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Palynological Marine Index Studies and Lithofacies analysis of Mandhali Member in Jotana ML in Mehsana Block, Cambay Basin, Gujarat, India

Large volume of in place hydrocarbon is established in Mandhali Member of Kadi Formation in Jotana field of Mehsana block. The reservoirs are primarily fine grained sandstones having argillaceous matrix with ubiquitous presence of shale. Two transgressive events as marked by Older Cambay Shale (OCS) and Lower Tongue Shale respectively denote the bottom and top of the Mandhali member.A detailed laboratory study has been carried out in Jotana field to precisely date and demarcate the Mandhali member in to mappable units and prepare facies distribution maps.

Mandhali Member has been subdivided into four informal sub units on the basis of stacking pattern of sediments observed in subsurface samples and standard logs.The distinction with OCS is made on the basis of progressive upward increase in carbonaceous matter and siderite in Mandhali Member and its complete absence in OCS. The overlying Lower Tongue member is a thin low resistivity, high gamma shale which has very high Palynological Marine Index (PMI) values, an implication of maximum flooding event close to Mandhali Member top.The demarcation of OCS and Mandhali members has been done on the basis of former having high PMI values and total absence of carbonaceous matter and siderite.

PMI have been developed by assigning to each sample a minimum and a maximum value to express the degree of marine incursion. The dominance of terrestrial palynoflora and low frequency of marine phytoplankton is marked by low PMI values between 100 and 125 in OCS and Mandhali member,thereby suggesting supratidal to intertidal environment. Moderately high values of PMI, ranging between 130 and 165, in the Lower Tongue section is suggestive of subtidal conditions. In the Lower Tongue a higher PMI value ranging from 170 to 200 has been recorded which is suggestive of inner neritic environment and support a transgressive event. This is also supported by the occurrence of dinocyst event of *Glaphyrocysta ordinata* (51 Ma) at the top of Lower Tongue Member in all the studied wells. The sediments have been dated as Early Eocene in age based on the occurrence of *Areoligera senonensis and Glaphyrocysta ordinata.* A typical estuarine/deltaic environment to shore face/strand plain mode of deposition for the sands in Mandhali member has been proposed.

Introduction

The Mandhali Member is mainly characterised by shale and sandstone facies with limited development of coal whereas the Mehsana Member has very thick coal with thin sandstone and shale beds. In Jotana field a large number of wells have so far been drilled for exploration and exploitation of hydrocarbon in Mandhali member. However due to complex depositional setup, much ambiguity remains in their distribution. Detailed sedimentological and biostratigraphic studies have been carried out in selected wells, and distribution of sands & depositional environment of Mandhali has been proposed.

Objective

To firm up the Mandhali member/Lower tongue and Mandhali member / OCS boundaries with litho-stratigraphic, PMI, biostratigraphic attributes and standard logs. The other objective include demarcation of lithofacies variations within Mandhali Member temporally and spatially along and also across the footwall block of Jotana fault down to Warosan low and prepare a facies based process response depositional environment model of Mandhali Member.

Methododology

The material considered for the present study includes conventional cores, cuttings and side wall cores (SWC) of selected wells in Jotana, Warosan and Linch fields. The workflow for execution of the studies is mentioned below:

- Palynological studies for corroboration of boundaries and infer the paleo-ecology by PMI data Megascopic, petrographic, X-ray diffractmetric studies and construction of litho-columns against standard logs in Mandhali and Mehsana Member.
- Estimation of the total effective thickness of the sandstone/siltstone and sand: shale ratio.
- Stratigraphic correlation encompassing most of the wells studied along seven strike profiles and five dip profiles culminating into slicing of Mandhali Member into four informal units overlying the Older Cambay shale (OCS), Member/Neck Marker.
- Preparation of sediment distribution maps for each unit and demarcate the sub-environments within Mandhali Member.
- Evolving a predictive depositional model based on the facies distribution maps.

