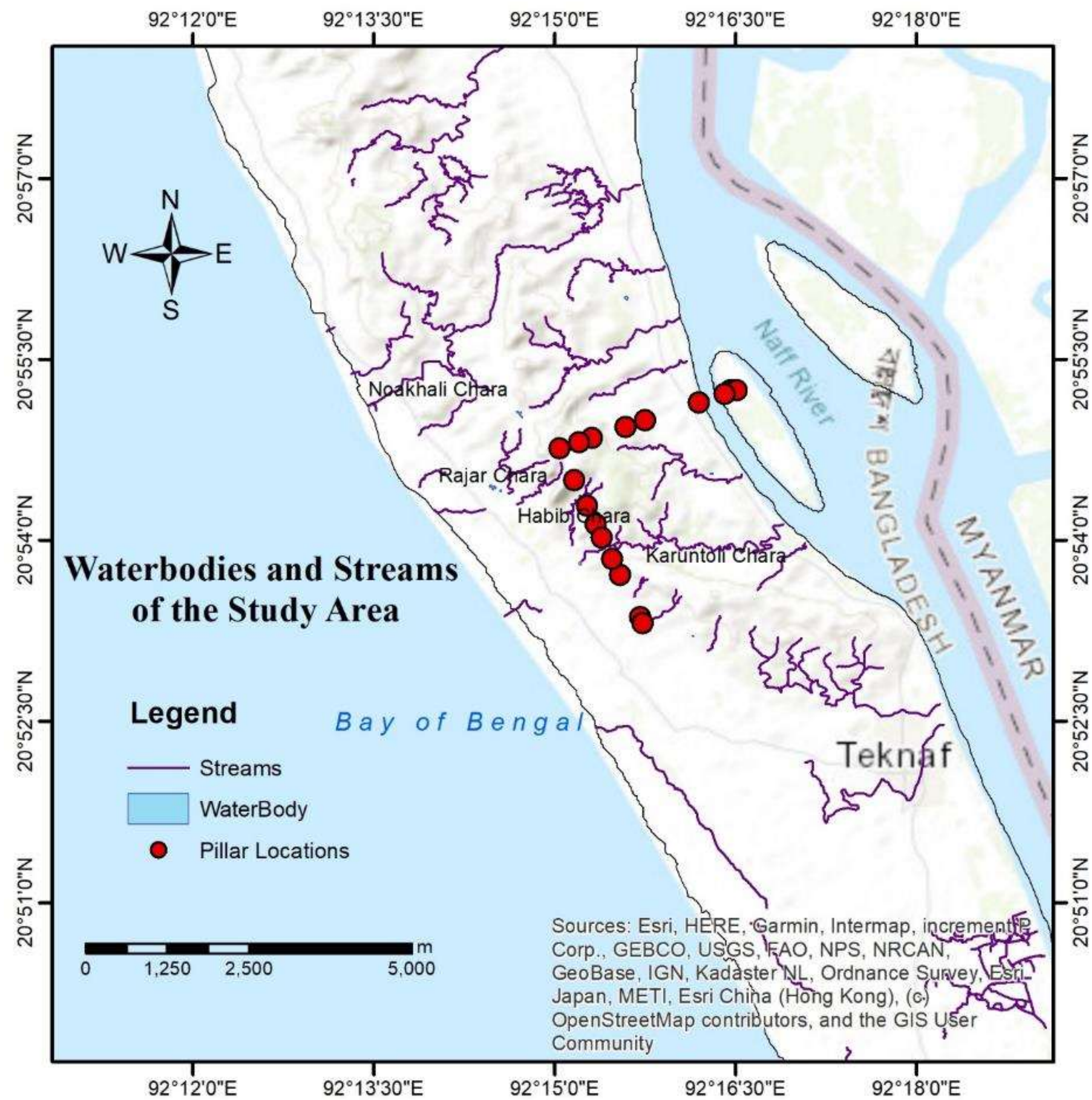


Figure 2: Drainage Map of the study area

1.6. Vegetation and cultivation

The studied area is highly vegetated. The hills are covered with green forest. The most common trees are Jarul, Gammary, Koroi, Chapalis. Bamboo is also found in the hills. Mangrove forest is seen on the bank of the Naf River. The soils of the valley are fertile, but the sloppy land of the hill is less fertile. Most of the areas are fit for cultivation through the year. Soil and climate are not suitable for jute cultivation. Fruits such as pineapple, Papaw, banana etc. and various types of seasonal vegetables are also cultivated.

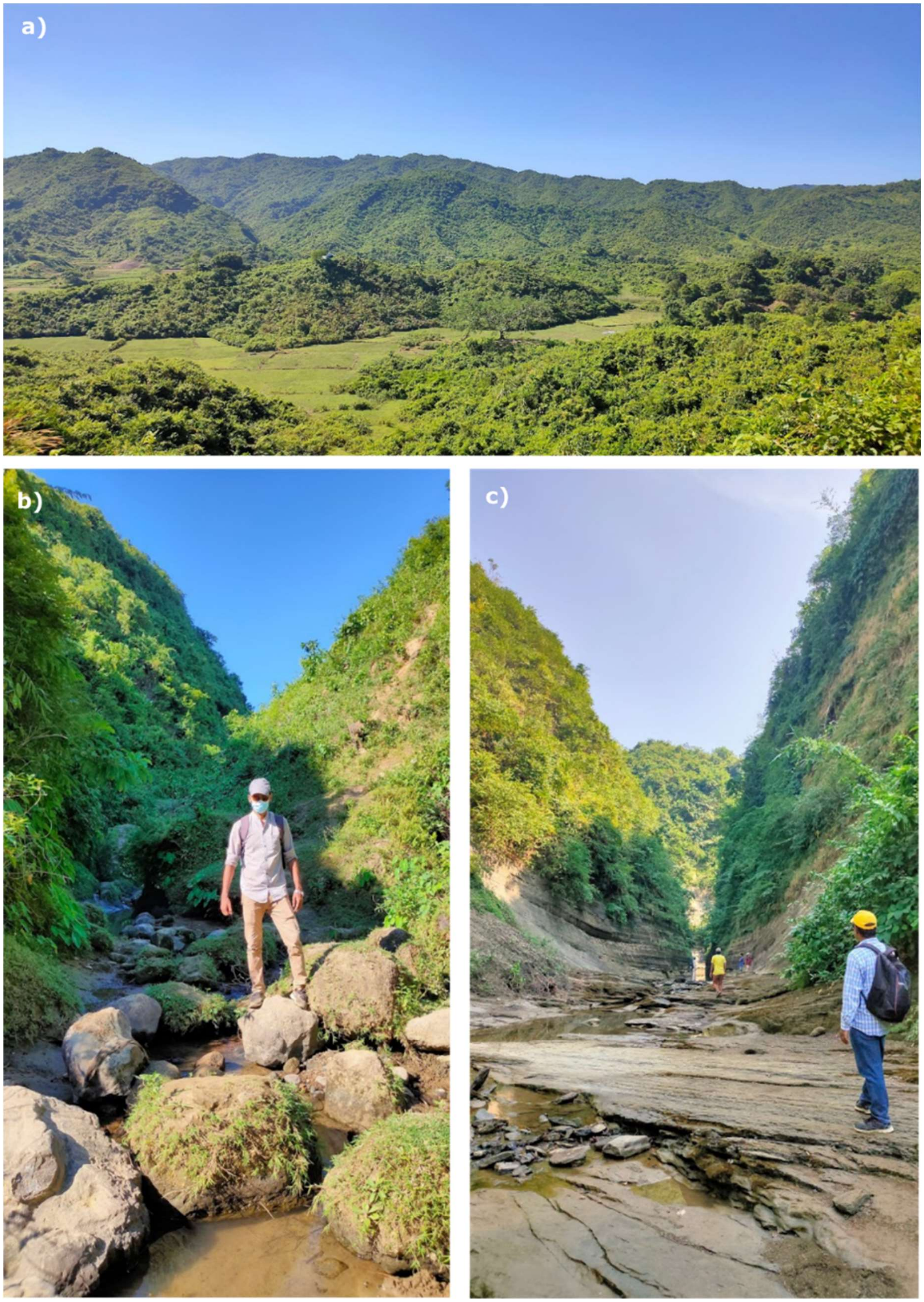


Figure 3: The pictures show: a) the hilly terrain b) & c) Streams or Charas in the study area

