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Integrated geological studies of Oligocene-Miocene succession, Southwest of Mumbai High: Depositional setup and Diagenesis

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Abstract

Sedimentological and biostratigraphic analysis of seventeen cores from wells (B-5, B-4, D-1, B-3, B-2, B-1 and D-2) are carried out to understand microfacies, porosity trends, diagenesis and depositional setup of Oligocene-Miocene succession in southwest of Mumbai High. The succession in the northern region is dominantly low energy carbonates i.e. foraminiferal wackestone-mudstone, minor shale and carbonaceous shale intercalations. In the southern region (wells B-4, B-3, B-2 and B-1) increased sedimentary thickness is encountered with occasional presence of high energy facies such as algal-foraminiferal packstone and grainstone. Good porosity represented by vugs, solution channels, molds and micropores is recorded. The foraminiferal assemblage and litho-microfacies association of the Oligocene-Miocene succession suggests deposition in unstable shallow marine carbonate platform; the environment of deposition varying between low energy shallow shoreface, high energy shoals and restricted backshore (represented by carbonaceous shale). Based on present study, the Late Oligocene carbonates in the southern part of the study area has emerged as potential reservoir facies represented by high energy packstone.

Introduction

The Oligocene-Miocene succession in the study area (Figure 1) is represented by carbonates with minor shale intercalations. The limestone is dirty white to grey, hard and compact with branching to near parallel stylolaminations. Nodular limestone is also common. The intercalated thin shale is fissile, greenish to dark grey and carbonaceous at places. The carbonates are represented mainly by low energy foraminiferal wackestone, foraminiferal coralline wackestone, foraminiferal dolomitic wackestone, dolomitic mudstone, algal wackestone and argillaceous coralline wackestone. Mudstone and calcareous claystone facies are also observed. The most common diagenetic features observed are sparitization, dolomitization, recrystallization and blocky calcite growth. Occasional presence of high energy facies of algal-foraminiferal packstone and grainstone has also been observed in the Oligocene succession of wells B-3, B-2 and B-1 in southern part of the area (figure 6a, b). The diagenetic processes have remarkably occluded the organic as well as secondary porosity due to re-precipitation of calcium carbonate destroying the reservoir quality. Dolomitization has least effect on porosity enhancement and is inferred to have occurred in meteoric–marine mixing zone. Pyrite, present as grain fillings has also destroyed the organic porosity. Ferruginization is also observed at many places indicating short spans of sub-aerial exposure. The dissolution activities and leaching of the sediments however, have resulted in good porosity development at some intervals. Pressure solution seams (wispy and low amplitude) and stylolitic features (anastomosing and branched), filled with insoluble argillaceous residue infer late stage chemical compaction during diagenesis which has also resulted in porosity and permeability reduction.

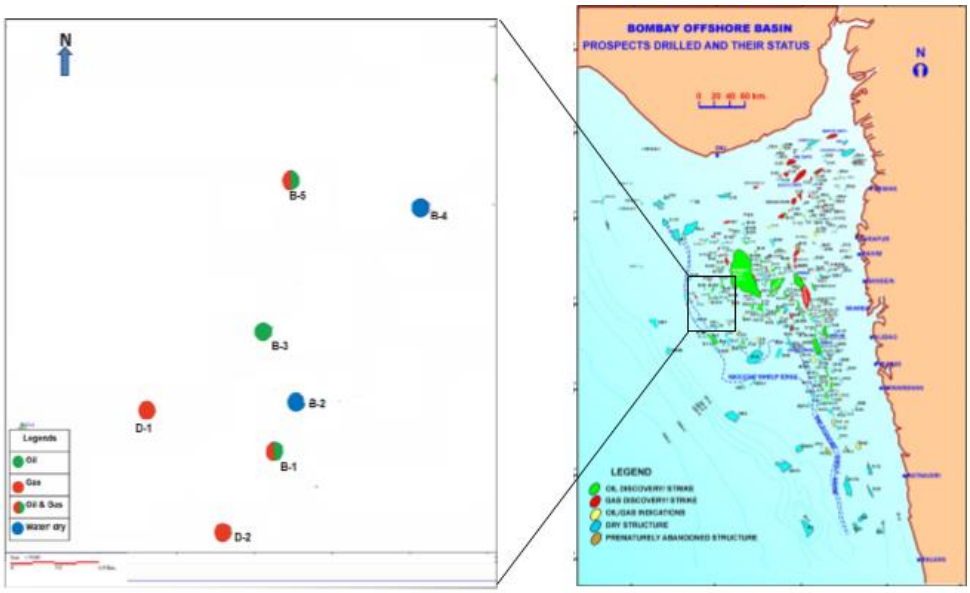

Figure 1: Location map of Study area

Methodology

Biostratigraphic studies are carried out on all the cores and cutting samples in the studied interval to determine the environment of deposition and paleobathymetry. Sedimentological studies include detailed megascopic and microfacies analyses to bring out lithological variations, mineralogical composition, environmental interpretation and reservoir characterization of the studied succession.