STRATIGRAPHY AND GENERAL GEOLOGY

The area of the study is a part of Ahmedabad-Mehsana tectonic block (Fig.1) which is the largest block of Cambay basin, limited to the south by the Nawagam - Wasna basement uplift whereas the northern limit to the north of Mehsana horst is arbitrary. The study area lies east of Mehsana horst in Jotana field and to down thrown block of prominent Jotana normal fault. The generalized stratigraphy of the area by Pandey et al., (1993) is given in Table-II below.

AGE	FORMATION	MEMBER	SAND UNITS
Pliocene to Recent	Gujarat Alluvium	-------	------
E.arly Miocene to Late Miocene	Jhagadia Kand Babaguru	------ ------- Babaguru Pays	------
Late Eocene to Oligocene	Tarapur Shale	Balol Pays/ Limbodra Pays	-------
Late Eocene to Middle Eocene	Kalol	Wavel	KS-I to KS-V
		Kansari Shale	
		Sertha	KS-V to KS-XI
	Nandasan Shale	-----	------
Early Eocene	Kadi / Younger Cambay Shale	Upper Most Tongue	
		Chhatral	KS-XII
		Upper Tongue	
		Mehsana / Sobhasan	SS-I to SS-IV
		Lower Tongue	------
		Mandhali /Wadu	MU-I- MU-III & Wadu pays
	Shale unit above neck marker		
	Neck Marker as unconformity		
Paleocene to Early Eocene	Cambay Shale	Older Cambay Shale	S.Kadi pays
	Olpad	------	Nawagam Pays, Dholka Lower. Pays & Olpad Sands
Late Cretaceous	Deccan Trap	------	---------

The Jotana field is a NNW-SSE trending fault closure against Jotana fault truncated by orthogonal cross fault. It is bounded by Santhal field is due west, Mewad and Sobhasan fields are to the north east and Linch field is located south of Jotana field (Fig.1)

PALYNOLOGICAL STUDIES

The study included palynofloral investigation of well cuttings and side wall cores from the six wells, namely, Jotana#152,172,170,186, S.Warosan#1 and Warosan#5. Identification of palynofloral assemblages were carried out at regular interval of 10 - 20m. The palynofloral yield is moderate to good throughout the studied section and having assemblages of angiosperm pollen, gymnosperm pollen, pteridophytic spores, fungal spores and dinoflagellate cyst taxa. The assemblages have been grouped under two heads, marine and terrestrial. The population of palynofloral assemblages have been plotted against depth in frequency chart and distinct ecozones demarcated by taking the frequency of marine phytoplanktons as basis. The Palynological Marine Index (PMI) analytical technique has been employed to pick up relatively strong marine events in the subsurface sedimentary sequence.

Palynological Marine Index (PMI)

The Palynological Marine Index (PMI) analytical technique is helpful in recognizing synchronous paleoenvironmental changes both within the basin and regionally.

The Palynological marine index (PMI) is calculated based on the formula devised by Helenes Guerra and Vasquez, (1998).

PMI= (Rm/Rt+1) x 100

Rm = Richness of marine palynomorphs counted as the number of taxa per sample

RT = Richness of terrestrial palynomorphs counted as the number of taxa per sample.

The exact marine dinoflagellate palynofloral and terrestrial palynomorph counts are substituted in the formula and PMI is calculated and plotted on the graph to generated paleo-environmental interpretation curves by assigning to each sample a minimum and a maximum value to express the degree of marine incursion. Null values of PMI are indicative of terrestrial origin. Low values of PMI are interpreted as indicative of subtidal influence. High PMI values are indicative of marine conditions of deposition.The palynozonation of the sedimentary sequence in the studied wells is based on the concept of assemblage zone outlined by Hedberg (1976). The age has been assigned based on the LAD of statigraphically significant palynotaxa, frequency of occurrence, appearance, disappearance and dominance of palynoflora (Thanikaimoni et al., 1984 and Kar, 1985).