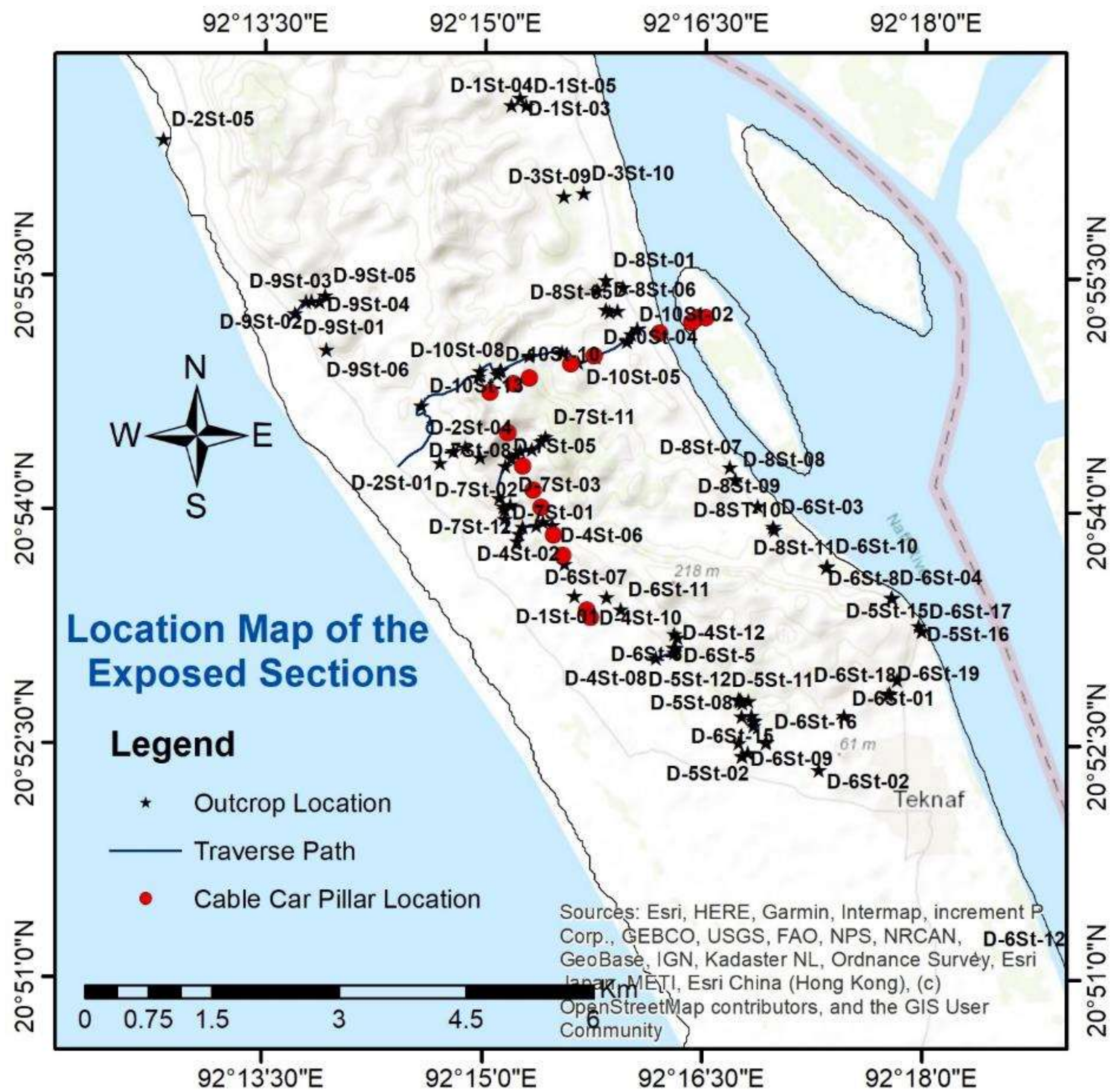


Figure 4: Location map of the studied outcrops

1.7. Methods

A detailed fieldwork has been carried out in the study area from 10th November 2020 to 23th November 2020. This field work has been performed by traverse method along five E-W trending charas, one complete E-W traverse section and along the N-S directional Cox's Bazar-Teknaf old marine drive road, and the Cox's Bazar-Teknaf main road within study area of the Dakshin Nhila anticline. In these traverse sections total 105 stations have been studied (Figure 4) in detail to understand the rock formation, structure, lithology etc. The rocks of Surma group are well outcropped in these stations. The exposed rocks are studied by naked eyes and hand lenses and identified by its color, texture, composition. The cementing materials, hardness, grain size have been measured by observed color, HCl acid, geologic hammer and pocket lens. The attitude of beds was measured by compass-clinometer to identify the attitude of the beds of the study area. All the information was recorded and noted in the field notebook. During this field work, systematic mapping, sampling was done and photography was taken. Several rock samples were collected from different lithological units for grain size and petrographical studies. Relevant reports, publications, existing data were also collected and interpreted for this work.

Chapter 2: Structure and Tectonics

2.1. Regional Context

The Bengal basin lies on the eastern side of the Indian sub-continent and occupies most of Bangladesh and west Bengal of India as well as part of the Bay of Bengal (Alam, 1989). The eastern margin of the Bengal Basin coincides with the Indo-Burman ranges, which includes two tectonic belts, the Mizo Fold belt in the east and the Chittagong-Tripura Fold belt in the west. This western zone is characterized by subparallel, arcuate, elongated folds of N-S trending. This area has gone through complex tectonic, geologic and geomorphic processes to reach its existent pattern. The overriding Burmese plate onto the Indian plate has created the main pushing force to develop the compressional tertiary folds. Due to this east –west directional tectonic force intensive deformation has occurred in the east and progressively weak to the west in the Chittagong Fold belts.

The study area falls in the tectonically active southeastern hill tracts of Bangladesh often referred to as the Mio-Pliocene Indo-Burman Range (IBR). This is an integral part of the convergence zone between the Indian and Burmese plate. The average rate of subduction is 17 mm/yr (Rangin et al., 2013; Steckler et al., 2016). The subduction between these two plates resulted in upliftment, folding and faulting of the Mio-Pliocene sedimentary rocks. Sedimentary rocks are folded into a series of anticlines and synclines generally trending in NNW-SSW direction. The intensity of folding increases towards the east.

Regionally, the study area encompasses several anticlines and synclines. The northwest-southeast trending, elongated, asymmetric, and box-like anticlines separated by synclines are the dominant structural features. The major anticlines in the area are Dakshin Nhila Anticline in the south, Inani Anticline in the northwest, and Olatang Anticline in the northeast (Figure 5). Several longitudinal and transverse faults cut through these structures (BAPEX, 1981). Inani anticline is in the north of Dakshin Nila, which is separated from Dakshin Nila by a low relief saddle. Dakshin Nila anticline plunges and merges with the coastal plain in the south and the altitude in this area varies from 0 to 260mAOD (DOE, 1999). In between Inani and Olatang anticlines there are two well-developed synclines. The northern syncline is named in this study as the Ramu syncline and the southern syncline is named as the Ukhia Syncline. The Naf river valley is represented by another syncline bounded by the Dakshin Nhila anticline in the west and the Olatang anticline in the east.

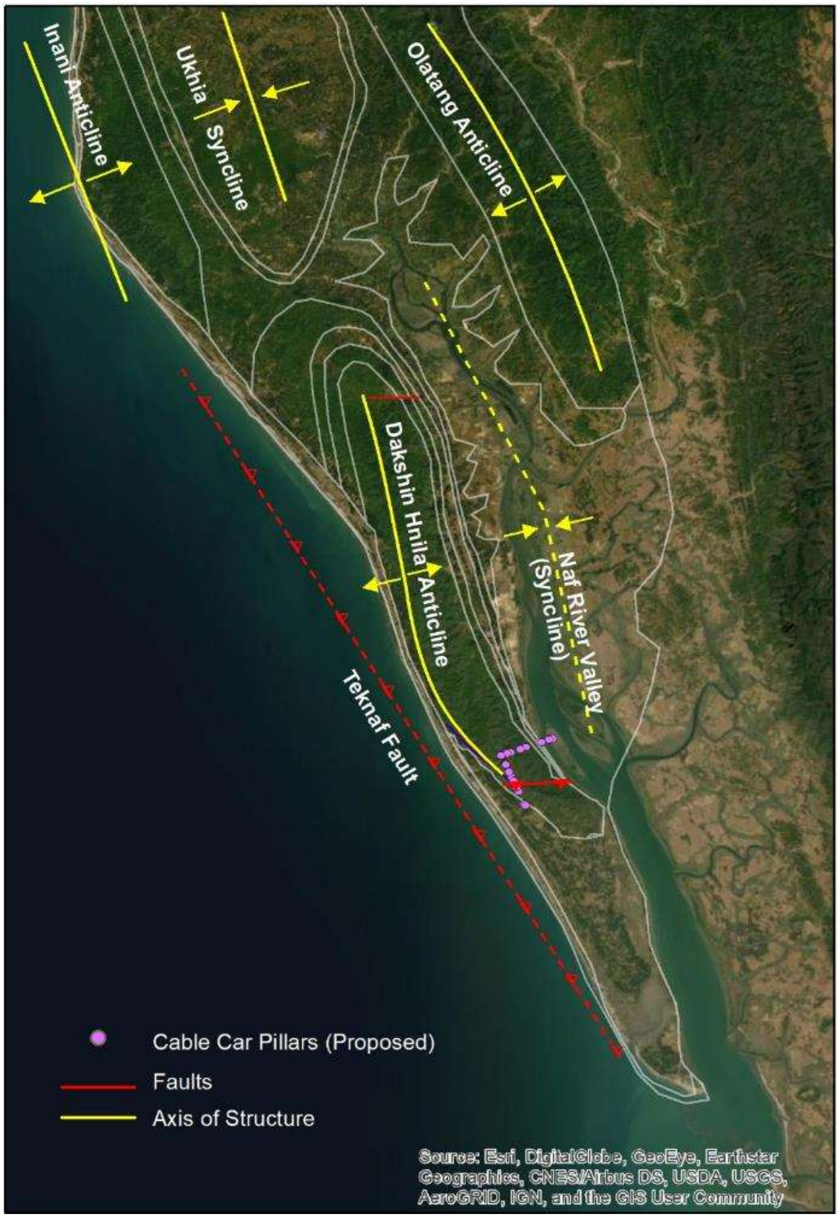


Figure 5: Map showing regional geological settings of the study area

Regional seismic section indicates that to the west in the offshore region there are series of anticlines and synclines similar to that in the onshore area (Figure 5). However, the intensity of folding of the offshore structures is much less than that in the onshore. Besides folding, the structural deformation of the Dakshin Nhila anticline is controlled by the NNW-SSE trending reverse fault, the Dakshin Nhila anticline represents the hanging wall of the fault.

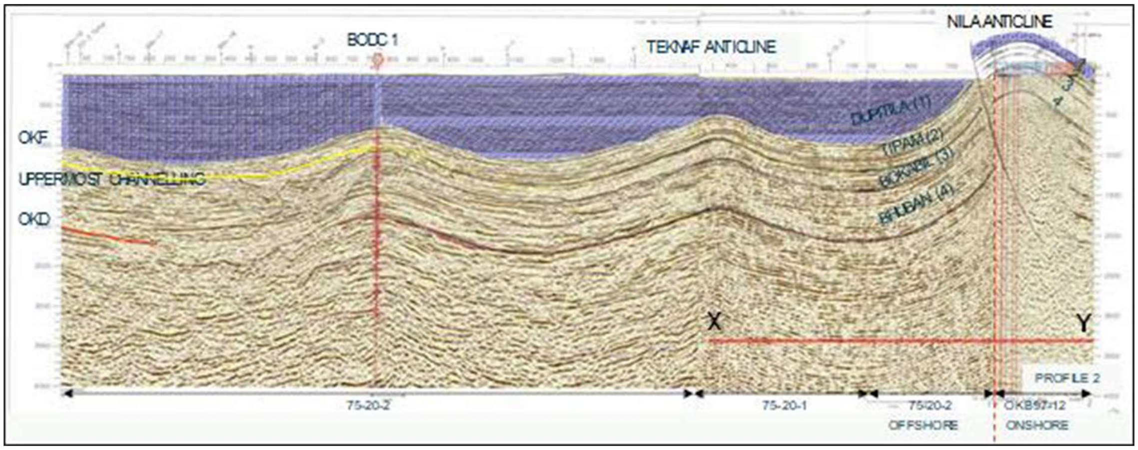


Figure 6: Seismic line showing the Dakshin Nhila Anticline and teknaf fault. Major geologic Formations interpreted by McKenna (2006) are also shown in the figure. Seismic section runs approximately perpendicular to the Nhila anticline across the southern extremity

2.2. Structures in the Study area

2.2.1. Folds

The Dakshin Nhila anticline is a narrow, elongated anticline with its axis running along NNW-SSE direction almost parallel to the regional trend of folded belt. It is about 35km long and 6 km wide. It is separated from the St. Martin anticline by a buried syncline in the south and Inani anticline by a low relief saddle named Monakhal in the north and Olatang anticline in the east is separated by Naf valley. From the morphological studies, this anticline is characterized by double plunging box type structure and the folding nature is asymmetric with gentle axial region dipping at an angle to 5^0 to 7^0, sub- crestal part at 20^0 to 40^0 and the steep flank at 70^0 to 85^0 dip. In our study area, the dip amount varies from 75^0 to 10^0 and gradually increases toward east in the eastern flank of the anticline. The western flank is only partly exposed, where the dip amount varies from 8^0 to 68^0 which gradually decreases towards east. Area in between the two flanks characterized by low angle to almost horizontal bedding indicates the axis of the anticline. In our field study we cross the axis only at the Noakhali chara section. Apparently, from the structural information the eastern flank is steeper than the western flank, a common feature of the structures in this region. However, a seismic section across this structure indicates that the western flank is interrupted by a N-S trending regional fault and caused the western flank to be steeper than the eastern flank (Figure 6; McKenna, 2006). The beds at the southern portion of the anticline dip toward south which should dip either east or west. This character designates that the southern portion of the anticline is a plunging area.

