PaperID **AU217**

Author **Deepsikha Bhuyan , ONGC , India**

Co-Authors **Jyoti Borthakur, Lusuchu Phor, P.S.Pangtey**

Mineralogy of Lakwa Barail Sequence (LBS) in Lakhmani area: evaluation of low resistivity sandstone reservoirs

Abstract

A careful examination of the log motifs in certain intervals of Lakwa Barail Sequence (LBS) indicates hydrocarbon anomaly where oil from low resistivity sands were detected and later confirmed by well testing results. The complication with the sands is that in certain zones the logs indicate low resistivity, but hydrocarbon is being produced. Therefore, in order to understand the mineralogy of the sands detailed sedimentological studies including megascopic, petrographic, XRD and SEM of LBS are being carried out. The study reveals that the detrital framework constituents of the LBS sandstones are dominated by quartz, feldspar, subordinate rock fragments and micas. Cement types recognized in this study include quartz, calcite and kaolinite as dominant and iron as minor cement. Dominant clay mineral in all the LBS sands is kaolinite, followed by illite and chlorite. Chlorite bearing sandstones usually give low resistivity signals, and are thus erroneously identified as non-pay zones, even if they exhibit good preserved porosities. Presence of significant non-clay minerals other than muscovite, quartz and feldspar are chamosite in LBS VI, IV, II and I; Pyrite in LBS-VI and LBS-I in the well Lw-A. However, in the well Lw-B, siderite is present in LBS V and LBS II. The mechanisms responsible for low resistivity phenomenon may be due to inclusion of clay or iron minerals which includes pyrite, chamosite and siderite. Clean sands indicate high resistivity, but when this rock contains clay or heavy minerals such as pyrite, the resistivity can become low. Pyrite has a good electrical conductivity that is usually comparable to, or even higher than the conductivity of the formation water. Even though the concentration of pyrite is low, the influence on resistivity can be significant as the crystals of pyrite may form a continuous network.

Introduction

Hydrocarbon potential of Barail has been well established in Upper Assam North Block wherein a number of pay sands are present. The pay sands within Barail stratigraphic sequence has been primarily divided into two major units – Barail Coal Shale (BCS) and Barail Main Sand (BMS). Within Barail Coal Shale sequence the major pays are represented by channel sands. In Lakwa Field there are six (6) recognized pay sands within the Coal Shale unit which are named as Lakwa Barail Sequence/ LBS-I, II, III, IV, V & VI from older to younger stratigraphy respectively. LBS-I, LBS-II & LBS-V are the main producers. The sandstones of Barail Group are moderate to good reservoirs. LBS-I and LBS-II reservoir sands are laterally quite extensive like sheet sands. However, LBS-III & LBS-IV sands have very limited vertical and lateral extension. LBS-V & LBS-VI are relatively better reservoirs than LBS-III & LBS-IV sands. LBS-V is a promising hydrocarbon bearing zone in Lakwa - Lakhmani area. A sharp reduction in resistivity is observed in the log data of some wells even though the section is hydrocarbon bearing. Therefore, in order to know the reason behind, detailed sedimentological studies of two specifically selected nearby wells is being carried out.

Regional Geology and Stratigraphy

Lakwa-Lakhmani field is situated in the Upper Assam Shelf of the Assam-Arakan Geological Province. The Assam Shelf is a southeast dipping shelf in the foreland part of Assam-Arakan Basin in North-eastern part of India which covers about 40,000 sq.km of area and belongs to the north-eastern prolongation of the Indian Peninsular Shield. It is bounded by Shillong Plateau & Mikir hills (composed mostly of Precambrian granitic and metamorphic rocks) towards its west, Mishmi hills along its northeast boundary and Naga Schuppen belt to the south. Tectonically, Assam-Arakan Basin has been defined as a poly-history basin that evolved synchronous with the other East-Coast basins of India, concomitant with the rifting and subsequent drifting of the Indian Plate from Eastern Gondwana land. The location map of the study area is represented in Figure 1.

In the Assam Shelf lithostratigraphy, the Barail Group is underlain by Kopili Formation and overlain by Bhuban Formation. The Barail Group in the Shelf is divided into Disangmukh, Demulgaon and Rudrasagar Formations. The LBS sands fall within the Rudrasagar Formation. The generalized stratigraphy of Upper Assam North is shown in Table 1.

