Islamic Azad University
Mashhad Branch

Md. Ahosan Habib and Abu Reza Md. Towfiqul Islam / Iranian Journal of Earth Sciences 6 (2014) /12-23

Paleoenvironmental Reconstruction of Miocene Surma Succession in the Rashidpur # 04 Well of Bengal Basin Using Log Facies Interpretation

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Received 2 February 2014; accepted 15 April 2014

Abstract

Detailed log facies studies of the Miocene Succession in the Rashidpur-04Well, Rashidpur Structure, Surma Basin, were carried out by integrating wireline logs and limited core sample data in order to reconstruct the paleoenvironment of the deposition. Based on the analysis of log motifs, grain sizes, sand/shale ratios and major changes in gamma ray log motifs, two major depositional sequences were identified in the Rashidpur-04 Well which consist of 17 para-sequence sets and 22 para-sequences. Serrated bell, funnel, cylindrical, egg/bow and linear log facies were identified in the study well. Lithology indicates that the whole well interval consists of alterations of sandstone, siltstone, shale and prodelta facies. Rashidpur Sequence-2 is thought to have been deposited in tidal flat to shallow marine conditions with prograding and retrograding delta front conditions, whereas Rashidpur Sequence-1 is assumed to have been deposited under tidal channel, distributary channel, tidal flat, mudflat, marine inter-distributary bay to shallow and deep marine conditions. Rashidpur Sequence-2 was deposited in comparatively deep water conditions while Rashidpur Sequence-1 was deposited in relatively shallow water conditions. From the present study it can be concluded that the Miocene Succession was coarsening upward in nature and may have been deposited under a prograding deltaic system.

Keywords: *Paleoenvironments, Log facies, Rashidpur-04 Well, Bengal Basin and Deltaic system.*

1. Introduction

The NNW-SSE trending, anticlinal Rashidpur Structure is situated in the south central part of the Sylhet Trough under the Bahabul Upazila of the Habiganj District and flanked by the Khowai Syncline in the west and the Srimangal Syncline in the east. The area is located between the latitudes 24º 32" N to 24º 18" N and the longitudes 91º 30" E to 91º 43" E (Fig. 1). Wireline logs and core sample analysis were integrated to reconstruct palaeoenvironments of deposition in the Bengal Basin [1-7]. Mondal et al. [8] carried out the study of the electrofacies analysis of the Neogene Sequence in the Shahbazpur-1 Well, Bhola, Bengal Basin. Rahman et al. [9] carried out the electrofacies and core analysis of the subsurface Neogene Surma Group of the Bengal Basin encountered in several wells of the Sylhet Trough. Islam [10] carried out the study of the depositional environment of the Neogene Reservoir Succession encountering several gas wells in the Bengal Basin constrain using lithofacies and electrofacies analysis. Islam et al. [11] also studied the interpretation of the depositional environment of the Miocene Sequence using electrofacies for the Bakhrabad-09 Well, Bengal Basin. The discovery of ancient depositional environments is very important in the exploration of hydrocarbon and the development of hydrocarbon-bearing wells in order to estimate reserves and production. However, no detailed log facies studies have been carried out for the reconstruction of paleoenvironment depositions in the studied well. Therefore, present research attempts to reconstruct the palaeoenvironment of the Rashidpur Structure, Surma Basin are very important to the petroleum sector in Bangladesh. The main objective of this research is to reconstruct the paleoenvironment of the Miocene Sedimentary Succession of the Rashidpur-04 Well based on the analysis of log facies and limited core sample data.

2. Geological Background

The Bengal Basin of Bangladesh is a young, prolific, gas-bearing basin [5]. It forms a fault-bounded trough confined by the Precambrian Basement Complex of the Shillong Massif in the north and along the Chittagong-Tripura Folded Belt [12] in the east and northeast. This basin is the most important in terms of sediment thickness, likely exceeding 20 km, and economic deposits [13]. The Rashidpur Structure may have been formed during the late Orogenic stage due to

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subsidence along the Dauki Fault System and Plio-Pleistocene uplift of the Shillong Massif [14]. The Rashidpur Structure is situated in the southeastern portion of the Bengal Basin. The tectonics of the basin are considered to be Neogene to Recent with a severe period of crustal disturbance. The tectonics of the structure consist of a series of north-south oriented asymmetrical anticlines in eastern Bangladesh [15]. The N-S trending Rashidpur Structure, at the surface, is a narrow anticline roughly 40.25 km long and 4.83 km wide [14]. The sub-surface stratigraphy of the Rashidpur Structure was established on the basis of well log data drilled by the BOGMC [16]. The Lower to Middle Miocene Surma Group, consisting of the underlying Bhuban Formation and the overlying Boka Bil Formation, were deposited during repeated transgression and regression phases of a marine environment [17]. The lithological sequences encountered in the structure range in age from Miocene to Plio-Pleistocene (Table 1).

3. Materials and Method

Data sets for this research were made up of hard copies of gamma ray (GR) logs and core samples of the Rashidpur-04 Well from the BAPEX (Bangladesh Petroleum Exploration and Production Company Limited) data center. All the required analog versions of the log data were manually converted into digital data maintaining caution in order to restore optimum resolution. Next, the digital log data was transferred from the record book to Excel software. The digital data was then corrected and scrutinized. All logs were regenerated at a scale of 1:1000 for the convenience of the study. The paleoenvironmental study was done using only gamma ray (GR) log shapes. The gamma log responses were placed at equal depth intervals in order to support correlation. Only the gamma ray (GR) logs were analyzed in the identification of the log facies, cycles, sequences and associations of the Miocene Succession in the Rashidpur-04 Well of the Rashidpur Structure to interpret the palaeoenvironments of deposition for the Miocene Sedimentary Succession. A flow chart for log facies analysis is given in figure 2.

4. Results

The sedimentary environments were interpreted by comparing the shapes of wireline logs with depositional patterns [18-19]. Log facies are more advantageous for revealing stratigraphic paleoenvironments [20], whereas, Borehole Logs are widely used to interpret particular paleoenvironments [21-22]. Modern sedimentary environment studies reveal that vertical profiles of grain sizes from specific environments have certain characteristics and are useful in lithofacies analysis [23]. The GR log is complemented by the SP log as well as resistivity logs [24]. Vail and Wornardt [25] used the log shapes resulting from a combination of GR or SP logs to interpret the depositional system. GR logs are the most useful form of analysis for facies delineation. Their curves show a greater amount of detail and are able to show a greater variety of shapes and characteristics than other logs [26]. They are used in the interpretation of lithologies to establish shale and clean rock base lines (as for SP) supplemented by a median line separating shales from non-shales [27]. GR log trends showing thickness are interrelated to sedimentary facies cycles and sequences. Their associations indicate the basin experiencing extensive events [28]. A prediction of the depositional environment can be made based on lithological characteristics such as SP, resistivity and GR log shapes [29]. Para-sequence sets are related to allocyclic depositional systems in response to the eustatic fluctuation of sea levels i.e. transgression or regression, tectonics, subsidence, upliftment, increase or decrease in sediment supply and accumulation [30]. Para-sequences are formed due to the lateral migration of various sub-environments within an environment regime in response to the autocyclic mechanism [31-33]. Generally, two types of trends/sequences are identified by the GR log responses. GR logs were used as an analytical tool for this study.