However, the southern plunging area is topographically elevated from the natural trend of plunging which is caused by E-W trending thrust fault.

2.2.2. Faults

Regionally, the Dakshin Nhila anticline is subjected by three transverse faults and three major longitudinal faults (BAPEX, 1981). Among these longitudinal faults, two lies in the eastern flank and another one is located on the western flank which is named Teknaf fault (McKenna, 2006). The large-scale longitudinal fault known as Teknaf fault is identified based on seismic line. It runs parallel to the general trend of the anticline and disrupts the western flank of the Dakshin Nhila structure. The transverse faults were identified on the basis of dip variation between neighboring sections whereas longitudinal faults were recognized by reverse reading of dip direction (BAPEX, 1981).

In our study area, a thrust fault was identified during our field investigation. The E-W trending thrust fault is outlined along the Keruntoli chara. Due to this thrusting, the plunging of the southern area of the anticline is complex. Both faults were recognized on the basis of sudden or abrupt change of topography, structural irregularities and lithological variations during our field study.

Slickensides were present at Habib Chara section (Station No. D5_St 9 & D5_St 10; Figure 4) potentially indicating local faults in the neighborhood, although none were identified during the field investigation.

2.2.3. Joints

A joint is a fracture in the rocks along which there is no displacement. Joints form in solid, hard rock that is stretched such that its brittle strength is exceeded (the point at which it breaks) which leads to the development of a single sub-parallel joint set. Continued deformation may lead to development of one or more additional joint sets. In our study area, joints are developed in the both flanks. Vertical, nearly vertical, diagonal joints were recognized mostly in the shale but not uncommon in sandstone (Figure 7).

Figure 7: Joints observed in the field. a) and b) Parallel joints, oblique to the bedding plane at section D4_St4 (a), and at section D9_St4 (b). c) and d) are closely spaced, multiple sets of joints causing breaking of the rocks into small pieces at sections D2_St5 (c) and D4_St5 (d). All belong to stratigraphic Unit-1.

Chapter 3: Stratigraphy

3.1. Regional Stratigraphy

The Chittagong – Tripura Fold Belt (CTFB) of the Bengal Basin has exposed a significant amount of Neogene sediments. This fold belt is characterized by alternating shale, mudstone, siltstone and sandstone in varying proportions. Generally, the stratigraphic succession of this fold belt has been lithostratigraphically subdivided into Surma, Tipam and Dupi Tila groups. These sediments were deposited in fluvial to deltaic to shallow marine to deep marine environmental conditions, from younger to older successions. The Surma group of Miocene age is the oldest rock unit characterized by more argillaceous sediments exposed along the cores of the anticlines in the CTFB. The Surma group comprises two Formations. The older is the Bhuban Formation and the younger is the Bokabil Formation. Both these two Formations are characterized by alternating sand and shale, however, the Bhuban Formation contains a higher proportion of shale than sand, whereas the Bokabil formation is relatively sandier. Depositional environment of the Bhuban formation ranges from deep marine to deltaic. The Depositional environment of the Bokabil Formation ranges from deltaic to coastal plain. The surma group is unconformably overlain by the Tipam Group of Pliocene age. The Tipam sandstone is composed of mostly cross bedded sandstone and minor claystones. The deposits are thought to be of Braided river deposits. The Upper unit of the Tipam Group is a thick clay unit, namely the Girujan Clay Formation. The Girujan clay Formation is thought to be deposited in a lacustrine environment. Overlying the Tipam group is the Pleistocene sandstone formation called Dupi Tila Formation. The Dupi Tila Formation is composed of cross bedded sandstone and interbedded claystone deposited in a meandering river system. The regional stratigraphic succession of the CTFB is given in the following table.

Table 1: Regional stratigraphic successions of the CTFB, Bangladesh

Age	Group	Formation	Lithology	Thickness(m)
Pleistocene	Dupi Tila	Dupi Tila Sandstone	Yellowish brown to light brown colored, occasionally pinkish, weathered, medium to coarse grained, cross bedded and massive, loosely compacted, moderately sorted, highly porous sandstone, quartz pebbles are common. In some places soft, sticky and bluish grey mud clasts and clay galls are also present.	+2000
Pliocene	Tipam	Tipam Sandstone	Sandstone (75-80%): Mostly composed of sandstone alternating with little shale. The sandstone is characterized by yellowish grey to brownish grey, occasionally light grey, fine to medium grained, massive, cross bedded, moderately sorted and consolidated ridge forming, highly porous, mostly composed with light colored minerals with subordinate dark minerals. Shale (20-25%): Grey to bluish grey, laminated, moderately hard and compacted. Unconformity	2500
Miocene	Surma	Bokabil	Gray to light gray fine grained well sorted sandstone with sandy shale and siltstone. Lenticular bedding, micro cross lamination, ripple marks and concretion are present.	5000
		Bhuban	Alternation of sandstone, silty shale and shale. Grayish white to grayish gray through yellowish gray medium to fine grained hard sandstone and siltstone which are massive as well as variously structured by graded bedding, flat bedding, ripple lamination and lenticular lamination. Bluish black thinly laminated silty shale to shale. Blue to black laminated and exfoliated weathered shale with massive mudstone.	

3.2. Stratigraphy in the Study Area

Stratigraphy of the studied area is prepared based on geologic traverse and outcrop studies on a number of stream sections in the eastern and western flank of the anticline and a road-cut section near the plunge area of the structure (Figure-5). Columnar section was prepared based on compass traverse method and rock lithology was described in detail. Based on our detailed field study in different exposures, only Surma Group i.e. Bhuban and Bokabil formations have been found in our study area. The exposed rock successions in our study area can be divided into five rock units on the basis of color, texture, lithology, sedimentary structure. The overall gross stratigraphic succession of the study area is given in table 2 and their surface and subsurface distribution is shown in Figure 8 and Figure 9, respectively. Simplified and representative columnar successions are shown in Figure 10.

Table 2: Local stratigraphic subdivision in the study area based on field mapping

Geological Formation	Unit	Characteristics
Recent	Unit 6	Unconsolidated recent beach sand deposits on western part and recent tidal deposits on the eastern side
Bokabil	Unit 5	Hard and compact tidal deposits (heterolithic beds)
	Unit 4	Yellowish brown colored moderately compacted fine grained cross bedded sandstone
	Unit 3	Alternation of yellowish brown colored thickly bedded sandstone and grey colored laminated shale.
Bhuban	Unit 2	Very hard and compact fine-grained Submarine canyon fill deposits; characterized by thinly to thickly bedded muddy to sandy turbidites
	Unit 1	Hard and compact tidal deposits (heterolithic beds); characterized by silty clay to clayey silt or very fine sand (lenticular bedding), interlaminated/interbedding sand and mud (wavy bedding) and silty sand interbedded with clay lens (flaser bedding)

Details of the stratigraphic units identified from the field observations are described in the subsequent sections.

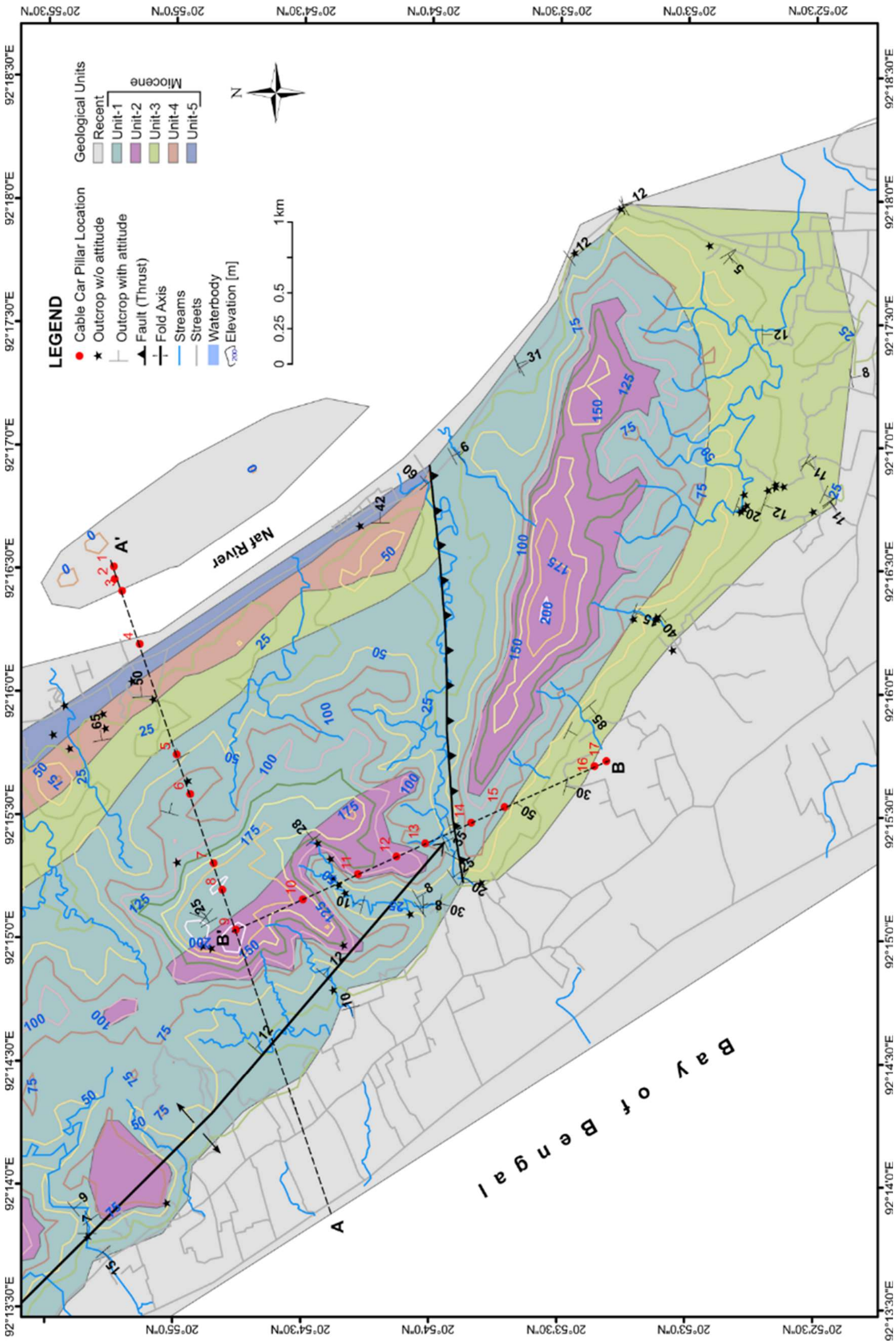


Figure 8: Surface geological map of the study area prepared based on field observations

