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Secondary Porosity Development in Bangladeshi Gas Reservoirs: A Case Study of the Fenchuganj Gas Field (Well no: 2)

Janifar Hakim Lupin[1], Smita Islam[2] and Mohammad Solaiman[2]

[1]Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh
[2]Petroleum Geoscience and Engineering, Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh

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ABSTRACT: The Fenchuganj gas field is located in Surma basin and is uniform throughout the whole southern area. This study deals with the development of secondary porosity of the gas bearing reservoir sandstone rocks with the microscopic analysis of the core sample rock slides from well 2 of Fenchuganj gas field. The study shows the secondary porosity was generated at the particular depths of 1479-1497 m, 2768-2783 m and 3615-3624 m of Fenchuganj well no.2. The study demonstrates that diagenetic parameters, such as compaction, pressure solution, and cementation, are not the only ones that affect reservoir quality. Other elements include the reservoir rock's chemical environment, acidic water infiltration or dissolution, the presence of any other secondary processes, etc.

Acidic water intrusion may have acted as an agent in generation of these secondary porosities. On contrast, the rocks in 2190 m, 3424-3432 m and rest of 3615-3624 m depth, had lost its porosity by the adverse effects of compaction, cementation as well as pore pressure solution. The overall porosity of the rock samples F-2 (1479–1497 m), F-6 (2768–2783 m), and F-10b (3615–3624 m) is around (35–40%), (30–35%), and (20–25%), respectively, indicating excellent, very good, and good reservoir quality for rock slide F-2, F-6, and F-10b, respectively. Changing of chemical environment and consequent dissolution process may contribute to enhance the potentiality of reservoir rock.

Keywords: Fenchuganj Gas Field; Secondary Porosity; Diagenetic Effect; Dissolution Properties; Reservoir Sandstone

INTRODUCTION

Bangladesh is a component of the world's largest deltaic system, as well as the Bengal Basin, which contains the world's largest sedimentary basin. The formation and development of the Bengal Basin is very favorable for hydrocarbon generation and accumulation in the subsurface. The geological exploration of the Bengal Basin has been ongoing for decades and has sparked a lot of attention because of its petroleum potential. Individual regions of the basin and neighboring areas have made significant contributions to regional geology, petroleum prospects, sedimentology, and tectonic evolution. (Gani and Alam, 1999, Gani and Alam, 2003; Alam et al., 2003; Davies et al., 2003; Chowdhury et al., 2003).

In this area, little is known about the diagnostic history and its influences on the distribution and quality of sandstone reservoirs. There are a few studies on the diagenesis of sandstone and reservoir quality from the central and southern Bengal Basin's Surma Group (Islam, 2009; Imam and Shaw, 1987). The Neogene Surma Group reservoir sandstones from the Surma Basin (northeastern Bengal Basin) have diagenetic influences on the reservoir quality, but these controls are not well understood (Rahman and McCann, 2012)

There still are gaps in our understanding of diagenesis and secondary porosity based on geochemical changes in gas field reservoir sandstones. The goal is to figure out what causes secondary porosity and the diagenetic changes hereafter. The petrophysical parameters of reservoir rocks are described in this paper based on microscopic investigation of collected samples from the Fenchuganj gas field.

Primary porosity is the void space that forms at the time of formation of the rock. Secondary porosity might happen as a result of dissolution or the formation of a fracture. It is a subsequent or distinct porosity system in a rock that generally improves total porosity. In the late stages of the diagenetic history of the Surma Group sandstones, secondary porosity is frequently developed by the dissolution of Fe-calcite cement, detrital feldspars, and some lithic grains and is easily visible in the more deeply buried sequences (> 2000 m) (Imam and Shaw, 1987). The maturation of nearby Miocene source rocks containing primarily

Corresponding author: Janifar Hakim Lupin
Email: j.hlupin@du.ac.bd

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terrestrially produced humic organic matter may be connected to the acidity of the pore fluids engaged in the secondary porosity processes in the Surma Group sandstones.

The development of acidic pore fluids connected to the formation of CO_2 and carboxylic acids via the maturation of organic matter might result in the production of volumetrically large amounts of secondary porosity at depth (Giles and Marshall, 1986). During compaction and the squeeze-out of water from shale, there is an acidic pore water incursion into the sandstone from the thick underlying shale. When CO_2 is produced alongside hydrocarbons, organic materials may thermally mature and produce acidic water in the shale. This CO_2 may move to the sandstone above during compaction because it reacts with water to create acidic water.

Generally, there is a positive correlation between depth and rock compaction. With increasing depth, the rocks get more compacted. So, porosity decreases with increasing depth. The Surma Group sandstones of the Bengal Basin have been found to contain good reservoir quality sandstones with high porosities (20% to 30%) and permeabilities (34 - 1230 mD) at a variety of depths (between 2300 m and 3200 m) (Rahman and Worden, 2016). Secondary porosity is a frequent diagenetic characteristic in Neogene Sandstones that are buried deeper (>2000m). In some thin sections, this porosity could account for (35-40%) of the overall porosity (Imam and Shaw, 1985).

