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Assessment of Unconventional Hydrocarbon Potential in the Eastern Folded Belt of Bangladesh: A Comprehensive Geological Study

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Abstract
The thin-bed reservoir units of the Eastern Folded Belt are medium to fine-grained and well sorted, with frequent alteration of sand shale with the prevalence of parallel bedded sandstone. The samples collected from the field are studied in the laboratory to characterize the reservoirs more precisely. The overall workflow of laboratory analysis has been categorized into three sorts. In the petrographic study, the thin section of the samples is studied to determine their textural properties thoroughly. The porosity and permeability have been determined by analysing textural characteristics and diagenetic changes. This microscopic section evaluates the effects of diagenetic processes on reservoir quality. A scanning electron microscope was utilized to complement the inconclusive results. The most crucial finding from this study is that the thin bed of the unconventional reservoir and the conventional reservoir are in close proximity in the context of reservoir quality. The average porosity in a thin bed reservoir is 4 to 12%, and pore spaces are interconnected. So, the permeability rate is good enough to flow the hydrocarbon through these pore spaces. The thickness of the thin bed and tight reservoir (average porosity 2 to 8%, but pore spaces are not interconnected) is only as prominent as 1 or 2 meters. Subsequently, though the vertical thickness is not so high, they keep up a momentous tirelessness of horizontal progression. With advanced technology, the gas production rate from unconventional reservoirs in Bangladesh can be expanded significantly, and thus, the energy crisis might be reduced. At the same time, the dependency on LNG could be reduced, and the economy of Bangladesh could be sustainable.

Key Word: *Unconventional reservoir; Conventional reservoir; Reservoir quality; Energy crisis.*

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I. Introduction

In the last decade, unconventional gas resources have emerged as a viable energy source. This became possible after hydraulic fracturing and horizontal drilling successfully developed in the Mississippian Barnett Shale in the Fort Worth Basin.

In a petrophysical sense, thin beds can be defined as thinner than the resolution of the logging tools used to characterize them. This implies that the direct log values represent not the true bed or layer characteristics but an average of multiple beds (Helfardi et al., 2018). For a thin-bed reservoir to become a successful thin-bed gas play, the following characteristics need to be considered: (a) permeability, (b) lateral persistence, (c) gas-in-place, (d) maturation, (e) mineralogy, (f) brittleness and (g) pore pressure (Chong et al., 2017). Besides all these, the depth of the thin-bed gas formation should also be considered, as it will have a bearing on the economics of the gas recovery. An optimum combination of these factors leads to favorable productivity. Different thin-bed reservoirs have different properties, so it is imperative to study them before any exploitation plan is implemented (Hardage et al., 1998). Another vital point to consider is that such properties can be determined at the location of the wells where the borehole logs and core data are available.

However, different geophysical workflows must be used on 3D subsurface seismic data to characterize the thin-bed formations. These beds can be identified using the image logs, whereas the same is not detectable on the conventional (Resistivity, Neutron and Density logs) reservoirs (Hardage et al., 1994). Vertical resistivity increase indicates the presence of resistivity anisotropy caused by hydrocarbon-bearing thin beds.

Thin reservoirs with characteristic features like narrow layer thickness (~ 01 – 2 m), vast lateral extent, high-resolution sand-shale alternations, and porosity, permeability, water saturation, etc., which are distinguishable from the adjacent beds, are often observed in the field sections of Sylhet and Bandarban structures. Field investigations suggest that the reservoir quality of thin beds often deteriorates due to tight lithology with frequent lateral facies changes. Field study indicates that the thickness of thin bed reservoirs varies (5 cm to 155 cm) with broad lateral extents (> few km, in some instances). Therefore, their cumulative thickness is enough to consider them as a good-quality reservoir. This is the reason it can increase the overall hydrocarbon reserves.

Bangladesh has relied on conventional reservoirs for energy production for an extended period of time. It was not conceivable to focus profoundly on unconventional reservoirs as the idealized petroleum framework for natural gas is convenient for conventional reservoirs in Bangladesh. Now, the total reserve in Bangladesh is diminishing quickly. Non-renewable energy, like natural gas, is not interminable. That is why now the time has come to think of interchange assets from which we will satisfy our energy requirements.

II. Study Area

For the present study, detailed fieldwork is carried out in several road cuts and stream sections within the Sylhet Trough and Bandarban district.

Sylhet

Jaintiapur area is one of the most investigated sites in the Sylhet district. The geographic position of this area is within latitudes 25° 05' N to 25° 11' N and longitudes 92° 00' E to 92° 11' 15" E. Three sections are chosen in Jaintiapur area to conduct the field investigation. These are the Shari River Section, Tetulghat Sub-Section, and Nayagang Section.

Bandarban

Bandarban Anticline is the other investigated area located in the Bandarban district. This structure is located within latitudes 22° 05' N to 22°13' N and longitudes 92° 08' E to 92° 15' E. Three sections in the Bandarban area were chosen to conduct the field investigation. These are the Sangu River, Shoilopropat, and Rupali Jhorna.

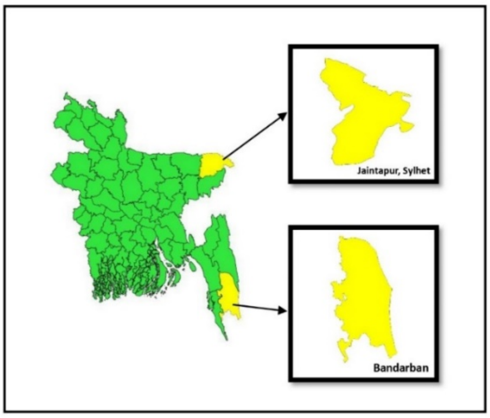


Fig. 1. Study area map.