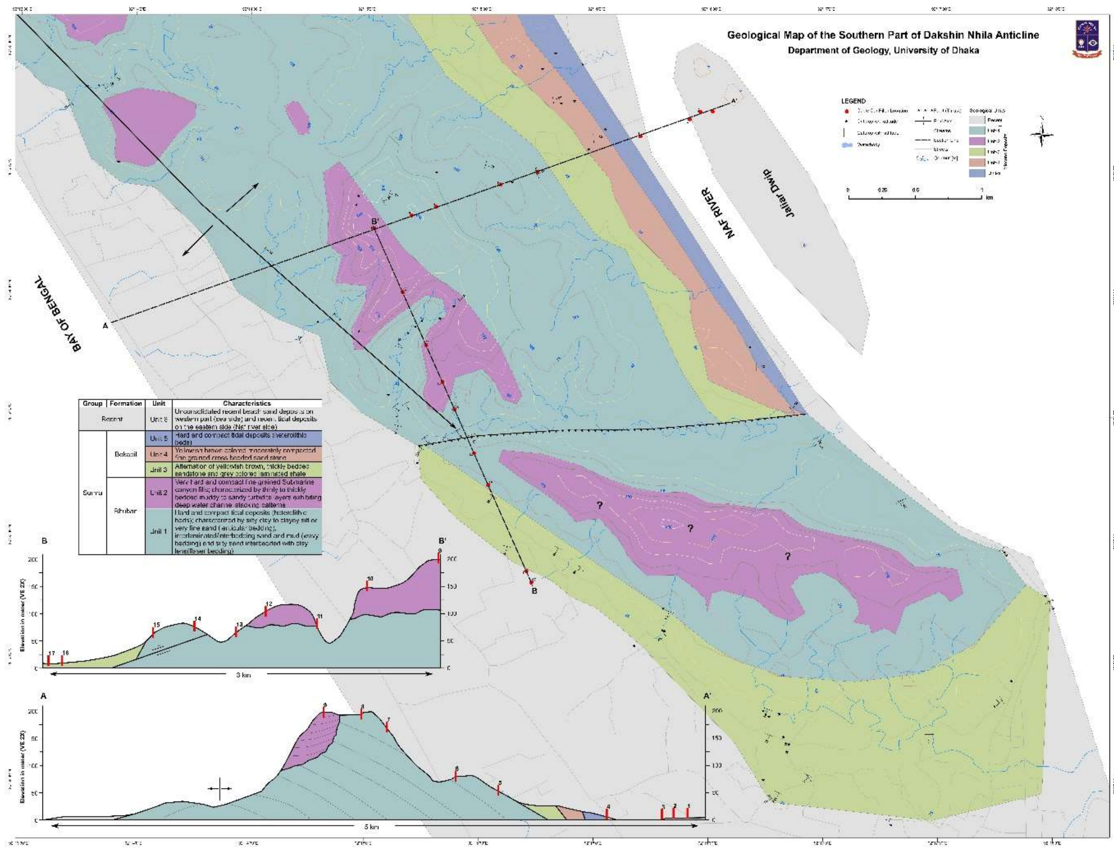


Figure 8 (a): Surface geological map of the relocated study area prepared based on field observations

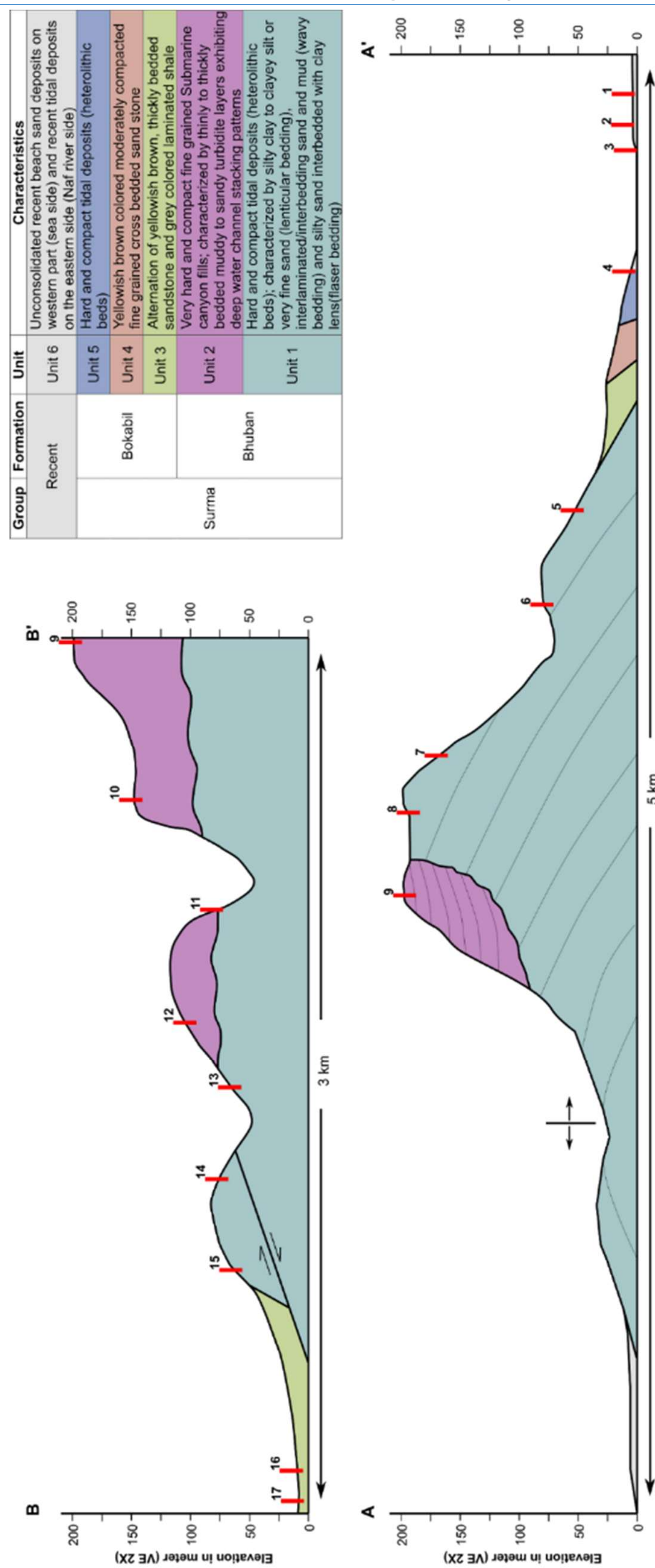


Figure 9: Cross section showing the subsurface distribution of the lithological units. Section lines are shown in Figure-7.

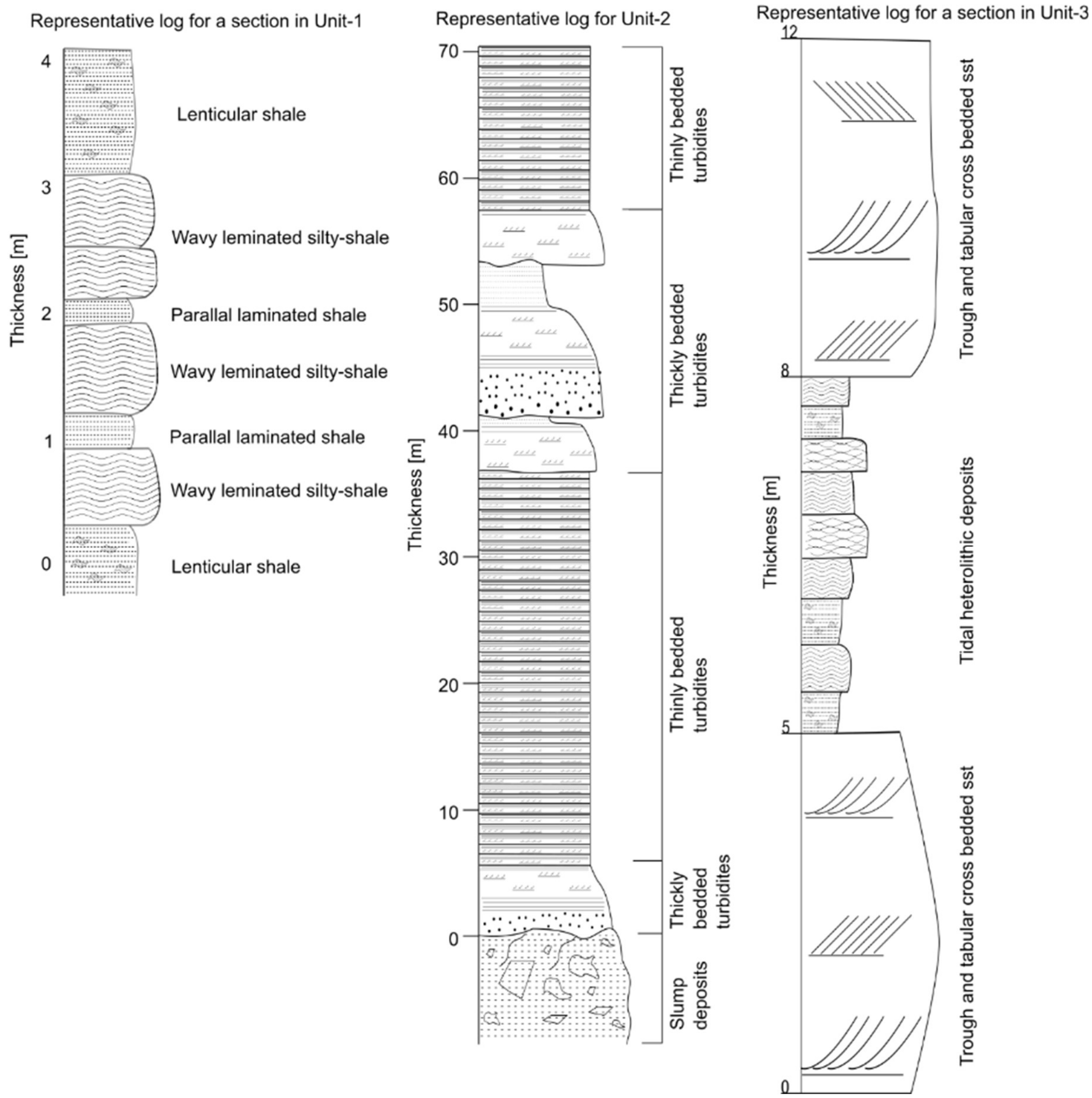


Figure 10: Simplified and representative columnar succession of Uni-1 to Unit-3.

