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A Review on Hydrocarbon Prospectivity in Chittagong Hill Tracts and Adjacent Area

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Abstract

Bangladesh is a country with limited sources of energy and since 1990 natural gas has been its main source of energy. Most of the exploration approaches had been conducted onshore especially in the central and eastern part of Bangladesh, particularly in northeastern Sylhet basin. Among the hydrocarbon provinces, the East Delta Hill Tract province is an under explored petroleum province in Bangladesh. An exploratory well drilled in Sitakund anticline was found dry but no reasonable cause was perceived why that well went dry. Although many works had been carried out in Chittagong Hill Tracts but none of them was cumulative and descriptive. In this study, the overall hydrocarbon prospect of the Chittagong Hill Tracts was analyzed by mapping of potential zones on the basis of the evaluation of regional structure and construction of lithocolumn of the prospective zones. The five elements of the petroleum system discussed thoroughly to find overall petroleum prospect of the study area. Source rocks of Chittagong Hill Tracts are mainly Bhuban shale, reservoir rock is sandstone from Bhuban-Bokabil formation, the way of migration path is both through longitudinal and cross fault. The data of source rock and seal is collected from previous researches. Multiple types of traps have been found there. Conventional anticlinal traps which are highly disturbed due to tectonic instability & the core part are shale diapirism. Most of the anticlines are plunging and the nose or plunge area might be prospective to HC for being comparatively less faulted. Broad synclinal areas between tight narrow anticlines are another prospective area for HC. These similar types of synclines are also found in Tripura, India which is a highly prospective area for petroleum and their small anticlinal hums within syncline are also prospective. Some stratigraphic traps have also been found in Tripura from where production has been started already. Both Chittagong Hill Tracts and Tripura Fold Belts are parts of great Arakan Fold Belts, so similar type of structures might be prospective here. Apart from these, Bangladesh is a deltaic country. So stratigraphic trapment like channel sand, pinch-outs is possible. Considering all the elements of petroleum prospectivity of the area and factors discussed above, it is quite clear that Chittagong hill tracts might be the next target for HC exploration program.

Keywords

Petroleum Prospect, Lithocolumn, Stratigraphic Succession, Petroleum System, Unconventional Reservoir, Channel Sand, Diapirism, Chittagong Hill Tracts

1. Introduction

Bangladesh is a gas-based mono-energy country. With a population of 163 million living in an area of 147,000 sq. km [1]. It is one of the most densely populated countries too. The country is presently going through an acute energy crisis. With the yearly increase in demand for natural gas estimated over 5 percent, the probability of gas being exhausted within a decade or a decade half perturbs all. Since 2005, the increased gas demand outpaced gas supply resulting in a gas shortage. Without exploration new petroleum resource, the country has entered into a period of major energy shortfall.

Exploration and discovery of gas fields are conducted mostly at the eastern fold belt's Sylhet region. Among the petroleum provinces, Chittagong Hill Tracts are less explored. In Chittagong Hill Tracts of Bangladesh, the presence of anticlinal structures like Sitakund anticline, Sitapahar anticline, Bandarban anticline, Teknaf anticline etc. with a major fault on the western flank and associated gas seepages, attracted various oil and gas companies for drilling the area. Nonetheless, these folds remained poorly studied regarding the surface and subsurface analysis from the geologic point of view.

In the Chittagong Hill Tracts, exploration had been done only in conventional anticlinal structures. An alternative way of the exploration could target unconventional and stratigraphic traps. These are not formed by any fold structure but by the inherent lithological changes (called facies changes) within the subsurface rock layers making their identification difficult.

Further way of petroleum exploration in the Chittagong Hill Tracts lies not only on the conventional stages but also on unconventional targets including underneath the wider synclinal (sloping downward to form a trough) valleys, channel sand, clay diapirs with overpressure shale in the deeper subsurface, thinly bedded plays and so on. None of these had been targeted seriously in Bangladesh. Because of the intense folding and faulting, the source rock and reservoir rocks are exposed at the surface and the anticlines are breached by erosion (USGA-Petrobangla 2001). As the major structures have been breached by erosion, likely explorations targets would be along with the noses of major plunging anticlines where the structures descend into the surface.

With modern technologies being introduced in explorations, unconventional plays have started showing their worth. Attaining a mature stage of exploration implies that the area has to be taken under active consideration.

1.1. Purpose and Scope of Study

The purpose of this research work is to study the petroleum prospect of the comparatively less explored Chittagong Hill Tracts. This research work further focuses on:

- Identification of sandstones with possible reservoir quality of the area;
- Detailed study of different structural type;
- Determination of sand bodies (Lithology, depth, type);
- Characterization of conventional anticlinal traps;
- Identification of other conventional (Complex trap) Trapping;
- Suggesting possible unconventional trapping (Thin bedded play, Synclinal prospect);
- Analysis of stratigraphic Trap Prospect (Channel sand, Sheet sand);
- Overall prospect analysis of the area.

1.2. Study Area

The Chittagong Hill Tracts area is located in the southeastern part of the Bangladesh (Latitude—21˚25'N to 23˚45'N and Longitude—91˚54'E to 92˚50'E [2]. It shares on the south and southeast borders with Myanmar, on the north and northeast with India, and the Chittagong district of Bangladesh on the west. The area of the study is about 20,857 km^2. The Chittagong Hill Tracts encompassing 5 districts—Chittagong, Cox's bazar, Rangamati, Khagrachari and Bandarban (Figure 1).

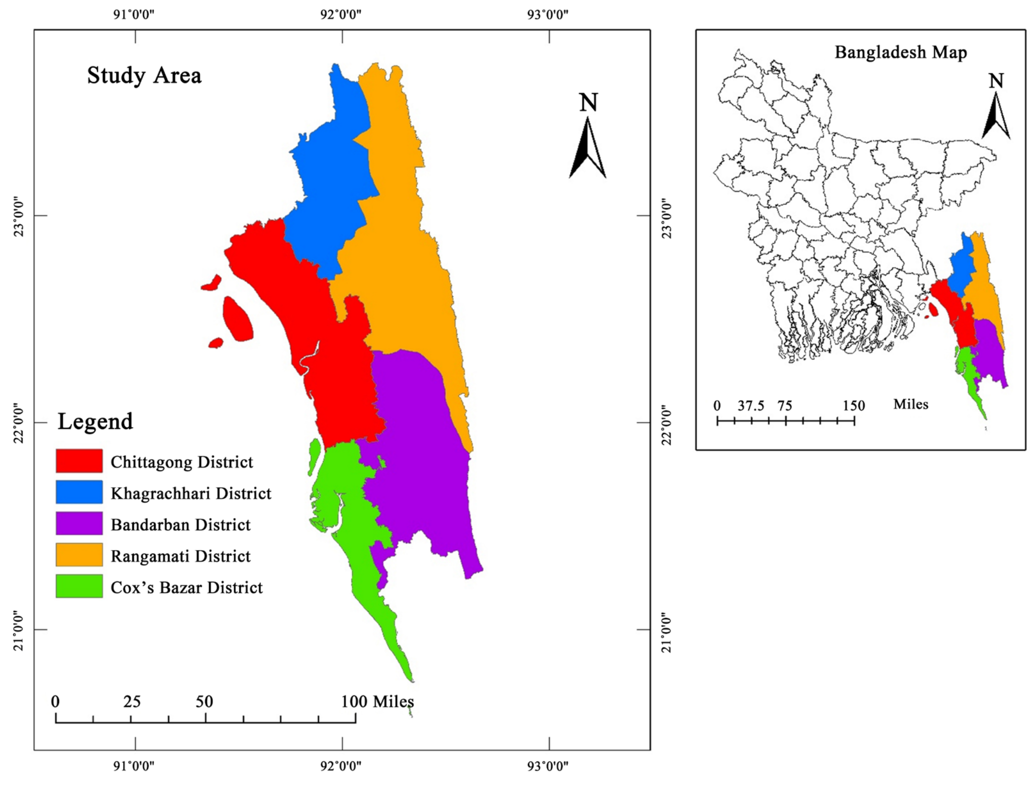

Figure 1. Location of the study area [3].

2. Methodology

The flow chart below (**Figure 2**) shows the steps of the works that have been carried out during the study.

2.1. Petroleum System Analysis

The petroleum system is based on a single source rock or source strata (as well as can be known) and the hydrocarbon accumulations associated with that source. The system can be known, hypothetical, or speculative. The resulting petroleum system is the sum of several factors that act together to enable the accumulation of conventional hydrocarbons. Factors affecting conventional hydrocarbon accumulations include:

- Source rock (a rock layer in the region that has sufficient organic content to provide for hydrocarbons);
- Maturation (the burial of the source rock sufficient to generate hydrocarbons from the organic material within the source rock);