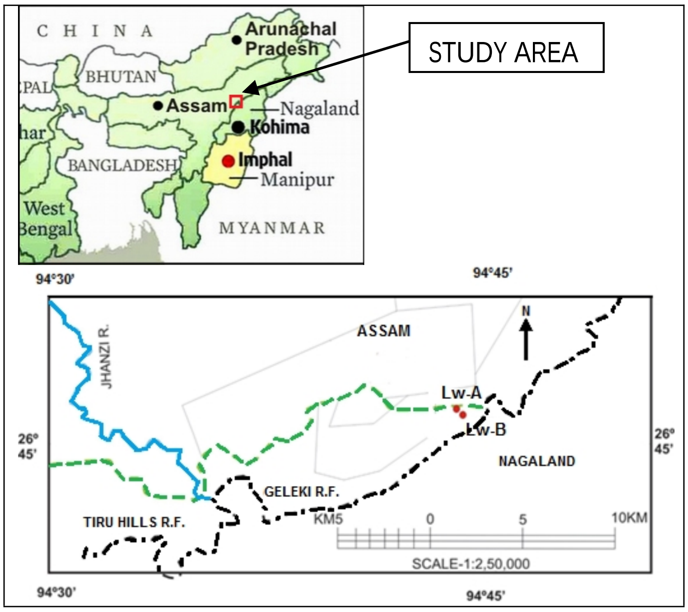


Figure 1. Location map of the study area. The map shows the location of the wells Lw-A and Lw-B.

Material and Methodology

The sedimentological studies presented herein were performed on a set of seventy four (74) samples of two selected wells viz. Lw-A and Lw-B. The study includes detailed megascopic and petrographic study of the cutting samples along with XRD analysis to infer the mineralogy of the sands and SEM analysis to infer the reservoir characteristics.

Megascopic study was carried out on samples at 5-10 meters interval, observing the lithologic breaks and recording all the physical properties of sediments. Thin sections were prepared from nine (9) clean sandstone sections which were impregnated with polyester resin with proper ratio of hardener for petrographic study. The dry casting is mounted on a flat 2X3 inch micro slide with epoxy resin at room temperature and ground to a fine finish. The petrographic study was carried out with Carl Zeiss Axio Scope A1 Pol Polarizing Microscope mounted with Nikon camera.

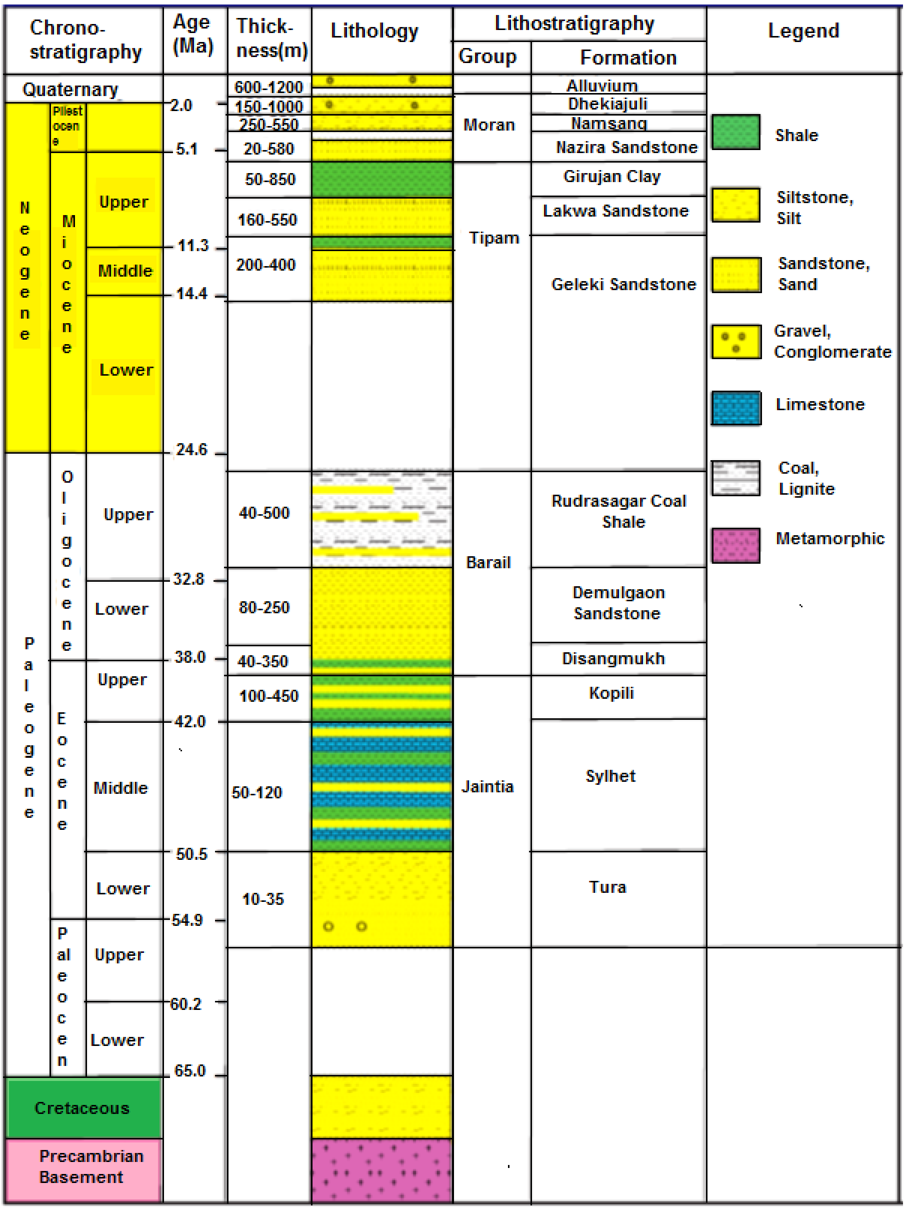
Samples were prepared for SEM analysis by removing small rock fragment measuring less than 1 cm diameter and then analyzed using a Scanning Electron Microscope (SEM) fitted with Energy Dispersive Spectrometry (EDS) system.