4.1 Description of log facies:

On the basis of GR log motifs or shapes, log facies were grouped into five categories which were identified in the studied well:

Bell shaped log facies indicate a fining upward sequence as well as an increasing shale content in an upward direction. The GR value increases regularly upwards from a low value of GR having transitional upper and lower abrupt boundaries relative to transgressive or prograding sequences. Grain size profiles as well as depositional energy decreases in an overall upward direction. This shape suggests retrograding distributary and tidal channels [34]. Bell shapes are identified at different depth intervals (Fig. 3A). Among them serrated bell shapes (1,567-1,595 m) were identified (Fig. 3B). This curve was also found in alluvium fan, fluvial channel, point bar and deltaic channel environments. Funnel shaped log facies indicate a coarsening upward sequence where shale content decreases in an upward direction. This indicates prograding delta or crevasse splays deposition [35-36]. Funnel shapes are observed at depth intervals of 1,384-1,447 m, 1,858-1,926 m, 2,061-2,150 m, 2,225-2,250 m and 1,958-2,034 m, with serrated funnel shapes being found at 2,290-2,314 m (Fig. 4C). This funnel shape indicates prograding delta, alluvial fan and regressive shallow marine bar sub-environments. Linear shapes are generated in thick mudstone, claystone with interbedded sandstone, siltstone marsh coals or shales. This is indicative of deep, calm, quiet marine conditions. Linear shapes are identified at a depth interval of 1,803-1,858 m (Fig. 3D). This linear shape reflects shallow marine, inter-distributary bay, lagoon, flood plain and marsh sub-environments. Egg shaped log facies are identified at depth intervals of 1,310-1,384 m, 2,536-2,612 m with serrated shapes being found at a depth of 2,485-2,536 m (Fig. 3E). The serrated egg shaped profiles exhibit both a coarsening upward and fining upward sequence which suggests the aggradation of shale or silt [37]. According to Coleman and Prior [38] the depositional environments include channel floodplains, sub-tidal channels, inter-tidal sand flats, mud flats etc. A cylindrical shape indicates a shale free, sand dominated sequence with sharp upper and lower contact. Depositional energy is essentially constant, which may indicate aggrading fluvial channels, deltaic distributaries and tidal sands. Cylindrical shapes are identified at depth intervals of 1,550-1,567 m and 1,926-1,958 m becoming asymmetric in nature at 2,314-2,339 m (Fig. 3F). This curve may be smooth or serrated. It may also indicate a slope and fan channel environment [39].

A detailed study of wireline log responses from a depth range of 1,310-2,773 m is required for sedimentation pattern, depositional energy and reconstruction of depositional palaeoenvironments of the Miocene Sedimentary Succession which involves the analysis of gamma ray (GR) log shapes and their upward and downward trends. The Miocene Sedimentary Succession comprises two sequences in the Rashidpur-04 Well which are described below:

4.2 Analysis of the Rashidpur Sequence-2 (Para Sequences 1-2):

Rashidpur Sequence-2 (RPS-2) comprises 2 distinct para-sequence sets (RPS2-1 and RPS2-2) and at least 2 para-sequence/cycles (Fu) were identified (2,773-2,536 m) based on their log shapes and grain size trends, sand/shale ratio, core sample data and major changes in the log pattern of the sequences. Para-Sequence Set-1 shows a fining upward sequence at a depth of 2,657-2,773 m having a thickness of roughly 116 m (Fig. 4). The sand/shale ratio of this cycle is approximately 60:40 which indicates a sand dominated unit for the sequence. After deposition in the lower portion of the cycle a major break of log trends or abrupt change values was identified. This may be an erosional surface, unconformity or fault line. The serrated bell shaped log facies suggest sand to shale facies which points to retrograding distributary channel environments of deposition. This cycle shows a coarsening followed by fining upward sequence with minor variations in the thickness of this cycle at about 76 m (2,536-2,612 m). Egg shaped log facies indicate low-high-low hydrodynamic conditions and shale dominating units with siltstone. Para-Sequence-2 may have been deposited under a tidal channel or mudflat sub-environment (Fig. 4). Para-Sequence Set-2 (RPS2-1) (116 m) is thicker than that of Para-Sequence Set-1 (RPS2-2) (76 m). The change of depositional energy was more frequent during the deposition of the RPS2-1 cycle than that of the RPS2-2 cycle. The core of the lower portion of Sequence-2 is comprised of microfossils within gray colored sandstone to dark laminated shale facies (Fig. 5A). The upper portion contains bluish-gray, wavy, laminated shale and thin, stratified siltstone (Fig. 5B). Core sample data is supportive of a marine transgression condition prevailing during the deposition of Rashidpur Sequence-2 (Table 2). Possible depositional environments of Rashidpur Sequence-2 are thought to range from shallow marine tidal flats, to prominent middle to lower deltaic conditions with fluvio-marine tidal channel and multiple retrogressive distributary channel deposits.

4.3 Analysis of the Rashidpur Sequence-1 (Para Sequence 1-5):

Rashidpur Sequence-1 (RPS-1) comprises 15 distinct para-sequence sets (RPS-1-15). A minimum of 20 para-sequences/cycles were identified depending on the log shapes and grain size trends, sand/shale ratios, core sample data and major changes in the log patterns of the sequences. Para-Sequence Set-1 lies at a depth range of 2,485-2,536 m, with a thickness of roughly 51 m. This cycle shows a coarsening upward followed by a fining upward sequence with minor variations. Sandy and silty shaley horizons cover approximately 30% and 70% respectively of the total sequence. The serrated egg shaped log facies indicates a channel floodplain sub-environment (6A). Para-Sequence Set-2 lies within a depth range of 2,352-2,485 m measuring approximately 133 m in thickness. A fining upward sequence with approximately a 40% silty shaley units for the whole cycle was observed, therefore suggesting a sand dominated sequence. The serrated bell shaped log facies suggests an aggrading distributary channel floodplain sub-environment (Fig. 6A). Para-Sequence Set-3 measures at a depth range of 2,225-2,352 m with a thickness of 127 m showing a fining upward trend with minor fluctuations (Fig. 6A). Five para-sequences were identified, three fining upward and two coarsening upward. Within this cycle sandstone, silty shale and shale horizons constitute about 40% and 60% of the whole cycle respectively. In this para-sequence set different types of log shapes were observed such as serrated bell, cylindrical and serrated funnel shaped which indicates various sub-environments of deposition. The serrated bell shaped log facies suggest sandy shale facies indicating a retrograding distributary channel floodplain. The serrated funnel shape of the sandstone facies indicates a prograding delta and tidal flat. Egg shaped log facies suggest an aggrading distributary channel floodplain and deltaic conditions. The frequent fluctuating nature of the log facies indicates a sedimentary sequence of the same nature which is only present in the sequence of a middle to lower deltaic plain under tidal flat to shallow marine conditions.