STUDY AREA AND GEOLOGY

The project's research area is the Fenchuganj gas field, which is located in Bangladesh's southern region, namely in the Sylhet division, some 200 kilometers northeast of Dhaka. It is located in the Surma basin and is known for its water-driven gas reservoir (Islam et al., 2014). It is located in Fenchuganj upazila, nearly 40 kilometers south of Sylhet city. The field is located in Block 14 (Fig. 1). The boundary Longitude is E 91º 53' – 92º and Latitude is N 24º 30' – 24º 37'. The field is thirty kilometers long and eight kilometers wide (Deb et al., 2014). It was discovered by PetroBangla in 1988 (Imam, 2005). The age of the whole area extends from the Oligocene to the Pliocene. The structure's gas-bearing fresh sandstones are from the Late Miocene Lower Bokabil formation to Upper Bhuban (Deb et al., 2014). The reservoir contains Miocene alternating dark gray to gray clay and fine to extremely fine grained sandstone (RMP-2 project, 2009).

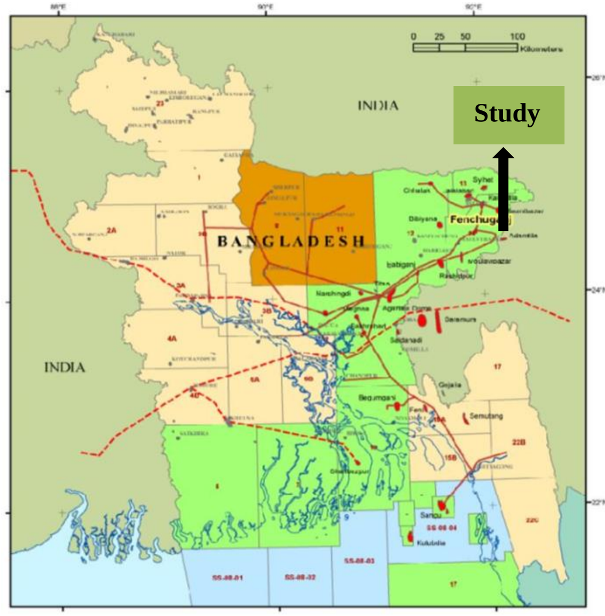


Figure 1: Generalized Stratigraphy of Fenchuganj (BAPEX, 1988)

The Fenchuganj gas field is located on the eastern boundary of the central Surma Basin, in the transition zone between the central Surma Basin and the folded belt to the east. The tectonic evolution of Surma basin is related to the eastward subduction of the Indian plate along the Arakan-Yoma suture and the subsequent development of the Indo-Burman orogenic belt during Eocene time. Since Miocene, sediments continued to be laid down in a shallow paralic basin of Surma Group. The post Oligocene eastward Subduction and Collision of the Indian plate along the ArakanYoma sutured zone led to the development of numerous folding and faulting in Surma basin. The Shillong Massif has been continuously uplifted, forming the Fenchuganj structure, which corresponds to the broad lowlands of the Surma valley.

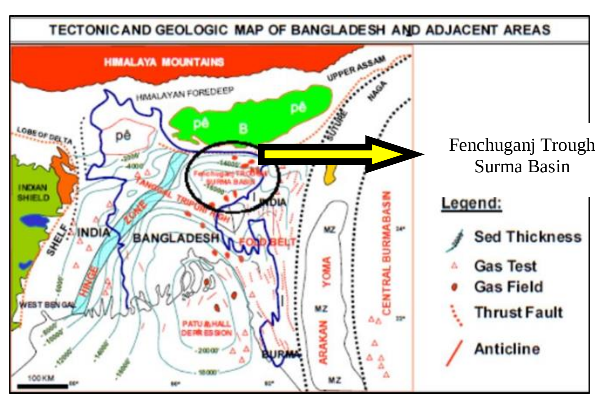


Figure 2: Regional Tectonic Map of Bangladesh and Adjacent Areas

Fenchuganj's structure is a NNE-SSW trending reversely faulted anticline. The number of dips on the eastern flank ranges from 30-350, while the number of dips on the western side ranges from 20-250, and the number of dips on the flanks rises with depth. (Fig. 3)

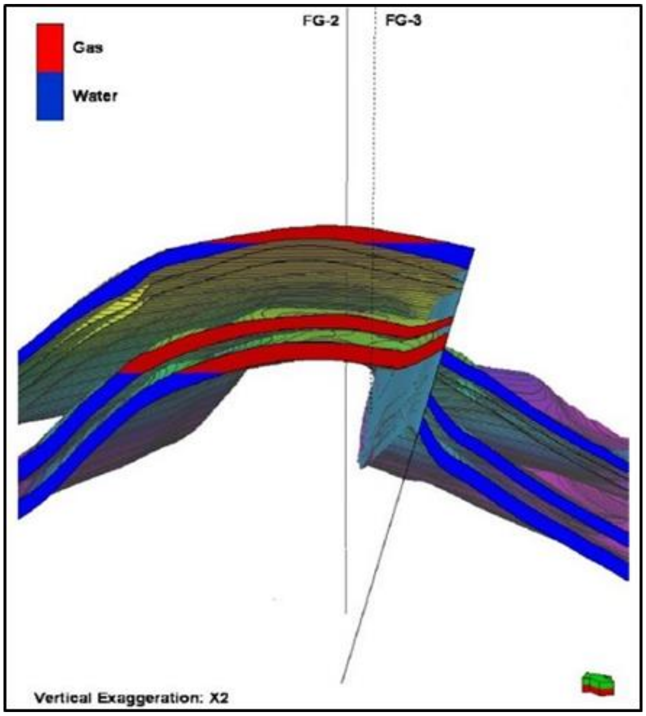


Figure 3: Structural Cross Section through Fenchuganj Anticline [Source: "Fenchuganj Geological Study", RPS Energy, 2009]

The Fenchuganj Gas Field's stratigraphic succession was created using well and petrophysical data, as well as laboratory analysis representing the Renji, Bhuban, Bokabil, Tipam & DupiTila formations (Table-1).