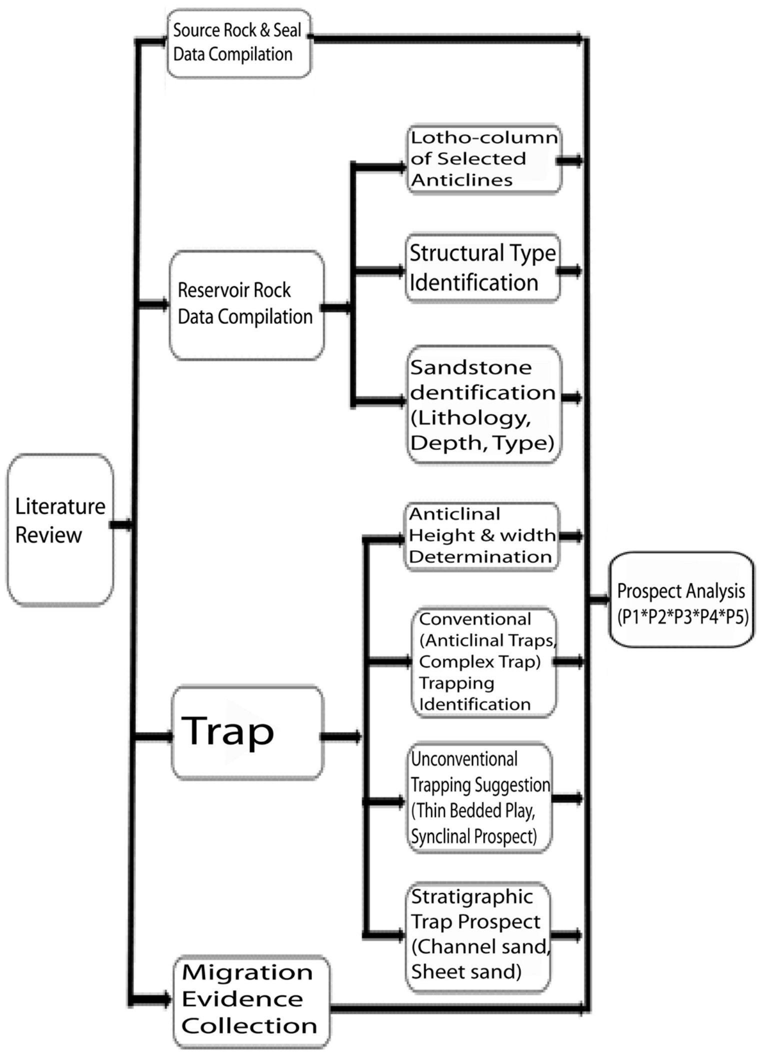

Figure 2. Workflow [3].

- Reservoir rock (one or more rock layers that has sufficient porosity and permeability to store hydrocarbons);
- Trap (the structural or stratigraphic configuration that involves the reservoir rock and where migrated hydrocarbons reside);
- Seal (a layer that is impermeable to hydrocarbon and prevents the hydrocarbon from escaping the trap);
- migration (the path of movement of the generated hydrocarbons from the source rock to a trap);
- And timing (the events must occur in the correct order to create and preserve a hydrocarbon accumulation).

Evaluation of this group of factors is termed "Basin Analysis". The formal presentation of this type of analysis has been developed into the "petroleum system" [4] and subsequent refinements.

In Bangladesh, a Tertiary Composite Total Petroleum System has been described by the U. S. Geological Survey (2001) and a Jenam-Bhuban-BokaBil Petroleum System by Curiale *et al.* (2002). Source rock of the Chittagong Hill Tracts area is Miocene Bhuban shales. The reservoirs are Late Miocene to Pliocene sandstones. A petroleum system can be identified at three levels of certainty. This is indicated by (!) for known, (.) for hypothetical, and (?) for speculative [4]. The Eastern Fold belt Petroleum province is the proven petroleum system.

2.1.1. Prospect Analysis

The prospect of finding an accumulation of natural gas or oil in an area depends on satisfactory coefficient of several factors in the subsurface [5]. Factors are (1) Source Rock (2) Reservoir rock (3) Trap (4) Seal (5) Migration (**Figure 3**).

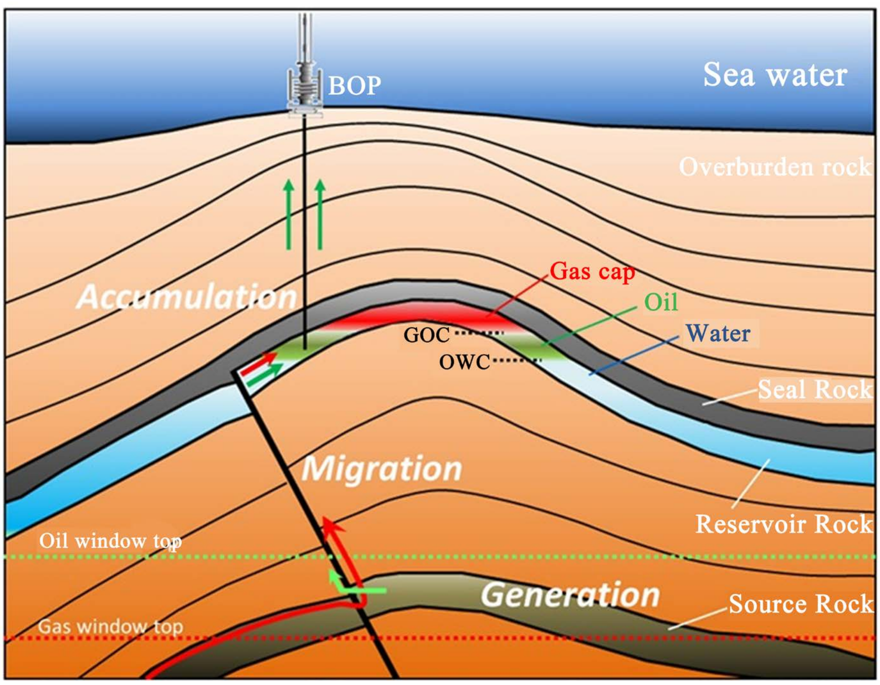

Figure 3. Elements and processes of a petroleum system [6].

The probability of finding petroleum in an area ranges from 1.0 (100% Probability) to 0.0 (no probability) [5] [7].

$$\text{Probability of success} = P_1 * P_2 * P_3 * P_4 * P_5$$

where,

P_1 = Probability of finding source rock;

P_2 = Probability of finding reservoir rock;

P_3 = Probability of finding trap;

P_4 = Probability of finding seal;

P_5 = Probability of finding timely migration.

3. Geology of the Study Area

3.1. Geomorphology

Geographically Chittagong Hill Tracts fall under the Northern and Eastern Hill unit and the High Hill or Mountain Ranges sub-unit. This area covers most of the Chittagong district, some small area of southern Habigonj and the south and eastern borders of Moulvibazar. The Chittagong Hills Tracts has constituted significant hill system in the country, rise steeply to narrow ridge lines, with height from 600 to 1000 meters above sea level. Highly elevated peaks of this area can also be called mountains as hills above 2000 ft. (600 m) with a distinct peak are referred as mountains. Most of the ranges have scarps in the west, with cliffs and waterfall.

The area of Chittagong Hill Tracts is characterized by an immense network of trellis and dendritic drainage consisting of many major rivers draining into the Bay of Bengal. These rivers are Karnafuli, Sangu, Matamuhuri and Feni. The Karnafuli River has many important tributaries, these are Rainkhiang, Chengi, Kasalong, etc.

The hill ranges and the river valleys of Chittagong Hill Tracts are longitudinally aligned. Four ranges, with an average elevation of over three hundred meters, strike in a north-south direction in the northern part of the hill tract districts. These are Phoromain range (Phoromain, 463 m), Dolajeri range (Langtrai, 429 m), Bhuachhari (Changpai, 611 m) and Barkal range (Thangnang, 735 m). There are seven main mountain ranges within Bangladesh. These are: Muranja range (Basitaung, 664 m), Wayla range (most of this range is in Myanmar), Chimbook range (Tindu, 898 m), Batimain range (Batitaung, 526 m), Politai range (Keokradang, 884 m; Ramiu Taung 921 m, Saichal-Mowdok range (Bilaisari, 669 m) and Saichal range [8].

Many of these Hill ranges comprise important geological structure to form very good structural traps for natural gas accumulation. The structures are: Semutang anticline (Average elevation is 80 m except in some areas where it reaches over 160 m), Sitapahar anticline (245 to 330 m in the south to middle of the structure and 330 to 410 m in the northern part), Matamuhuri anticline (Average elevation ranges from 245 to 330 m in the northern part, but in the southern part it increases from 410 to 570 m and the maximum elevation is 710 m in the south) and Bandarban anticline (Maximum elevation varies between 650 and 800 m, with three peaks of around 935 m, 960 m and 965 m located from north to south) [8].

3.2. Tectonic Setup

The Chittagong Hill Tracts is originated as a result of the collision between Indian and Eurasian plates. Chittagong Hill Tracts the Upper Tertiary sandy-argillaceous sediments have been folded into a series of long sub meridional (NNW-SSE) anticlines and synclines represented in the surface topography by elongated hill ranges and intervening valleys [8]. The folded structures are characterized by en-echelon orientation with an increasing degree of intensity and complexity toward the east. Accordingly, the folded flank is divided into three parallel almost N-S trending zones from west to east (**Figure 4**).