XRD analysis was carried out for both clay mineral and bulk mineral identification by using Model ULTIMA-III of Rigaku Make having Copper as target metal. For bulk mineral identification the sample is grinded with an agate mortar upto <2μm and mounted on the slide. However, for clay mineralogy, only the clay fraction (<2μm) of the samples was separated and clay minerals were identified. Initial disaggregation was conducted under distilled water in an agate mortar. The sample was then transferred to a suitable beaker together with a dispersing agent in order to prevent flocculation. Standing the beaker overnight facilitated liberation of the clay component. The 2 μm fraction was removed from suspension with a pippete and transferred to a glass slide. The slide is then allowed to dry at room temperature.

Reservoir Lithologies

The modal analysis data are presented in Table 2. Reservoir rock LBS-VI of both the wells is composed of intercalations of coal and sandstone with minor amounts of shale. Microfacies (Lw-A1, Lw-B1 & Lw-B2) include quartz wacke. Quartz grains are medium to very fine grained and subangular to subrounded. Feldspars are mostly plagioclase and microcline. Mica bending as well as grain orientation is well observed in certain intervals. In the well Lw-B, cement is dominantly calcareous with minor amounts of ferruginous patches. However, in the well Lw-A, cement is dominantly argillaceous with few iron patches. XRD clay mineralogical analysis indicates that the dominant clay mineral in the well Lw-A

Table 1: Generalized stratigraphy of Upper Assam Shelf, North Block, A & AA Basin (after Pandey et al., 1997).



is chlorite followed by kaolinite and then illite. Non-clay minerals include muscovite, quartz, feldspar, chamosite and pyrite. However, in the well Lw-B kaolinite is dominant, followed by illite and then chlorite. Non-clay minerals include muscovite, quartz and feldspar.

In the wells Lw-A and Lw-B, the sediments of LBS-V are composed of intercalations of sandstone and coal with minor amounts of shale and claystone. Petrographic study indicates the sandstone (Lw-A2 & Lw-B3) to be quartz arenite and quartz wacke with fine to very fine grained and subangular to subrounded grains. Feldspars are mostly plagioclase and microcline. Cement is dominantly calcareous in the well Lw-B. However, in the well Lw-A, cement is dominantly argillaceous with minor iron patches. XRD study in the well Lw-A indicates dominance of clay minerals with kaolinite, followed by illite and then chlorite. Muscovite, quartz and feldspar are the common non-clay minerals in both the wells. However, chamosite is present in the well Lw-A and siderite in Lw-B. LBS-IV in both the wells is composed of intercalations of coal, siltstone and silty shale with minor amounts of shale. As the sequence is dominantly argillaceous, thin sections were not prepared for LBS-IV. LBS-III is absent in both the wells. The lithology of LBS-II of the wells Lw-A and Lw-B, is composed of siltstone with minor amounts of sandstone, shale, claystone and coal. Microfacies (Lw-A3 and Lw-A4) vary from quartz arenite to quartz wacke. In the topmost and the lowermost parts of LBS-II, cement is dominantly argillaceous with point to line grain contact. But, in the middle part cement is dominantly calcareous