Table 1: Generalized Stratigraphy of Fenchuganj (BAPEX, 1988)

Thick-ness (m)	Formation	Age	Lithology
30	Alluvium	Recent	Unconsolidated sand, silt and clay
298	Dupi Tila	Late Pliocene	Brown to light brown, coarse, consolidated, moderately sorted, highly ferruginous sandstones with dark grey, soft clay
852	Tipam	Middle Pliocene	Light to off white, medium, poorly consolidated, ferruginous, very coarse to medium sandstone with soft clay
316	Upper Bokabil	Late Miocene	Grey to Bluish grey, soft to moderately hard and compact and also laminated shale
300	Middle Bokabil		Medium to fine sandstone with well laminated shale
470	Lower Bokabil		Light colored, fine to very fine, consolidated, well sorted, mild calcareous sandstones and well laminated shale.
Varies from 914 to 2741	Upper Bhuban	Late Miocene	Alteration of sandstone and shale with minor calcareous siltstone.
1140	Middle Bhuban	Middle Miocene	Minor sandstones with intercalated shale
530	Lower Bhuban	Early Miocene	Laminated shale with coarse to very fine minor sandstone
157+	Renji	Oligocene	Well laminated silty shale & fine sand-stone

DATA COLLECTION AND METHODOLOGY

Data Collection

The study analysis includes eight rock slides from core samples of the Fenchuganj well no. 2 shown in Table - 2. This well was drilled in 1985 and total depth is 4977 m. A total of 15 cores were cut within depth range of 4939 m in this well of which the analysis includes rock thin sections constructed from six cores.

Table 2: List of Rock Slides with Depth of Fenchuganj Well no.2

Slide no	Core no	Depth of core (m)
F-2	F-2	1479-1497
F-4a	F-4	2190
F-6	F-6	2768-2783
F-8a	F-8	Not known
F-9a	F-9	3424-3432
F-9b		3430
F-10a	F-10	3615-3624
F-10b		3615-3624

Work Methodology

The rock slides of the sample cores were studied under petrographic microscope with different magnifications (4x, 2x and 20x). Different diagenetic properties were identified under both plane and cross polarized light; especially in plane polarized light to identify the diagenetic and dissolution properties along with other textural and chemical properties leading to secondary porosity.

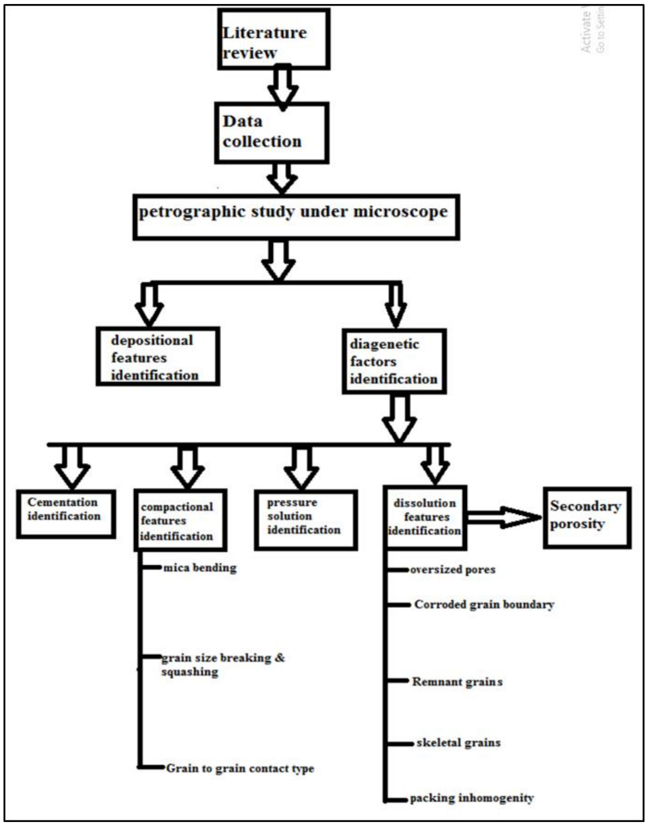


Figure 4: Flow Chart of Work Methodology

RESULTS

Primary Depositional Features

The primary depositional features in rock - framework grain, matrix, cement, primary porosity and sorting were observed. Petrographic analysis shows total amount of framework grain is about 50-75 %, 55-60 %, 75-80 %, where Quartz is 20-25%, 25-30%, 40-45%, Feldspar is 20-40% and Mica is 2-3%, 2-3%, 3-4% respectively and rest of the particles in framework grain are dark colored minerals. The amount of matrix is about 3-5 %, Primary porosity is about 2-4 % and the grains are moderately to poorly sorted.

The amount of Fe-Calcite cement is about 25-30% and the grains are well sorted.

