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An Integrated Litho-Biostratigraphic Analysis To Evaluate Genetically Related Facies And Parasequences Within Middle Eocene Transgressive System Tract: Hazad Member, Gandhar Field, Cambay Basin, Gujarat, India*

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Abstract

The prospective Hazad Sands are thin and hence beyond the resolution for mapping on seismic sections which poses difficulty in modeling and determining dispersal pattern of these sands. Present investigation includes identification of the different litho-biostratigraphic boundaries and detailed examination of the sedimentary features to understand the depositional environment of the Hazad sand units through integrated study of conventional cores, SWC and cuttings. Hazad Member of "Middle to Late Eocene Transgressive System Tract" of Cambay Basin is subdivided into four units based on litho-biostratigraphic analysis and electro logs: Unit-I to Unit-IV from bottom to top, separated by the intervening Transgressive shales viz. Shale-1, 2 and 3. The four units have been classified as four parasequences because of their continuity in time and space. Correlatable shales identified as "Flooding surfaces" are characterized by abundant, species diverse calcareous nannoplanktons, and foraminiferal assemblages, along with fine-grained sediments rich in authigenic minerals glauconite and siderite. Six distinct lithofacies have been identified for pay sands. Overall fining upwards trend observed for the entire sequence is indicative of Transgressive System Tract. The reservoirs are deposited as mouth bars, distributary channels, tide influenced channels and fluvial channels in deltaic set up. Features like V-shaped abrasion pits and small etch pits observed on the surface of quartz grains in Scanning electron microscope study also indicate water to be the transporting medium for these sediments. Intergranular porosity development is fair to good towards the bottom of the channels and topmost part of mouth bars. Provenance analysis of the main detrital minerals including quartz, feldspar, mica and heavy minerals indicate acid igneous and metamorphic source for pay sands. Heavy mineral assemblage and textural analysis suggest mature nature of these sediments. Reservoir sands are diagenetically affected and Unit-I exhibits maximum effect of diagenesis. Infiltrated clays are identified as the earliest diagenetic stage. Authigenic pore filling Kaolinite and grain coating Chlorite clays are present which along with precipitated calcareous and siliceous cement have led to reduction of pore spaces. Based on biostratigraphic studies, three dinocyst events have been deciphered within Hazad Member. The top of Hazad Member has been dated to 44Ma, Shale-2 as 48Ma and the top of Cambay Shale dated with a 2Ma hiatus at 51/49Ma. Configuration of the identified parasequences based on laboratory analysis, therefore, can enable better understanding of sedimentary

dynamics, sand dispersal patterns and their reservoir characteristics, which will add to precise estimation of reserves, proper development and enhancement in the recovery of hydrocarbons from this mature field.

Introduction

Gandhar Field is situated in Broach Depression in southern part of NNW-trending Cambay Basin, Western India. The hydrocarbons of the field are contained in the lower part of Middle-Upper Eocene Ankleshwar Formation, which is subdivided into Hazad, Kanwa, Ardol and Telwa members. It contains up to 14 stacked reservoir sandstone units within the Hazad Member, each containing a separate hydrocarbon pool sealed by intraformational shales and ultimately sealed by the Kanwa Member. The highly prospective Hazad Sands are thin and hence beyond the resolution for mapping on seismic sections. The reservoir interval in the field has a layer-cake to jigsaw-puzzle geometry, which poses difficulty in modeling and determining the dispersal pattern of these sands.

Present investigation includes identification of the different litho-biostratigraphic boundaries and detailed examination of the sedimentary features to understand the depositional environment of the Hazad sand units through integrated study of conventional cores, sidewall cores and cuttings. Megascopic, petrographic, Scanning Electron Microscope and X-ray Diffractometer analysis were carried out for facies characterization, reservoir petrography and heavy mineral analysis to establish the diagenetic history and provenance of the sediments. Biostratigraphic studies including qualitative-quantitative spore-pollen, dinoflagellate cysts and micropaleontology were used for identification of depositional environments, interpretation of paleo bathymetry and demarcation of the age boundaries.

Discussion

Based on the lithology, grain size, dominant sedimentary structures and Gamma ray log signatures distinct lithofacies types were determined and interpreted as below (Figure 1 and Figure 2):

Lithofacies A: Fining up dirty white to off white Sandstone: Dirty white, medium to coarse, occasionally very coarse and moderately sorted cross-bedded sandstone associated with thin irregular laminae of carbonaceous and argillaceous matter. This section on the Gamma ray log shows lower erosional contact and overall fining upwards trend suggestive of deposition in distributary channel.

