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Role of estuarine and tidal processes during deposition of Mandhali Member in Jotana field, Cambay Basin Gujarat, India

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Abstract

Jotana field in Cambay Basin comprises a number of discrete hydrocarbon bearing pays within Early Eocene Mandhali Member of Kadi Formation. The sediments were deposited in tide dominated estuary and widespread tidal flats and have considerable facies heterogeneity. Due to lack of our proper understanding of the depositional processes, it is often difficult to establish a lateral facies correlation over the entire area. A depositional process initiated model has thus been conceptualized for Mandhali Member in the Jotana field and the adjacent Warosan Low on the basis of sedimentological studies. The present day sediment distribution pattern in Gulf of Cambay has also been taken as guide to validate the envisaged model. The Mandhali Member has been subdivided into four lithofacies units as MU-3a, MU-3, MU-2 and MU-1 in ascending order. The sedimentation in Mandhali Member took place towards the culmination of the Eocene transgression in the basin with the initiation of a tide influenced estuary in the northern extremity of the Warosan Low and development of a number of prominent tide influenced sand lobes (MU-3a). However, the central and southern part of Warosan Low and entire Jotana field was developed as linearly oriented tidal flat with isolated occurrence of sandstone. With increase in sediment supply, there was further development of estuary in the northern part and part of the sand were also carried down by the ebb currents and deposited both along the Warosan low as shore parallel sandflat, mixed flat facies (MU-3) and also within Jotana field. With further reduction in accommodation in the Warosan low and starvation of sediments from north, there was destruction of the estuary and the area was turned in to a tidal flat with isolated sandstone occurrences. The remnant sand was rearranged all along the Warosan low and western part of Jotana field as prominent sandflat / strandplain and mixed flat by tidal and shore parallel currents and occasional tidal channels (MU-2). The end of Mandhali sedimentation was marked by further encroachment of Tidal flat to the south and southwest and dominance of carbonaceous shale with thin coal in north and central part of Jotana and Warosan low and development of additional shoreparallel shoreface sands (MU-1) to the southwestern coast and extended towards North Kadi and beyond. A prominent transgressive event, marked by deposition of Lower Tongue shale signify the end of Mandhali sedimentation in the area.

Introduction

The Cambay Basin is a narrow elongated pericratonic rift basin, which came into existence consequent upon large outpouring of Deccan Basalt lava during Late Cretaceous. A number of north-south trending longitudinal faults define the eastern and western limit of the basin (Fig.1). The sedimentation in the basin commenced with synrift alluvial fan deposits of Olpad Formation during early Late Eocene and spread over the entire basin. This was followed by basin wide transgression during Late Paleocene-Early Eocene, that resulted in deposition of thick Cambay Shale Formation. With near culmination of the transgressive phase, a major prograding event ensued during late Early Eocene in Mehsana and part of Ahmedabad block, that caused deposition of Kadi Formation as thick clastic wedge within Cambay Shale, which is characterized by deltaic sediments of sandstone and thick coal and further divided in to Mandhali and Mehsana members from bottom to top with Lower Tongue shale in between and Upper Tongue transgressive shale at the top (Pandey et al., 1993). During the initiation of progradation and sedimentation of Mandhali Member, small scale estuarine conditions prevailed in Jotana-Linch and

Sobhasan fields in Mehsana, along with development of wide spread tidal flats, adjacent to prominent lows due to gradual shallowing of the basin. This led to unequal distribution of the reservoir facies in the area and significant hydrocarbon accumulation both in Kadi and Cambay Shale formations. Due to diversity of depositional processes succeeding large scale transgressive events in the basin, a systematic understanding of the distribution pattern and mode of deposition of these reservoir facies is required. An attempt has therefore been made to understand the sequential processes involved in deposition of Mandhali Member in Jotana field and adjacent Warosan Low in Mehsana block (Fig.1). A typical sedimentological process response model has been conceptualized for the deposition of these vertically stacked multiple reservoir facies and their distribution in Jotana, Warosan Low and also further to the south in Linch field and towards North Kadi in southwest.