Table 1. Stratigraphic Succession in the Rashidpur-04 Well of the Rashidpur Structure (After BOGMC [16])

Age	Group	Formation/Sequences	Lithologic description	Thickness (m)
Plio-Pleistocene	Dupi Tila	Dupi Tila	Mainly consists of unconsolidated sandstone, gray in color, medium to fine-grained with a few soft ,soapy sticky, gray areas of clay and intercalation of silt	96
	Tipam	Tipam Sandstone	Consists of gray, brown to pale gray coarse-grained sandstone with an intercalation of shale	1030
Miocene	Surma	Boka Bil Formation/ Rashidpur Sequence-I	Sandstone and siltstone with alteration of shale	1380
		Bhuban Formation/ Rashidpur Sequence-II	Composed mainly of sandstone, silty sandstone and shale. The upper part of this formation consists essentially of sandstone, light gray, moderately consolidated very fine-grained with calcareous cement.	566 +

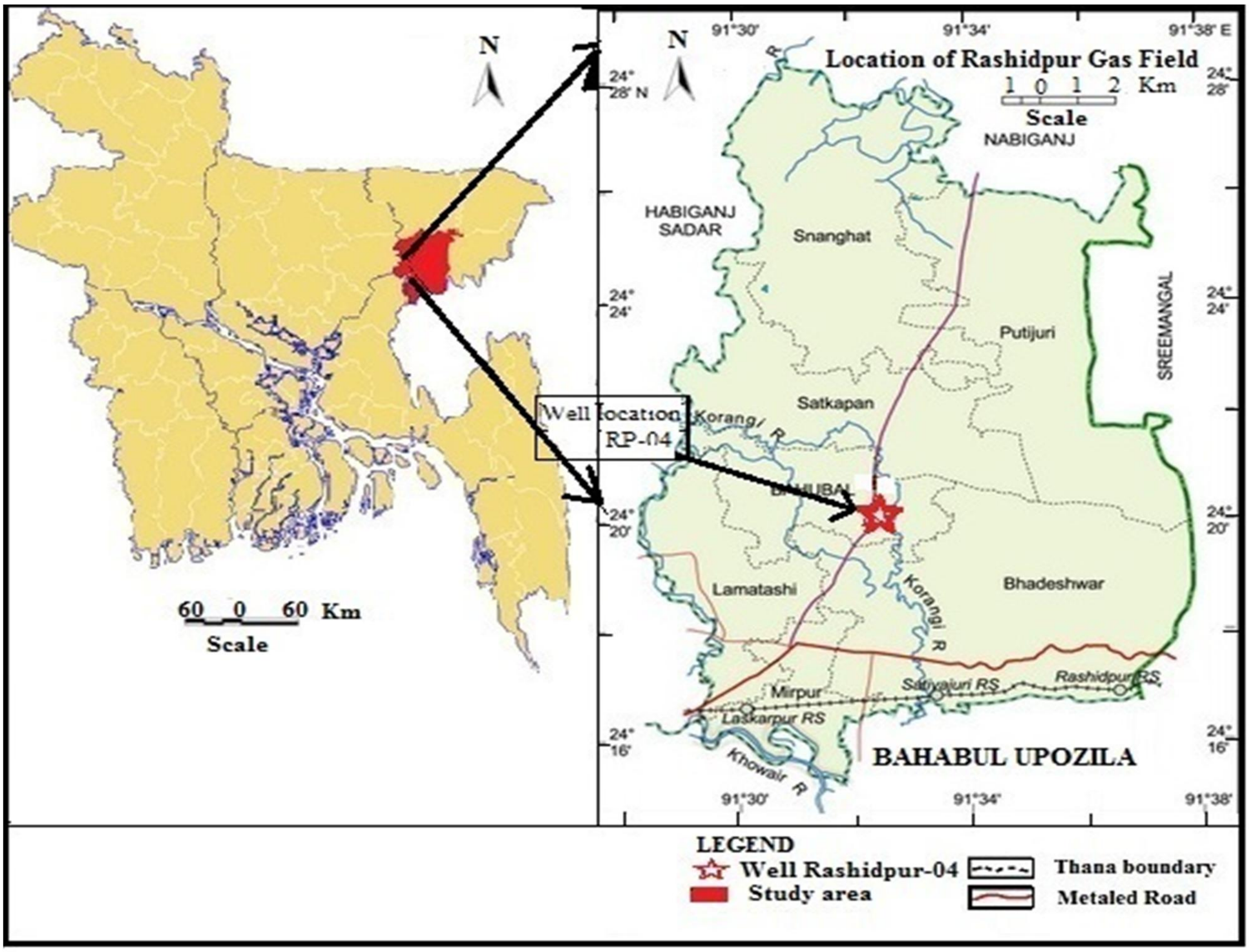

Fig. 1. Map showing the location of the Rashidpur-04 Well in Rashidpur Structure.