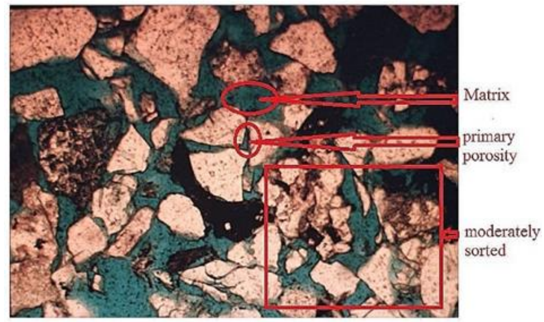


Figure 5: Depositional Features under Plane Polarized Light [Slide No. F-2, Mag: 10x]

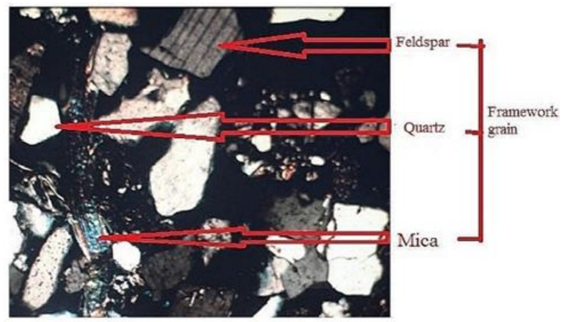


Figure 6: Depositional Features Under Cross Polarized Light [Slide No. F-2, Mag: 10x]

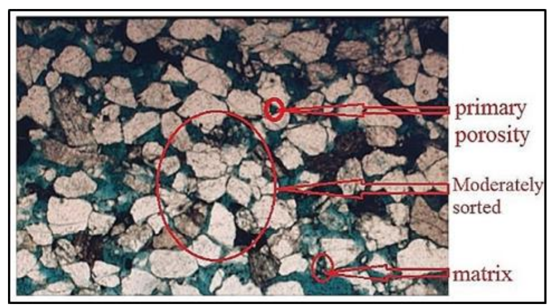


Figure 7: Depositional Features under Plane Polarized Light [Slide No. F-6, Mag: 4x]

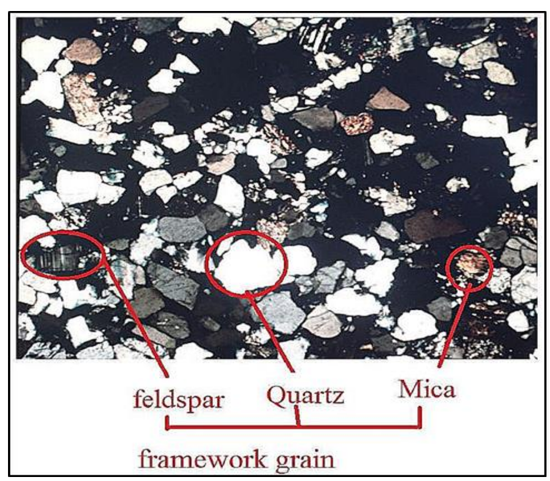


Figure 8: Depositional Features Under Cross Polarized Light [Slide No. F-6, Mag: 4x]

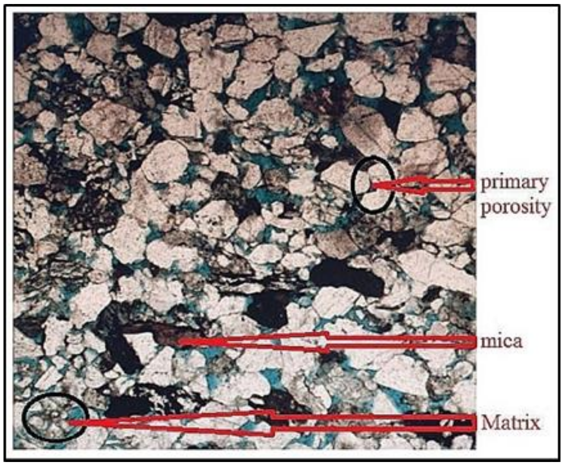


Figure 9: Depositional Features under Plane Polarized Light [Slide No. F-10b, Mag: 4x]

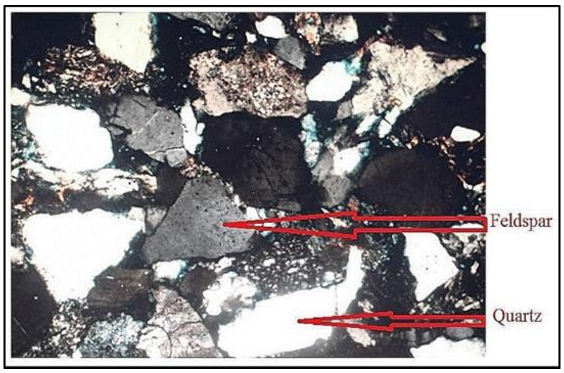


Figure 10: Depositional Features Under Cross Polarized Light [Slide No. F-6, Mag: 4x]