Experimental Details

Detailed lithofacies and textural characteristics studies of a large number of cutting and core samples in 35 wells drilled in Jotana and adjacent Warosan Low were examined (Fig.1). The stratigraphic top of all the members of Kadi Formation viz. the Upper Tongue, Mehsana, Lower Tongue members and Older Cambay Shale (OCS) have then been demarcated on logs along selected profiles connecting prominent wells in order to establish their lateral correlatablility and also distribution of the reservoir facies (sandstone/siltstone) in Mandhali Member in the area. The Mandhali Member is subdivided into four lithounits, namely: MU-3A, MU-3, MU-2 and MU-1 in ascending order, each having a broad stacking pattern. In wells where the stacking pattern is not discernible, the regional gradient has been considered for subdivision of Mandhali Member and correlation of each unit. MU-3A has been considered as equivalent to the shale above neck marker of Bhandari and Mathur (1968). The distribution pattern of the reservoir units, its thickness and litho-association have been used to conceptualize the process response facies model of each of the four lithounits in Mandhali Member in the Jotana, Warosan Low and part of Linch fields. The time structure map available on top of Mandhali Member (Fig.2) has been referred for understanding the then nature shoreline along the then Warosan Low during the deposition of Mandhali Member. The distribution pattern of the sediments in Mandhali Member as envisaged has been related to the similar conditions taking place today in the Gulf of Khambat as recorded by using Google Earth map (Fig.4) where sediments which are being brought by the two rivers are redistributed by tidal currents.

Results and Discussion

Jotana field is a linear structure developed somewhat along a roughly NW-SE trending Jotana fault. It was bordered to the east by a narrow structural low occupied by a prominent water body called Warosan Low. This narrow arm of the sea formed a bay / gulf having relatively shallow bathymetry and had inundated a large area both during the deposition of Mandhali Member (Fig.2). The major areas of the Jotana field were developed parallel to this low and were periodically inundated by the tidal currents. As a result, widespread tidal flat was formed with selective development of sandflat, mixedflat and strandplane facies especially in the western part in Jotana field close to the low. Based on lithofacies and log correlation, four lithounits within Mandhali Member have been demarcated as MU-3a, MU-3, MU-2 and MU-1a & MU1-b.

The bottom most unit, MU-3A, equivalents to the shale above neck marker overlying OCS is predominantly shale/silty shale in central and southern part of Jotana field and in Warosan low. However, there is development of prominent sand maxima in the northern extremity of the study area having thickness ranging from 18-66m in wells JT-A to JT-D (Fig. 3A).The texture of sandstone in general is immature comprising fine to medium grained, poorly sorted, subangular quartz with argillaceous matrix and having imprints of tidal activities. The overall distribution of the sandstone and associated facies suggest initiation of a tide dominated estuary with longitudinal bars and intervening shale and a feeding fluvial channel further to the north. It is presumed that part of the sand from the estuary has also been transported and deposited along either side of the Warosan Low by ebb currents in proximity to the main estuary as evident in well JT-D in the north eastern part (Fig.3A) Most of the area in central and south Jotana however, remained deficient in sand supply and comprise silty shale deposited as suspended load with minor disseminated carbonaceous matter.

During deposition of the MU-3, there was increase in sediment supply from north in to Warosan Low which led to further growth of estuary or development of a deltaic conditions. Good sand development has been observed all along the western flank of Warosan low in central and southern part of Jotana field. A number of isolated sand bars are also observed along the axis of the Warosan low. Rest of the area has mostly shale and has very little development of reservoir facies. The lithofacies at places, is often laminated siltstone-shale having thin coal and carbonaceous shale which indicate a mixedflat tidal depositional environment along the Warosan coast in the north and west. With progradation of the estuary to the south, there is reallocation of sand through the ebb currents and part of it were redistributed by the shore parallel currents all along the western flank into Jotana field and within the Warosan low (Fig.3B).

During deposition of the overlying unit MU-2, there has been a near starvation of sand supply from the north and complete destruction of the estuary with average sand thickness of 6m and very low sand:shale ratio. Similar picture was also observed in Warosan low and central Jotana having dominance of shale, thin coal. On the contrary, there is development of thick shore parallel sandstone in central and south along the Warosan Low having maximum gross thickness of about 36m. The source of the coarser clastic in shore parallel sandflat / mixed flat facies in the south Jotana is not clear and it is possible that a part of it may have been from the now destroyed eatuary in the north and rest transported by flood tidal currents from the adjacent low towards south west and later redistributed by the ebb currents in as stradplain along Warosan low (Fig.3C).

The uppermost unit MU-1 continued to witness the starvation of sand supply from the north and with that the entire area in northern part of Jotana and Warosan Low turned in to mudflat with isolated sand bodies deposited by tidal channels initiated from Warosan Low. There was further constriction of the Warosan Low and development of thick sandstone facies along its modified shoreline in south and southwest (Fig.3D). On the basis of lithofacies, the unit-1 has been subdivided in to two subfacies: an alternating sand-shale below (MU1a) to the south and a thin coal and shale alternation facies (MU1b) above to the north formed as typical mudflat. There is thick sand development in well JT-F (Fig.3D) in the south showing the coarsening upward log signature and fairly well sorted sandstone. This further confirms that there has been an alternate input of coarser clastics from a source lying to the southwest of the Warosan Low, which has also resulted in deposition of thick reservoir facies of Mandhali Member in North Kadi field. This needs further probing and may open up new area of sand development.