Table 2: Modal analysis data of the LBS sands in Rudrasagar Formation, Barail Group.

		Quartz				Feldspar		Rock Fragments			Cement						
Sample no.	Depth (m)	Qnu	Qu	Qp2-3	Qp>3	P	K	Ls	Lm	Li	Sil	Arg	Fer	Cal	Matrix	Mica	Chert
Lw-A1	3700-05	17	18	5.2	5.1	2.5	1.5	1.5	0	0	1.8	8.5	2.1	0	32.5	0	5
Lw-A2	3760-65	15	20	2.5	2	2.5	2	2	0	0	2.1	5.1	13	0	29.3	0	5
Lw-A3	3850-55	15	19	2	0	2.1	1	1	0	0	2	5.5	1	0	47.6	0	5.1
Lw-A4	3890-95	16	8.1	3	7.1	5.1	2	2	1	0	0	0	0	35	9.1	1.2	10.2
Lw-A5	3920-25	5	20	2.5	7.2	1	0	2.2	0	0	2.2	7.1	2.1	0	45	0	5.6
Lw-A6	3940-45	7.1	21	5.1	8.2	2.1	0	2.1	0	0	2.1	8.5	2	0	34.3	0	8
Lw-B1	3665-70	16	20	6.7	5	2	1	0	2.2	0	3	9.2	2	0	28.5	0	5
Lw-B2	3680-85	17	19	6.1	5.2	4.1	2	0	3	0	2.1	10.5	1.2	0	22.2	2	5.5
Lw-B3	3710-15	16	8	3.1	8.1	6.2	2	2	3	2	0	0	0	33	2.5	1.2	15.1

Non-undulatory monocrystalline quartz (Qnu), undulatory monocrystalline quartz (Qu), polycrystalline quartz with 2-3 subgrains (Qp2-3), polycrystalline quartz with >3 subgrains (Qp>3), plagioclase (P), potash-feldspar (K), sedimentary lithic (Ls), metamorphic lithic (Lm), igneous lithic (Li), cement which includes siliceous (Sil), argillaceous (Arg), ferruginous (Fer) and calcareous (Cal).