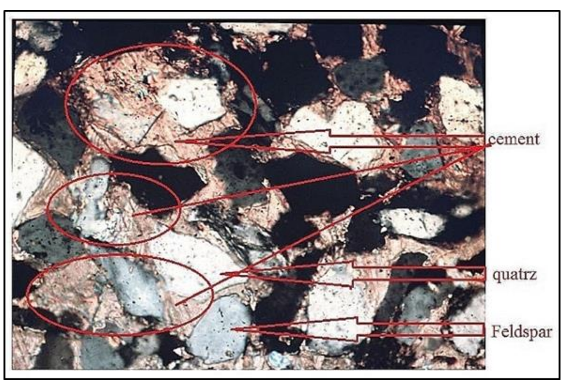


Figure 11: Depositional Features under Plane Polarized Light [Slide No. F-9b, Mag: 10x]

Diagenetic Changes

Diagenesis is a continuous process in which sedimentary mineral assemblages react to re-establish equilibrium with changing pressure, temperature, and general chemical conditions. Porosity can be enhanced, modified, or destroyed by these reactions. Various evidences of compaction are identified by mica bending due to pressure. High compaction leads to high deformation and due to that mica gets deformed as we see it (Fig. 12).

When the grains of similar brittleness and similar hardness collide with each other as a result of compaction, the larger grain sides break and squash. Also the grain contact gets altered as tangential contact indicates loose or moderate compaction; suturing and concavo-convex contact indicates high compaction in rock with pressure solution evidence (Fig. 13 & 14)

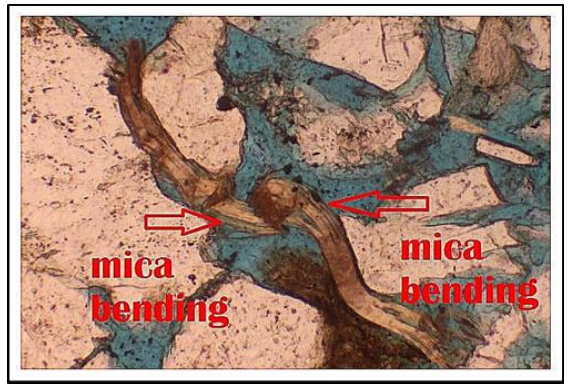


Figure 12: Mica Bending under Plane Polarized Light [Slide No. F-6, Mag: 10x]

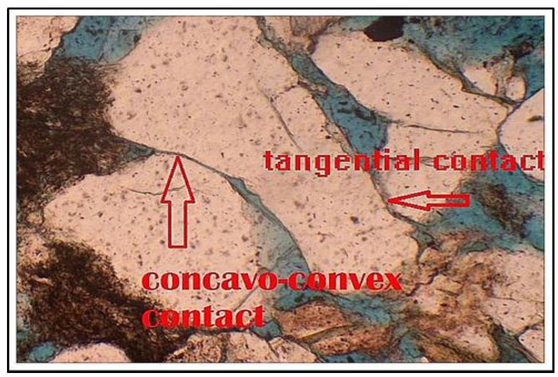


Figure 13: Tangential and Concavo-Convex Contact under Plane Polarized Light [Slide No. F-6, Mag: 10x]

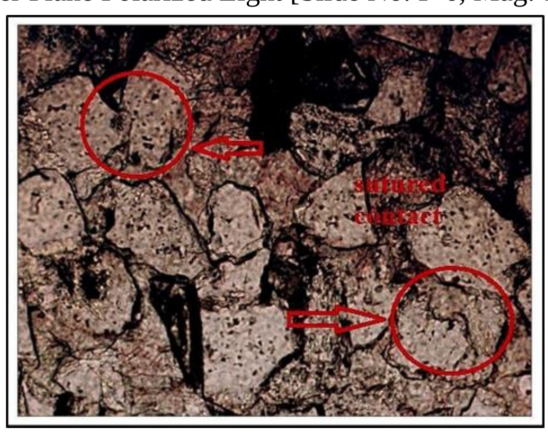


Figure 14: Suture Contact under Plane Polarized Light [Slide No. F-9a, Mag: 10x]

Chemically precipitated cements do not play well with reservoir quality as these blocks the pore spaces and the voids get filled. We can see quartz cement in these rock samples identified by quartz dust line, overgrowth of quartz and subhedral quartz (Fig. 15). In sample F-9b calcite cement is the most destructive for reservoirs. The presence of calcite cement indicates there is no secondary porosity present. It is identified by its pinkish/reddish color and sets of cleavages under plane polarized light (Fig. 16 & 17)

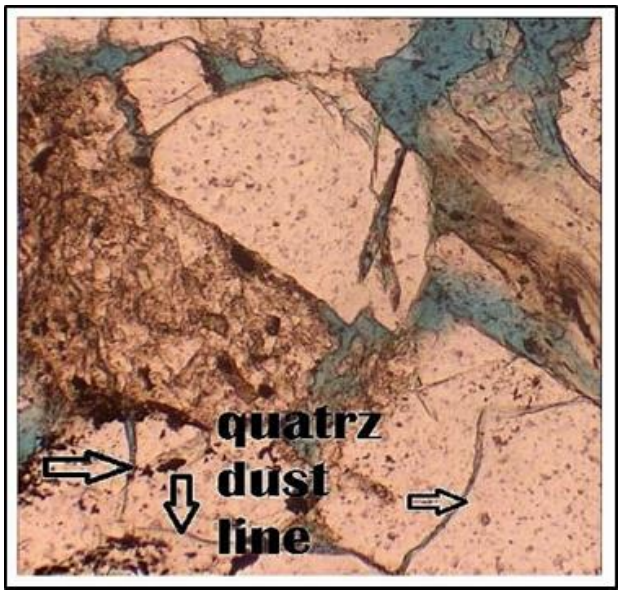


Figure 15: Quartz Dust Line [Slide No. F-6, Mag: 10x]