III. Materials and Methods

Different tools and techniques have been rigorously integrated to find a way to characterize the thin-bed reservoirs of Bangladesh properly.

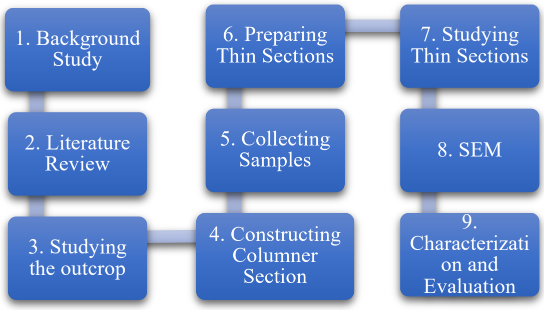


Fig. 2. The flowchart represents the methodology which has been followed in this study**.**

For proper sampling and studying structural and stratigraphic information, rigorous fieldwork was carried out to enrich the interpretation of the work from different angles. A total of 36 samples were selected for the thin-section petrographic study. Selected samples were found either loose or moderately indurated.

So, impregnation was essential for each sample. Slabs with dimensions of 3 cm length, 2 cm width and 1 cm thickness were cut and washed with water and acetone to remove gases or bubbles from the samples. An adhesive glue was prepared by mixing Araldite resin and Araldite hardener in a ratio of 1:1 and was diluted with toluene to increase its viscosity (glue 30%; toluene 70 %). Then, the samples were sunk in it and kept for three days, then heated in an oven at 40°C for two days to increase their rigidity. One side of the impregnated slab was polished on a coarse grinding lap and further on a glass plate using 400-grade. After rinsing 600-grade carborundum powder with water until a smooth and flat surface was achieved, the polished surface was scrubbed with running water to remove the carborundum and dried. The flat and smooth surface of the slab was mounted on a clean microscope slide and kept at room temperature for 72 hours as the slab became fixed on the glass slide. The free face of the sample was further ground on a glass plate using 400-grade and after rinsing 600-grade carborundum powder. The thickness of the rock sample was checked regularly using a polarizing microscope until the required thickness (0.03 mm.) was gained.

Friedman's (1959) method was followed to distinguish calcite from dolomite. According to Friedman, an acidified Alizarin Red S. solution stains calcite red while dolomite remains unstained (R. L. Folk, 1980). The required solution was prepared by dissolving 0.1 gm Alizarin Red S. in 100 ml 0.2% HCl. Half of the slide was immersed in the solution for 2-3 minutes; the slide was washed in distilled water. The calcite turns red on staining, while dolomite does not react.

A detailed qualitative and quantitative analysis was conducted using the Research Petrographic Microscope (LEICA) model DM750P. The photos were taken by the LEICA ICC50E module, which is integrated with the microscope. The diagenetic study includes examining diagenetic processes, growth of minerals, their types, mutual textural relationships, etc. A few images were taken from the JEOL JSM- 7600F scanning electron microscope (SEM) fitted with a backscattered electron detector operated at the Bangladesh University of Engineering and Technology, Dhaka. The high-resolution examinations were investigated using SEM, including clay minerals, pore geometry, permeability, dissolution effect, cement, quartz overgrowth, texture, and other related diagenetic imprints.

IV. Result

The result mainly dealt with identifying and characterizing unconventional reservoirs through field investigations and laboratory analysis of Surma Group sandstones in the Eastern part of Bangladesh. The unconventional reservoirs include thin beds as well as tight sands. The study focuses on the outcrop and exposures of the reservoir sandstones by analyzing their physical appearance, texture, facies association, sedimentary structures, reservoir properties, etc. The Surma Group sandstones represent Bangladesh's main reservoir (S.Y. Jhonson & A.M.N. Alam, 1990). The Miocene-Pliocene Surma Group is the most prolific reservoir unit in Bangladesh (M. A. Islam, 2010a). Frequent sand shale alteration is observed here, and the ratio is so close such as sand: shale ratio 1: 1 (Fig. 3A). Surma basin thickness ranges from 10 to 15 km (Fig. 3A). The sediments are deposited in deltaic conditions, with marine incursions mainly in the Oligocene-late Miocene (Gani & Alam, 2003). Late collision sediments cover the upper Bhuban unit by the Tipam and Dupitila (Tucker, 1996). The sandstone reservoirs can be broadly divided into two major groups. One is a conventional reservoir, and the other is an unconventional reservoir.

The conventional reservoir mainly occurs in the upper part of the Surma Group (Fig 3A) (Farhaduzzaman et al., 2015). The upper gas sands are easily friable, texturally medium to fine-grained, moderate to well-sorted, porous and permeable (porosity range 10 to 20%) (M. A. Islam, 2010b). Many thin-bed reservoirs have been observed in the field studies, which facilitate characterizing the thin-bed lithology. Thin-bed reservoirs are as good as conventional reservoirs in terms of quality. The characteristics of thin-bed reservoirs are easily friable, texturally mature to sub-mature (Fig. 3B). From the textural, mineralogical and reservoir quality viewpoints, thin-bed reservoirs are comparable to conventional reservoirs. Field investigations indicate that the reservoir quality would be inferior in thin-bed reservoirs with tight lithology (Fig. 3C). Frequent sand and shale alternations are observed in the thin-bed reservoirs.