The Folded Belt of the Chittagong Hill Tracts can be sub-divided into three subzones namely:

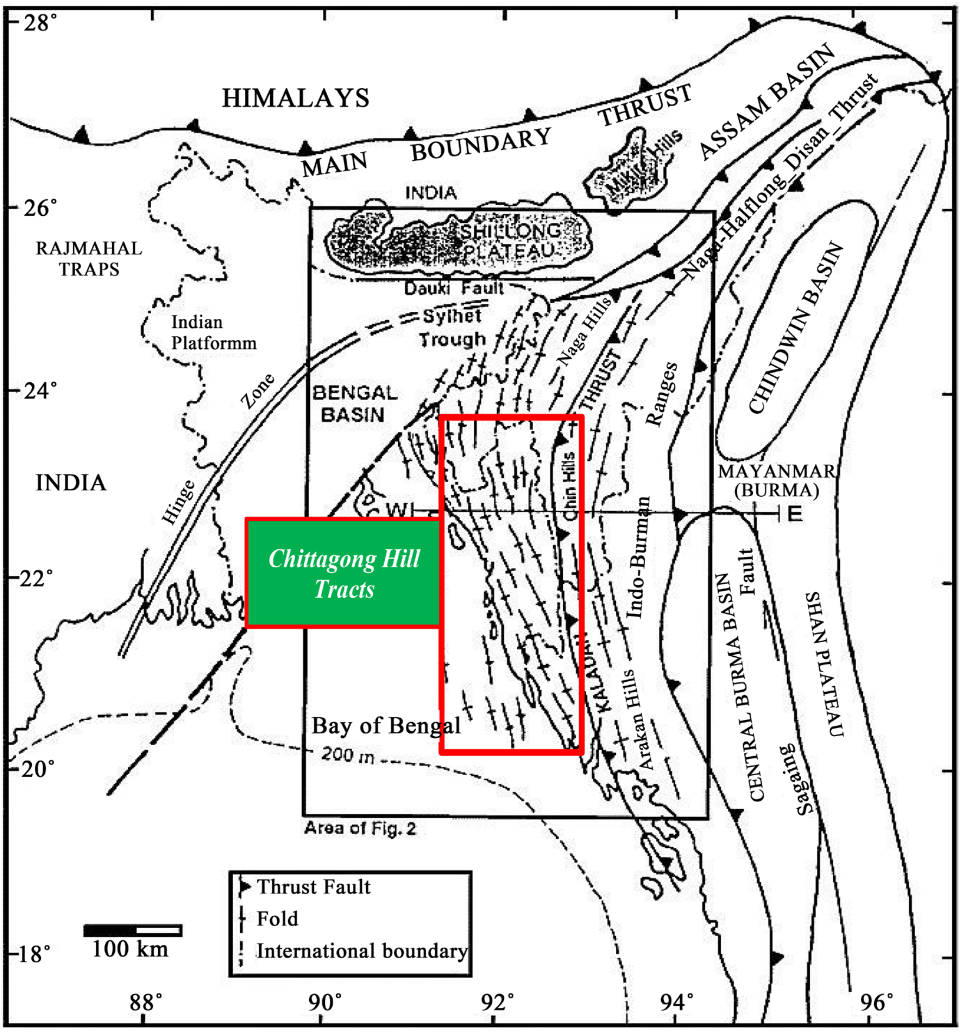

Figure 4. Regional tectonic setting of the Bengal Basin showing its tectonic elements. The hinge zone separates the shallow Indian Platform from the central deep basin and the eastern fold belt [9].

- Western most gentle subzone of box-like structures;
- Middle subzone of asymmetrical and faulted structures;
- Eastern subzone of highly compressed and disturbed structures.

3.3. Stratigraphy of Chittagong Hill Tracts

Detailed stratigraphy of the sedimentary succession and depositional history of the Bengal Basin are not adequately known to date and the time relationships essential for an authentic paleogeographic reconstruction are also not well-established as yet. Conventional stratigraphic procedures have had limited success in the Bengal Basin because of the great thickness of the apparently similar sediment (Table 1). The traditional lithostratigraphic scheme locally used for the moving Indian Plate with the Eurasian Plate took place in Paleocene/Lower Eocene.

Table 1. Stratigraphy of the Chittagong Hill Tract [10].

Age	Group	Formation	Name of the Rock	Description
Upper Miocene Pliocene		Dupi Tilla (2500 to 3000 feet)		Coarse Ferruginous soft sand tone with numerous layers of quartz and chert pebbles; clays sometimes sandy and mottled, occur at intervals. Pebbly sandstone conglomerate beds and fossil wood common.
Unconformity				
Middle Miocene	Tipam	Tipam (About 4000 feet)	Girujan Clay	Dark grey and bluish grey clay with mottling's; lower part consists of ferruginous sandstones.
			Tipam sandstone	Coarse and gritty ferruginous sandstone with interlayers of clays; sandstones are massive, cross bedded and yellowish brown colored; conglomerates in pockets; fossil wood and lignite (about 1600 feet thick in Sitapahar).
	Surma	BokaBil (4000 - 6000 feet)	Upper unit	Bluish grey shales with conchoidal fracture lenses of hard calcareous shale.
			Middle Unit	Alterations of 75 - 350 feet bands of massive and bedded sandstone and th.in layers of shales and siltstones; lenticular and spheroidal concretions common at the top; fossiliferous conglomerates occasional.
			Lower Unit	Thin bedded, bluish grey shales with intercalations of shaly siltstone.
		Bhuban (7500 - 13,000 feet)	Upper unit	Bands of massive and sandstone with interlayers of siltstone at the top, laminated sandy shales interbedded with sandstone at the middle and alternation of sandstone and siltstone at the base.
			Middle Unit	Predominantly a shaly and silty unit with numerous partings of arenaceous material; upper part sandy.
			Lower Unit	Highly micaceous bedded to massive compact sandstones and fossil shales.

3.4. Basin Evolution

According to the continental drift theory, the supercontinent Pangaea divided into two parts. One is Gondwana and the other is Laurasia. The separation of East Gondwanaland comprising India, Australia and Antarctica took place into three major stages.

The first contract of the northwards. Subsequent subduction led to the formation of an ophiolite and mélange belt and later to the rising Indo-Burman Orogeny. The latter finally separated the Burmese basins in the east from the Bengal Basin in the west. The eastern margin of the Bengal Basin coincides with the frontal Fold Belt of the Indo-Burman Ranges. Molasses like Miocene-Pliocene deposits were folded into a series of elongated, generally N-S striking anticlinal and synclinal structures. The Fold Belt stretches from the Chittagong Hill Tracts in the southeast to the southern edge of the Shilong Massif in the north, traversing the Indian state of Tripura and the eastern portion of the Surma Basin (**Figure 5**).

4. Result and Discussion

4.1. Source Rock

A rock that is capable of generating or that has generated movable quantities of hydrocarbons is called source rocks. Source rocks are the first factor to be assessed for any petroleum system and in Bangladesh, the source rocks are present in Late Cretaceous through to Miocene strata (**Table 2**).

Source Rock Potential

Source rock studies have indicated that there are two primary areas that contain strata that are within the hydrocarbon generating window. One is to the south of the Shillong Plateau and corresponds to the Surma Basin or Sylhet Trough and the other is south of the Tangail-Tripura High corresponding to the Hatia Trough (Curiale *et al.*, 2002; Ismail and Shamsuddin, 1991; Shamsuddin and Khan, 1991). Within these two "kitchen" areas the early mature gas generation window is in the lower portion of the Bokabil formation. In addition to these hydrocarbon "kitchen" areas, western Bangladesh contains half-grabens located on the rifted margin of the India Plate that contains Gondwana strata that are mature for hydrocarbons. Studies have also predicted the presence of mature oil windows in Paleocene through Eocene age strata along the Bogra Shelf. These strata could be both oil and gas prone.

The Miocene Bhuban shale is widely developed over the Bengal Basin, including the Eastern Fold Belt, and is probable the youngest source rock unit capable of generating gas, the formation, deposited under a wide range of environmental regimes, from shallow marine deltaic to fluvio-deltaic, has been characteristics by different proportions of alternating shales, silts and sands, with an overall increase of shale content southwards. The sequence is poor to lean in terms of source rock potential, with TOC values averaging from 0.2% to 0.7% (Bangladesh-Petroleum potential and resource assessment 2001). The hydrocarbon

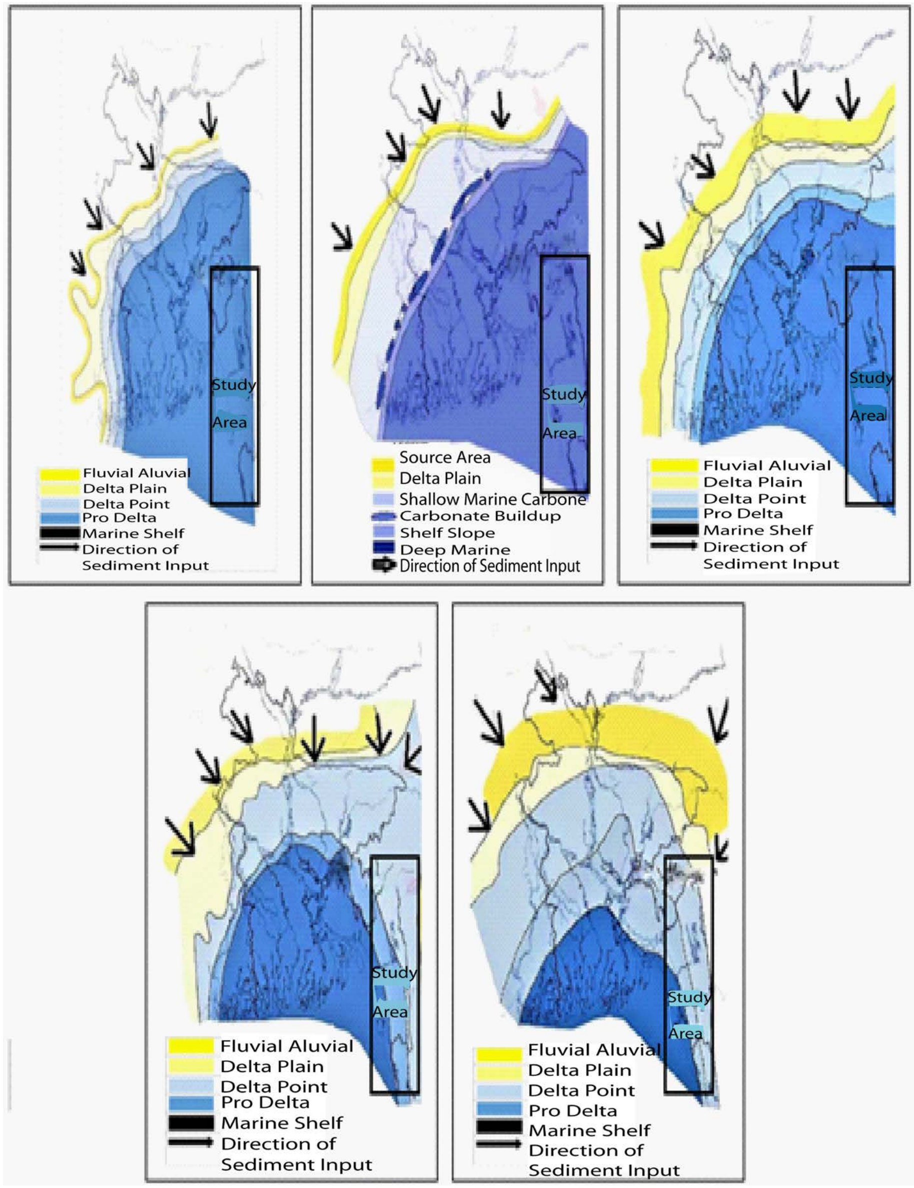

Figure 5. Paleogeographic map of Bengal Basin (Modified after Unpublished Bangladesh Petroleum Potential Resource Assessment Report, 2001).