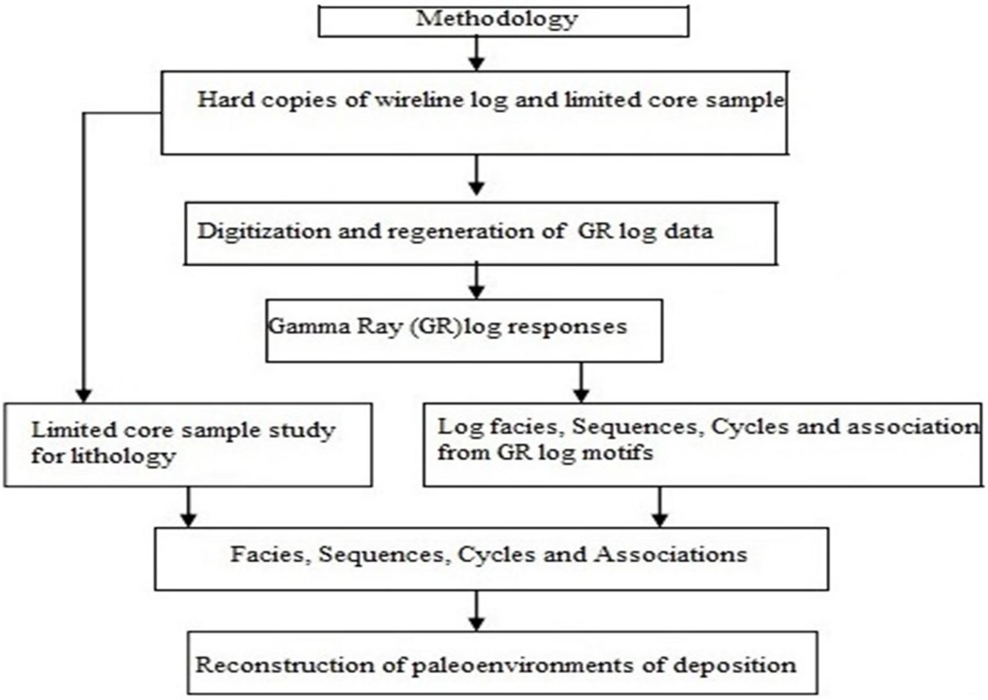

Fig. 2. Flow chart showing log facies interpretation of the study area.

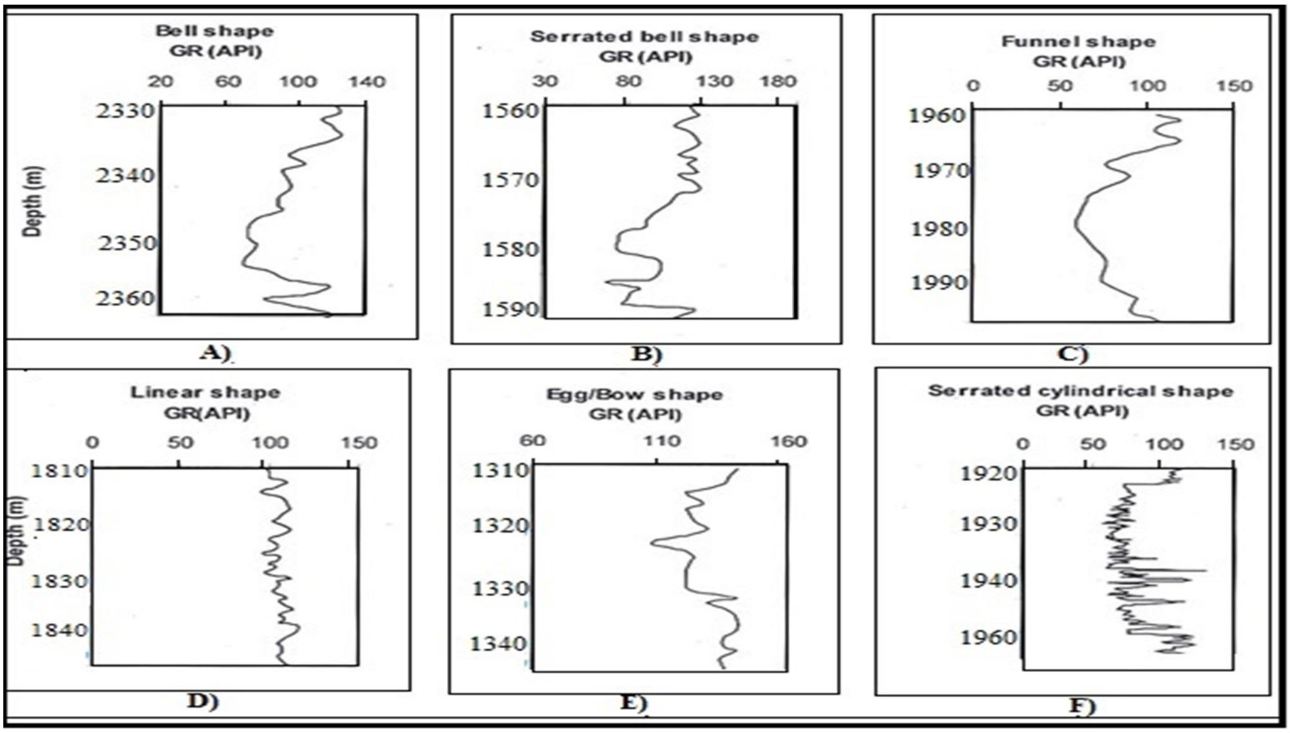

Fig. 3. Identified common gamma ray (GR) log shapes of Miocene succession in the Rashidpur-04 Well.

Table 2. Studies of limited core sample data with depth, lithology and possible environments of deposition in the Rashidpur-04 Well.

Age	Sequence/Formation	Sample No.	Depth (m)	Core No.	Dominant Lithology	Possible environments
MIOCENE	Rashidpur Sequence-1	35	1310	2	Light gray sandy silt	Tidal channel floodplain
		36	1311	2		
		40	1595	3	Dark gray shale	Retrograding channel distributary
		41	1996	3		
		50	1830	4	Light color shaly sand	Prograding channel, tidal sandflat
		51	1831	4		
		58	1850	5	Bluish gray sandy shale	Shallow marine
		59	1851	5		
		61	2130	6	Dark to light gray shaly sand	Aggrading channel
		62	2131	6		
		65	2471	7	Light gray laminated silty sand	Tidal flat
		66	2472	7		
	Rashidpur Sequence-2	70	2536	8	Light to dark gray sandy shale	Sub-tidal channel
		71	2537	8		
		74	2658	9	Bluish gray wavy laminated shale	Tidal mudflat
		75	2659	9		
		80	2750	10	Dark gray shaly sand	Retrograding channel