3.2.1 Lithologic characteristics of Unit-1

In our study area, Unit 1 is well exposed in both the eastern and western flanks of the Dakshin Nhila anticline. This unit was found at the stream beds of Habib chara, Raja Chara, Noakhali chara, Bahar charas, on the base of vertical cliffs in the westrn side and in some hillcut and stream sections of the eastern side of the investigated area. The Unit 1 is an overall muddy sequence characterized by hard and compacted lenticular silty shale/Shale, wavy laminated very fine sandstone, siltstone, Silty Shale and Ripple laminated very fine sandstone and Siltstone occasionally showing banded calcareous concretion. The muddy deposits in this unit are highly jointed (Figure 7). Upon weathering, the heterolithic beds in this unit break into small pieces about 1 to 2 cm across. As the unit is relatively hard and compact, it is resistant to erosion and as such stand hill ranges with inconsistent valleys. Ripple cross lamination, wavy bedding, lenticular bedding, flaser bedding (Figure 11a to c) and occasionally found burrows in this unit indicate that the depositional environment of this sequence might be tide dominated shelf-slope transitional zone (Gani 1999). The description of the rock types in this unit is enumerated below:

Figure 11: Sedimentary structures typical of tidal deposits (a to c) and calcareous bands indicated by arrows in (d)

Silty shale/Shale: This silty shale/shale is grey to light grey colored, well laminated when shale and poorly laminated when silty shale, hard and compacted, occasionally breaks in conchoidal fracture (Figure 7c), numerous joints have been developed along the dip direction at regular intervals, non-calcareous, presence of thin lenses of sand/silt, sometimes parting found along the bedding plane of shale. Calcareous bands were also present within this rock (Figure 11d).

Siltstone: Siltstone is grey to bluish grey colored, hard and compacted, non-calcareous, cementing material is argillaceous, less porous.

Sandstone: The sandstone in this unit is bluish grey to occasionally light grey colored, very fine grained, cross laminated, consolidated, mostly composed of light-colored minerals with considerable amount of dark colored minerals (Figure 15 a & b). Flaser bedding is commonly found in this rock (Figure 11c).

3.2.1 Lithologic characteristics of Unit-2

This unit comprises thinly to thickly bedded turbidites with characteristic depositional pattern suggesting submarine canyon fills (Figure 10). The approximate thickness of this unit is 70m.

On the base of this unit more than 10 m thick slump beds are present (Figure 12a & b). These slump beds are chaotic in nature, distorted and sometimes these beds contain dispersed blocks. Heterolithic structures are also observed in these slump beds (Figure 12a and 12b). Thickness of individual turbidites varies from ~10 cm when thinly bedded and ~1m when thickly bedded. Channel and levee aggradation patterns are also visible in this unit at multiple sections (Figure 12a to 12 c). In our study area the individual turbidites characterized from base to top by graded bedding massive sandstone (Ta), parallel laminated sandstone (Tb), ripple cross laminated sandstone (Tc) and very fine grained parallel laminated sandstone (Td) (Figure 12 d). However, in most cases the upper mudstone (Te) was absent in the study area. The base of the Ta division is sharp to slightly eroded. Due to rapid settings of grains, Ta is almost structureless except graded bedding. Grain Size analysis shows that the sandstone of Ta contains 72% sands and 28% finer materials, with D_{30} = 0.065 mm, D_{60} = 0.12mm, and fineness modulus of 1.14 (see Annex-1 for the graph). Flame and pipe sedimentary structure, convolute lamination is common in Td division (Figure 13).

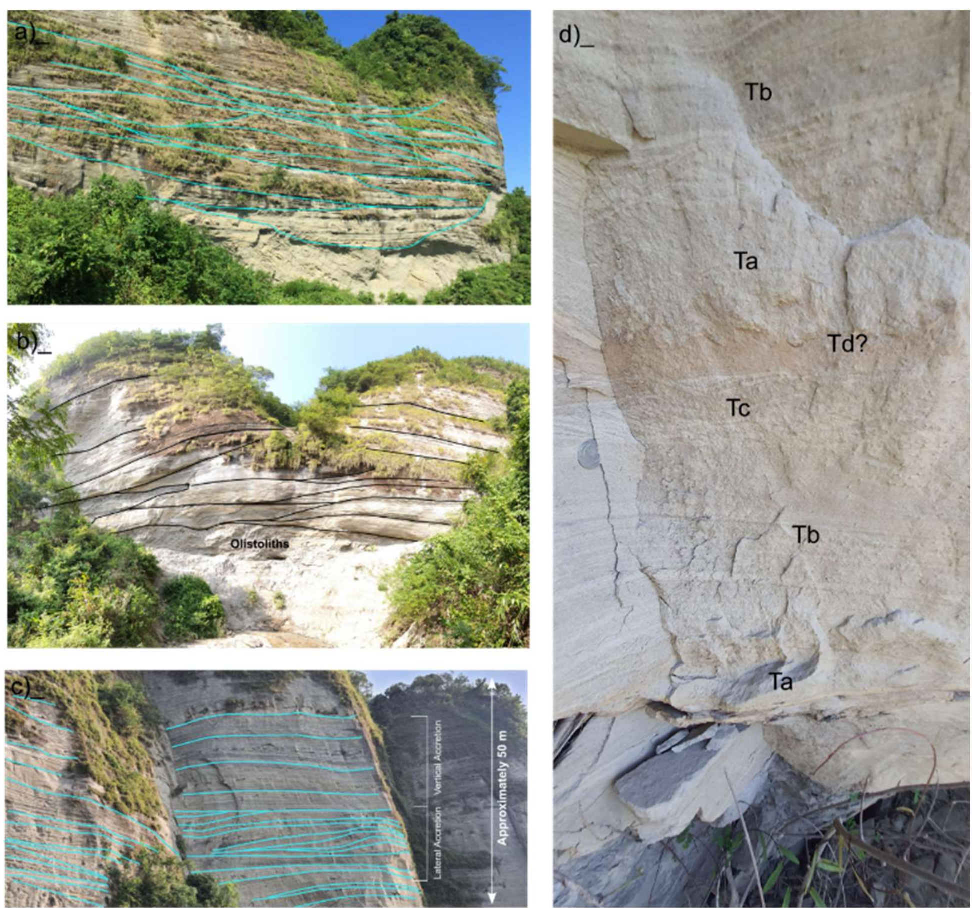


Figure 92: Depositional pattern and sedimentary structures in Unit-2. a) to c) channel and levee aggradation pattern at different cliff sections, d) typical signature of turbidites as seen in the thickly bedded sandy turbidites.

Based on stratigraphic position of this unit and surrounding tide dominate deposits, repetitive thick bedded to thin bedded sequences, water escape structures such as dish and pillar, internal convolution within the coarse siltstone or very fine sandstone, ripple cross lamination etc suggest that the Unit 2 might be deposited in a submarine canyon (Gani, 1999). This submarine canyon fill deposits traced out along the N-S trending all the cliff sections in this structure. This Unit 2 is well distributed in the top of the vertical cliffs such as Raja Pahar, Bahar Chara cliff (locally known Ilias Kobra Pahar), Habib Chara cliff in our study area.

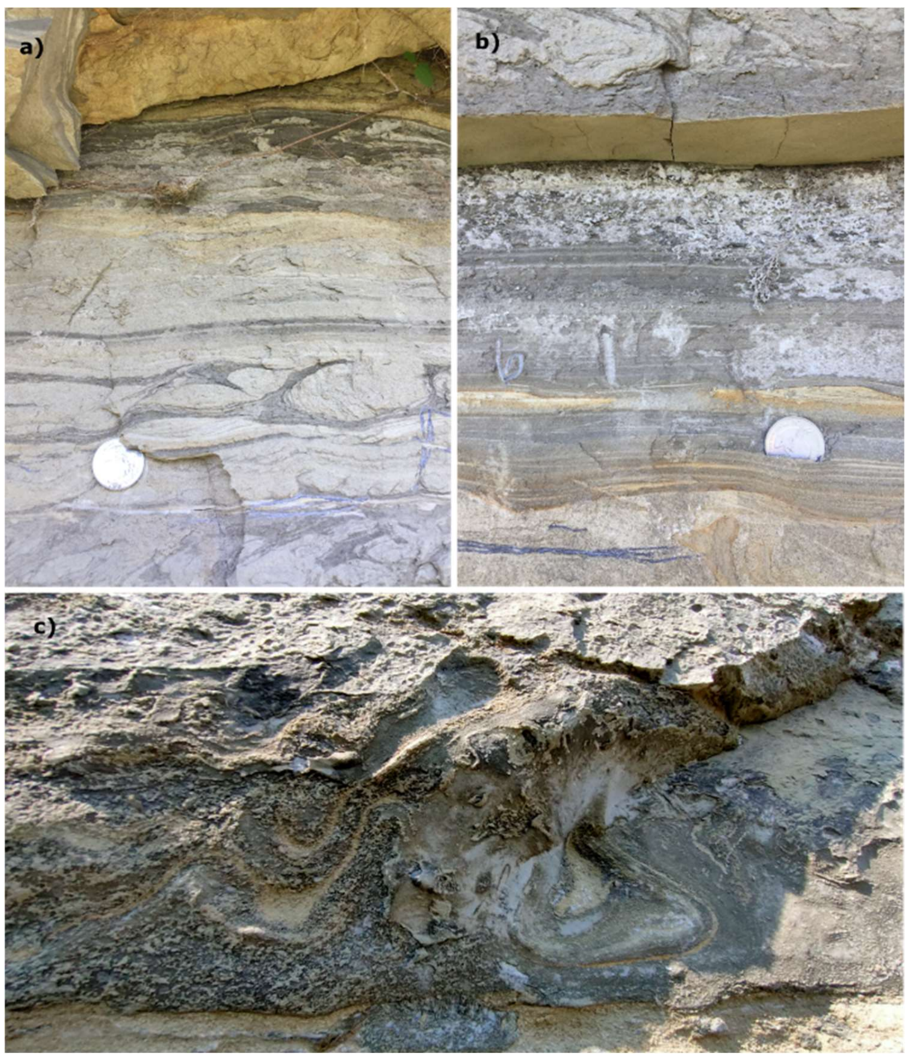


Figure 13: Soft sediment deformation structures. a) flame structure, b) pillar structure at the bottom of the photograph, adn c) convolute bedding

3.2.3 Lithologic characteristics of Unit 3

The sediment deposits of this unit are predominantly represented by alternation of thick bedded sandstones unit and laminated shale to heterolithic shallow marine deposits. This unit is exposed in the eastern flank and southern plunging zone in the western flank. Due to E-W thrust fault, this unit is missing in the south –east portion of the anticline. The main rock types of this unit described below:

Figure 14: a) Exposure of yellowish brown colored cross bedded sandstone of Unit 3, b) Fossiliferous fine-grained sandstone considered as the marker bed of Unit 3.