Table 2. The potential source rocks in Bangladesh [11].

Age	Unit	Sample	TOC (%)	Other
Pliocene/late Miocene	Tipam, Boka Bil, U Bhuban	Beani Bazaar-1 well, Rashidpur-3 well	0.2 - 1.5	HI 104 - 225 mg/g
Mid-Miocene	L Bhuban	Adamtila-1 well (India)	1.76 (avg)	2 - 3 mg/g (avg), Rock-Eval S2
Mid-Miocene-Oligocene	Atgram, Renji, U Jenam?	Atgram-1 well plus wells in Surma Basin	0.4 - 1.2	HI to 155 mg/g, marginally mature
Oligocene	U Jenam	outcrop	1.4 - 2.7	HI 121 - 166 mg/g, Up to 0.15% extractable hydrocarbons
Eocene-Paleocene	Kopili, Cherra	outcrop	up to 16	gas prone
Tertiary	Undifferentiated	Titas-1 well	0.45 - 3.60	100% humic organic matter
Mesozoic	Gondwana	surface and subsurface	up to 60	gas prone

unit ratio of this unit suggests that this unit might have some potential for gas generating.

4.2. The Trap

Traps are underground rocks formation where a porous and permeable reservoir rock underlying by impermeable seal rock and where oil and gas are accumulated. It may be conventional traps (anticline, fault closure trap, etc.), unconventional traps (synclinal areas) and stratigraphic traps (channel sand, pinch-outs).

4.2.1. Conventional Traps

1) Simple Trap: Anticlinal Trap

The eastern portion of Bangladesh is characterized by anticlines due to the tectonic regime resulting from plate subduction. The Chittagong-Tripura Fold Belt, or Eastern Fold Belt, trends NE-SW in the northeast then arcs around to trend NW-SE in the southeast. The NW-SE trending anticlinal structures are potential traps for hydrocarbon accumulation. Hence the petroleum system of the study area becomes very prospective [12]. Gas and condensate are the primary products from the fold belt but oil seeps, shows, and minor oil production indicate oil discoveries in Miocene age strata may be possible.

A highly disturbed anticline is always of least importance for hydrocarbon accumulation, whereas undisturbed have the highest potentiality to host hydrocarbon. Anticlines of the Chittagong Hill Tracts are intensely disturbed by thrust faults often with diapiric intrusion in the subsurface.

The Chittagong Hill Tracts have a series of long sub meridional NNW-SSE directional anticline and syncline (Table 3). The folded anticline is characterized

Table 3. Determination anticlinal size of Chittagong Hill Tracts from Geological map of Bangladesh, N.E. India and N. Burma by Norwegian petroleum directorate.

Anticline name	Length (KM)	Width (KM)
1. SITAKUND	70	11
2. SEMUTANG	19.25	6.875
3. CHANGOTANG	24.5	4.5
4. SARDINA	26.25	5
5. SHISHAK	21.25	5
6. JAMPAI	43.25	7.5
7. KASALONG	21.325	3.95
8. BALASARI	26.25	4.375
9. GOBAMURA	41.875	3.75
10. BARKAL	31.75	5.5
11. SITAPAHAR	38.75	4.375
12. PATIYA	25.75	6
13. JALDI	26.75	6.25
14. GILASARI	27	5

by en-echelon orientation. The fold structures generally have higher intensity towards the east.

The traps in Chittagong Hill Tracts are structural traps *i.e.* folded anticlines. Generally, the anticline is affected by once or more faults. In some of the folded anticlinal traps, a number of faults cause compartmentalization of the reservoirs thus disrupting the continuity of the latter, In the extreme eastern part of the fold belt, the anticlinal structure is severely disrupted by major thrust faults often with diapiric intrusion in the subsurface, These structures are thus breached and their trapping capabilities are damaged or destroyed (**Figure 6**).

Anticlines are prospective for petroleum accumulation around the world. Chittagong Hill Tracts are highly disturbed due to faulting and diapirism (**Figure 6**). It is evidence from a few of the studies. For example, the structural composition of Sitakund anticline is quite complex (**Figure 7**). The western flank is affected by a longitudinal fault running close and almost parallel to the axis [13].

Due to thus complex faulting mechanism, hydrocarbon cannot accumulated in this region. For example, a well (Sitakund well-1, 1990 by Burmah Oil Company (BOC) [14] drilled in the central portion of the Sitakund anticline. It is clearly evident that the central portion is highly affected by faulting (**Figure 8**).

Finally, all of the anticlines in the Chittagong Hill Tracts and adjacent areas are affected by thrust faults and diapiric intrusion. So, crestal part of those anticlines is not the prospect for hydrocarbon trap. Prospect can be lied in the nose or plunge area of an anticline.

2) Complex Trap: Fault Closures Traps

Downthrown fault closures in the fold belt may trap hydrocarbons (**Figure 9**). An example of this type of trap is the Chhatak, East downthrown fault closure. More of this kind of potential structural trap undoubtedly exist in the fold belt.

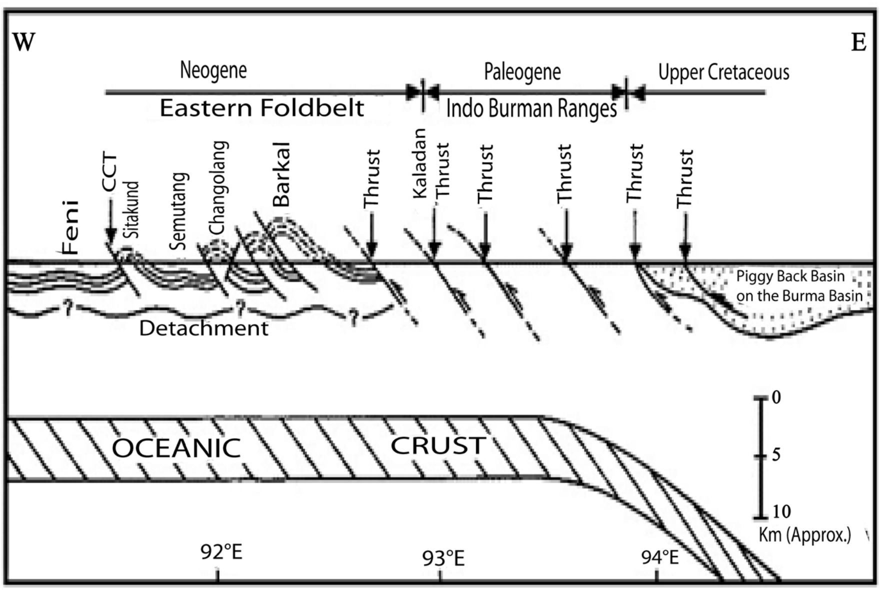

Figure 6. A geologic cross section constructed using surface geologic mapping and data from oil and gas wells (Source-Geologic Map Foundation).