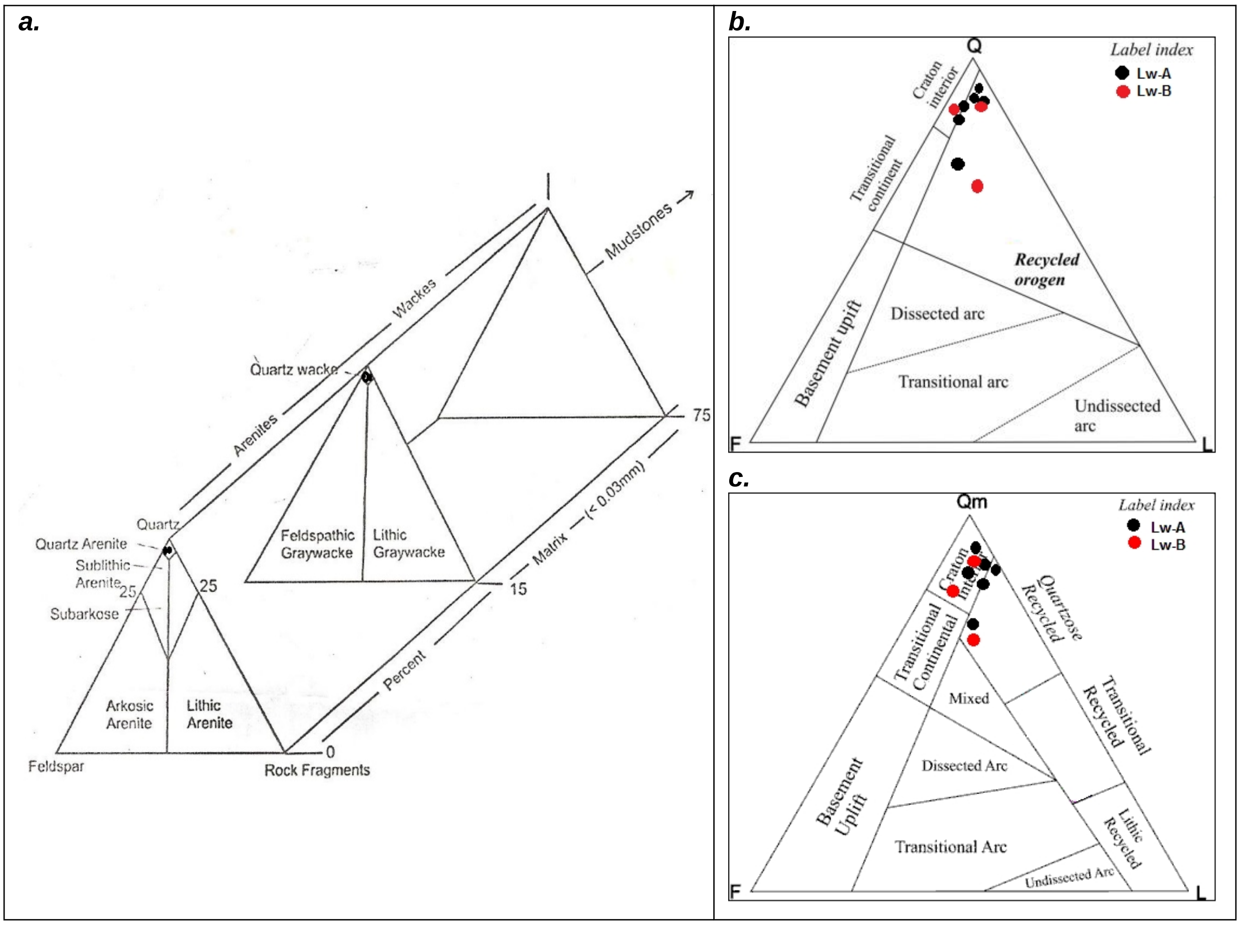


Figure 2. *a.* Classification of the LBS of Barail Group in the study area (after Dott). ***b.*** Q-F-L and ***c.*** Qm-F-L triangular plots for the LBS of Barail Group for tectonic set-up discrimination (after Dickinson et al.).

Q= Qnu+Qu+Qp2-3+Qp > 3, non-undulatory monocrystalline quartz (Qnu), undulatory monocrystalline quartz (Qu), polycrystalline quartz with 2-3 subgrains (Qp2-3), polycrystalline quartz with >3 subgrains (Qp>3); F, feldspar; L, rock fragments; Qm= Qnu+Qn, Non-undulatory monocrystalline quartz (Qnu), undulatory monocrystalline quartz (Qu).

with the sparry calcite destroying the reservoir properties. XRD study indicates the dominant clay mineral as kaolinite, followed by illite and chlorite. But in the well Lw-B, illite is dominant, followed by chlorite and then kaolinite. Muscovite, quartz and feldspar are the common non-clay minerals in both the wells. However, chamosite is present in the well Lw-A and siderite in Lw-B.