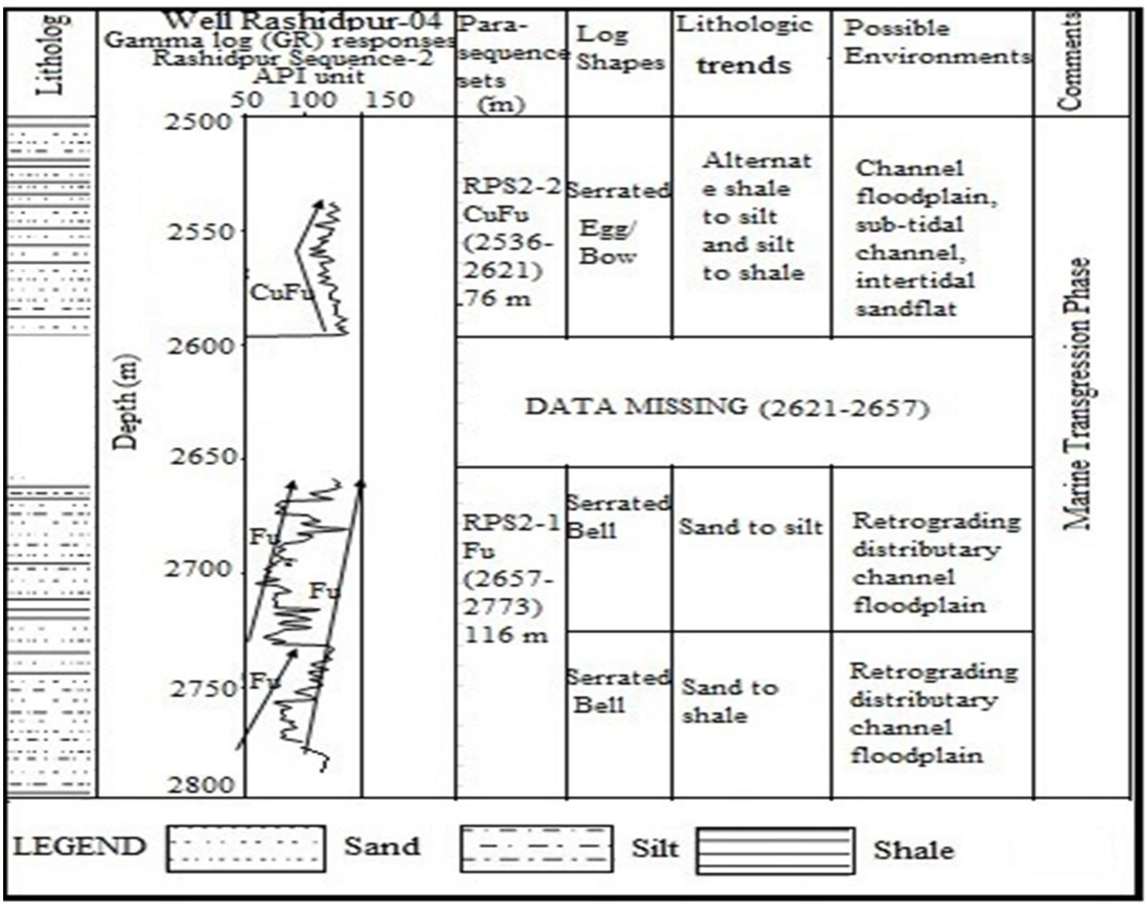

Fig. 4. GR log responses, para-sequence sets, log shapes, lithologic trend and possible environments of deposition of Rashidpur Sequences-2 (RPS-2) in the Rashidpur-04 Well.

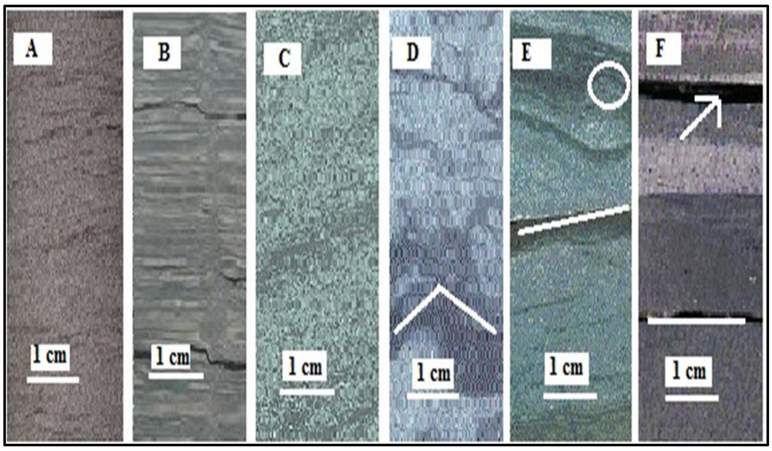

Fig. 5. Core photographs of the Rashidpur-04 Well show lithofacies: A) Grey sandstone and shale facies; B) Laminated shale and siltstone facies; C) Trough cross bedded sandstone facies; D) Wavy bedded sandstone facies; E) Bioturbide sandstone facies; F) Prodelta facies. Shale appears as a dark grey color, sand a light grey color and siltstone a moderately grey color (After BAPEX, [14]).