Spatio-Temporal variation of reservoir facies:

A) Early Oligocene: The Early Oligocene succession (Mukta/Heera formations) in the wells is represented by limestone with minor intercalations of shale. The average thickness ranges from 60-80m however a maximum thickness of 130m is encountered in the northern well B-5. The carbonate lithofacies is represented by low energy mud supported wackestone in wells B-5 and B-3 in the north to foraminiferal packstone (well D-2) in the south (Figure 2). At places mudstone and calcareous claystone facies have also been encountered in southern most well D-2 (Figure 2). In wells (B-2 and D-2) high energy grain supported packstone and grainstone facies have been observed in the lower part of the formation, suggesting periodic high energy pulses in overall low to moderate energy conditions. The interbedded shale is compact, poorly fissile and pyritic with few foraminifers. The characteristic foraminiferal suite includes larger benthic foraminifera such as *Nummulites vascus*, *N. fichteli, Archaias* sp. along with smaller benthics. Bathymetry of 20-30m is inferred for the deposition of these sediments. The foraminiferal assemblage & litho-microfacies association suggest deposition of Early Oligocene sediments under shoreface setting. The common diagenetic features are sparitization, dolomitization, stylolitic laminations, recrystallization and blocky calcite growth. In addition, pyritization, ferruginization and dissolution activities are also observed in some intervals. Sparitization and secondary calcite growth in existing vugs and molds has substantially destructed the porosity in most of the wells. However, secondary porosity is preserved in the form of isolated vugs, solution channels and moldic porosity. The southernmost well D-2 shows moderately good porosity at places. Hydrocarbon occurrences have been observed in wells B-3 and B-1.