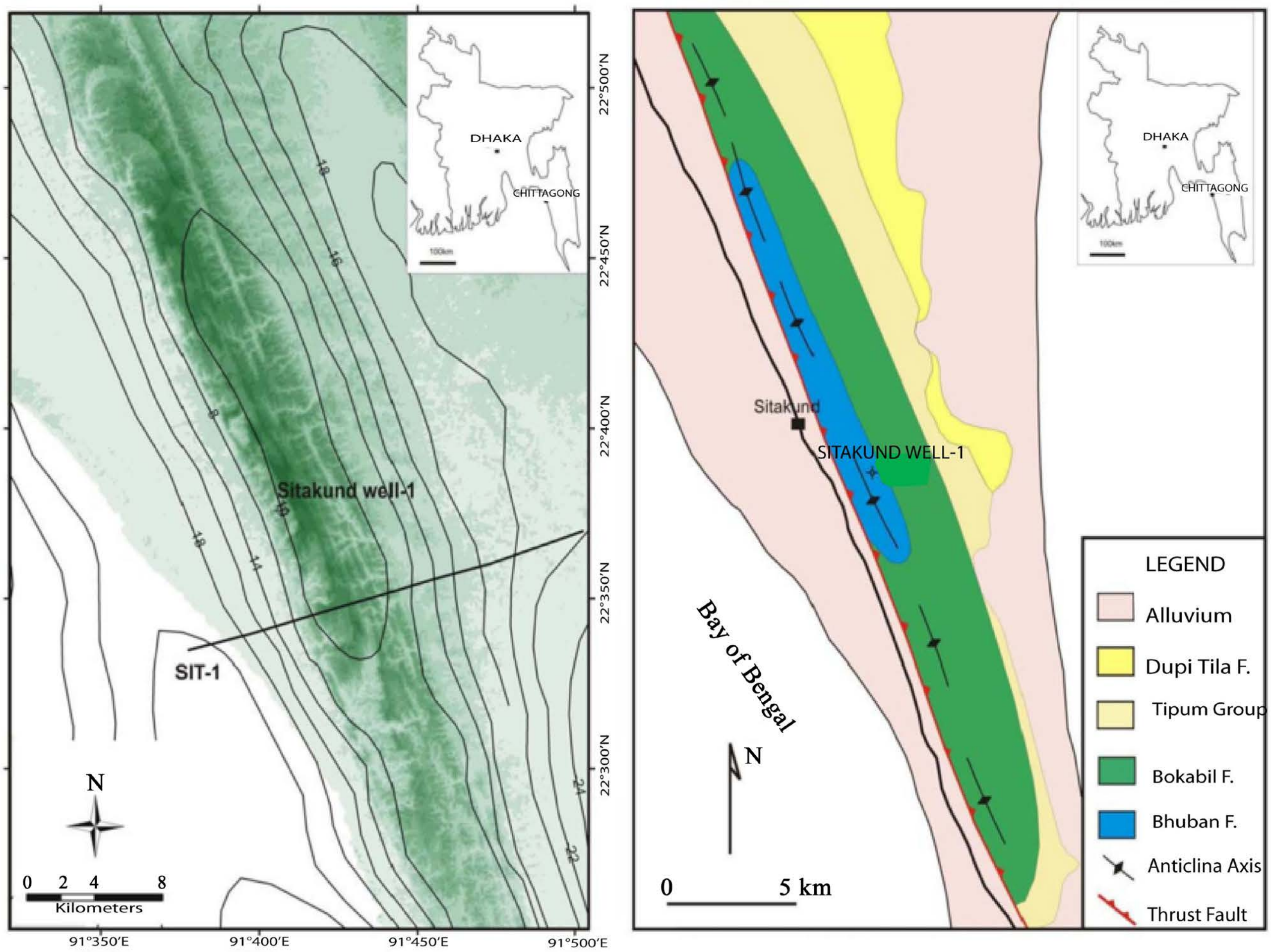

Figure 7. Geological map (right) of the Sitakund anticline is showing the generalized NNW-SSE axial trend with a major thrust fault verging west [15].

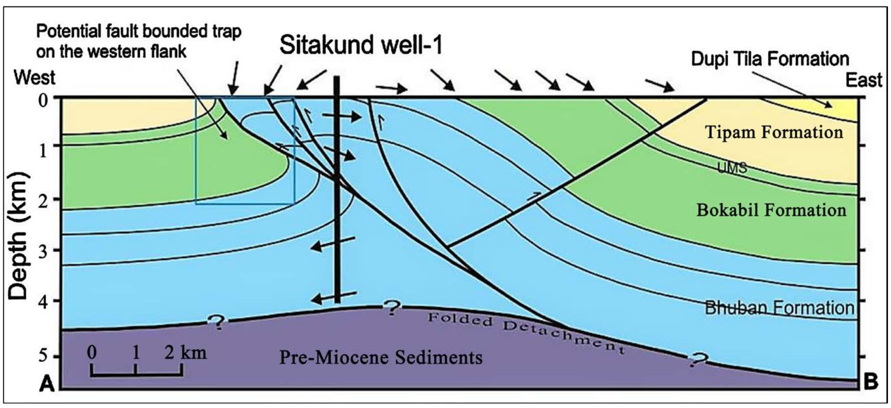

Figure 8. Anticlinal structure map of Sitakund anticline well-1 [15].

4.2.2. Unconventional Trap: Synclinal Areas of Chittagong Hill Tracts: (A New Opportunity)

In structures of Chittagong Hill Tracts, the entrapment of gas is mainly structural and limited to anticlinal highs. Till now, the exploration was mainly limited to these highs only. But a bit deviation from the conventional anticlinal exploration,

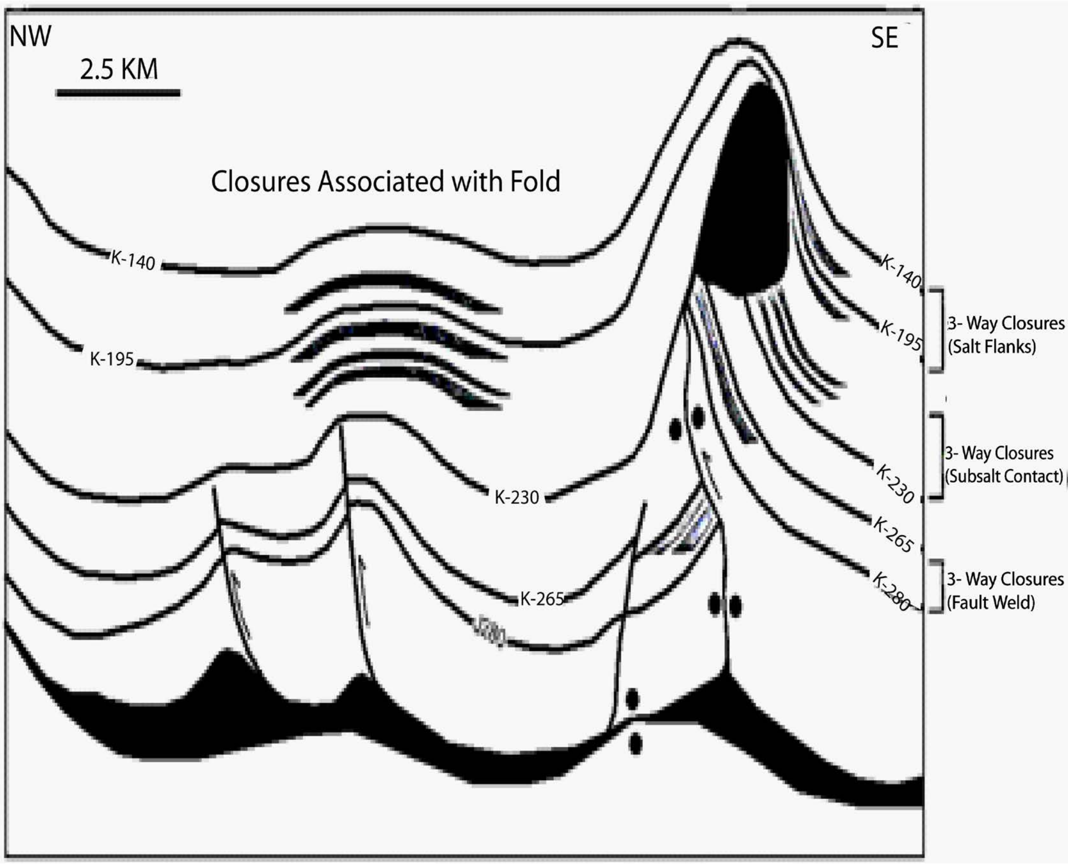

Figure 9. 3 way fault closure trap (Source—CNSOPB).

the adjacent broad flat synclines can be targeted for stratigraphic traps with a bit of caution.

Exploration in synclinal areas of Chittagong Hill Tracts has not been conducted yet. Till now, the anticlinal highs were the main target for exploration. Due to rapid latero-vertical facies variation coupled with tectonic disturbances, targeted reservoirs in anticlinal closures sometimes give setbacks.

Some exploratory successes in synclinal parts of Tripura Fold Belt region, like Sundalbari and Khubal structures in stratigraphic plays of Bhuban Formation of Miocene age attracts consideration to the geoscientists to think a bit unconventional until now (**Figure 10**). And most of the anticlines in the Tripura are the continuation anticline in the Chittagong Hill Tracts. So synclinal prospect is also applicable for Chittagong Hill Tracts.

The adjacent eastern synclinal area of Sundalbari structure in Tripura, India produced gas approximately 160,000 m^3/d [16]. Similarly, a sand belonging to Middle Bhuban Formation of Miocene age produced gas approximately 145,000 m^3/d in Khubal structure, which is also in synclinal area. The up dip pinch-outs in the limbs of the anticlines in adjacent synclinal areas, fault closures in plunge parts of the structures, unconformity related entrapments can be the potential targets. The understanding of stratigraphic traps, their trapping mechanism has brought these successes. These discoveries have established that a significant regional potential exists in the synclinal areas of Chittagong Hill Tracts because many of these structures are the continuation to the Chittagong Hill Tracts and adjacent areas.

4.2.3. Stratigraphic Trap

1) Channel Sand

Channels if are filled with sands, can act as a good reservoir for hydrocarbon. If channel itself is sand filled and banks are shale or clay filled then hydrocarbon can be trapped there. Similar sand filled channels can be found exposed in the outcrops of rocks in different places of the hill tracts area (**Figure 11**). This type

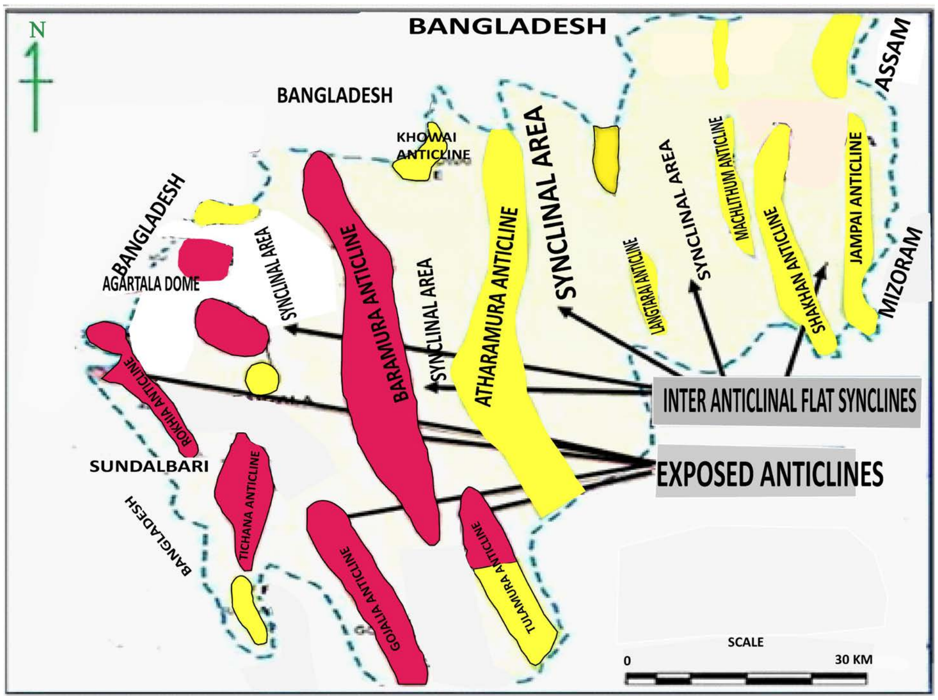

Figure 10. Structure of the tripura fold belt [17].