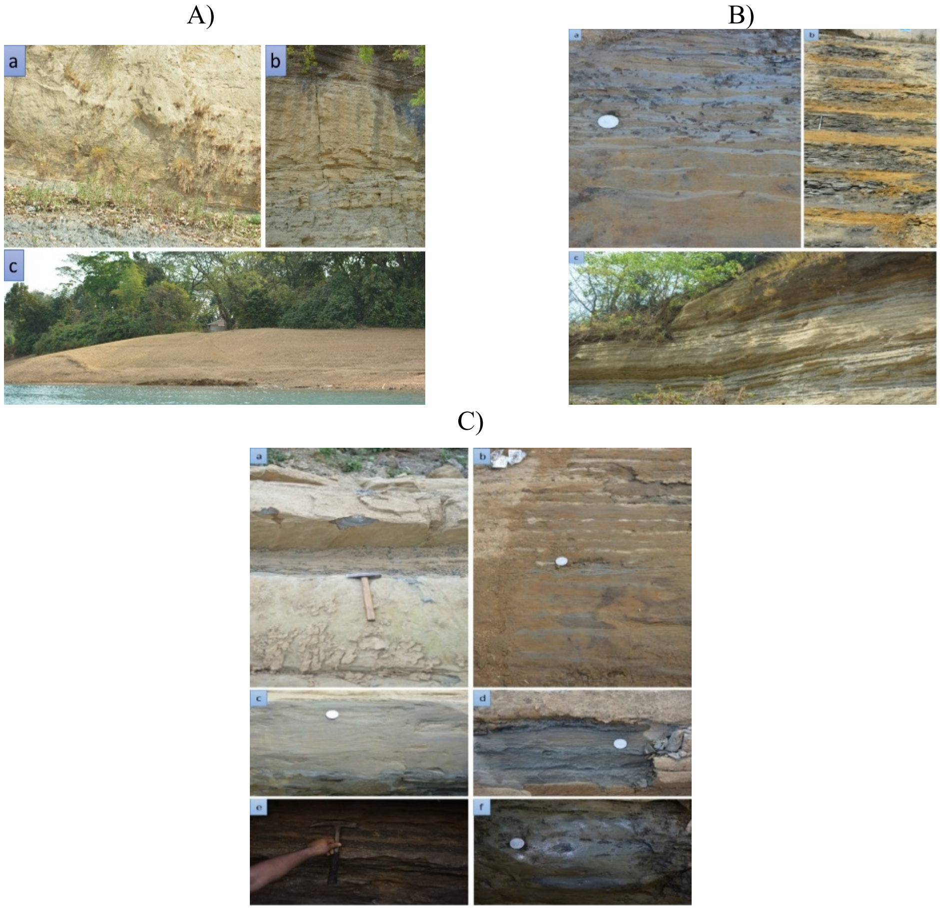


Fig. 3. Reservoir units of the Eastern Folded Belt: A) Conventional reservoirs, B) Thin bed reservoirs, C) Tight reservoirs.

Lithologic outcomes

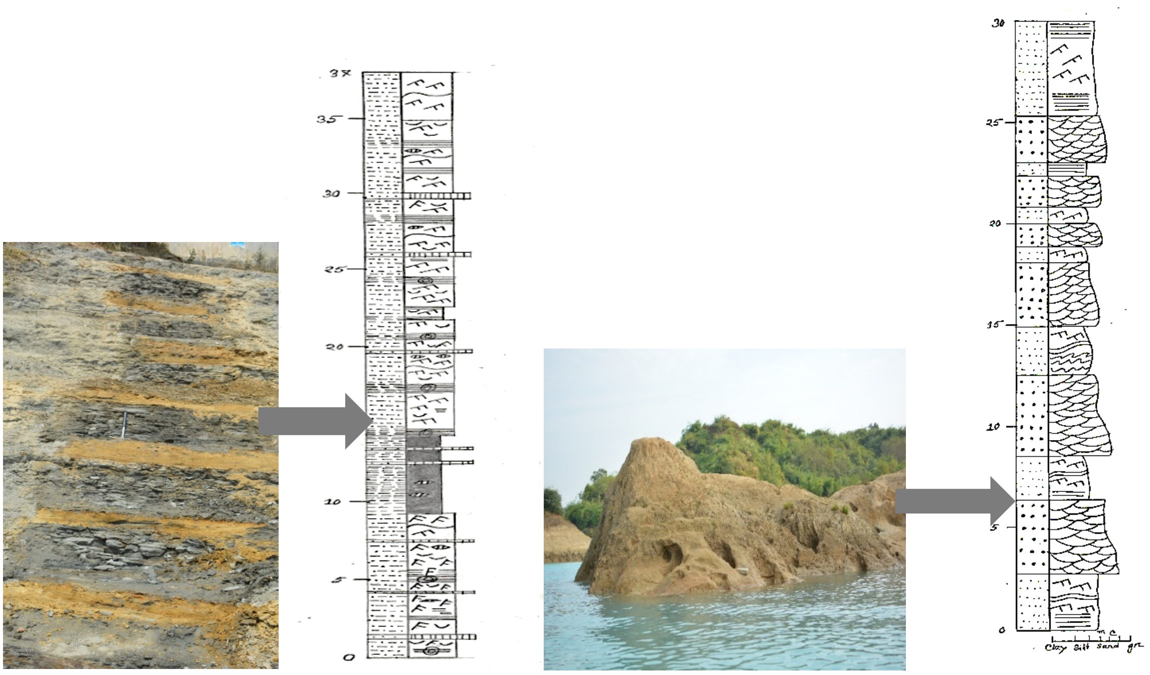
The upper gas sand is the main hydrocarbon reservoir encountered in most of Bangladesh's gas fields, including Sylhet, Titas, Habiganj, Kailastila, Sangu gas fields, etc (Aminul Islam, 2009). This type of sandstone is found in both Sylhet and Bandarban structures. The upper gas sand represents a massive sand body of homogenous lithology in the context of texture and mineralogy (M. B. Imam, 1983). It is a clastic sedimentary rock predominantly composed of sand-sized particles with good porosity and permeability.