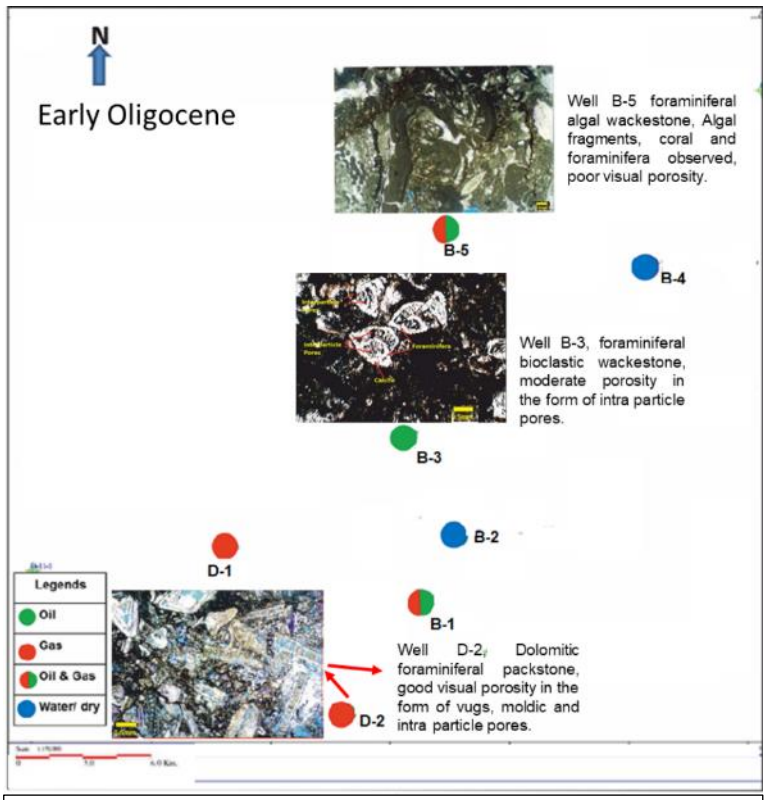

Figure 2: Microfacies distribution map of Early Oligocene

B) Late Oligocene: The Late Oligocene (Panvel Formation) in the area is represented by limestone with minor intercalations of shale. The average thickness of the succession is around 230-240m and attains a maximum thickness of up to 350m in southern most well D-2. The carbonate lithofacies varies from high energy foraminiferal packstone in northern region (well B-3 and B-4) to low energy foraminiferal wackestone and foraminiferal algal wackestone in southern region i.e. wells B-1and B-2 (figure 3). The characteristic foraminiferal assemblage includes *Spiroclypeus ranjanae, Austrotrillina howchini, Miogypsinoides formosensis, Heterostegina* sp*., Lepidocyclina* spp. *Archaias* sp., *Sphaerogypsina* sp. *Pararotalia* sp. and other smaller benthics.

The foraminiferal suite suggests that the Late Oligocene sediments were deposited in a bathymetry of 10-20m. The foraminiferal assemblage and litho-microfacies attributes of Late Oligocene sediments suggest shallow shoreface setting with high energy conditions prevailing in the northern part (well B-3 and B-4). The commonly observed diagenetic features are sparitization, dolomitization, recrystallization and secondary calcite growth. Stylolitic laminations filled with argillaceous matrix are also commonly observed. The porosity is poor. Sparitization and secondary calcite growth in existing vugs and molds has substantially destructed the porosity in most of the wells. However, occasional isolated vugs, solution channels and moldic porosity is developed in these wells. The packstone facies with solution vugs, channels and molds render moderate to good porosity. Hydrocarbon occurrences have been observed in the southern part of the area (Wells B-3 and B-1).

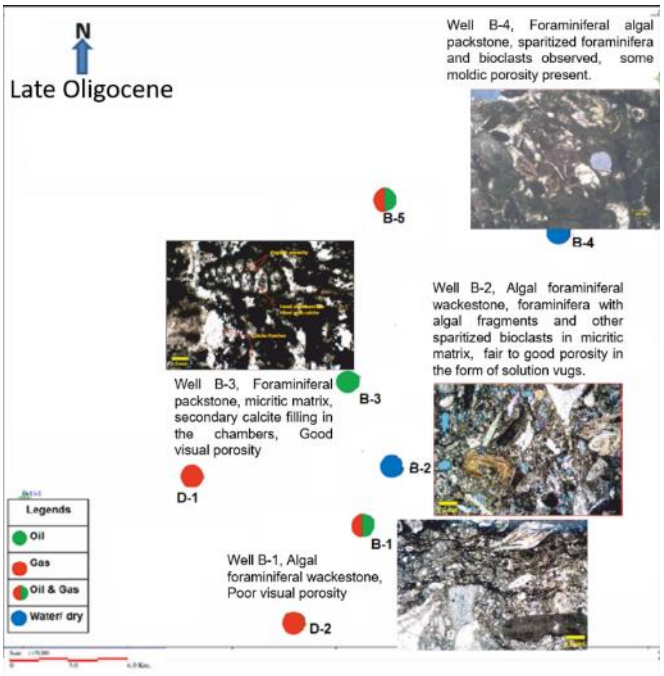

Figure 3: Microfacies distribution map of Late Oligocene

C) Early Miocene: The Early Miocene (Ratnagiri and Bombay formations) is represented by limestone with minor shale intercalations and occasional presence of dark grey, fissile carbonaceous shale. The thickness of this litho-stratigraphic unit shows a slight increase towards central part with a maximum thickness of 517m encountered in the well B-3 and a gradual decrease in thickness is observed in the surrounding area. The litho-microfacies is represented by low energy foraminiferal wackestone in well D-2 and B-1 towards the southern part of the area, dolomitic foraminiferal wackestone is observed towards northern region (Well B-5) (figure 4). The succession is characterized by rich assemblage of larger as well as smaller benthic foraminifera viz. *Heterostegina* sp., *Elphidium* sp., *Miogypsina* sp., *Amphistegina* sp., *Borelis* sp., *Lepidocyclina* sp., *Sphaerogypsina* sp., *Operculina* sp., *Archaias* sp. The bathymetry is inferred to be 10-20m, occasionally in wells B-5 and B-1, the bathymetry reduces to 5-10m. The litho-microfacies and faunal assemblage suggest shallow shoreface to restricted backshore depositional set-up. Sparitization, dolomitization, recrystallization, carbonate nodules and blocky calcite growth are the commonly observed diagenetic features. Occasional stylolitic laminations filled with argillaceous matter are present. Pyritization, ferruginization, and leaching have also been observed. Moderately good porosity is rendered by small isolated vugs, micropores, molds and hairline fractures along stylolaminations.