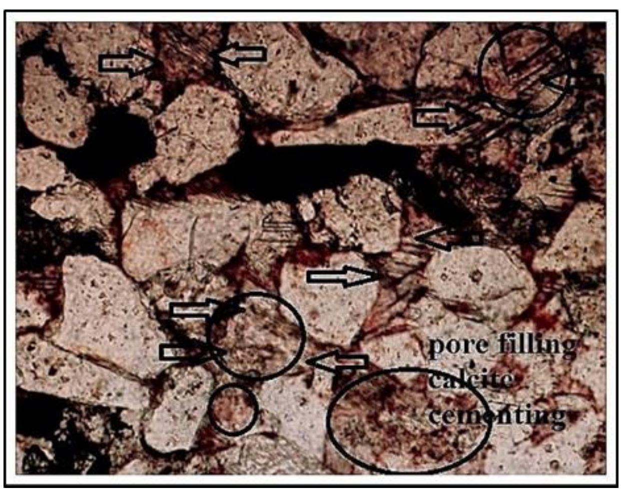


Figure 16: Pore Filling Calcite Cement [Slide No. F-9b, Mag: 10x]

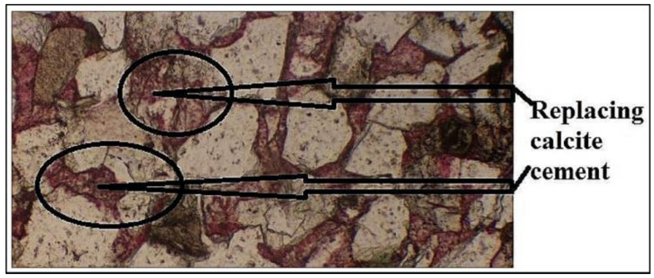


Figure 17: Replacing Calcite Cement [Slide No. F-9b, Mag: 10x]

Besides these, hematite and chlorite cement were seen in samples identified by opaque and light green colour respectively under plane polarized light.

Secondary Porosity in Fenchuganj Well

It has been seen from different studies that the sandstones of Fenchuganj gas fields had gone through several diagenetic processes as compaction, pressure solution, cementation, dissolution etc. To determine if there is presence of secondary porosity or not, and if present, its impact on reservoir quality, sandstones of different depths were studied and different features were identified.

Sample F2 [Depth of Core: 1479-1497m]: Diagenetic properties show maximum tangential contact among grains, compaction is loose and cement is absent. Dissolution properties show partial dissolution, skeletal grain and corroded grain boundary (Fig. 18). Corroded grain boundary is indicative of acid water intrusion. Consequently, the oversized pores generated. Dissolution properties are more prominent than diagenetic properties (Fig. 19).

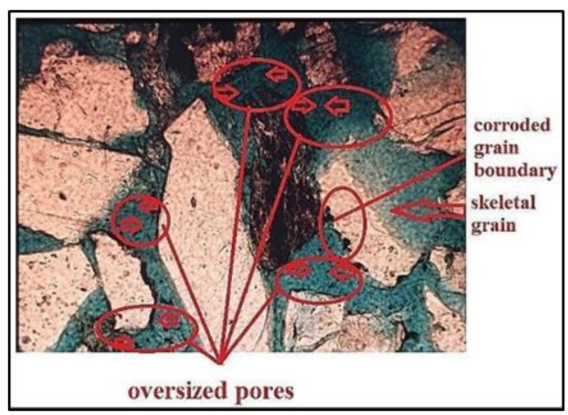


Figure 18: Oversized Pores, Corroded Grain Boundary, Skeletal Grain under Plane Polar [Slide No. F-2, Mag: 10x]

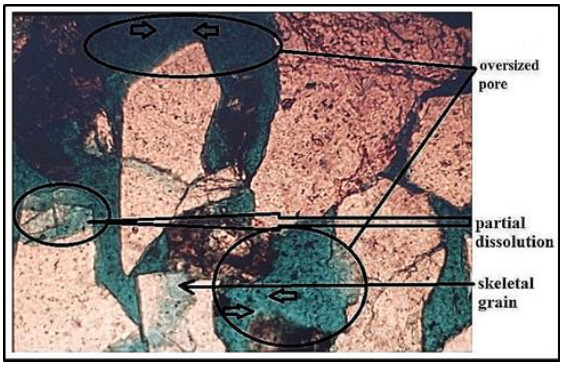
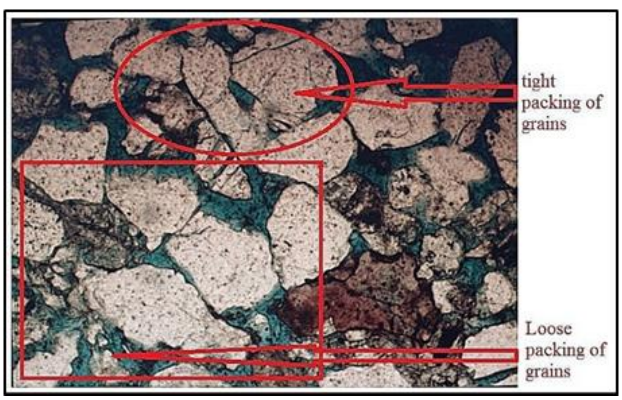