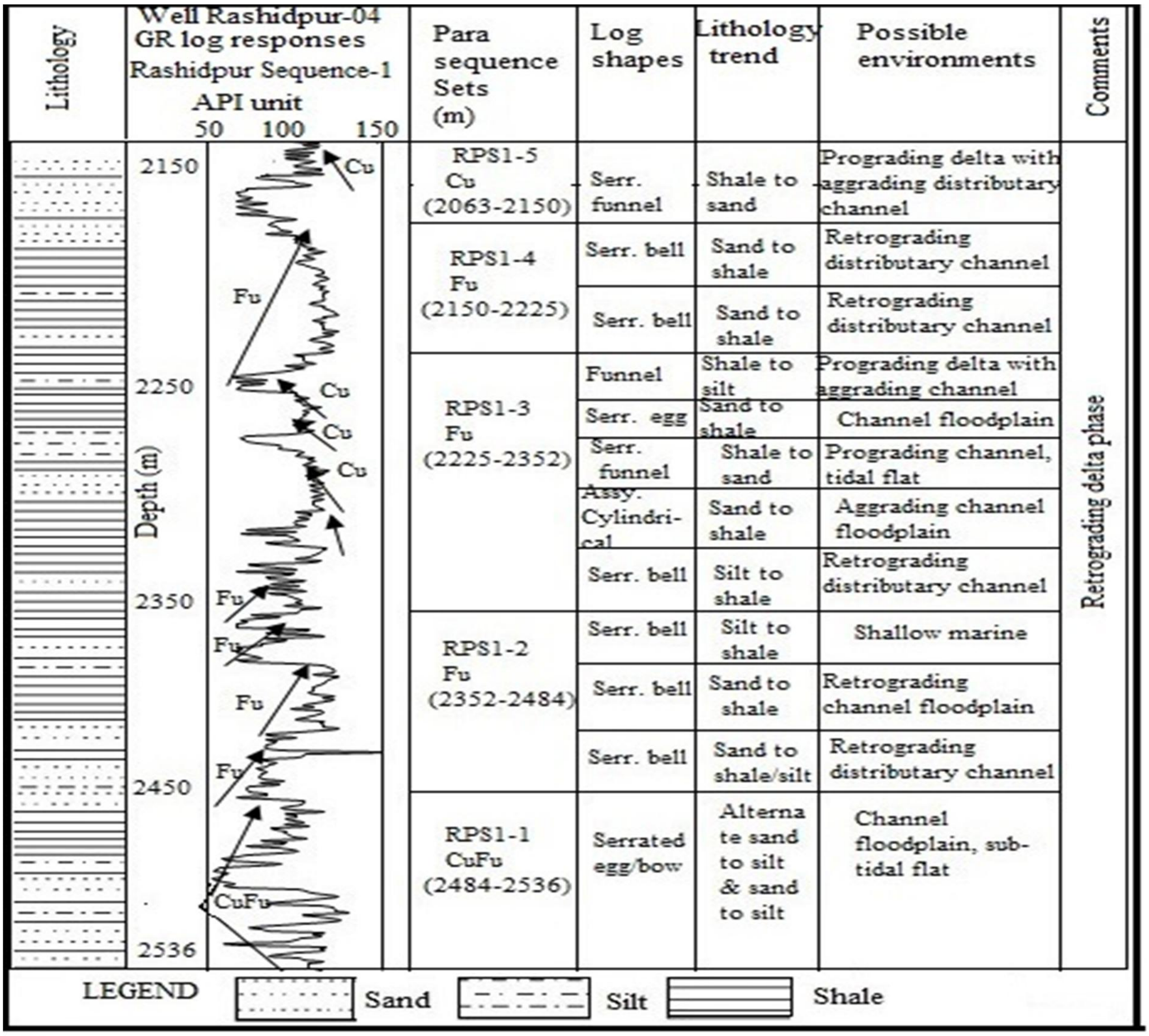

Fig. 6A. GR log responses, para-sequence sets, log shapes, lithologic trend and possible environments of deposition for Rashidpur Sequence-1 (RPS1-5) in the Rashidpur-04 Well.

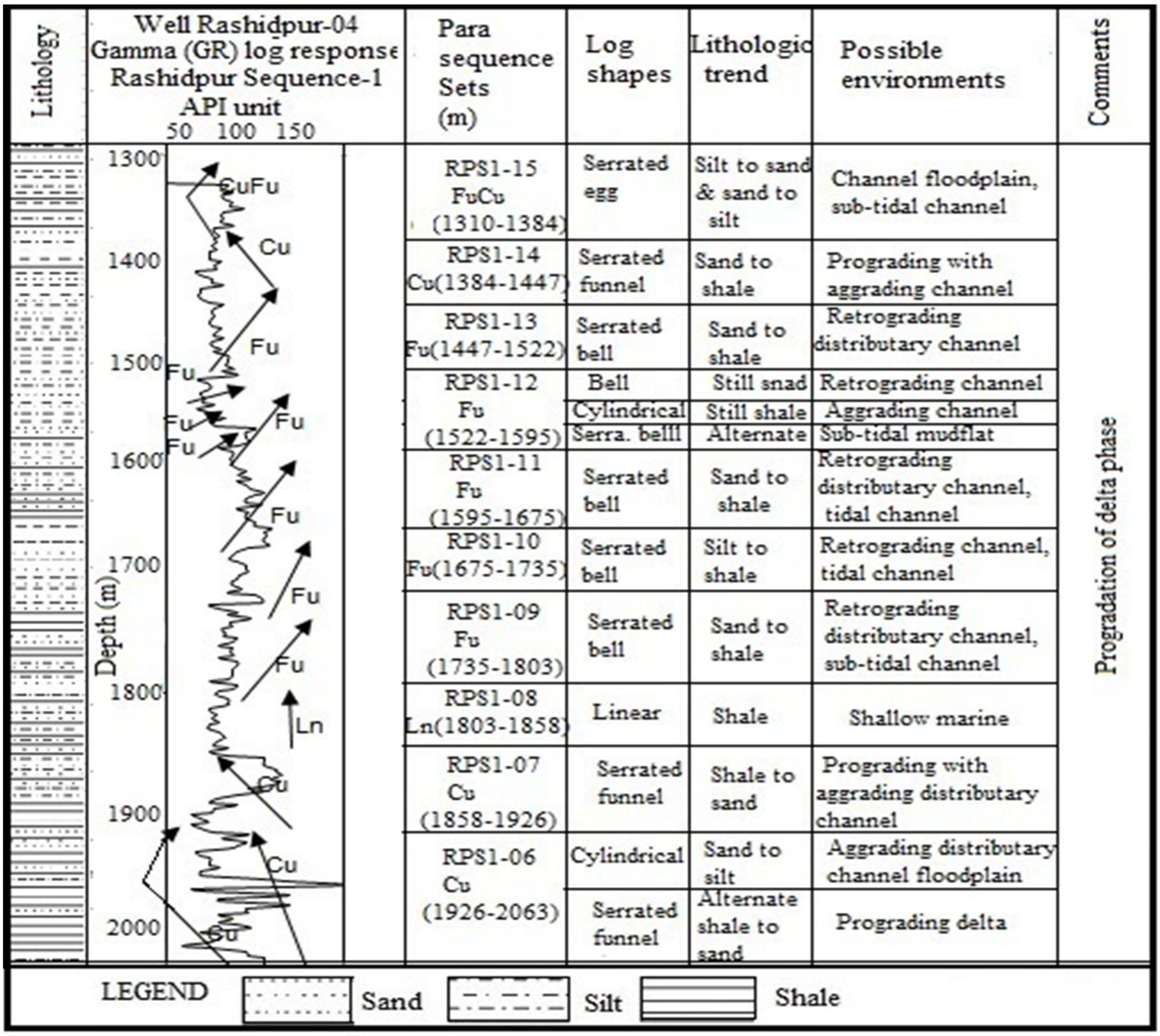

Fig. 6B: GR log responses, para-sequence sets, log shapes, lithologic trend and possible environments of deposition of Rashidpur Sequence-1 (RPS6-15) in the Rashidpur-04 Well.

The depth of Para-Sequence Set-4 ranges from 2,150-2,225 m showing a thickness of approximately 75 m with a fining upward sequence of sand and shale units covering roughly 29% and 71% respectively for the whole cycle. This indicates a shale dominating sequence with calm, quiet conditions whereas a sandy sequence is indicative of highly energetic conditions (Fig. 6A). The log shape of this para-sequence set is defined as a serrated bell, which suggests a retrograding distributary channel floodplain sub-environment. Para-Sequence Set-5 shows that an overall coarsening upward sequence lies within the depth range of 2,063-2,150 m with a thickness of roughly 87 m (Fig. 6A). Approximately 35% sandstone and 65% silty shale or shaley units constitute the cycle. The cycle shows a serrated funnel shape suggesting a prograding delta.