Lithofacies B: Coarsening up Sandstone: Light grey to dirty white, medium to coarse and moderate to poorly sorted sandstone. Association of carbonaceous clay matrix as high as 30%, intense bioturbation, coarsening up trend and gradational lower contact on Gamma Ray log suggest deposition of this facies in distributary mouth bars.

Lithofacies C: Fining up grey sandstone: Dominantly light grey, very fine to medium, occasionally coarse, poorly sorted, argillaceous, non-calcareous, occasionally feebly calcareous and carbonaceous sandstone. Bimodality, burrows, wavy and lenticular bedding along with carbonaceous matter and clay laminae, overall fining up sequence and serrated fining up Gamma ray log are suggestive of deposition in tide-influenced channels.

Lithofacies D: Sandstone with Intercalated Shale: Dirty white, fine to medium, moderately sorted sandstone, intercalated with brownish grey shale, which is carbonaceous and sideritic in nature. Fining up overlain by coarsening, presence of siderite and bioturbation represent short periods of deeper water deposition possibly caused by floods or erratic transport of sediments under calm water condition.

Lithofacies E: Shale: Dark grey, highly fissile, rich in finely divided organic matter, occasionally calcareous, often associated with authigenic glauconite and siderite. Pure shales rich in organic matter indicate that the deposition took place under calm water condition as prodelta mud.

As per sequence stratigraphic framework of Cambay Basin Hazad Member of Middle Eocene age represents Transgressive System Tract part of second order Middle to Late Eocene sequence (Figure 3). In the present study, Hazad Member of Middle Eocene has been subdivided into four units: Unit-I to Unit-IV from bottom to top, separated by the intervening transgressive shales viz. Shale-1, 2 and 3. The four units have been classified as four parasequences because of their continuity in time and space. These major correlatable shales are identified as "Flooding surfaces" as are characterized by abundant, species diverse calcareous nannoplanktons, and foraminiferal assemblages, along with fine-grained sediments rich in authigenic minerals glauconite and siderite. Fossil assemblages include foraminifera and nannoplanktons belonging to families *Coccolithaceae* and *Discoasteraceae*. Concentration of these faunal assemblages gradually decrease towards eastern and northern parts of the field indicating marine incursion from southern part and paleoslope towards south west at the time of deposition.

Results and Conclusions

The study suggests that the reservoirs are deposited as mouth bars, distributary channels, tide influenced channels and fluvial channels in deltaic set up. Features like V-shaped abrasion pits and small etch pits observed on the surface of quartz grains in Scanning electron microscope study (Figure 4 and Figure 5) also indicate water to be the transporting medium for these sediments. Intergranular porosity development is fair to good towards the bottom of the channels and topmost part of mouth bars. Diagenetic studies show that reservoir sands are diagenetically affected and Unit-I exhibits maximum effect of diagenesis. Infiltrated clays are identified as the earliest diagenetic stage. Authigenic pore filling kaolinite and grain coating chlorite clays are present which along with precipitated calcareous and siliceous cement have led to reduction of pore spaces. Provenance analysis of the main detrital minerals including quartz, feldspar, mica and heavy minerals indicate acid igneous and metamorphic source for pay sands. Heavy mineral assemblage and textural analysis suggest mature nature of these sediments.