Sylhet

In the Shari River Section, a succession of 48 meters has been studied rigorously to identify and distinguish the unconventional (tight and thin) reservoir from the conventional reservoir (Fig. 4a). This section predominantly represents a conventional reservoir. The massive sandstone is overlain by 100 m thick upper marine shale. In this section, 17 thin beds were observed. The characteristics of these thin-bed reservoirs can be described as fine to medium-grained (sometimes very fine-grained) and well-sorted. These thin-bed reservoirs are laterally extensive compared to conventional reservoirs, although their vertical thickness is less than that of conventional reservoirs. This section records 48 m total section, whereas 42 m is sandstone (Fig. 4a).

Meanwhile, in the Tetulghat Sub-Section, in the 37 m recorded part, 48 thin beds are detected from field investigation. Therefore, this section is a good one for the unconventional reservoir. 17 heterolithic beds are found in this section. In these heterolithic beds, the combination of flaser bedding, wavy bedding, and lenticular bedding was observed for each sequence, which ended up with clay at the top. A frequent change of sand-shale alteration is seen here. The average thickness range of individual beds is about 0.1 m to 1.45 m. However, the cumulative thickness is about 22 m, which makes it a good reservoir unit for hydrocarbon exploration.

In the Nayagang Section, a 30 m succession has been studied thoroughly (Fig. 4b). This area represents the conventional reservoir. In this area, seven thin beds are assessed. The characteristics of these thin-bed reservoirs can be depicted as fine to medium-grained (in some cases exceptionally fine-grained) and well-sorted. In this segment, the 30 m area is recorded while 22 m is sandstone. That outcrop refers to a section of the conventional reservoir.



a. **b.**

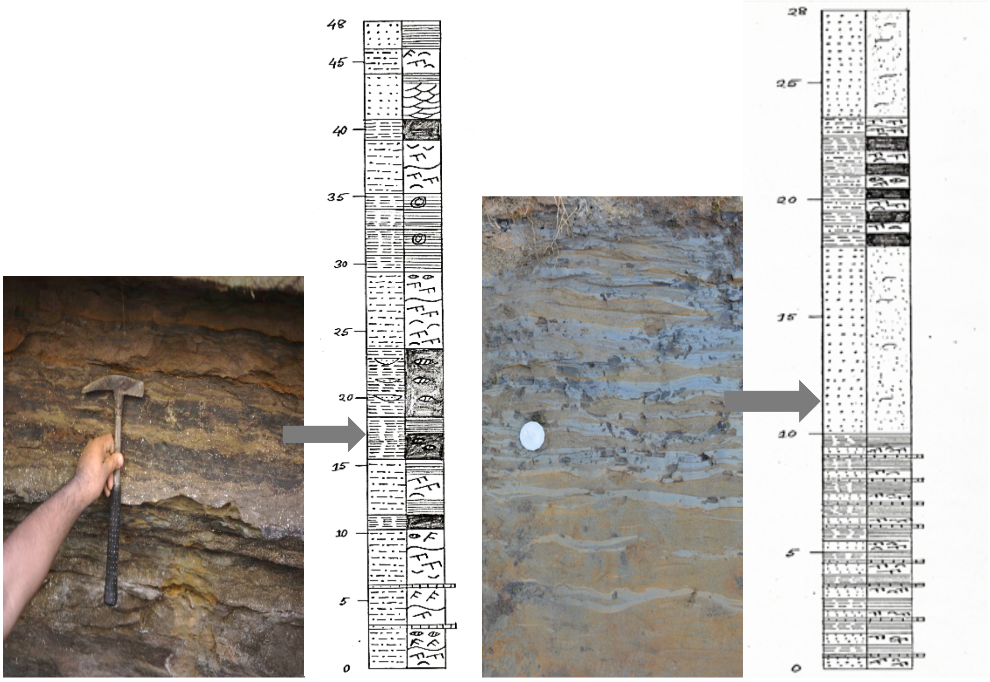
Fig. 4. Lithologic column of Sylhet region (a. Shari River section and b. Nayagang section).

Bandarban

In the Sangu River Section, an exposure of 28 m is studied point by point. 14 thin-beds are observed in this section, which are fine- to medium-grained in texture and easily friable. Frequent facies changes are easily noticeable here (Fig. 5b). This section represents unconventional and conventional reservoirs. This section is an ideal section for comparison between conventional and unconventional reservoirs.

In the Shoilopropat Section, a good number of heterolithic beds along with thin-bed units (38 thin beds) were observed in the 48 m studied section (Fig. 5a). Parallel bedded sandstones exist here. The average thickness of individual beds ranges from 0.1 - 1.45 m. Frequent sand shale alteration is seen here. Each heterolithic bed predominantly consists of flaser, lenticular, and wavy bedding.

In the Rupali Jhorna Section, the 20 m recorded part mainly refers to conventional reservoirs. This unit is composed of alternating bluish-grey shale and yellowish-brown sandstone. The sandstones are fine to medium-grained, moderately compacted, and moderately poorly sorted with mineralogical and textural variations. This sandstone has moderate to low porosity and permeability. The vertical thickness of this sandstone is 15 m, and lateral continuity is extensive. This section compares the quality with the unconventional reservoirs found in the previous sections.



a. ***b.***

Fig. 5. Lithologic column of Bandarban region (a. Shoilopropat section and b. Sangu River section).