Sandstone: This sandstone is characterized by yellowish brown to yellowish grey to occasionally grey colored, moderately hard and compact, fine grained often medium grained, well sorted, sporadically spheroidal to tabular concretions. The sandstone is composed of light-colored minerals with a considerable amount of dark colored minerals (Figure 15 c & d). The grey colored fine-grained calcareous sandstone is often containing shallow marine fossils. This fossiliferous sandstone is considered in this study as a marker bed and used in stratigraphic subdivision. Through cross bedding, tabular cross bedding, channel deposits are common in these rocks. Grain Size analysis shows that the sandstone contains 71% sands and 29% finer materials, with D30 = 0.06 mm, D60 = 0.1mm, and fineness modulus of 0.61 (see Annex-1 for the graph).

Shale/ Silty shale: This rock type is grey to bluish grey colored, well to poorly laminated, moderately hard and compact, non-calcareous occasionally tabular calcareous siltstone noted.

Silty sandstone: This rock is bluish grey, fine to very fine grained, laminated to thinly bedded siltstone, clay lenses are commonly noted within this sandstone.

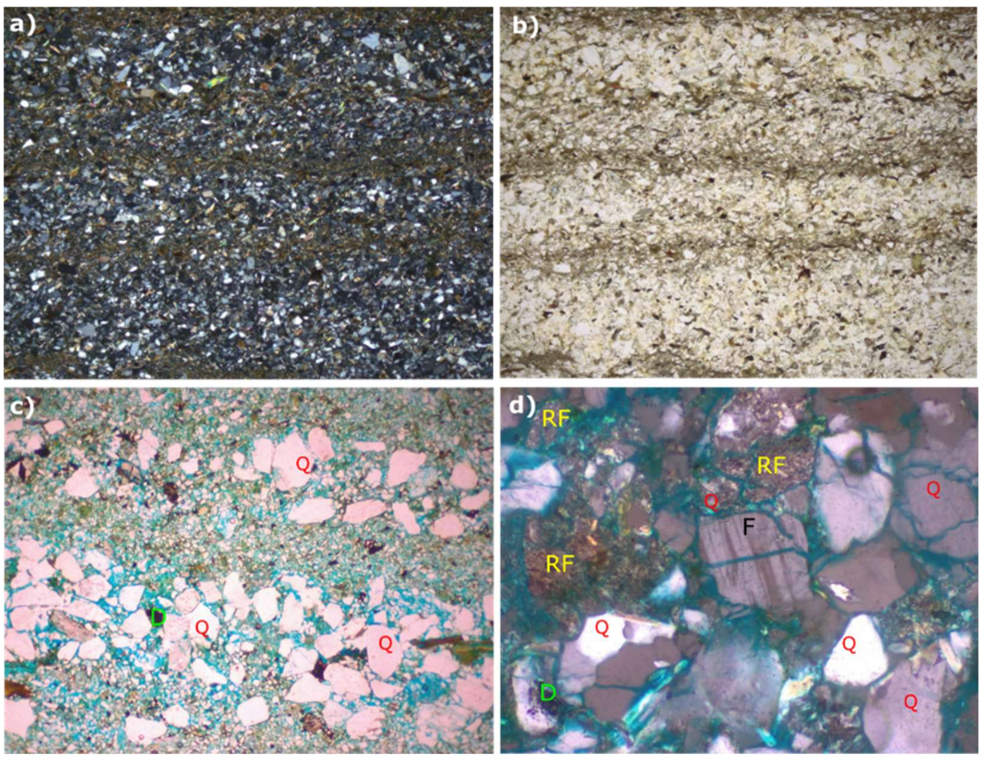


Figure 10: a & b) Photomicrograph of Unit 1, sample no 3, under PPL and CPL (x10). Detrital framework grains are mostly quartz (Q). Different grain size bands are also observed. c & d) Photomicrograph of Unit 3, sample no 2 under PPL(x20) and sample no 3 under CPL (x40). Detrital framework grains are quartz (Q), feldspar (F) and rock fragments (RF). The blue colored stains represent the pore spaces of the rock. Dark minerals are indicated with letter D.

3.2.4 Lithologic characteristics of Unit-4

Unit 4 is found in the eastern flank of the Dakshin Nhila anticline whereas in the western flank Unit 4 is eroded. In our study area, this unit is well outcropped in the northern side of the E-W crossing thrust fault, however due this faulting the surface exposure of Unit 4 is missing in the southern plunging zone of the anticline. The Unit 4 is predominantly characterized by yellowish brown colored, moderately hard and compacted, fine grained, ridge forming, well sorted, cross bedded sandstone (Figure 16). This sandstone is composed of light-colored minerals with subordinate considerable amounts of dark colored minerals. Grain Size analysis shows that the sandstone contains 90% sands and 10% finer materials, with D_{30} = 0.12 mm, D_{60} = 0.15 mm, and fineness modulus of 1.76 (see Annex-1 for the graph)

Figure 116: The figure shows the outcrop of Unit 4 which is characterized by yellowish brown colored fine sandstone.

3.2.5 Lithologic characteristics of Unit-5

The Unit 5 is characterized by tide dominant heterolithic deposits. Rocks of this unit are relatively soft and are composed of bluish grey to grey colored laminated lenticular bedded silty shale to shale, alternation of wavy natured very fine sandstone and silty shale, and ripple cross laminated grey colored very fine sandstone subordinate with clay or silty lenses (Figure 17). The Unit 5 is exposed along the Teknaf- Cox's Bazar highway in the eastern flank of the anticline, however due to erosion Unit 5 is absent in the western flank.

Figure 127: Exposure of Unit 5, consists of tide-dominant sedimentary rocks.

Unit 6: The Unit is composed of loose, unconsolidated medium to fine grained beach sands and tidal muds. The tidal mud is found in the eastern side of anticline specially the Jaliar Dwip and banks of the Naf river. On the other hand, western side of the anticline is characterized by unconsolidated beach sands.

Chapter 4: Geologic Hazards

4.1 Faults and Earthquake Hazards

Faulting is the offset of the ground surface by differential movement along a fault during an earthquake. This effect is particularly limited in the earthquake prone areas and generally linked with magnitude 5.5 in Richter scale earthquakes. The displacements of the rock body may range from a few millimeters to several meters, and the damage usually increases with increasing displacement. Significant damage is usually restricted to a narrow zone ranging up to 300 meters wide along the fault, although subsidiary ruptures may occur three to four kilometers from the main fault. The length of the surface ruptures can range up to several hundred kilometers (http://www.oas.org/dsd/publications/unit/oea66e/ch11.html). In our study area, two faults are identified; 1) a regional longitudinal fault which is known as 'Teknaf Fault' and 2) E-W Trending Thrust fault. The longitudinal fault is relatively far from the study area, whereas E-W trending thrust fault is located within the study area. This E-W thrust fault runs through the Keruntoli Chara from eastern side of the anticline. During our field investigation, the possible displacement of the thrust fault couldn't have been identified.

Owing to the existence of the E-W Trending Thrust Fault, the study area was relocated, resurveyed, reinvestigated relocation study soil and reanalyzed to avoid this fault. Both the 1) regional longitudinal fault which is known as 'Teknaf Fault' and 2) E-W Trending Thrust fault are now found far away from the relocated study area as shown in Figure 8 (a).

Tectonically, Bangladesh is situated in the triple junction of India, Eurasia and Burma plates. The Indian plate collided with the Eurasian plate in the North and converged obliquely into the Burma plate in the east. Due to the convergence of India and Burma plate, the Chittagong – Tripura Fold Belt has emerged. These plate margins are very susceptible to earthquakes. Several devastating earthquakes have occurred in the past especially in the CTFB (Gani and Alam, 2003). Our study area for the proposed cable car network in the southern part of the Dakshin Nhila anticline is included in this tectonically active CTFB. According to the proposed BNBC-2017, this study area is situated in Zone-III (Figure 18), which is more vulnerable to earthquake hazards. However, there is no evidence of recent time earthquakes occurring in this area except the Moheshkhali earthquake in 1999 (Ansari et, al.,2000). Moheshkhali Island is situated at the northern tip of the Inani anticline which is adjacent to the Dakshin Nhila anticline. Besides this, in 1762 a major earthquake happened in the Arakan segment of the Mega Thrust which is far away from the south-eastern coast of Bangladesh. According to Mandal (2018), some upliftment traces have been observed in St. Martin and Teknaf coast due to this mega-earthquake. However, the relationship between upliftment traces and earthquakes is not not clearly understood in the Teknaf coastal area according to their study.

Figure 138: Seismic zonation map of Bangladesh (Source: BNBC-2017)

4.2 Mass Wasting

Vertical cliffs are characteristically steep features, which are hazardous and dangerous at the time of retreatment due to the erosion. The rate of recession of these cliffs depends on geological factors such as the exposure of the rock formation and its resistance, the type of the adjacent shore, the tide range, and the degree of wave action (Sunamura, 1992). If the cliffs consist of hard rock formations such as Granite and Basalt, they erode slowly. Whereas, sandstone or clay cliffs may retreat a meter or more per year. Moreover, the presence of joints, fractures, bedding planes, and faults facilitate the disintegration of rock formations in the cliff sections. The western part of the study area is characterized by several vertical cliffs. These cliffs are approximately 200 m elevated from the sea level and are composed of mostly hard and compacted sandstone. Several fractures and joints were observed in these cliff sections during our field investigation (Figure 19). Based on the local information, the rate of retreatment is about 1-2 ft every year.