4.4. Analysis of the Rashidpur Sequences-1 (Para Sequence 6-15):

Para-sequence Set-6 lies within the depth range of 1,926-2,063 m with a thickness of roughly 137 m and exhibits a coarsening upward sequence (Fig. 6B). Approximately 55% sandstone and 45% shale, silty shale horizon constitute the whole cycle. Three para-sequences were observed including serrated funnel and cylindrically shaped indicating various sub-environments of deposition. The overall sequence was deposited under an aggrading distributary channel floodplain and prograding delta. The thickness of Para-Sequence Set-7 is approximately 68 m and lies within the depth range of 1,858-1,936 m showing a coarsening upward trend which indicates increasing hydrodynamic conditions toward the top of the cycle (Fig. 6B). Within this cycle, sandy and shale horizons cover roughly

55% and 45% respectively of the whole cycle. Serrated funnel shaped log facies were identified. These characteristics and associations suggest that Para-Sequence Set-8 was deposited under a prograding delta and tidal sand flat sub-environment. This cycle shows linear shaped log facies which suggests a thick, shaley sequence with a thickness of approximately 55 m deposited under calm, quiet hydrodynamic conditions in a shallow marine environment (Fig. 6B).

Parasequence Set-9 was identified at a depth range of 1,735-1,803 m with a thickness of roughly 68 m and shows a fining upward sequence (Fig. 6B).This cycle is comprised of approximately 55% sand and 45% shale. The serrated bell shaped log facies observed indicates a retrograding channel floodplain sub-environment. Para-Sequence Set-10 lies within the depth range of 1,675-1,735 m with a thickness of approximately 60 m with fining upward shale dominating the sequence of the whole cycle (Fig. 6B). Approximately 33% sand and 67% shale constitutes the whole cycle. The serrated bell shaped log facies indicates a retrograding distributary channel floodplain and tidal channel sub-environment. A cycle of approximately 80 m thick lies within the depth range of 1,595-1,675 m and shows a fining upward sequence (Fig. 6B). This cycle is comprised of roughly 45% sand and 55% silty shale units. The identified serrated bell shaped log facies indicates a retrograding distributary channel flood plain and tidal channel sub-environment. Para Sequence Set-12 measured 1,522 to 1,595 m in depth with a thickness of approximately 73 m and exhibited a fining upward sequence (Fig. 6B). Approximately 75% sand and 25% silty shale units constitute the whole cycle. The cycle is a sand dominated unit. In this cycle, different types of log facies including bell, serrated bell and cylindrically shaped were identified. Bell shaped log facies suggests a retrograding distributary channel floodplain. Serrated bell shaped log facies suggests relatively stable, broad and shallow sub-tidal and inter-tidal sand flats and mudflats. Cylindrically shaped log facies suggest an aggrading distributary channel floodplain. The overall sequences were deposited under distributary channel and tidal flat sub-environmental conditions. Para-Sequence Set-13 shows a gradually fining upward sequence lying from 1,447 to 1,522 m in depth with a thickness of approximately 75 m (Fig. 6B). Roughly 89% sand and 11% silty shale units constitute the whole cycle which suggests a sand dominated sequence. The identified serrated bell shaped log facies is believed to have been deposited in a retrograding, distributary channel sub-environment. The thickness of Para-Sequence Set-14 is approximately 63 m and lies between 1,384 to 1,447 m in depth. The cycle shows a coarsening upward sequence which indicates a gradual decrease of GR log response with minor variations and grain size increase in an upward direction (Fig. 6B). This coarsening upward sequence indicates an energetic condition increase toward the top of the cycle. This cycle is a completely sandy sequence with minor silty units also found. The log facies identified was funnel shaped which suggests a retrograding delta with aggrading distributary channel sub-environments. The sand to shale ratio within this unit was roughly 55:45. Para-Sequence Set-15 is made up entirely of sandstone with minor siltstone sediments. It lies at a depth range of 1,310 to 1,384 m and has a thickness of roughly 74 m. Both a coarsening and fining upward sequence were observed within this cycle (Fig. 6B). Approximately 53 % sand and 47 % shale constitutes the cycle. The identified serrated egg shaped log facies suggests that this cycle was most likely deposited under channel floodplain and sub-tidal channel environmental conditions.

At least 11 phases of prograding with aggrading distributary channels and 7 phases of retrograding distributary channels as well as tidal floodplain, sub-tidal channels and flat to shallow marine conditions were identified in Rashidpur Sequence-1 (Fig. 6A and 6B). The core of the lower portion of this sequence was composed of light grey, fine grained, trough and cross-bedded stratified sandstone facies with thin calcareous siltstone (Fig. 5C). The middle portion contained ripple laminated sandstone-siltstone facies and dark grey shale within fine to medium grained sandstone with fossil fragments (Fig. 5D). The core of the upper portion of the sequence was fine grained, moderately sorted, non-calcareous sandstone with coal fragments and bioturbation with some dark grey hollow (Fig. 5E). Prodelta facies consist of dark to light colored sandstone with thick siltstone and thin bedded shale facies (Fig. 5F).The Miocene Surma Group sediments were deposited in a large mud rich delta system [17]. Alam, [2] suggests a micro-tidal, coastal setting of inter tidal and sub-tidal environments within a proto-delta. Core sample data suggests that a retrograding delta phase occurred at the lower portion while a prograding delta phase was deposited at the upper portion of Sequence-1 (Table 2). Reimann [40] also interpreted the Miocene Surma Group as an alternating cycle of marine transgression and regression phases.

5. Discussions

Reconstruction of the paleoenvironment and paleoclimate of the Miocene Succession of the Surma Group in the Surma Basin of Bangladesh was carried out based on log facies and limited core sample data. The Miocene Surma Group consists of alternating shale, sandstone and sandy shale, indicative of repetitive deposition from delta, delta front and paralic facies with partial marine facies [41-42].The Miocene Surma Group in the study well consists of 17 para-sequence sets and 22 para-sequences. Five basic sequences/cycles were identified in the study well including Fu, Cu, CuFu, FuCu and linear. Several episodes of marine incursions together with minor regressive phases occurred during the deposition of the Miocene Surma Group in the study well.