Conclusions

The initiation of sedimentation in Mandhali Member took place with development of a tide influenced estuary formed at the mouth of the narrow Warosan Low forming a bay. With increase in supply of sand from north, the sediments were partially carried to the south by ebb currents and were deposited as shore parallel prominent sandflat, mixedflat facies and starndplain. Due to shallowing of the Warosan Low and total starvation of sand supply from the north, there was destruction of the estuary in the middle and upper part and sandimentation took plays as linear shore parallel bodies deposited as longitudinal bars in the central and southern part leaving the northern part of the Jotana field as wide spread tidal flat. With lopment of tidal flats in north, it is presumed that additional sand supply pren brought in to the Warosan

Low from south and redistributed along the shore. Increase sand thickness in adjacent North Kadi field needs further probing and may lead to additional area of sand domination and hydrocarbon success. The sand distribution pattern as envisaged above can be seen taking place in Gulf of Khambat today wherein, sands from Mahi and Sabarmati rivers are being redistributed along the shore and also within the low.

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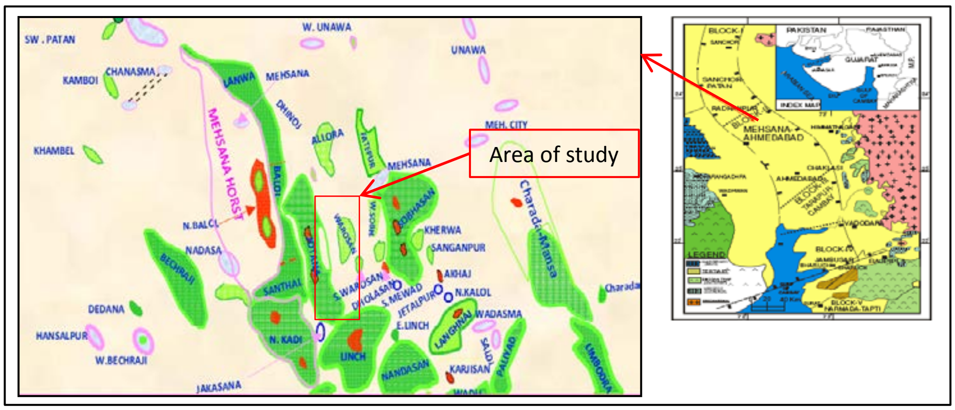

Fig.1: Tectonic map of Cambay Basin (After Kundu et al.,1996) and prospect map of Mehsana Tectonic block showing location of area of study

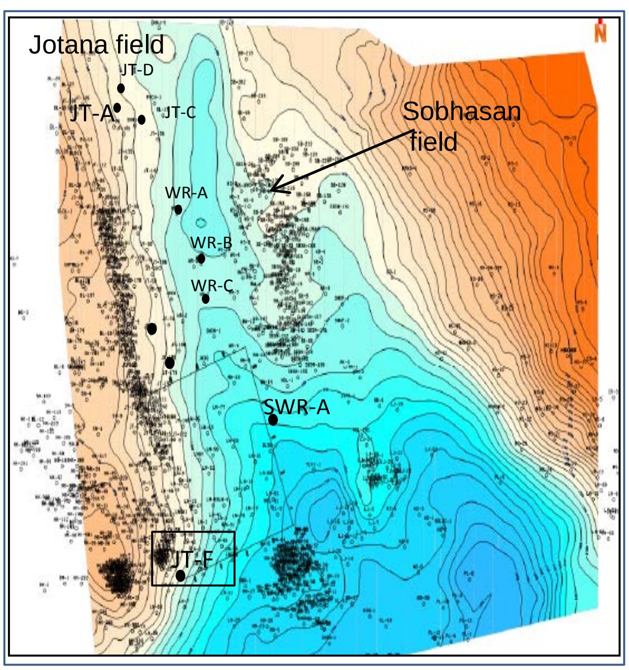

Fig. 2: TWT relief map at Mandhali top (above MU-1) showing position of Warosan low and bifurcation of the marine arm towards Jotana and Sobhasan fields