Micrographic outcomes

Thin bed reservoirs

Textural study indicates that thin beds of Surma sandstones of the Eastern folded belt of Bangladesh are fine to medium-grained (in most cases), sub-angular to sub-rounded and well to very well sorted. Studied sandstone samples are texturally mature, containing less than 5% matrix.

Identifying the inter-granular and intra-granular pore spaces from the thin section of the thin-bed reservoirs is relatively easy. In the thin sections, pore spaces are distinct; to some extent, pore canals are visible in thin sections (Fig. 6). Because of similar characteristics of a conventional reservoir, the thin-bed reservoir can be considered as good in quality as conventional ones. Noticing the pore spaces created by fractures can often be understood from the thin sections. Those fractures maintain almost an oriented direction; therefore, they are presumed efficient in thin sections and SEM. The mode of occurrence of clay minerals in thin-bed or conventional reservoirs is usually grain-coating or pore-filling. The percentage of clays in most instances is insignificant. Therefore, the appearance of clays could only partially destroy the reservoir quality, i.e. porosity and permeability. The SEM facilitates a better understanding of the appearance of clays, morphology of the pores, and connectivity of permeability clearly (Fig. 6). This investigation promotes the comparison of thin beds with tight reservoirs by analyzing porosity, permeability, tortuosity (Fig. 6) of flowing path of hydrocarbon fluid so therefore helps to identify and characterize thin-bed reservoirs of the Eastern Folded Belt of Bangladesh.

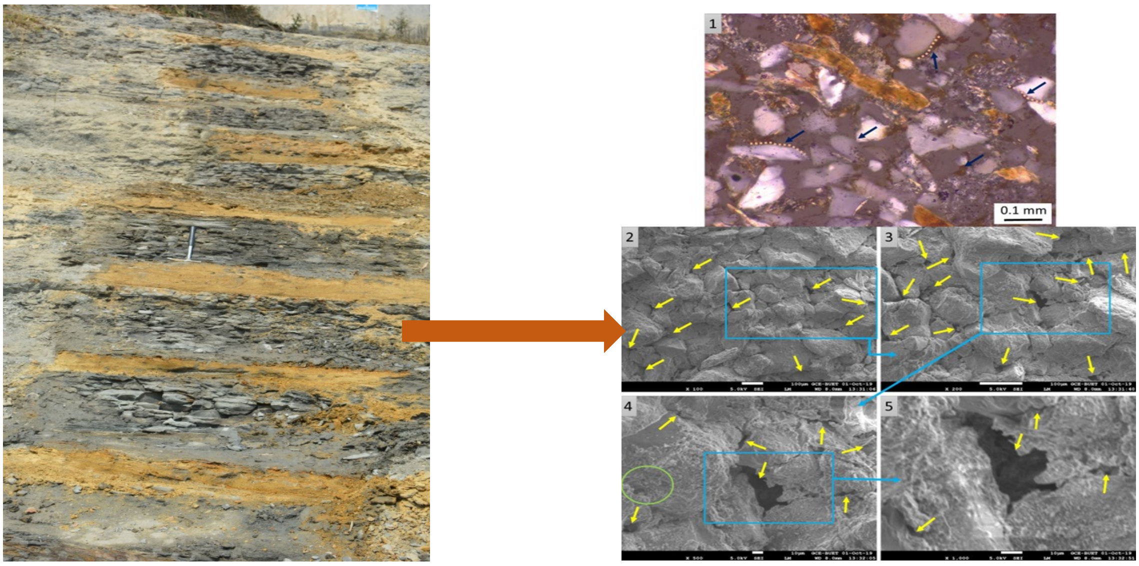


Fig. 6. A microscopic section of the thin-bed reservoir with 9 to 10% porosity, and yellow dotted lines indicate a pore canal.

Tight reservoirs

Tight gas is natural gas produced from reservoir rocks with such low permeability that massive hydraulic fracturing is necessary to produce the hydrocarbon. Tight gas reservoirs generally have less than 0.1 millidarcys (mD) matrix permeability and less than 10%matrix porosity. The permeability degree depends upon the pores' size and shape and their interconnection. Tight gas sands are considered unconventional reservoirs observed in Sylhet and Bandarban structures.

Tight reservoirs in the Tatulghat section in Sylhet and Shailopropat section in Bandarban. This unit is very fine-grained, compacted, and moderate to well-sorted. The unit is characterized by heterolithic beds (Fig. 3C). Heterolithic bedding is mainly composed of three types of bedding: flaser, wavy, and lenticular bedding. Sand-dominated thin beds with clay drapes (shale) are known as laser bedding. The beds with equal sand and clay are known as wavy bedding. Clay-dominated thin beds with sand lenses are known as lenticular bedding. Tight gas sands are laterally persistent, comprising the stacking of sedimentary layers. This type of Heterolithic bedding is the leading gas producer in the Sangu gas field. Heterolithic bedding is identified in Eastern parts of Bangladesh, such as Fenchugang well-2, Teknaf outcrop, etc.

The porosity and permeability of a tight sand reservoir can be identified from the thin section study. Tight reservoirs are composed of sandy shale, silty shale, and silty sand (Fig. 3C). From the outcrop studies, it is not easy to distinguish and characterize porosity in tight sands. The fine-grained lithology makes pore spaces very small (usually micropores). Porosity determination is difficult even in the thin sections under a petrographic microscope. By examining thin sections and SEM, porosity is measured, and the reservoir quality of tight sand is characterized.