Figure19: The collage pictures show the vertical cliffs and associated vulnerable areas of mass wasting in the study area

Acknowledgement

The authors would like to convey thanks and gratitude to the Bangladesh Economic Zone Authority (BEZA) for providing funds for the investigation in order to conduct the study successfully. The authors are sincerely gratified to the Chittagong University of Engineering and Technology for giving the opportunity to carry out this geological investigation. The authors are also grateful to Teknaf Upazila Nirbahi Officer (UNO), Teknaf Thana Police, and Border Guard of Bangladesh for their immense support during the fieldwork.

References

Ansary, M. A., Al-Hussaini, T. M., & Sharfuddin, M. (2000, July). Damage Assessment of July 22, 1999 Moheskhali Earthquake, Bangladesh. In *8th ASCE Specialty Conference on Probabilistic Mechanics and Structural Reliability, Indiana, USA*.

Alam, M. (1989). Geology and depositional history of Cenozoic sediments of the Bengal Basin of Bangladesh. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *69*, 125-139.

Alam, M., Alam, M. M., Curray, J. R., Chowdhury, M. L. R., & Gani, M. R. (2003). An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. *Sedimentary geology*, *155*(3-4), 179-208

BAPEX (1981). Geological Report on the Dakhin Nhila Anticline conducted by the Geological Party during the 1980-1981 Field season.

Gani, M. R., & Alam, M. M. (1999). Trench-slope controlled deep-sea clastics in the exposed lower Surma Group in the southeastern fold belt of the Bengal Basin, Bangladesh. Sedimentary Geology, 127(3-4), 221-236.Geoscience, 9(8), 615-618.

McKenna, J., 2006. High Impact Opportunities that are Focussed to Succeed, Presented at 2006 Capital Markets Day, Retrieved from: http://files.investis.com/twl/pdf/asia_b.pdf

Mondal, D. R. (2018). Evidence of the 1762 Arakan and Prior Earthquakes in the Northern Sunda Subduction.

Rangin, C., Maurin, T., & Masson, F. (2013). Combined effects of Eurasia/Sunda oblique convergence and East-Tibetan crustal flow on the active tectonics of Burma. *Journal of Asian Earth Sciences*, *76*, 185-194.

Steckler, M. S., Mondal, D. R., Akhter, S. H., Seeber, L., Feng, L., Gale, J., ... & Howe, M. (2016). Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges. *Nature*

Sunamura, T. (1992). Geomorphology of rocky coasts (Vol. 3). John Wiley & Son Ltd.

Annex-1: Grain size analysis reports

Client: BEZA **Location:** 20.217106; 92.232051
Project: Naf Tourism Project **Borehole No.: N/A**
Sample No.: Station ID: D2_St3 (Ta in Unit 2) **Depth: Outcrop**
Soil Description: Silty fine SAND **Date of Test:** 12/12/2020

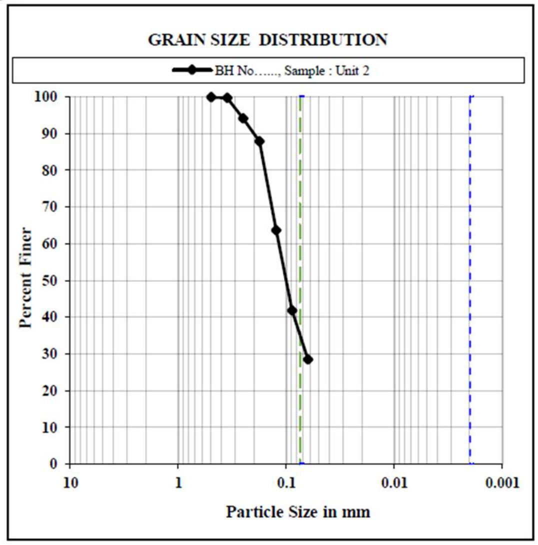
Particle Size Analysis of Sediments by sieve Analysis (ASTM D1140 & ASTM C136)

BH No……, Sample : Unit 2

sieve analysis data Total weight of sample, W_s = 100 gm

MESH no.	Opening (mm)	Wt. of sedi (gm)	% of sedi retained	Cum. % retained	% finer
35	0.495	0.15	0.15	0.15	99.85
45	0.351	0.27	0.27	0.42	99.58
60	0.250	5.58	5.58	6.00	94.00
80	0.177	6.23	6.23	12.23	87.77
120	0.124	24.21	24.21	36.44	63.56
170	0.088	21.83	21.83	58.27	41.73
200	0.063	13.34	13.34	71.61	28.39
Pan	< 0.063	28.29	28.29	99.90	—

Fineness Modulus (FM) =	1.14
D_{10} (mm) =	x
D_{30} (mm) =	0.065
D_{60} (mm) =	0.12
C_u =	x
C_C =	x
Sand:	72
Silt & Clay:	28



Client: BEZA **Location:** 20.886471; 92.272095 (Siliceous sst)
Project: Naf Tourism Project **Borehole No.: N/A**
Sample No.: Station ID: D4_St-12 (Unit 3) **Depth: Outcrop**
Soil Description: Silty fine SAND **Date of Test:** 12/12/2020

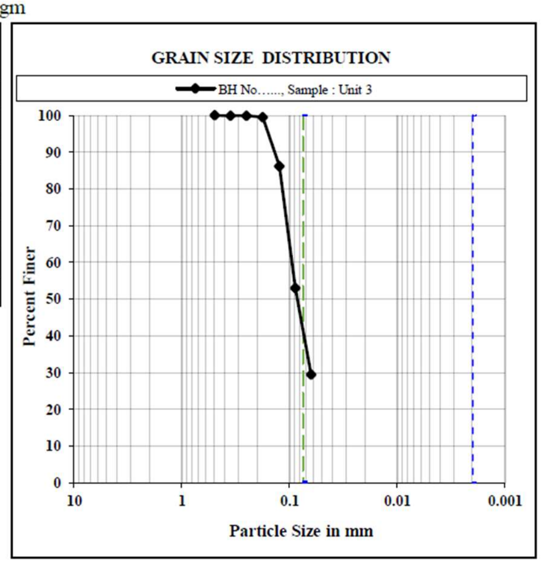
Particle Size Analysis of Sediments by sieve Analysis (ASTM D1140 & ASTM C136)

BH No……, Sample : Unit 3

sieve analysis data Total weight of sample, W_s = 100 gm

MESH no.	Opening (mm)	Wt. of sedi (gm)	% of sedi retained	Cum. % retained	% finer
35	0.495	0.00	0.00	0.00	100.00
45	0.351	0.04	0.04	0.04	99.96
60	0.250	0.07	0.07	0.11	99.89
80	0.177	0.44	0.44	0.55	99.45
120	0.124	13.21	13.21	13.76	86.24
170	0.088	33.25	33.25	47.01	52.99
230	0.063	23.54	23.54	70.55	29.45
Pan	< 0.063	29.23	29.23	99.78	—

Fineness Modulus (FM) =	0.61
D_{10} (mm) =	x
D_{30} (mm) =	0.06
D_{60} (mm) =	0.1
C_u =	x
C_C =	x
Sand:	71
Silt & Clay:	29



Client: BEZA | **Location:20.978105, 92.23757**
Project: Naf Tourism Project | **Borehole No.:**
Sample No.: Station ID (D3_St2b) Unit 4 | **Depth:** NA
Soil Description: Silty fine to medium SAND | **Date of Test:** 12/12/2020

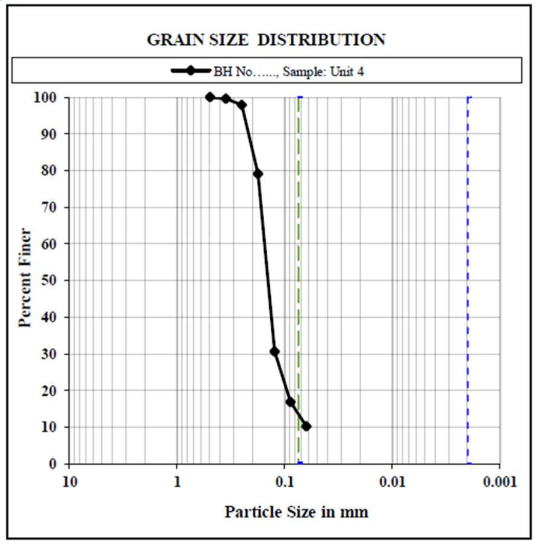
Particle Size Analysis of Sediments by sieve Analysis (ASTM D1140 & ASTM C136)

BH No……, Sample: Unit 4

sieve analysis data — Total weight of sample, W_s = 100 gm

MESH no.	Opening (mm)	Wt. of sedi (gm)	% of sedi retained	Cum. % retained	% finer
35	0.495	0.05	0.05	0.05	99.95
45	0.351	0.34	0.34	0.39	99.61
60	0.250	1.70	1.70	2.09	97.91
80	0.177	18.83	18.83	20.92	79.08
120	0.124	48.52	48.52	69.44	30.56
170	0.088	13.68	13.68	83.12	16.88
230	0.063	6.64	6.64	89.76	10.24
Pan	< 0.063	9.98	9.98	99.74	—

Fineness Modulus (FM) =	1.76
D_{10} (mm) =	0.055
D_{30} (mm) =	0.12
D_{60} (mm) =	0.15
C_u =	2.7272727
C_C =	1.7454545
Sand:	90
Silt & Clay:	10

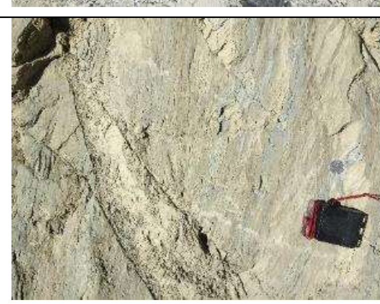


Annex-2: Summary Table of Outcrops

Date	Station	Location		Attitude		Photographs	Description
		Latitude	Longitude	DD	AD		
11/11/2020	D-1St-01	20.89085	92.26033	S15 W	30	 	Thinly laminated (3 to 5 mm) sandstone-shale alteration (heterolithic beds). Presence of lenticular and wavy bedding.
	D-1St-2	20.89431	92.25921	S30 W	50		Thinly laminated (3 mm) heterolithic beds. Presence of lenticular and wavy bedding.
13/11/2020	D-2St-01	20.90505	92.24504	N75 E	10		Highly jointed fissile shale. Joint spacing is about 4 to 6 inch.