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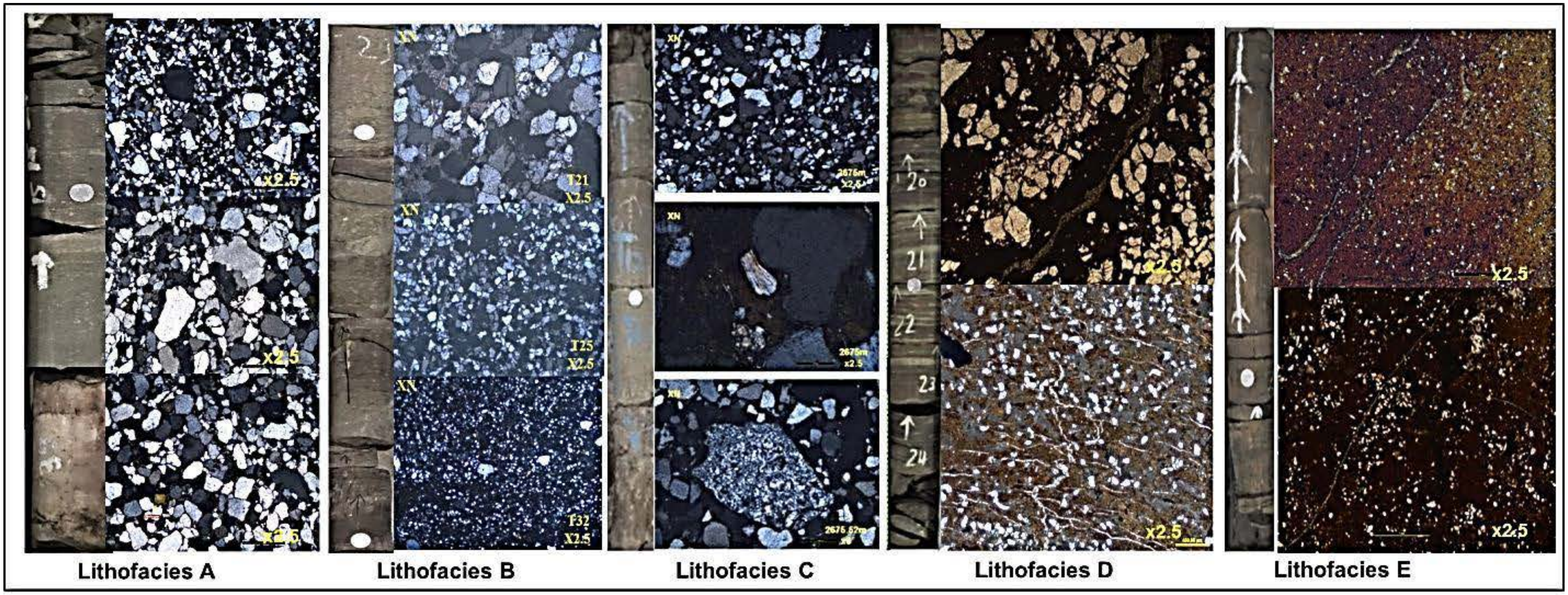

Figure 1. Lithofacies identified within the Hazad Member.

Figure 2. Close up core photographs from Eastern part of the study area (left two images) showing cross bedded sandstone and bioturbated as well as lenticular bedded argillaceous siltstone (right image) from south western part.