From the thin section of the tight sand reservoirs, it was tough to identify the intergranular and intragranular pore spaces clearly (Fig. 7). As they are so compacted at the point of view of thin sections, sometimes it becomes challenging to observe the micropores of tight reservoirs. Noticing the pore spaces created by fractures from the thin sections was also challenging as they were so narrow. In addition, some porosities present as micropores within the clay minerals, usually not seen in the thin sections. However, these can be studied using the Scanning Electron Microscope (SEM) (Fig. 7).

After going through the SEM study, a considerable number of pore spaces were detected in the range of 4% to 8%. It was understood that both inter-granular and intra-granular porosities frequently occur in tight reservoirs (Fig. 7). The SEM study also indicates that the pore spaces were not connected. Therefore, permeability in the tight reservoir is insignificant. However, plenty of pore spaces are there. If the pore spaces could be connected through fracturing, then these tight reservoirs have a potential for hydrocarbon exploration.

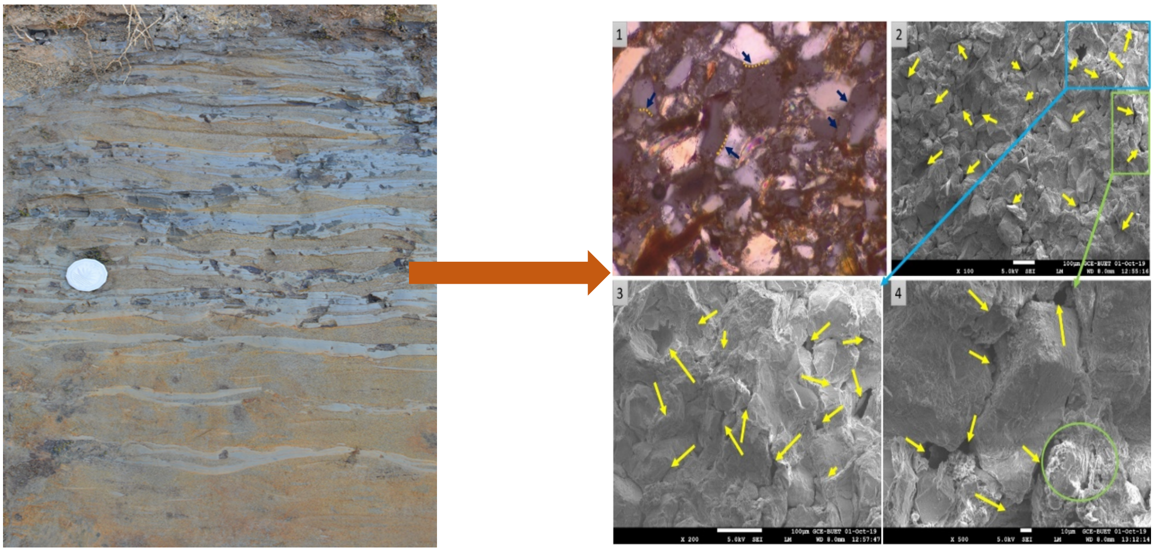


Fig. 7. A tight gas sandstone with an average porosity of 7 to 8%. In addition, dissolution porosity enhances reservoir quality here.

Conventional reservoirs

From the observation point of view, the inter-granular and intra-granular pore spaces are evident in a thin section of the conventional reservoir of Surma sandstone. After using blue dye in laboratory analysis, inter-granular and intra-granular pore spaces were marked magnificently by the blue region in the thin section (Fig. 8). That is why they were so distinct in the microscopic study. Therefore, the characteristics of a conventional reservoir are much like the thin-bed reservoir. Again, in a thin-section study, the pore spaces created by fractures are easily noticeable (Fig. 8). Most of the time, these fractures are seen oriented in a preferred direction. The clay minerals in conventional reservoirs are usually grain coating or pore filling by mode of occurrence, and they are not so significant in most instances (M. S. Islam, 2018). Therefore, porosity and permeability could only be partially destroyed by clays' appearance, as clays are inconsequential on most occasions (Alam et al., 2003). For a superior understanding of the appearance of clays, morphology of the pores, and connectivity of permeability, SEM was done in the laboratory of Bangladesh University of Engineering and Technology. This study facilitates the significant comparison of thin beds with a tight reservoir, as this is the basis for characterizing and analyzing the reservoir quality of Surma sandstone in the Eastern Folded Belt of Bangladesh. Since the tortuosity is low hydrocarbon can pass easily through pore spaces.

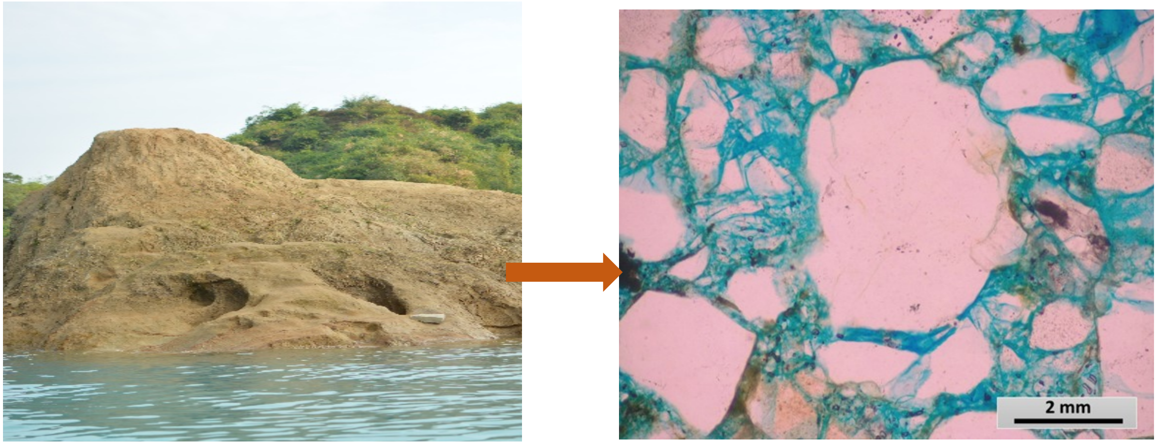


Fig. 8. Photomicrograph showing the thin section of a conventional reservoir with 18 to 20% porosity range.