Figure 19: Partial Dissolution and Oversized Poresunder Plane Polar [Slide No. F-2, Mag: 10x]

Sample F6 [Depth of Core: 2768-2783m]: Diagenetic properties show a moderate to high compaction indicated by presence of both sutured & concavo-convex contact and bending of mica. Cement is negligible. Dissolution properties show oversized pores, corroded grains, skeletal grains, remnant grain, partial dissolution and packing inhomogeneity indicating generation of secondary porosity. The calcite portion in corroded grains is washed away by passing of acid solution. The corresponding oversized pores forms as a result of these dissolution processes. Dissolution properties are more prominent than diagenetic properties (Fig. 20).



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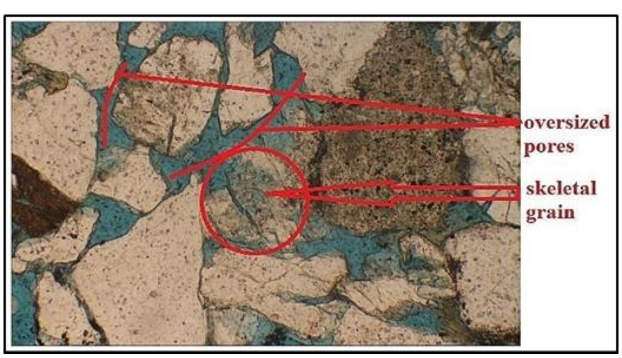

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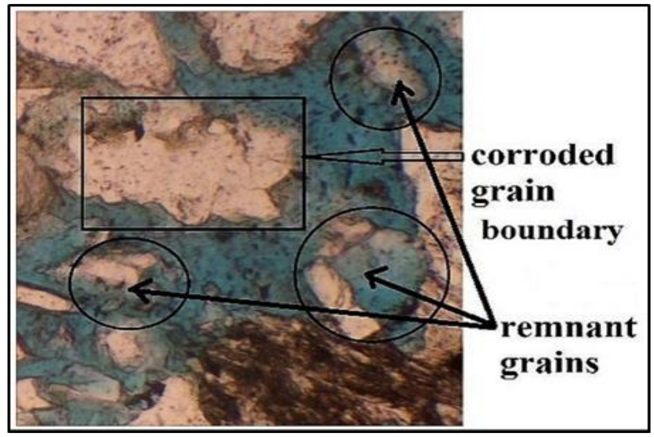

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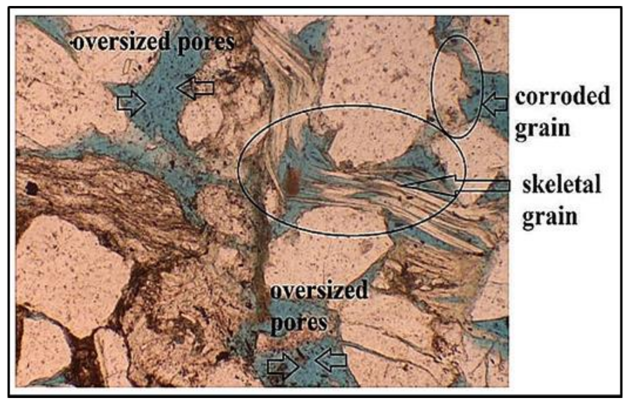

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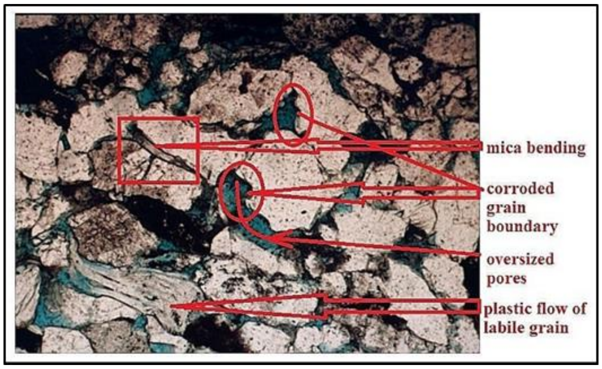
Figure 20: a) Packing Inhomogeneity b) Skeletal Grain of Feldspar and Oversized Pores c) Corroded Grain Boundary and Remnant Grain d) Skeletal Grain and Oversized Pore under Plane Polar [Slide No. F-6, Mag: 10x]

Sample F10b [Depth of Core: 3615-3624m]: Diagenetic properties indicate moderate to high level of compaction indicated by the degree of bending of mica. Cement is negligible. Dissolution properties show oversized pores, corroded grains and skeletal grains are present indicating generation of secondary porosity. Also the dissolution properties are more prominent than diagenetic properties (Fig. 21).