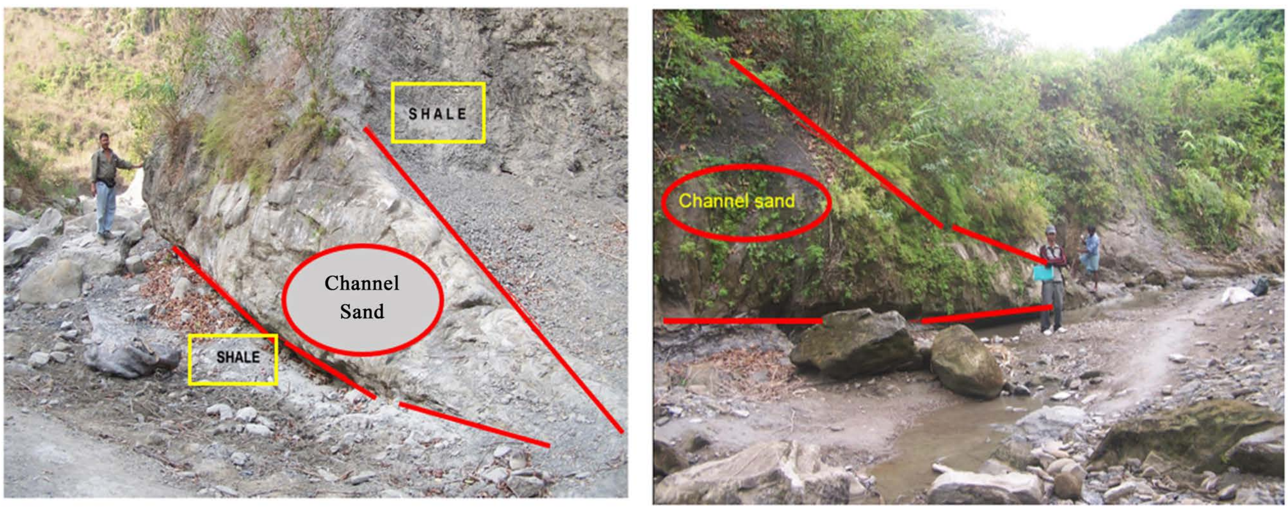

Figure 11. Channel sand in Teknaf anticlinal area [18].

of features can be seen in many places for example, Baghbhuna Chara section of Dakshin Nihla anticline at Teknaf, Inani Anticline at Cox's Bazar and many more.

2) Pinch-Outs

The termination by thinning or tapering out of a reservoir against a nonporous sealing rock creating a favorable geometry for becoming a reservoir (**Figure 12**). Bengal basin has been formed by the sediments brought in by the river through the erosion of the uplifted Himalaya. Lateral facies changes are prominent in Bengal Basin. This changed facies create different stratigraphic anomalies. Stratigraphically, there is no massive homogeneous sand body found in hill tracts region. As a result, some stratigraphic traps are prominent in Chittagong Hill Tracts areas like pinch-outs. Pinch-outs traps are very potential reservoir in all over the world like Bell creek Oil field, Montana, USA. So, that's why pinch-outs trap is also possible reservoir for hill tracts region.

4.3. Reservoir Rock

A reservoir is a subsurface rock formation where natural gas is accumulated. Reservoir rock has must be reasonable porosity and permeability. There are two most common type of reservoir rock throughout the world that is sandstone and limestone.

Sandstone is the only reservoir rock of all the gas field of Bangladesh. The sandstone belongs to the Surma group unit (Bhuban and Bukabil formation) of Miocene-Pliocene age. The repetitive alternation of sandstone and shale in the Bhuban and Bukabil formation provide adequate reservoir combination for the gas to be accumulated provided suitable traps exist [19]. The depth of the reservoir rock of Surma group from less than 1000 m to more than 3000 m.

Barail group is overlying by Surma group. This group is broadly exposed to the surface and also observed in all the wells in eastern Bangladesh. The Bhuban and Bokabil formations are middle to lower Miocene Surma group, have been deposited during transgressions and regressions. In the Evans (1932) lithostratigraphic scheme, the Bhuban and Bukabil formations are subdivided based on the relative proportion of the argillaceous or arenaceous beds.

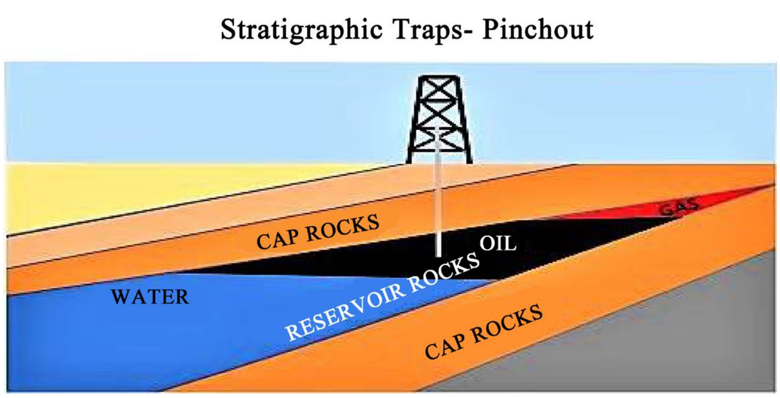

Figure 12. Stratigraphic trap: Pinch-outs (*AONG*).

The porosity and permeability properties of the reservoirs are good to excellent. The general range of porosity from 15% to 20% and the permeability 100 to 400 millidarcy [1].

4.3.1. Sitakund Anticline

The Sitakund anticline, north of Chittagong is one of the most westerly anticlines in the fold belt. Seasonal fluctuations in water and sediment discharge to the shelf were the principal controls on sedimentation in this region. These seasonal fluctuations control the current velocity and the dominance of sand/silt sedimentation over clay deposition from suspension. The sedimentary rocks were mostly shale, sandstone and sandy shale alteration which were exposed by the road cutting and erosion by streams (**Table 4**). Absence of index fossil made it hard to identify the accurate age of rock units of the area but the hill range is the continuation of Alpine-Himalayan orogeny and the hill range was formed during the Miocene epoch.

The sediments record an overall coarsening upward, progradational trend. The reservoir rock of Sitakund anticline is lower deltaic sandstones of the Bokabil Formation is considered as the potential reservoir rock (**Figure 13**).

The potential reservoir rock accumulated during Miocene to Mio-Pliocene period. Type of reservoir rocks is quartzose sandstones in composition with low feldspar, low volcanic lithic grains and abundant sedimentary and low grade metamorphic lithic grains. Mechanical compaction, cementation, dissolution, and precipitation of authigenic clays all affect significantly the porosity. Thickness of the reservoir rock approximately little more than 330 (meters). Porosity

Table 4. Stratigraphic succession of the sitakund anticline [19].

Group	Formation	Member	Lithological Description	Thickness (m)
Surma	Bokabil		Erosive contact 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. Conformable surface.	330+
	Bhuban	Upper	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.	260
		middle	Mainly shale with subordinate sandstone and siltstone. Black thinly laminated shale with lenses of sandstone and siltstone, which are grayish white. Bluish gray to gray massive and variously stratified sandstone. Matrix supported conglomerate locally present. Base not found.	130

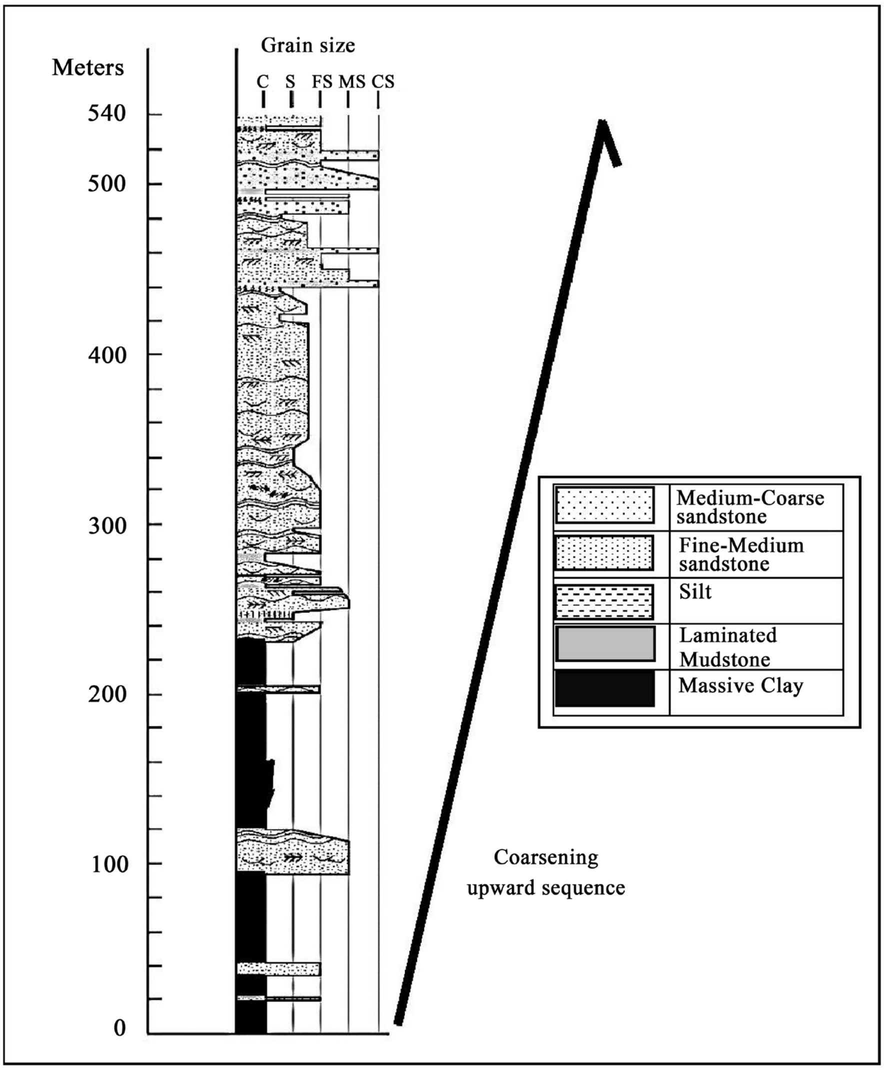

Figure 13. General litho-stratigraphic column of Sitakund anticline [20].

ranging up to 14% [21].