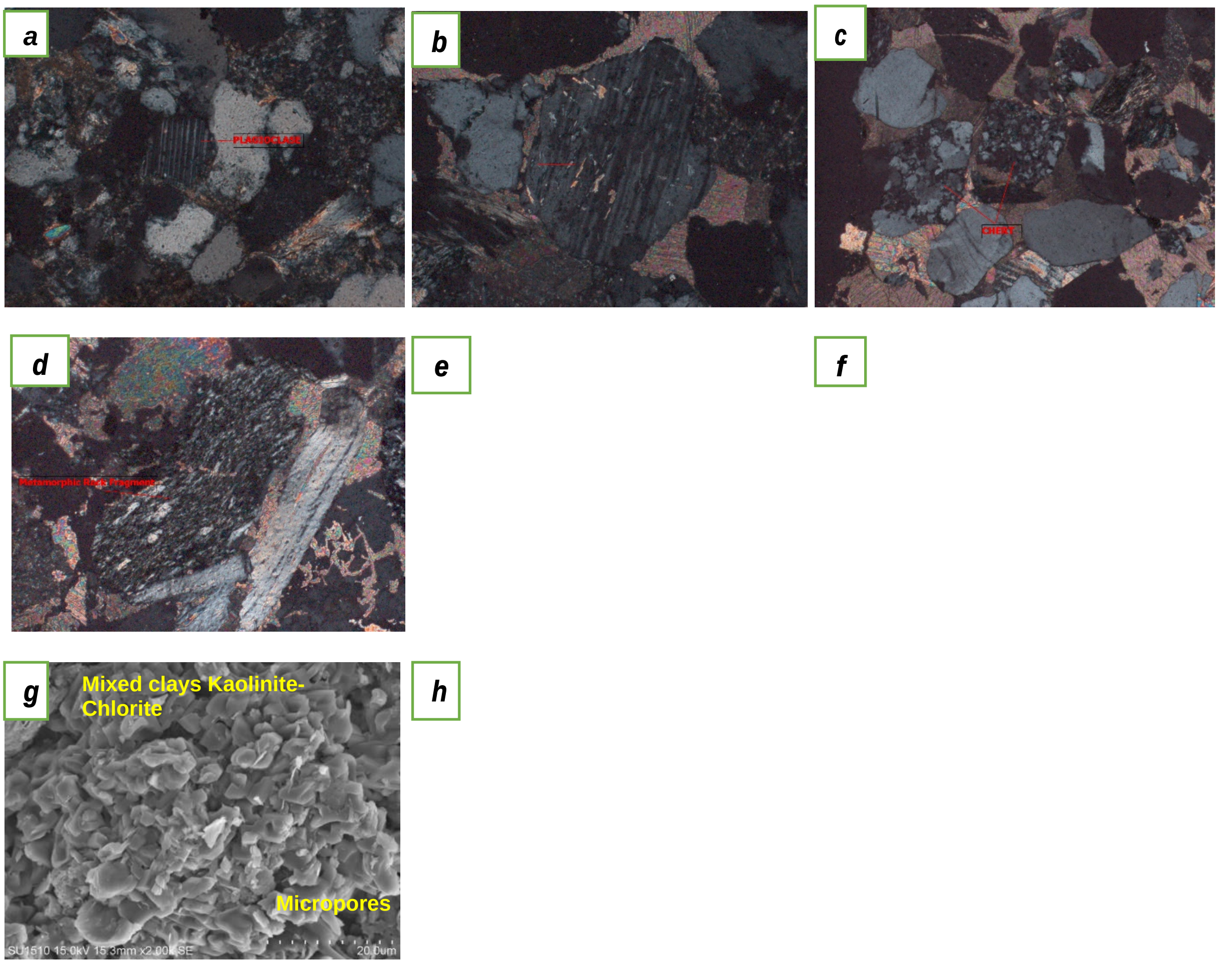


Figure 3. ***a.*** Plagioclase (lamellar twinning); ***b.*** Dissolution of feldspar; ***c.*** Precipitation of secondary chert; ***d.*** Metamorphic rock fragment; ***e.*** Pore space occluded by mica; ***f.*** Quartz overgrowth and kaolinite filling the pore spaces; ***g.*** Micropores present in the mixed clays kaolinite-chlorite; ***h.*** Presence of plagioclase with confirmation by EDS.

LBS-I in the wells Lw-A and Lw-B is composed of dominantly silty shale with minor amounts of sandstone and coal. Petrographic study indicates the sandstone (Lw-A5 & Lw-A6) to be quartz wacke with fine to very fine and subangular to subrounded grains. Cement is dominantly argillaceous. Grains have point to line grain contact. XRD clay mineralogy indicates that in the well Lw-A, the dominant clay mineral is kaolinite, followed by illite and then chlorite. Muscovite, quartz, feldspar, chamosite and pyrite are the non-clay minerals.

Sandstone mineral composition are shown in Figure 2b and 2c, following Dickinson et al. 1983. It appears that sediments are the products of craton interior, recycled orogen and quartzose recycled sources. The sediments derived from cratonic interior provenance are characterized by the dominance of quartz and minor presence of feldspar, and it indicates probable low relief cratonic sources that had undergone prolonged transport across continental surfaces having low gradients. High quartz-to-feldspar ratio represents collision-derived fold thrust belt and distant uplifted cratonic blocks as their sources (Borgohain et al. 2011). SEM study of the LBS indicates that quartz is the main framework grain and it is fine to very fine and occassionally medium with moderate to poorly sorted. At places, formation of kaolinite has reduced the porosity as well as permeability of reservoir rock (Figure 3f). Reservoir anatomy shows tight nature with isolated pore spaces (Figure 3g). Incipient clay is predominantly seen with associated kaolinite & chlorite with increasing depth. At places ductile/flaky minerals like mica is occluding the pore spaces (Figure 3e). The reservoir quality of the sands is poor to moderate.