Amongst the palynomorphs, dinoflagellate cysts have the advantage of including a planktonic stage in their life cycle. These have globally documented biostratigraphic ranges and make them very useful as biostratigraphic indicators in shallow marine environments. Together with terrestrial palynomorphs, dinoflagellate can also help in recognizing paleo-environmental changes in the strata.

Paleoenvironmental interpretation curves (PMI) have been developed by assigning to each sample a minimum and a maximum value to express the degree of marine incursion. In the Jotana area, dominance of terrestrial palynoflora and low frequency of marine phytoplankton is marked by low PMI values between 100 and 125 in OCS and Mandhali member. This is suggestive of supratidal to intertidal environment. Moderately high values of PMI, ranging between 130 and 165, in the Lower Tongue section is suggestive of subtidal conditions. In the S. Warosan and Warosan however, there is marked increase in the PMI values in Mandhali Member, similar to that in OCS. In the Lower Tongue a higher PMI value ranging from 170 to 200 has been recorded which is suggestive of inner neritic environment and support a transgressive event. This is also supported by consistent dinocyst event of *Glaphyrocysta ordinata* (51 Ma) at the top of Lower Tongue Member in all the studied wells. (Fig. 2)

SEDIMENTOLOGICAL STUDIES

Detailed lithofacies studies of selected wells in Jotana and Warosan area were carried out and based on lithological attributes, corroborated with standard logs and regional correlation, the Upper Tongue Member, Mehsana Member, Lower Tongue Member, Mandhali Member and Older Cambay Shale (OCS) Member in Kadi and Cambay formation have been identified.(Fig. 3). A number of correlation profiles connecting selected wells along the strike and the dip of the regional structural trend were selected in order to establish the lateral correlation and distribution of the reservoir facies (sandstone/siltstone) in the area of study. The distribution pattern of the reservoir units, its thickness and litho-association in the area have been used to prepare unit-wise deposition model for the Mandhali Member in the proposed study area and also beyond it.

Mandhali Member

In the present study, the Lower Tongue Member, overlying the Mandhali Member is low resistivity shale and the high gamma signature within this shale has been considered as the top of Mandhali Member. The Mandhali Member is subdivided into four subunits: units-3a, 3, 2 and 1 in ascending order, each having a broad stacking pattern of coarsening up at the bottom and fining up at top terminated by high gamma shale in key wells, low resistivity, and high neutron shale. In wells where the stacking pattern is not discernible, the regional gradient has been considered for subdivision of Mandhali Member and correlation of each sub unit. Unit-3A has been considered as equivalent to the shale above neck marker of Bhandari and Mathur (1968) which has arenaceous equivalents in the northern part in Jotana wells and is dominant shale in central and south Jotana.

The entire sedimentary succession sandwiched between Lower Tongue Member and OCS Member represents a continuity of sedimentary processes taken place in a transgressive coastal estuarine to shallow marine environment influenced by tidal activity in the Warosan low.

The study area has a prominent structural feature as roughly NNW-SSE trending Jotana normal fault hading towards east. Five longitudinal profiles along the Jotana structure, two profiles along the Warosan low and five profiles across the structural trend connecting Jotana field towards west to Sobhasan, Sanganpur, Kherwa and Kharwada areas towards east have been made. The top of Mehsana Member has been taken as datum and top of all the Mandhali Member units. All the sand thickness considered in the wells refers to cumulative sand which has extreme variation in thickness and are often distributed randomly within the respective sub units, separated by shale or coal. Due to prevalence of tidal activity in the area, it is often difficult to pick sands in logs due to very high matrix content.

DEPOSITIONAL ENVIRONMENT

A facies distribution map and resultant process response model of Mandhali member has been deciphered in the study area in Jotana and part of Linch field. The four units viz. units-3a, 3, 2 and 1 in ascending order between Neck marker (OCS) and the Lower Tongue of Early Eocene age has been studied with focus on their lithofacies, microfacies, thickness variations of sandstone (sand)/ siltstone/ shale and coal; sand : shale ratio and overall distribution pattern of these facies.