4.3.2. Sitapahar Anticline

The Sitapahar anticline, about 40 km in length and about 4.5 km in width, is a doubly plunging, elongated asymmetric anticline with an axial trend of N20˚W - S20˚E and a plunge of about 4˚. The steeper western flank dips at angles varying from 15˚ to 70˚ gentler eastern flank of the structure has dips varying from 10˚ to 45˚ [21]. The rock of the stratigraphic units exposed in the Kaptai-Chaondrghona area is sedimentary origin. On the basis of lithology the rocks have been divided into five formation:

- Sitapahar sand shale formation;
- Baraichari shale formation;
- Chandragona claystone unit;
- Lichubagan sandstone;
- Alluvium.

The oldest rock identified as shilchari sandstone and shale exposed on the axis. The youngest rock identified as lichubagan sandstone, Baraichari shale and Chandragona sandstone (Table 5).

Reservoir rock of Sitapahar anticline mainly sandstone. Accumulated during Plio-Miocene period. Sandstone is medium to fine grained yellowish brown, moderately compacted, Massive sandstone with the presence of quartz pebbles with some clay balls (Figure 14). Thickness of the reservoir rock is about 390 meters.

4.3.3. Bandarban Anticline

The Bandarban anticline belongs to the middle zone of the folded belt of Chittagong and Chittagong Hill Tracts. It is the extension of the Chimbook Hill Range. The structure is attached in the north by Sitapahar anticline, Lakhadong and Patia structure in the east, Jaldi, Matamuhur in the west. The trend of the Bandarban anticline is NNW-SSE. It is parallel to its both eastern and western sides hill ranges which make an echelon arrangement. Monoclinal flexures are present in both part of the limb. Thus, the anticline has a broad hinge zone which resembles that it is a box fold. Both the flanks were suffered by faulting which can be determined by field evidence. Younger rocks are thrusted upon the older rocks (Table 6). Both folds and faults are of Mio-Pliocene age when the Indian plate collided with the Burmese plate [22].

The reservoir rock of Bandarban anticline is sandstone with minor siltstone. Sandstones are yellowish brown, moderately compacted, medium to fine grained sandstone with interbedded shale (Figure 15). Age of the reservoir rock is

Table 5. Stratigraphic Succession of the Sitapahar Anticline [23].

Age	Group	Formation	Local Unit	Lithologic description	Thickness (m)
Recent			Alluvium	Unconsolidated sand, silt and clay	
Plio-Miocene	Tipam	Dupi Tila Sandstone	Lichubagan Sandstone	Medium to fine grained yellowish brown, Moderately compacted, Massive sandstone with the presence of quartz pebbles with some clay balls	390+
Middle Miocene		Girujan Clay	Changrachari shale	Bluish fray mudstone with greenish gray thickly laminated shale	556
		Tipam Sandstone	Chomdraghona Sandstone	Medium to coarse grained, reddish brown, thickly bedded, moderately compacted ferruginous sandstone	280
Early Miocene	Surma	Bokabil	Baraichari shaley-sandstone	Bluish gray, thin to thickly laminated shale alternated yellowish brown, medium to fine grained sandstone	973
		Bhuban	Wagga sandstone	Yellowish brown, medium to fine grained massive sandstone with shale and siltstone	115
			Shilchari sandstone and shale	Light gray, fine to medium grained, moderately compact siliceous sandstone alternated with bluish gray, moderately compacted, thinly to thickly laminated shale	778+
Base not Found.					

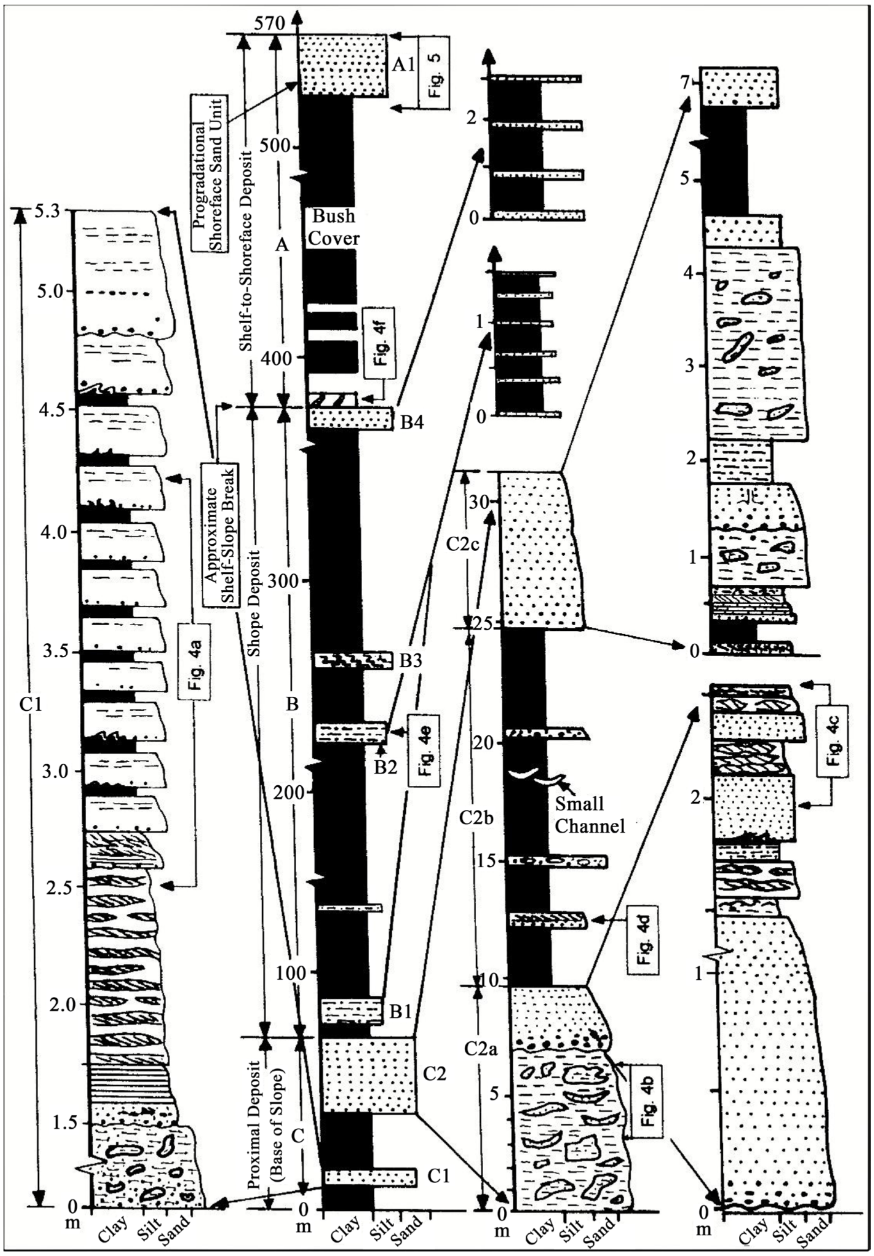

Figure 14. General litho-stratigraphic column of the lower part of the Surma Group exposed in the Sitapahar anticline with detailed sedimentological logs of salient portions [24].

Table 6. Stratigraphic Succession of the Bandarban Anticline [22].