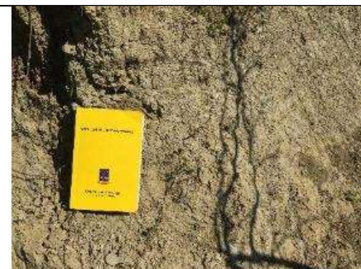
	D-2St-02	20.906283	92.246569	NA	NA		Jointed fissile shale.
	D-2St-03	20.905638	92.249568	NA	NA	  	Turbidite sequence. Presence of parallel & cross lamination, load cast and sedimentary melange.
	D-2St-04	20.906701	92.247887	S40E	12	 	Upper part of this section is fissile shale and lower part is nodular shale.

14/11/2020	D-3St-02b	20.978105	92.237578	NA	NA		Sandstone.
	D-3St-02c	20.979287	92.239233	NA	NA		Fine sandstone.
	D-3St-04	20.979989	92.242631	NA	NA		Laminated shale.
	D-3St-05b	20.979791	92.243293	NA	NA		Sandstone and shale alteration.
	D-3St-05c	20.979761	92.243412	NA	NA		Heterolithic bed.
	D-3St-06	20.953402	92.248616	NA	NA		Compacted sandstone.

	D-3St-07	20.953344	92.248394	NA	NA		Laminated shale
	D-3St-09	20.9336	92.258984	NA	NA		Sandstone
	D-3St-10	20.933908	92.261203	NA	NA		Sandy surface.
15/11/2020	D-4St-01	20.896687	92.253829	NA	NA		Compacted and calcareous fine sandstone.
	D-4St-02	20.897504	92.254035	S30 W	20		Highly weathered heterolithic bed. Presence of lenticular and wavy bedding.
	D-4St-03	20.898471	92.255321	Due E	10		Hard and compacted heterolithic bed. Presence of lenticular and wavy bedding.

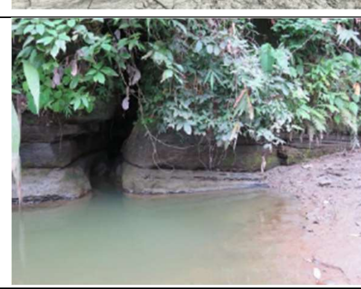
							
	D-4St-04	20.898371	92.25596	S60 E (?)	35		Heterolithic bed. Presence of lenticular and wavy bedding.
	D-4St-05	20.898762	92.256762	S25 E	35		Heterolithic bed. Presence of lenticular and wavy bedding.
	D-4St-06	20.898451	92.257821	S15 E	50		Heterolithic bed. Presence of lenticular and wavy bedding.
	D-4St-07	20.898236	92.254415	S35 E	25		Highly weathered heterolithic bed.
	D-4St-09	20.88537	92.271658	NA	NA		Fossiliferous sandstone.

	D-4St-10	20.886471	92.272095	S20 W	15	 	Heterolithic bed (tidal sequence) at the top and massive compacted sandstone at the base.
	D-4St-11	20.88531	92.271779	NA	NA		Fossiliferous sandstone.
	D-4St-12	20.884887	92.271752	S50 W	40	 	Contact between cross bedded sandstone and heterolithic bed.
16/11/2020	D-5St-01	20.873814	92.279439	S50 W	15	 	Contact between weathered massive sandstone and heterolithic bed.

	D-5St-02	20.874152	92.28009	S25 W	21		Heterolithic bed. Presence of lenticular and wavy bedding.
	D-5St-03	20.875243	92.282168	S55 W	12		Heterolithic bed. Presence of lenticular and wavy bedding.
	D-5St-04	20.8771	92.280727	NA	NA	 	Weathered shale at the top and cross laminated sandstone at the base.
	D-5St-05	20.877623	92.280882	NA	NA		Heterolithic bed (flaser bedding).
	D-5St-06	20.877655	92.280660	NA	NA		Alteration of thickly bedded sandstone and heterolithic bed.

	D-5St-07	20.878119	92.280483	NA	NA		Alteration of thickly bedded sandstone and heterolithic bed.
	D-5St-08	20.878077	92.279415	S20 W	12		Alteration of thickly bedded sandstone and heterolithic bed.
	D-5St-09	20.879511	92.2794296	NA	NA		Heterolithic bed.
	D-5St-10	20.87969	92.279181	NA	NA	 	Fossiliferous and compacted sandstone.
	D-5St-11	20.879835	92.279279	S20 W	20		Alteration of thickly bedded sandstone and heterolithic bed.

	D-5St-12	20.879911	92.279003	NA	NA	 	Channel sandstone deposit and heterolithic bed at the top.
	D-5St-13	20.879684	92.28018	NA	NA		Compacted fine grained sandstone.
	D-5St-14	20.875189	92.279023	NA	NA		Heterolithic bed.
	D-5St-15	20.887279	92.299785	S10E	15	 	Contact between calcareous massive sandstone and heterolithic bed.

	D-5St-16	20.8877599	92.2994185	NA	NA	 	Fossiliferous (Rhynconellida) sandstone.
17/11/2020	D-6St-01	20.87817	92.29104	180	12		Gray shale
	D-6St-02	20.87237	92.28819	168	8	 	Alteration of fine sandstone and shale.
	D-6St-03	20.89836	92.28288	151	6		Very hard gray shale.

							
	D-6St-04	20.89083	92.29635	142	12		Alteration of shale and fine sandstone
	D-6St-05	20.885322	92.271831	NA	NA	 	Fine to medium grained dark gray colored sandstone
	D-6St-06	20.886842	92.27171	NA	NA		Fine to medium grained dark gray colored sandstone
	D-6St-07	20.89077	92.264	207	60		Shale (Slumped?)

	D-6St-08	20.890778	92.296459	NA	NA		Sandstone (upper), shale (lower).
	D-6St-09	20.87384	92.27949	235	11		Upper part is sandstone and lower part is heterolithic bed.
	D-6St-10	20.89414	92.28908	161	31		Gray shale
	D-6St-11	20.88946	92.26558	230	85		Shale
	D-6St-12	20.8522	92.30604	252	35		Shale and sandstone nodule
	D-6St-14	20.882	92.297	NA	NA		Fine grained, gray colored massive sandstone

	D-6St-15	20.87384	92.27949	235	11		Alternating sandstone and shale
	D-6St-16	20.87536	92.28222	210	11		Shale
	D-6St-17	20.88724	92.29978	148	12	 	Fossiliferous sandstone.
	D-6St-18	20.8804	92.29601	222	5		Upper part is clay and lower part is sandstone.
	D-6St-19	20.88059	92.29618	240	11		Upper part is clay and lower part is sandstone.

18/11/2020	D-7St-01	20.899043	92.252365	S15 W	30		Highly compacted and jointed heterolithic bed.
	D-7St-02	20.90008	92.25236	Due S	8		Highly compacted and jointed heterolithic bed.
	D-7St-03	20.900558	92.253033	S45 W	8		Highly compacted and jointed heterolithic bed.
	D-7St-04	20.901305	92.251718	NA	NA		Alteration of sandstone and heterolithic bed.
	D-7St-05	20.904751	92.252435	N15 E	10	 	Compacted heterolithic bed.

	D-7St-06	20.905547	92.25311	NA	NA		Highly jointed heterolithic bed. Presence of concretion and onion structure.
	D-7St-07	20.905981	92.253656	NA	NA		Highly jointed heterolithic bed. Presence of concretion and onion structure.
	D-7St-08	20.906379	92.254123	NA	NA		Weathered nodular shale
	D-7St-09	20.906518	92.255418	NA	NA	 	Alteration of sandstone and heterolithic bed.
	D-7St-10	20.907366	92.256457	NA	NA		Alteration of sandstone and heterolithic bed.

	D-7St-11	20.907866	92.256989	N50 E	28	 	Alteration of sandstone and heterolithic bed.
	D-7St-12	20.900388	92.25227	S38 E	13		Alteration of sandstone and heterolithic bed.
19/11/2020	D-8St-01	20.924632	92.263734	NA	NA		Highly inclined micro-cross laminated sandstone.
	D-8St-02	20.923557	92.262802	NA	NA		Sandstone
	D-8St-03	20.923884	92.2657349	NA	NA		Shale

	D-8St-04	20.921385	92.265137	NA	NA		Alteration of sandstone and heterolithic bed.
	D-8St-05	20.921228	92.264165	NA	NA		Alteration of sandstone and heterolithic bed.
	D-8St-06	20.921504	92.263746	N80E	65		Alteration of sandstone and heterolithic bed.
	D-8St-07	20.904686	92.277943	NA	NA		DTW
	D-8St-08	20.90336	92.27856	Due E	42		Cross laminated sandstone
	D-8St-09	20.90056	92.28109	N40E	60		Heterolithic bed.
	D-8St-10	20.898	92.2829946	S40E	Low		Heterolithic bed
	D-8St-11	20.8940175	92.28891	S30E	30		Heterolithic bed.
20/11/2020	D-9St-01	20.920963	92.228491	S50W	15		Highly jointed and compacted heterolithic bed.

							
	D-9St-02	20.922233	92.229749	NA	NA	 	Highly jointed and compacted heterolithic bed.
	D-9St-03	20.922244	92.230347	Due E	7		Highly jointed and compacted heterolithic bed.
	D-9St-04	20.922218	92.231237	N65 E	18		Highly jointed and compacted heterolithic bed.
	D-9St-05	20.922878	92.231888	S15 E	9		Highly jointed and compacted heterolithic bed.

	D-9St-06	20.917106	92.232051	NA	NA	  	Turbidite sequence. Presence of graded bedded sandstone, parallel & cross laminated sandstone, and mud deposit.
21/11/2020	D-10St-01	20.919465	92.267365	NA	NA		Almost vertical heterolithic bed.
	D-10St-02	20.918874	92.26669	Due N (?)	50		Yellowish brown sandstone.
	D-10St-03	20.918097	92.266163	NA	NA		Sandstone
	D-10St-04	20.916432	92.262589	N60E	20		Weathered shale.

	D-10St-05	20.915834	92.260633	NA	NA		Weathered shale.
	D-10St-06	20.916919	92.258848	S75 E	18		Highly jointed weathered shale.
	D-10St-07	20.916491	92.255142	NA	NA		Weathered shale
	D-10St-08	20.914976	92.251908	S70 E	15		Heterolithic bed.
	D-10St-09	20.914852	92.251767	N50 E (?)	10		Heterolithic bed.
	D-10St-10	20.91455	92.251446	N60 E	25		Heterolithic bed.
	D-10St-11	20.91485	92.249487	NA	NA		Micro-cross laminated sandstone and mud
	D-10St-12	20.914252	92.24934	NA	NA		Turbidite sequence at the base and tidal sequence at the top.

						 	
	D-10St-13	20.911136	92.242859	S50E	12		Heterolithic bed.