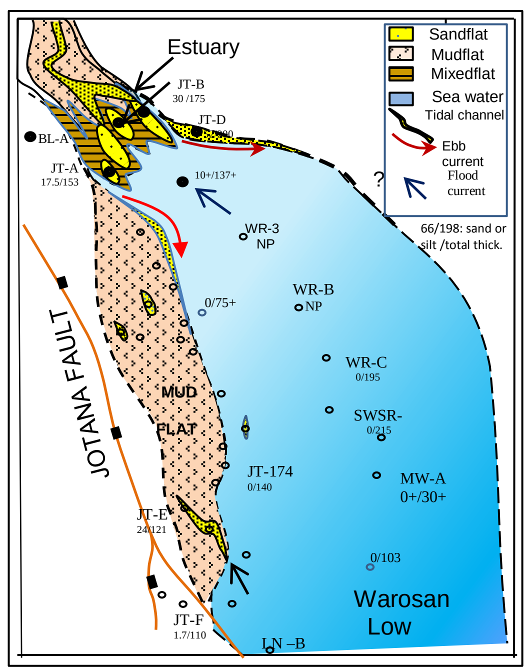

Fig. 3A: Facies map depicting a sand rich maxima in the north close to well JT- A to D forming an estuary and distribution shore parallel sand as sandflat and mixed flat in MU-3A.

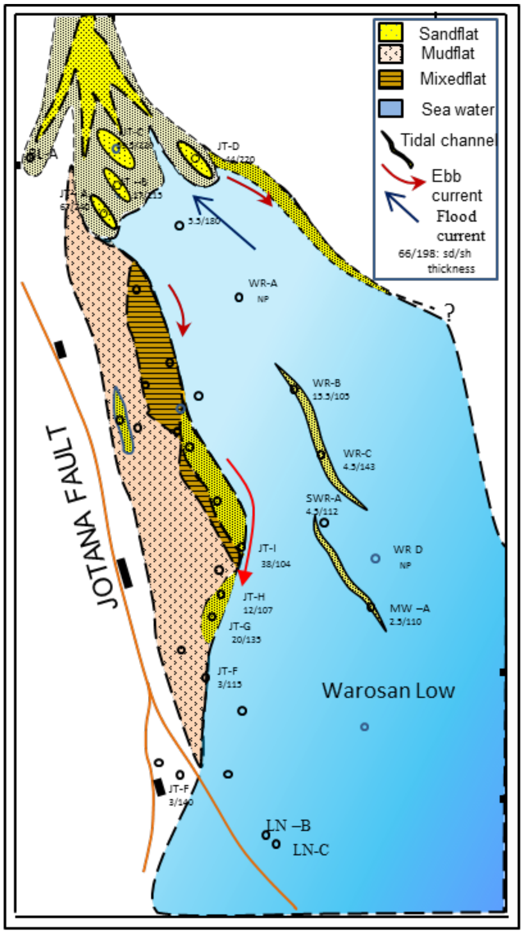

Fig 3B: Facies map depicting distribution of sand by ebb currents and formation of sandflat and mixed flat in MU-3. The estuary at the north has further grown almost to a delta.

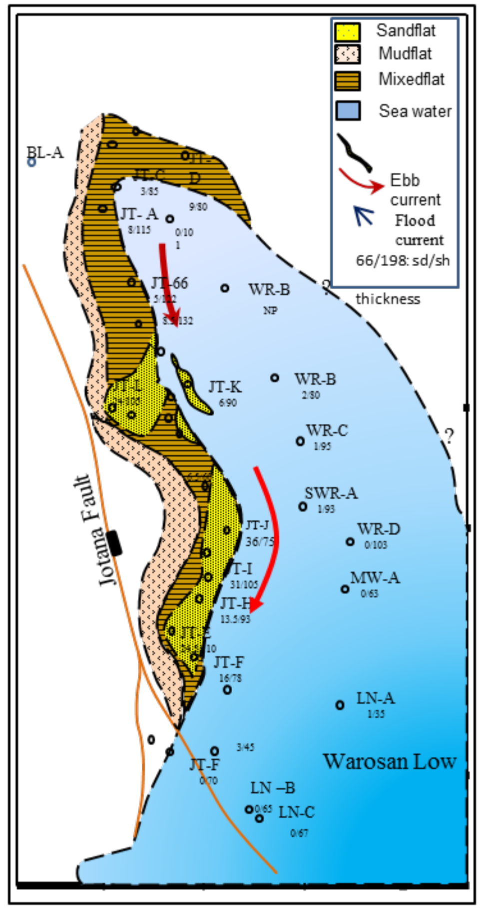

Fig. 3C: Facies map depicting sand dispersal pattern and formation of sandflat and mixed flat in **unit-2**.