Facies distribution and depositional model of Mandhali Member in Jotana field

Jotana field is a linear structure developed somewhat along the Jotana fault. It is bordered to the east by a prominent water body occupying the Warosan low. The main low during the initiation of sedimentation of Mandhali member was to the south and SSW of Jotana close to Linch field and its one arm bifurcated towards Jotana field forming a narrow opening having variable tidal activity (Fig.1). This narrow arm of the sea forming a bay / gulf having relatively shallow bathymetry had inundated a large area both during and after a major transgressive event terminating at OCS top. The Cambay Shale Formation underlying Mandhali Member is transgressive shale, mostly devoid of carbonaceous matter and coarser clastics and the Palynological studies indicate a moderate PMI value suggesting mostly an intertidal environment in the study area.

Mandhali sedimentation was initiated by formation of an estuary in north Jotana during Unit-3A which was tide dominated and was transformed into a delta during Unit-3 with adjacent sand flat and mixed flat facies, straddling along the east and north of west coast deposited under an overall regressive mode an arm moving engulfing Balol#14. The Unit-2 and unit-1 represents the accommodation filling sediments by dispersal through tides and probable sediment supply from southwest resulting total obliteration of the coastline and persistent development of sandflat all the coastline in central and south Jotana. A few tidal channels have been moving in towards Jotana fault and depositing sands with high matrix content. The upper part of Unit-1 is developed as shale-coal alternation and mark the initiation of next phase of transgression in Jotana field. (Fig. 4a-4d)

CONCLUSIONS

The following conclusions are drawn on the basis of the above studies:

- The palynological PMI techniques used to decipher the relative influence of both marine and terrestrial events show that mainly intertidal conditions prevailed in Jotana during close of OCS Member, intertidal to supratidal (terrestrial palynomorphs dominant) environment in Mandhali Member and subtidal environment during Lower Tongue.
- The demarcation of OCS and Mandhali members has been done on the basis of former having high PMI values and total absence of carbonaceous matter and siderite.
- Mandhali Member has been classified in to four sub units ,viz. unit-3A, 3, 2 and 1 in ascending order on the basis of lithological assemblages and mapped along the down thrown block of Jotana field and across to Warosan Low- Sobhasan-Kherwa and Sanganpur to the east.
- On the basis of sand:shale ratio, typical lithofacies attributes and distribution pattern of sands in Mandhali Member, detailed unit wise facies map and process response model have been prepared. The isochron map on top of OCS has been considered for mapping the paleo-coastlines and derive sediment transportation pattern.
- A typical estuarine/deltaic environment to shore face / strand plain mode of deposition for the sands in Mandhali member has been proposed. A large area having very low sand: shale ratio is due to wide spread tidal flat.
- The sedimentation in Mandhali Member was initiated by formation of an estuary in northern most part of Jotana field during unit-3A having sand ridges/bars flanked by matrix rich laminated facies thereby indicating a tide dominated estuary and associated sandflat on eastern flank along the coastline.
- The subsequent event during unit-3 lead to transformation of estuary in to prograding delta with higher sand content and often modified by tidal action and development of associated sand flats on western coastline by ebb tidal currents.
- The unit-2 sedimentation indicates near closure of the estuary/delta and stoppage of sediment supply followed by regression of coastline further to south and development of prominent sandflat all along the western coastline in central and south Jotana.
- The unit-1 has been divided into sand-shale rich unit-1a & coal-shale unit-1b below and forming sandflat and a few tidal channel in central and south Jotana & widespread mudflat in north.
- Culmination of Mandhali Member sedimentation is marked by initiation of transgression thereby turning most of the area into a mudflat with prominent coal.
- The sediment input for pronounced sand flats formed during unit-2 & unit-1 from south and southwest part of Jotana field need to be examined as northern supply during this time was negligible.

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