Rashidpur Sequence-2 (RPS-2) consists of 2 para-sequence sets (1 Fu and 1 CuFu). In Sequence-2 (RPS-2), 2 fining upward para-sequences and 1 coarsening, then fining upward para-sequence was identified. The lower para-sequence sets with depth ranges of 2,657-2,773 m and 116 m in thickness consist of two Fu para-sequences and bell shaped log facies. This indicates retrograding distributary channel sub-environments. The upper para-sequence sets with depth ranges of 2,536-2,612 m and 76 m in thickness show one CuFu para-sequence and egg shaped log facies as well as an alteration of grey laminated shale with siltstone facies, suggesting tidal channel floodplain sub-environments of deposition (Fig. 4).The overall sand/shale ratio is roughly 65:35 and the tidal channel shows a truncated erosional base. Rashidpur Sequence-2 (RPS-2) is believed to have been deposited under tidal channel floodplain to shallow marine conditions in retrograding delta front settings in response to basin subsidence, sea level rise and the autocyclic migration of different sub-environments. Mondal et al. [8] interpreted that SB Sequence-4 of the Upper Bhuaban Miocene Formation in the Shahbazpur-01 Well, Bengal Basin was deposited under a transitional shallow marine to tidal flat channel floodplain paleoenvironment.

Rashidpur Sequence-1 (RPS-1) comprises 15 distinct para-sequence sets (4 Cu, 8 Fu, 2 FuCu and 1 linear) with at least 3 coarsening upward, 15 fining upward and 2 coarsening, then fining upward, para-sequences being identified. As a whole Sequence-1 (RPS-1) represents a coarsening upward sequence. These para-sequence sets are approximately 51 m, 133 m, 127 m, 75 m, 87 m, 187 m, 68 m, 55 m, 68 m, 60 m, 80 m, 73 m, 75 m, 63 m and 74 m thick. The thickness of the cycles varies from the bottom to the top of Sequence-1. The maximum thickness is found in RPS1-6 which measures approximately 137 m thick with a sand/shale ratio of roughly 55:45 (1,926-2,063 m). A minimum thickness cycle of approximately 52 m (2,484-2,536 m) is found in RPS1-1. Sequence-1 is roughly1,175 m (2,485-1,310 m) thick which was identified using GR log responses. The overall sand/shale ratio is roughly 55:45. Identified log facies are serrated funnel, bell, serrated bell, cylindrical, serrated cylindrical, egg, serrated egg, and serrated linear in nature. Serrated funnel-shaped with prodelta facies suggests a gradual, prograding, deltaic environmental deposition whereas bell-shaped with wavy ripple bedded sandstone facies represents the transition of sandstone to shaley siltstone facies indicating a retrograding distributary channel sub-environment of deposition. Linear shaped facies represent shallow marine conditions while cylindrically shaped facies suggest an aggrading, channel floodplain, depositional sub-environment.

Sequence-1 is interpreted to be a succession of marginal marine tidal sediment, sub-tidal channels and tidal flats. A similar interpretation was made by [43-45] in the BokaBil Formation of northeastern Sylhet Trough, Bangladesh. The lower para-sequence set-RPS1-5 with depth ranges of 2,150-2,536 m shows serrated bell, funnel, serrated egg, asymmetrical and cylindrically shaped log facies with trough, cross bedded and wavy ripple sandstone facies suggesting a retrograding delta phase of deposition while the upper parasequence set-RPS-15 with depth ranges of 1,310-2,150 m consists of prodelta facies with funnel, linear and bell shaped log facies indicating a prograding delta phase of deposition. Depositional environments were between the sub-tidal to intertidal estuarine setup in the lower portion of the Boka Bil Formation within the Miocene Surma Group [46]. As a whole, Rashidpur Sequence-1 (RPS-1) is thought to have been deposited under tidal channel floodplain, retrograding distributary channel, tidal flat to shallow marine conditions (Fig. 6A & 6B). Haque et al., [47] interpreted the area to have been deposited under an aggrading as well as progradational channel environment. Islam et al. [11] asserts that deposition of the sequences in the Bakhrabad-09 Well, Bengal Basin occurred under a progradational delta system. Similar results were confirmed by the seismic interpretation of the Rashidpur Structure [14]. The prograding phase was longer for Sequence-1 than that of Sequence-2. Sequence-2 (RPS-2) was deposited in a deeper part of the delta than Sequence-1 (RPS-1). The paleoenvironment of both sequences seems to be indicative of marine influences similar to a modern delta system [5]. Sultana and Alam [3] have also interpreted the Miocene Surma Succession environment as ranging from shallow marine to a tide-dominated coastal setting within a cyclic transgression-regression regime. From the analysis of limited core samples and overall log facies, facies sequences, cycles and associations of the Miocene Sedimentary Succession in Well-04 of the Rashidpur Structure, it is evident that both sequence (RPS-1 and RPS-2) were deposited in prograding delta, retrograding distributary channel, aggrading tidal channel and shallow marine sub-environmental conditions (Table 2).

6. Conclusions

Integrated GR log and limited core sample data from the Rashidpur-04 Well was useful in generating a series of log facies for the reconstruction of palaeoenvironments of deposition for the Miocene Sedimentary Succession. Two major depositional sequences were identified within the Miocene Succession. Rashidpur Sequence-2 (RPS-2) consists of 2 para-sequence sets and 3 para-sequences. Serrated bell and egg/bow shaped log facies were prominent in Sequence-2. Rashidpur Sequence-1 (RPS-1) consists of 15 para-sequence sets and 20 para-sequences. Identified log facies are serrated egg/bow, serrated bell, cylindrical/box-car, serrated funnel and linear in nature. The log facies, cycles, sequences and associations of the Miocene Sedimentary Succession in the Rashidpur -04 Well reveals that both sequences (RPS1-2) may have been deposited in prograding delta front setting, retrograding distributary channel, aggrading tidal channel and shallow marine environmental conditions in response to regression and transgression of sea and basin subsidence in the tidal channel, distributary channel, inter-distributary bay, tidal sand flat to shallow marine environments. The study suggests that several phases of prograding delta and retrograding delta conditions exist in the study area. Through the analysis of the whole nature of GR log motifs and a limited core study, it can be concluded that coarsening upward sandstone dominated reservoirs and prograding deltaic sequences are believed to be the main factors in commercial hydrocarbon deposition in the Rashidpur-04 Well, Bengal Basin.

Acknowledgement:

The author would like to thank the Chairman of Bangladesh Oil, Gas and Mineral Corporation (Petrobangla) and the Managing Director, BAPEX for the data set and lab facilities for core samples used in the study. We are sincerely grateful to Prof. Dr. Sultan-Ul-Islam, Department of Geology and Mining, University of Rajshahi, Bangladesh for his suggestions, proper guidance and comments while conducting this research.

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