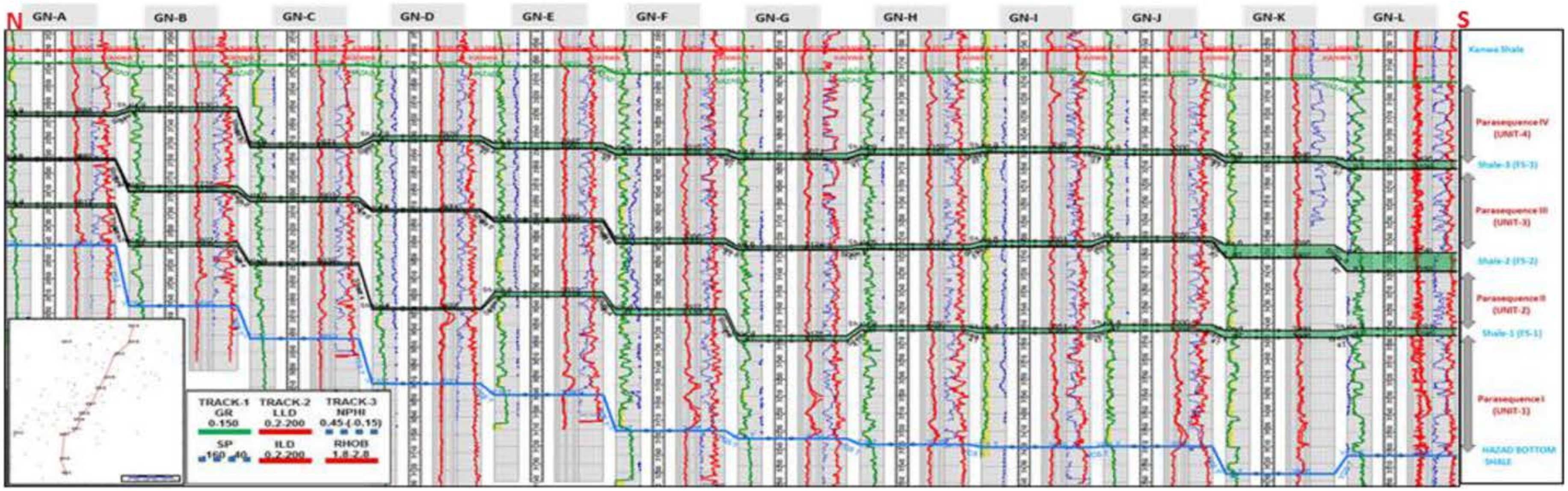

Figure 3. N-S Correlation profile showing identified Parasequences and correlated shale events (Flooding surfaces).

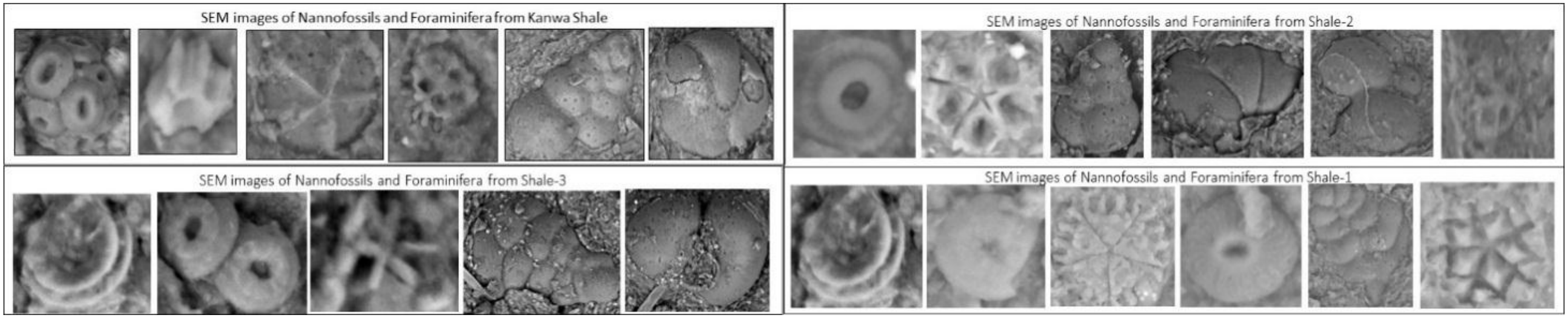

Figure 4. Scanning Electron Microscope images of calcareous nannoplanktons and foraminifera assemblages from Shales-1, 2, 3 and Kanwa Shale (fossil images not to the scale for better visibility).

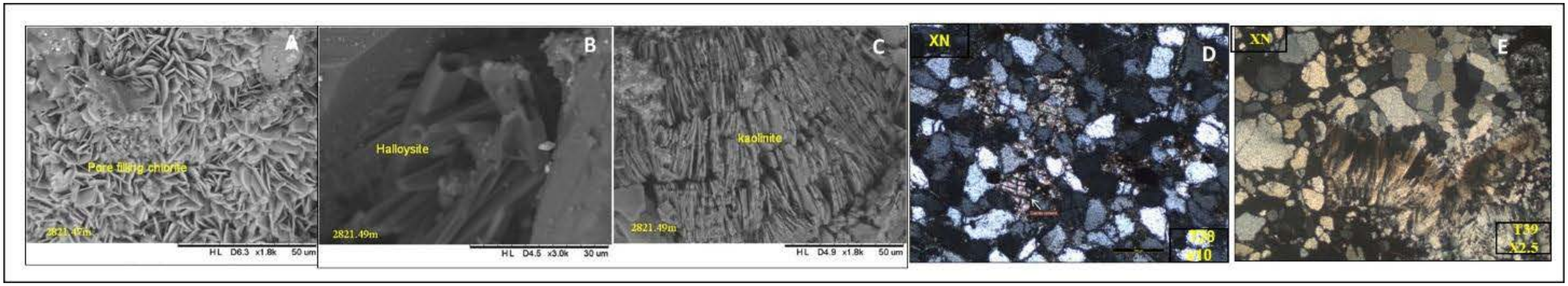

Figure 5. Scanning Electron Microscope images (A-C) showing authigenic clay minerals and petrographic images (D-E) showing sandstone where quartz grains are bound by calcareous cement (D) and siliceous overgrowths (E).

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