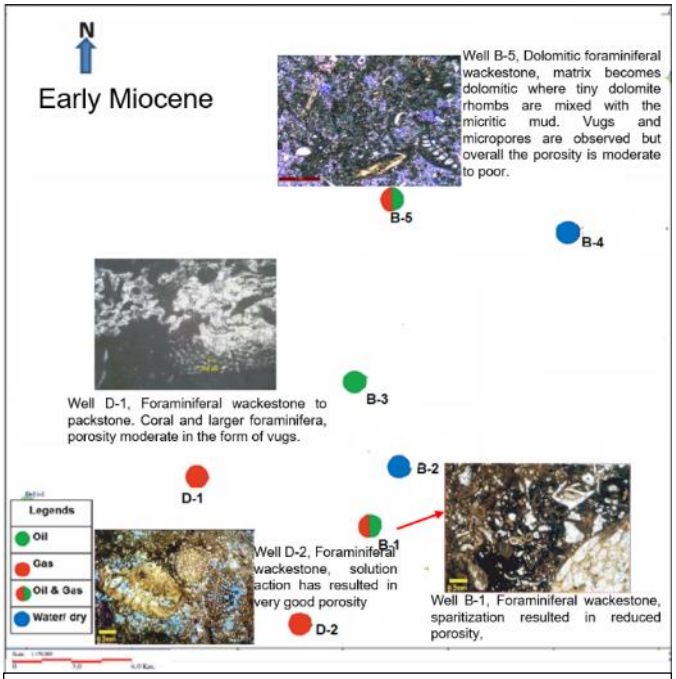

Figure 4: Microfacies distribution map of Early Miocene

D) Middle Miocene: The Middle Miocene (Ratnagiri and Bandra/Tapti formations) is represented by limestone with minor shale intercalations. The well B-5 exhibits maximum thickness of 410m. In the northern region well B-5, the carbonate facies is represented by foraminiferal coralline packstone, foraminiferal packstone to wackestone and dolomitic wackestone (figure 5). The lithofacies in the southernmost well (well D-2), however, shows low energy foraminiferal wackestone and mudstone facies. The southwestern well D-1 also shows low energy facies of coralline and foraminiferal wackestone with occasional mudstone. The succession is rich in larger foraminifera in well B-5 comprising of *Miogypsina globulina, M.(M) antillea , Cycloclypeus* sp., *Lepidocyclina* sp., *Operculina* sp. and *Archaias* sp. along with *Sphaerogypsina* sp., *Borelis* sp., *Cibicides* sp., *Ammonia sp.,* milliolids and ostracodes. Whereas, in well D-1 mainly *Borelis* sp. *with Archaias* sp., *Ammonia* sp., *Discorbis* sp., *Shphaerogypsina* sp., *Amphistegina* sp.,*Elphidium* sp., bivalve and miliolids are recorded. The paleo-bathymetry has been inferred as 10-20m towards north (Well B-5). While in the surrounding areas, the association of lithofacies and faunal assemblage suggests deeper shoreface depositional set-up (30-40m). Sparitization, dolomitization, stylolitic laminations, recrystallization and blocky calcite growth are commonly observed diagenetic features. Stylo-nodular features as well as diagenetic carbonate nodules are also very commonly observed in well B-5. However, pyritization, ferruginization and leaching have also been observed at places. The porosity is poor to moderately developed, rendered by vugs, micropores, molds, fractures and solution cavities at places.