Conclusions

Detrital framework constituents of the LBS sandstones are dominated by quartz, feldspar, subordinate rock fragments and mica. Cement types recognized in this study include quartz, calcite and kaolinite as dominant and iron as minor cement. Dominant clay mineral in all the LBS sands is kaolinite, followed by illite and chlorite. However, in the well Lw-A, the dominant clay in LBS-VI is chlorite, followed by kaolinite and illite. Moreover, in Lw-B, the dominant clay in LBS-I is illite followed by chlorite and kaolinite. The apparent dominance of illite over kaolinite in the sediment indicates that intensive mechanical breakdown of rocks prevailed in the source area. Occurrence of kaolinite may reduce the pore spaces while illite reduces permeability of the rock. Chlorite bearing sandstones usually give low resistivity signals, and are thus erroneously identified as non-pay zones, even if they exhibit good preserved porosities. Presence of significant non-clay minerals other than muscovite, quartz and feldspar are chamosite in LBS VI, IV, II and I; pyrite in LBS-VI and LBS-I in the well Lw-A. However, in the well Lw-B, siderite is present in LBS V and LBS II. It appears that the hydrocarbon bearing zones reflect low resistivity in the log due to presence of significant amount of iron minerals.

The mechanisms responsible for low resistivity phenomenon may be due to inclusion of clay or iron minerals which includes pyrite, chamosite and siderite. Clean sands indicate high resistivity, but when this rock contains clay or heavy minerals such as pyrite, the resistivity can become low. Pyrite has a good electrical conductivity that is usually comparable to, or even higher than the conductivity of the formation water. Even though the concentration of pyrite is low, the influence on resistivity can be significant as the crystals of pyrite may form a continuous network.

Acknowledgement

The authors wish to express their sincere gratitude to ED, Basin Manager, A & AA Basin and Block Manager of Upper Assam North Block, ONGC for their constant support. The authors gratefully acknowledge RGL, Vadodara for permitting to carry out the XRD analysis and RGL, Rajamundry for permitting to carry out the SEM analysis. The authors are grateful to Shri Mukunda Rajkhowa, Chief Geologist of ONGC for coordinating & providing all the necessary information to complete this task.

References

Dudek T.2012, Clay minerals as palaeoenvironmental indicators in the Bathonian (Middle Jurassic) ore-bearing clays from Gnaszyn, Kraków-Silesia Homocline. Vol. 62 (2012), No. 3, pp. 297–305.

Weaver C.E., A Discussion on the origin of clay minerals in sedimentary rocks, Shell Oil Company, Houston, Texas.

Wilson M.J., Wilson L., Patey I., The influence of individual clay minerals on formation damage of reservoir sandstones: a critical review with some new insights, Clay Minerals, (2014) 49, 147–164.

Osabor V.N., Itam A. E., Paleoenvironmental Interpretation Of Clay Deposits Within Odukpani, Southeastern Nigeria, Department Of Pure And Applied Chemistry, University Of Calabar, Nigeria, Department Of Geology, University Of Calabar, Nigeria.

Dott Jr, R.H., Wacke, greywacke and matrix-what approach to immature sandstone classification? J. Sediment. Petrol., 1964, 34, 625-632.

Dickinson, W.R., et al., Provenance of North America Phanerozoic sandstones in relation to tectonic setting. Geol. Soc. Am. Bull., 1983, 94, 222-235.

Islam M. A., Diagenesis and reservoir quality of Bhuban sandstones (Neogene), Titas Gas Field, Bengal Basin, Bangladesh, Journal of Asian Earth Sciences 35 (2009) 89-100.

Borgohain P., Hazarika S., Gilfellon G. B., Gogoi M. P., Petrography and diagenesis of the Upper Paleocene-Lower Eocene rocks of Nahorkatiya oilfield, Assam, Current Science, Vol. 101, No. 5, 10 September 2011.