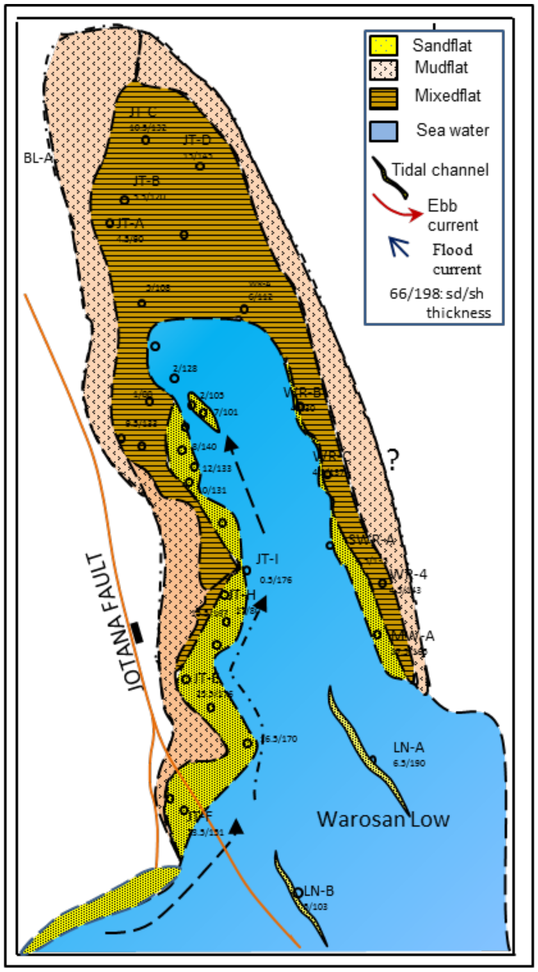

Fig. 3D: Facies map depicting sand distribution and formation of prominent sandflat and mixed flat in **unit-1** due to flood current bringing in sediments from southwest and little redistribution by ebb tidal current moving due south.

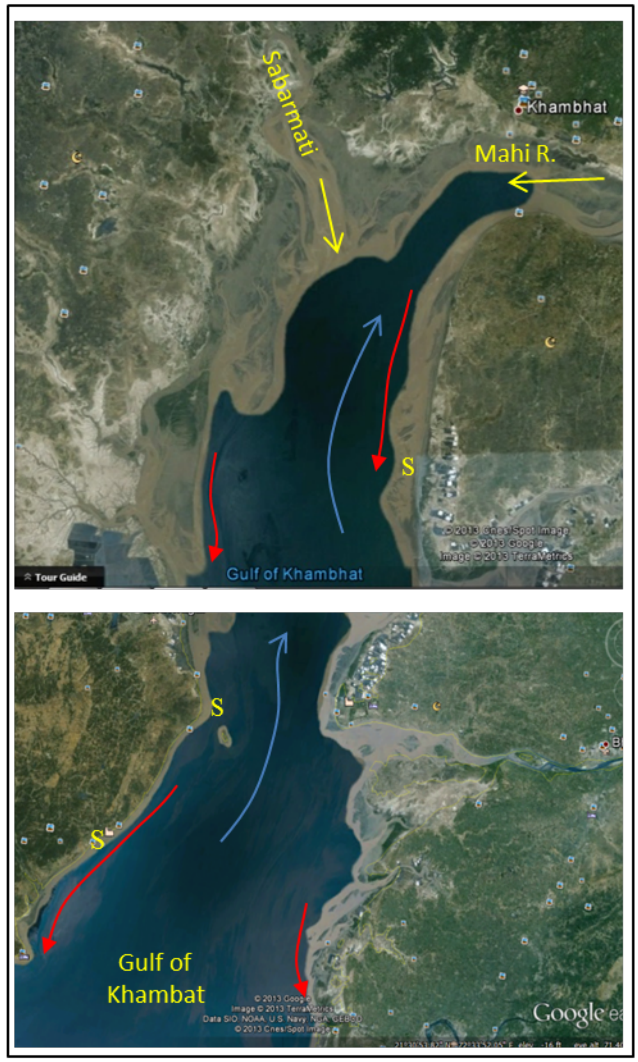

Fig. 4: Google Earth map of Gulf of Cambay showing dispersion pattern of sands from Sabarmati and Mahi rivers due to ebb tidal current (red arrow). Note the prominent sandflats (S) along the coast and also isolated sand bars in the gulf. The blue arrow indicate flood tide movement.