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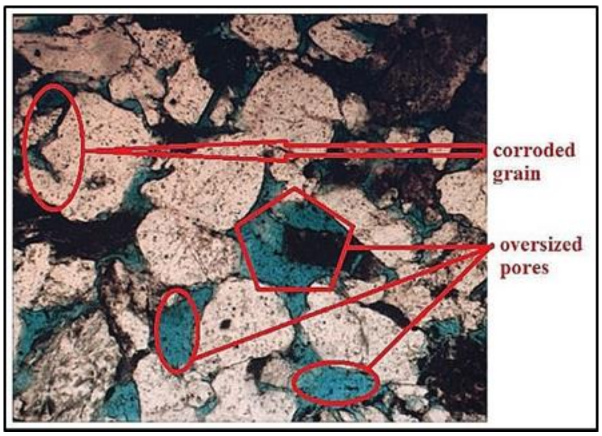

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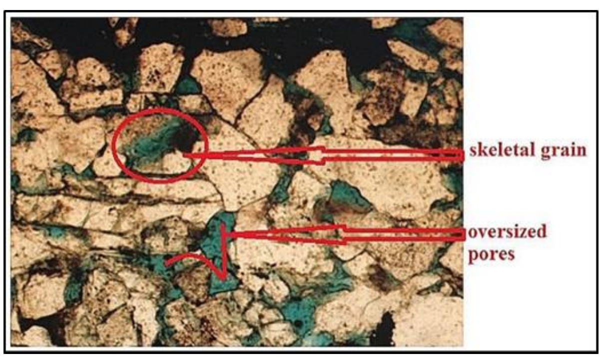

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Figure 21: a) Mica Bending & Plastic Flow b) Corroded Grain and Oversized Pores c) Skeletal Grain and Oversized Poreunder Plane Polar [Slide No. F-10b, Mag: 10x]

DISCUSSION

The examined slides show increased compaction with depth. Mica bending, grain side breaking, squashing, sutured, and concavo-convex contacts are compaction features that are lowest in depths of (1479-1497) m and highest in depths of (3615-3624) m. The preceding core samples can be divided into two categories based on whether or not cement was present: A) Calcite cement, B) No calcite cement (developed secondary porosity). The highest amount of calcite cementing is observed in core F-9 (depth: 3424m-3432m), slide no: F-9a and F-9b. Absence of calcite cement and generation of secondary porosity has been observed in slide no: F-2, F-6 and F-10b.

The highest concentration of the dissolution characteristics, such as skeleton grain, remnant grain, partial dissolution, corroded grain boundary, and oversized pores, was found in slide F-2, followed by slide F-6 and slide F-10b. Therefore, rock slide F-2 has the highest secondary porosity, followed by F-6 for the second highest, and F-10b for the lowest. The remaining five rock slides are completely secondary porous. Three distinct depths were affected by the dissolution process: (1479-1497) m (slide F-2), (2768-2783) m (slide F-6), and (3615-3624) m (slide F10b). The cement may change as a result of acidic water infiltration, and the calcite may have disintegrated. This intrusion could be a result of the chemical environment of rock changing.

Overall porosity of rock consists of both primary and secondary porosity. In the observed rock slides of Fenchuganj well no. 2, these three rock slides F-2, F-6 and F-10b contain good porosity, of which F-2 carries highest overall porosity of 35-40%. F-6 and F-10b cores contain about 30-35 % and 20-25 % porosity respectively. It is observed that the percentage of primary porosity decreases with increasing depth as in 3-4 % in 1479-1497m depth (slide no: F2); 2-3 % in 2768-2783 m depth (slide no: F6); and 1-2 % in 3615-3624 m depth (slide no: F10b). But slide no. F10b shows 20-25 % overall porosity.

The sample F6 (2768-2783 m depth) contains secondary porosity which is about 28- 33 %. This depth range lies between a very good hydrocarbon bearing zone of Fenchuganj gas field which is named as Middle Gas Sand (MGS). The depth of GWC of MGS is 2802 m and GIIP is 96 bscf. [Source: “Fenchuganj Geological study” for petrobangla, 2009. RPS energy]. So, there is a huge probability that secondary porosity has carried this reserve. So, it can be the prominent factor in enhancing reservoir quality in Fenchuganj gas field.

CONCLUSIONS

The Surma basin of North eastern part of Bangladesh contains sediments of Neogene succession which had undergone burial diagenesis at higher depths (>1400 m). The negative effects of these diagenetic features increased with depth - lowest in 1479-1497 m depth (sample: F2) and highest in 3615- 3624 m depth (sample: F10a). The primary porosity of these cores of Fenchuganj well no.2 was supposed to be destroyed by compaction, pressure solution, cementation etc. But the Fenchuganj well no. 2 is drilled up to 4977 m and very good to excellent quality reservoir rocks were found in three specific depths. By acidic pore water intrusion feldspar, calcite and clay minerals were dissolved and generated secondary porosity. The acidic water intrusion was maximum in 1479-1497 m depth, second highest in 2768- 2783 m depth and moderate in 3615-3624 m depth. Secondary porosity is the carrier of the reserve gas of Fenchuganj gas field as evident from the studied rock sample F6 which lies between the MGS (Middle gas sand) layer of Fenchuganj gas field.

The formation of secondary porosity is one of the explanations for the reservoir potentiality of the reservoir rock in the Fenchuganj gas field. It is recommended to keep concentrating on the development of secondary porosity because there are many prospective Neogene reservoirs at higher depths which have been neglected for the diagenetic processes acting on them. But dramatic changes in reservoir property may occur at any depth due to change in chemical environment. So, the aspect of secondary porosity development may open new window for Neogene gas reservoirs in Bangladesh.

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