V. Discussion

Comparison of Reservoir Quality

Texturally, thin-bed reservoirs are fine to very fine-grained. The texture of tight reservoirs is similar to the thin-bed reservoir. On the other hand, conventional reservoirs are texturally medium to fine-grained. Again conventional reservoirs have fewer facies' changes compared to unconventional reservoirs (Pearson & Alam, 1993). During the rigorous field analysis, combining the form of flaser bedding, lenticular bedding, wavy bedding, and an upper portion of clay formed a cycle of hetero-lithic bedding.

Furthermore, the thin bed and tight reservoir thickness is approximately 1 or 2 m. Therefore, though the vertical thickness is not so high, they maintain a remarkable persistence of lateral continuity. On the other hand, the thickness of a conventional reservoir is higher than that of an unconventional reservoir (Hossain et al., 2014). However, their lateral persistence is less than that of the unconventional reservoir. In a tight reservoir, pore spaces are enough to pass hydrocarbon through the reservoir system, but the problem is that pore spaces need to be connected (Gani & Alam, 1999). Meanwhile, in the thin-bed reservoir, pore spaces are distinct and connected, which is the most important for a reservoir to characterize its quality. Conversely, porosity and permeability are decent in the conventional reservoirs; the porosity range is about 10 to 20%.

Table 1: Comparison on reservoir quality.

Topic of Comparison	Thin Bed Reservoir	Tight Gas Reservoir	Conventional Reservoir
Facies, Sedimentary Structure and Textural Composition	Fine to medium (sometimes very fine grained).	Fine to very fine grained.	Medium to fine grained.
Porosity and Permeability	Pore spaces are connected, and average porosity range is 4 to 12%.	Pore spaces are not interconnected and therefore permeability rate is not good at all.	Average porosity is 10 to 20%, permeability rate is good enough for being a good reservoir.
Vertical Thickness and Lateral Persistence	Though vertical thickness of individual bed is small but lateral persistence is longer compared to conventional reservoir.	Vertical thickness of individual bed is small and laterally not so longer compared to thin beds.	Vertical thickness of individual bed is high enough, but lateral persistence is shorter compared to unconventional reservoir.
Cumulative Thickness and Production	Therefore, cumulative thickness is greater than conventional ones. Therefore, net production would be higher than conventional ones.	Because of low permeability rate, not so good in terms of reservoir quality.	Cumulative thickness is not higher than unconventional thin beds. Therefore, net production might be shorter than thin beds.

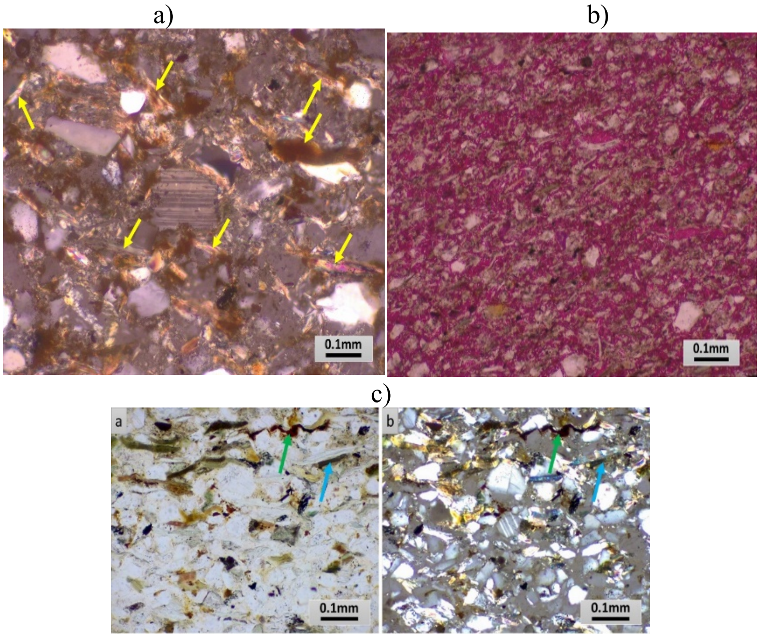
The major destructive processes:

The presence of clay minerals as grain-coating or pore-filling cement affects porosity and permeability significantly. Pore-filling illite-smectite slightly reduced porosity. Authigenic kaolinite locally occludes pore spaces, although much of it has replaced feldspars and resulted in re-distributional secondary microporosity. Poikilotopic calcite cement has locally reduced porosity and permeability to zero in some samples. Quartz cement has played only a minor role in reducing porosity and permeability. Chlorite grain coats inhibit quartz cement and help to preserve porosity.