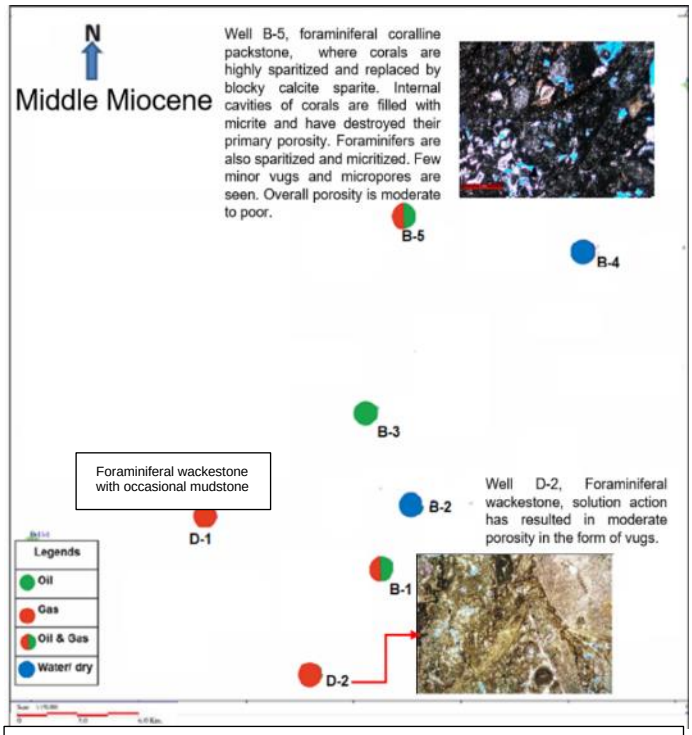

Figure 5: Microfacies distribution map of Middle Miocene

Two geological profiles have been generated across the various zones demarcated in the study area [Fig.6a-b]. The correlation of sedimentary data, diagenetic imprints in the respective age demarcated layers were mapped across the wells to understand the pattern of deposition and the subsequent diagenetic history. The geological profiles across the respective wells are listed below.

I. Figure 6a, Profile 1(SW-NE): Passing through wells D-1, B-3, B-4
II. Figure 6b, Profile 2 (SSW-NNE): Passing through wells D-2, B-1, B-2

Depositional Setup

The Early Oligocene carbonates deposited in shoreface environment within a bathymetry of 20-30m while during Late Oligocene, a gradual shallowing of basin is inferred as carbonates deposited in a bathymetry of 10-20m represented by shallow shoreface regime. In Early Miocene, the bathymetry is 10-20m, however in wells B-5 and B-1, the bathymetry reduces to 5-10m indicative of shallow shoreface to restricted backshore depositional set-up. The bathymetry of Middle Miocene sediments has been inferred as 10-20m towards north (Well B-5), while in the surrounding areas, the association of lithofacies and faunal assemblage suggests deeper shoreface depositional set-up (30-40m).

Diagenesis

The most common diagenetic features observed throughout the succession are sparitization, dolomitization, recrystallization and blocky calcite growth. These diagenetic processes have occluded the organic as well as secondary porosity due to re-precipitation of calcium carbonate, destroying the reservoir quality. Dolomitization is also commonly observed, mostly associated with the matrix and is inferred to have occurred in meteoric–marine mixing zone. The dolomitization has least effect on porosity enhancement in the area. Pyrite present as grain fillings has also destroyed the organic porosity. The oxidation of ferruginous materials observed at many places and is indicative of short spans of sub-aerial exposure. The dissolution activities and leaching of the sediments, however, have resulted in good secondary porosity development in the form of vugs, micropores and solution cavities at some intervals. Pressure solution seams (wispy and low amplitude) and stylolitic features (anastomosing and branched) filled with insoluble argillaceous residue infer late stage chemical compaction during diagenesis which has resulted in porosity and permeability reduction. From analysis of the above diagenetic features, various diagenetic environment such as meteoric phreatic zone, mixing zone and vadose zone are established. Sparitization is the common diagenetic phenomena in this area where the sparite is coarse blocky calcite suggesting diagenesis in freshwater phreatic zone. However, the presence of dolomite commonly observed