Age	Unit	Lithology	Depositional Environment	Thickness (m)
Plio-Pleistocene	Unit-3 (Equivalent to Dupitila Formation)	Yellowish brown, very loosely compacted, medium to coarse grained, Ferruginous sandstone with minor shale	Fluvial environment	1000+
Pliocene	Unit-2 (Equivalent to Tipam Formation)	Yellowish brown, moderately compacted, medium to fine grained sandstone with interbedded shale	Flavio to Deltaic environment	300
Miocene	Unit-1 (Equivalent to Surma group)	Alternation of sandstone and shale, yellowish brown, moderately compacted, matured, medium to fine grained sandstone and bluish gray laminated shale.	Shallow marine to Deltaic environment	1000+

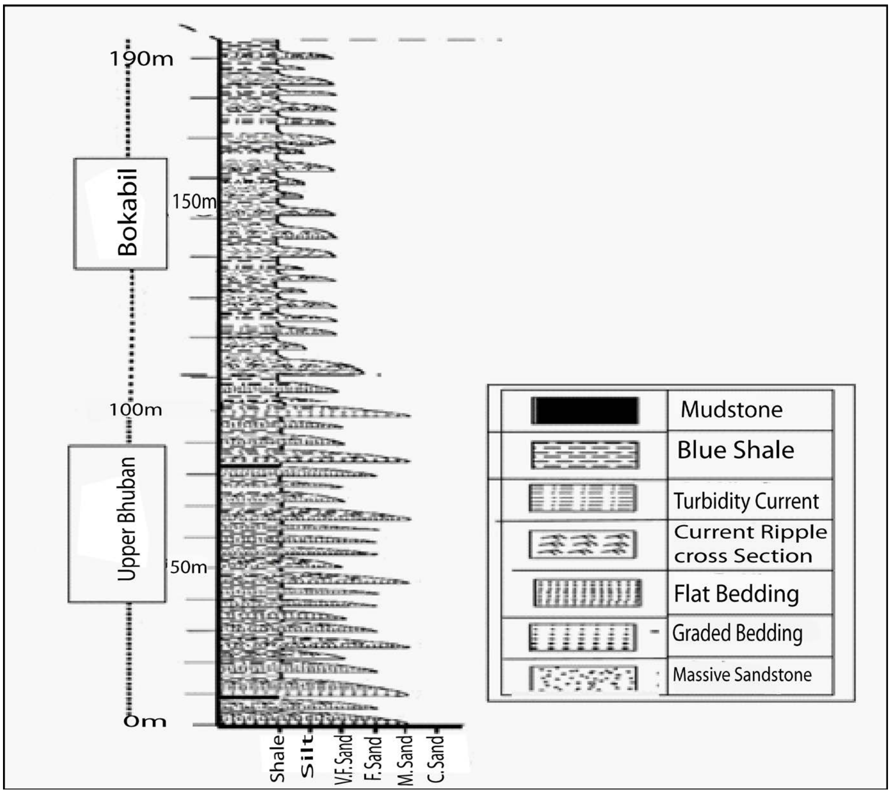

Figure 15. Vertical Lithosuccession of Nilgiri road cut section, Bandarban anticline, Chittagong Hill Tracts [22].

Miocene-Pliocene period. Porosity of the sandstone 15-20% [1]. This sand body approximately 973 m thick.

4.3.4. Dakhin Nhila Anticline

The Dakhin Nhila anticline located at the extreme southeast of Bangladesh territory. This structure is a double plunging elongated, asymmetrical and box like anticline with NNW-SSE trending elongated Dakhin Nila anticline is only 4.8 km wide. The exposed rock sequence in this area is Bokabill formation and Tipam sandstone (**Table 7**).

Sandstone is the potential reservoir rocks of Dhakin Nhila anticline. Mostly argillaceous sediments with little coverage of arenaceous sediments characterise the structure.

4.3.5. Teknaf Anticline

Teknaf anticline located in the SE Bangladesh. The 775 m thick stratigraphic sequence consists mostly of shale, silty shale, and mud beds of variable thicknesses (**Table 8**). Eight lens shaped channel sandstone bodies were identified at depths of 430 to 720 m, representing a gradual change from mud- to sand-dominating facies on a shallow marine shelf with tide influence.

The sandstones are mostly medium to fine grained, sub-angular to sub-rounded, well to very well sorted and texturally mature with a wide range of porosity (0% - 11%). The potentiality of these channel sandstones to form combination traps

Table 7. Stratigraphic Succession of Dakhin Nhila Anticline [25].

Age	Formation		Lithological Description
Pleistocene	Tipam Sandstone		Sandstone with little alternating bands of siltstone and shale.
Plio-Pleistocene	BokaBil	Upper Part	Mostly silty shale with sub-ordinate shale and minor sandstone bed and calcareous sandstone band. Shales are laminated, grey to bluish grey color and contain many streaks and lenticles. Yellowish brown colored, medium to fine grained, apparently massive sandstone and siltstone bed have occurred rarely.
		Lower Part	Mostly shale with subordinate silty shale, frequently channel sand body and occasional massive sandstone bed. Shale is mostly bluish grey colored, thickly laminated and silty shale are grey to light grey colored, thinly laminated with frequent silt streaks. Channel sandstone is yellowish brown to grey colored, fine to medium grained massive sandstone embedded in shale.
	Upper Bhuban		Sandstone, shale/silty shale, siltstone, silty sandstone.

Table 8. Stratigraphic Succession of the Teknaf anticline in Sear Zone [26].

Age	Formation	Lithological Description
Pleistocene	Tipam Sandstone	Light grayish, fine to medium grained sandstone with little alternating bands of shale and siltstone.
Plio-Pleistocene	BokaBil	Mostly silty shale with subordinate shale and minor sandstone bed and laminated, grey to bluish grey colored and contain many silt streaks and lenticles. Falser bedding are common, yellowish brown colored, medium to fine grained apparently massive sandstone and silt stone bed have occurred rarely.

requires their greater abundance in the subsurface within a structural closure. However, the discovery of a gas seep during this study in the axial zone of the anticline indicates a good probability for the occurrence of hydrocarbons, which requires confirmation by exploratory drilling or seismic survey.

4.4. Seal

The seal rock of the Chittagong Hill Tracts consists of a few regionally extensive and numerous locally effective shales. These seals are typically silty shales or mudstones with excellent sealing capacity and developed locally within Miocene-Pliocene succession. The abundance of stacked pay intervals in Bangladesh gas fields with separate gas-water contacts proves the effectiveness of intra-formational seals (Shamsuddin). Seal rocks of Chittagong Hill Tracts are not pure shale, they are silty shale. So these rocks are not very good for cap rock and that's why some hydrocodone migrated through these seal rocks. Some evidence also proved that like numerous surface seepages of gas in Chittagong hills areas.

4.5. Migration

Migration are two types: Primary migration and secondary migration. Primary migration, the emigration of hydrocarbon from the source rock (clay or shale) into permeable carrier beds (generally sands or limestones). Secondary migration refers to the subsequent movement of gas and oil within permeable carrier beds and reservoirs [27].

The gas migration from source to reservoir-trap is one of a very young geological episode of Bangladesh. The migration path of natural gas is very long distance. It has been suggested that the gas migrated as much as 4000 meters upwards from source rock to reservoir rock above (Petrobangla 2000).

Generally two types of migration occur in Chittagong Hill Tracts. These are: cross fault migration which is gas migrated from potential source rocks to potential reservoir rocks through a fault. For example, gas migration in Sitakund anticline. Some evidence suggests that gas is migrating till to date in Sitakund anticline. Various Gas seepages were found almost all over the Sitakund region. Gas seepages were at Lobonakkho chara and Barabkund Temple in Sitakund (**Figure 16**). Very little amount of gas is flowing at the temple, which helps to light up the fire beside that.

Another type of gas migration is longitudinal or vertical migration. Longitudinal gas migration is generally complex and pathway are along with faults and fractures. Maximum anticline in Chittagong Hill Tracts is thrusted. For example in Sitakund anticline, longitudinal faults runs through the western flank of this anticline and theses faults may be responsible for oil seeped at the surface [13].

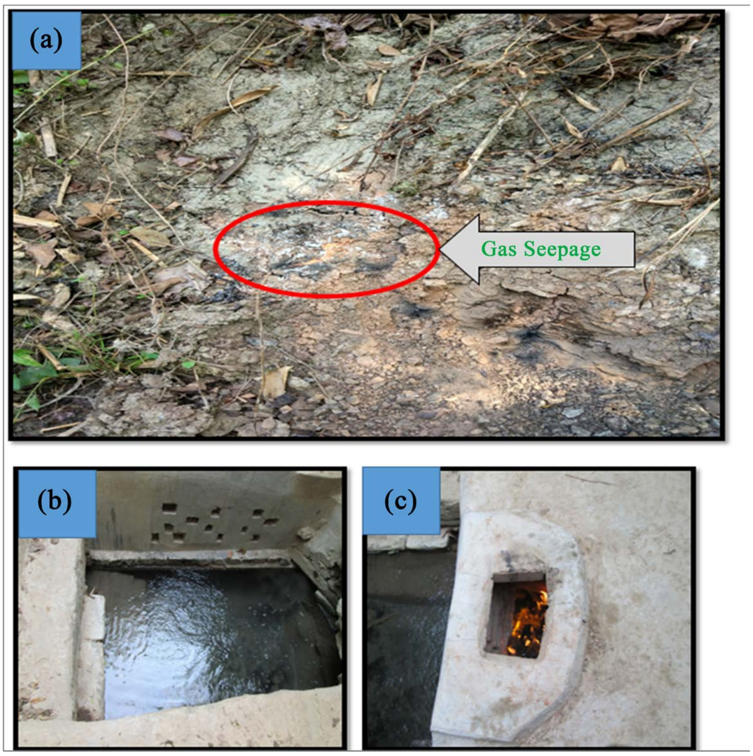

Figure 16. Gas seepage in Sitakund anticline region because of fault. (a) Lobonakhyo-Chara (49 *batch*, *Geology Dept. DU*); ((b) & (c)) Barabkundo, Sitakund anticline [28].

5. Conclusion

Conventionally, most of the gas fields of Bangladesh are confined in the central part, Sylhet zone and eastern part of Bangladesh. Chittagong Hill Tracts area has not been well explored till now. After discussing all five elements of petroleum system, it can be concluded that Chittagong Hill Tracts have very good prospect for hydrocarbon. Some evidences also support this like gas seepage, oil sand etc. This research is a compilation work. All data of this research are secondary data. If detailed field work had been done for collecting primary data, this project work would have been more resourceful. The collection of primary data could not be done due to lack of resources. The ultimate outcome of this research work is to find out the hydrocarbon prospect in Chittagong Hill Tracts. So, exploration geophysicists should conduct extensive exploration in this virgin area of CHT and its adjacent areas as well which might be a possible support to minimize the upcoming energy crisis of the country.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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