1. Compaction: The initial diagenetic process that affects sands immediately after deposition and burial below the sediment-water interface is compaction, which is involved in sediments due to overburden pressure (Yadav, 2012). Compaction due to overburden pressure reduces original porosity by packing readjustment, plastic deformation of labile grains and pressure solution (M. B. Imam, 1983). Packing readjustment causes tight packing of detrital grains by grain rotation and grain slipping past each other, which significantly reduces original porosity.

2. Chlorite Rims: When authigenic chlorite is thick and continuous around the detrital grains, particularly around the detrital quartz grains, the formation of quartz overgrowth cement is hindered because of a lack of direct connection between detrital quartz grains and silica-rich pore water and thus porosity of sandstones is preserved.

3. Cementation: The development of authigenic minerals by chemical precipitation from the pore fluids in the subsurface is termed cementation, and the minerals thus formed are called authigenic minerals or cement. Cementation is the most dominant porosity-reducing process in the Surma sandstone of Miocene's time. Early poikilotopic calcite cement is the most effective porosity-destroying process in the sequence. Though it affects only a few samples, it reduces porosity and permeability to zero (D. Basu, et al., 2019). Late ferroan calcite is the second most crucial porosity-reducing cement. Quartz overgrowths, mostly common at the lower part of the sequence, act as a significant porosity-reducing agent. Kaolinite also reduces porosity but in a lesser extent.



a) b) c)

Fig. 9. These photomicrographs represent a) Compaction, b) cementation, and c) chlorite rims.

The major constructive processes:

1. Dissolution: Dissolution contributes to total porosity of thin bed reservoirs. The dissolution of soluble constituents of sandstones (either completely or partially) has been observed in some samples of the Eastern folded belt structure.

Secondary porosity in Surma sandstones is the result of the dissolution of sedimentary materials such as feldspars, lithic grains, etc., dissolution of authigenic cement-like calcite, dolomite, etc (Hossain et al., 2014). and the dissolution of replacive materials, mainly calcite.

2. Fracturing: The present study observes that Feldspars and brittle lithic grains are susceptible to fracturing, observed in the present study. Fractures are developed due to stresses resulting from the shrinkage of rock constituents of whole rocks. Fractures may also be produced due to overburden pressure and tectonic forces. Sometimes, fractures in the grains are infilled by secondary cementing materials.

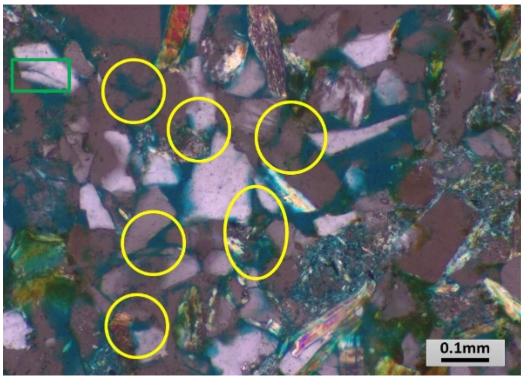


Fig. 10. Photomicrograph exhibiting porosity enhanced by dissolution (yellow circle) and fracturing (green rectangle).

Through all these discussions, there is an excellent possibility that we may find a sufficient amount of hydrocarbon in both tight sand and thin-bed reservoirs of the Eastern folded belt of Bangladesh. After that, we can use advanced technology like Artificial fracturing and Horizontal drilling methods, which are used nowadays in developed countries, to extract hydrocarbon from unconventional reservoirs such as tight sand and thin-bed reservoirs. Though their porosity is not as much as a conventional reservoir in percentage, these tight sand and thin-bed reservoirs can still be valuable for us and our country.

VI. Conclusion

Extensive fieldwork has been accomplished in the Eastern Folded Belt (Sylhet, Bandarban) of Bangladesh to identify the thin-bed reservoirs and characterize them with rigorous analysis. In the field, the outcrops of conventional and unconventional reservoirs (thin-bed and tight sands) units are investigated. The samples were collected for laboratory analysis. Thin sections were prepared from 36 outcrop samples for microscopic and SEM study. The petrographic sections principally dealt with the textural properties, composition, diagenesis, and observation of reservoir properties. Moreover, the effects of diagenetic events on reservoir quality are evaluated from the thin sections. In cases of inconclusive results, the SEM study helped to address these issues.

The field study demonstrates that thin beds are fine to medium-grained (sometimes very fine-grained), sub-angular to sub-rounded and well-sorted. Frequent change of sand-shale with the predominance of parallel bedded sandstone is observed. Inter-granular and intra-granular pore spaces, along with the pore canal, are the recognizable proof observed from laboratory analysis. The average porosity ranges from 4 to 12% and most of them are interconnected. The pore spaces within the tight reservoir are not interconnected, despite a considerable amount of pore spaces (average porosity 4%-8%) are there. Here, the permeability is very low.

On the other hand, conventional reservoirs are medium to fine-grained, well-sorted and contain an average porosity of 10% to 20%, most of which are connected.

The principal difference between thin beds and tight sand is the effectiveness of porosity. At the same time, the significant difference between conventional and thin-bed reservoirs is the vertical thickness and lateral continuity. In the unconventional (thin and tight) reservoir, the vertical thickness is generally less than 1 meter. However, the lateral continuity is long. Therefore, the cumulative thickness is good enough to be a good reservoir like a conventional one.

Serious steps must be taken to focus on an unconventional reservoir, particularly on a thin-bed reservoir, to reduce the dependency on the conventional reservoir. Therefore, this research work may extensively engage in future research and exploration programs of unconventional reservoirs in Bangladesh. Consequently, we must address Bangladesh's energy crisis by implementing new technology. Hence, the most recent technology can make significant improvements in Bangladesh's energy sectors.

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