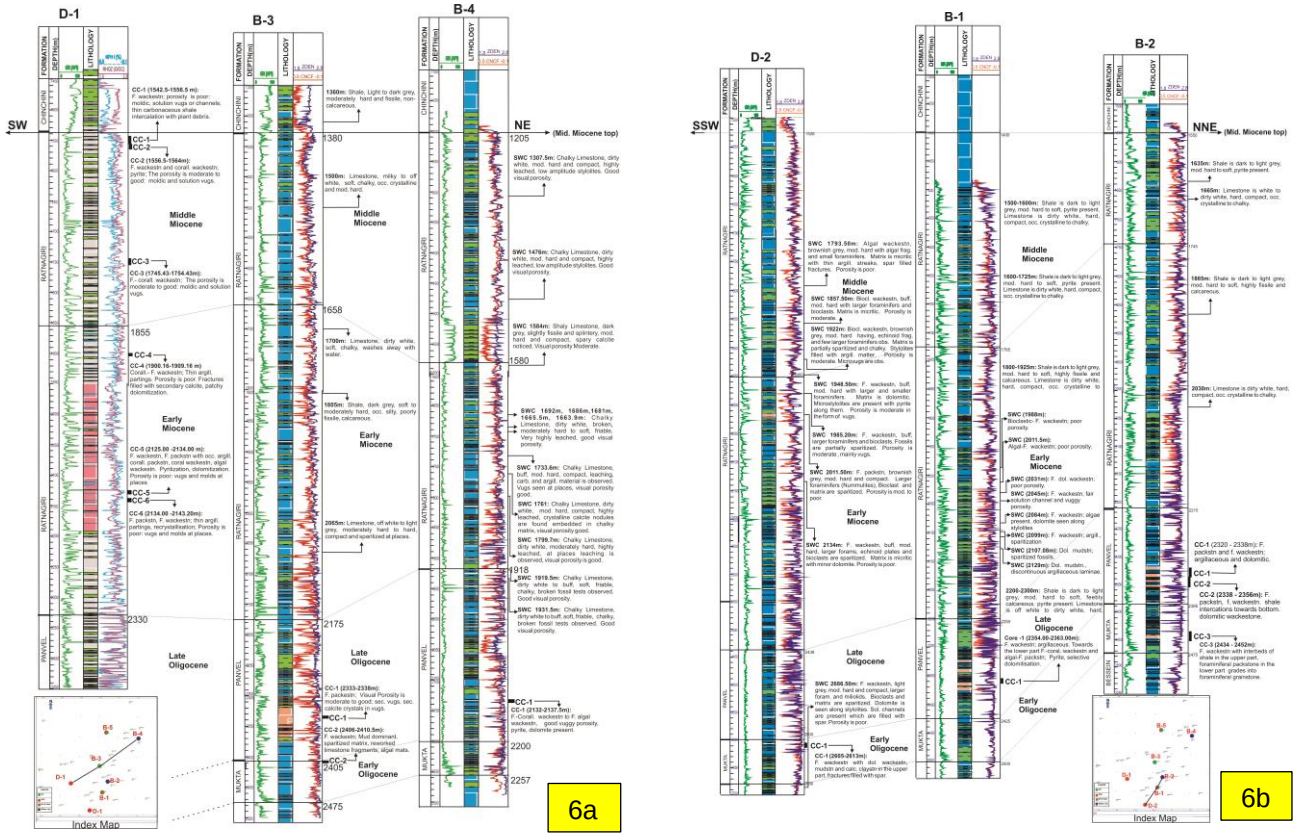

Figure. 6a: Correlation profile of Oligo-Miocene succession in SW-NE wells D-1, B-3 and B-4, **6b:** Correlation profile of Oligo-Miocene succession in SSW-NNE wells D-2, B-1and B-2, Southwest of Mumbai High.

Conclusion

The Oligocene-Miocene succession studied in the selected wells (B-5, B-4, B-3, D-2, B-2, B-1 and D-2) lying southwest of Mumbai High, is represented by carbonate facies with shale intercalations. Oligocene succession of wells B-4, B-3, B-2 and B-1 in southern part of the study area is characterized by increased thickness and better porosity development represented by vugs, solution channels, molds and micropores. The rich assemblage of larger and smaller benthic foraminifera and the litho-microfacies suggest that the sediments of Oligocene-Miocene succession are deposited in a shallow shoreface environment (bathymetry of 10-20m) in a fluctuating low to high energy regime, except at well D-1 (CC-1 (intervals 1542.5-1556.5 m)) represented by the carbonaceous shale with plant debris indicative of restricted backshore setup. Dolomitization is also commonly observed, mostly associated with the matrix and is inferred to have occurred in meteoric–marine mixing zone. The dolomitization has least effect on porosity enhancement in the area. The dissolution activities and leaching of the sediments have resulted in good secondary porosity development in the form of vugs, micropores and solution cavities at some intervals. Pressure solution seams (wispy and low amplitude) and stylolitic features (anastomosing and branched) filled with insoluble argillaceous residue infer late stage chemical compaction during diagenesis which has resulted in porosity and permeability reduction. In the southern part of the studied area (wells B-3 and B-1) hydrocarbon occurrences have been observed in Early and Late Oligocene which are characterized by development of high energy packstone facies. Based on present study, the Late Oligocene carbonate facies in the southern part of the study area has emerged as potential area of better reservoir facies represented by high energy packstone.

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