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GROSS DEPOSITIONAL ENVIRONMENT (GDE) MAPS OF ARIYALUR-PONDICHERRY SUB BASIN (BLOCK – I) FROM OXFORDIAN TO ALBIAN OF CAUVERY BASINS, INDIA

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Abstract

During the Late Jurassic - Early Cretaceous a regionally extensive cover of dominantly siliciclastic sediments was deposited across the Ariyalur-Pondicherry sub basin. Historically, these siliciclastic sediments have been considered to be a relatively heterogeneous lithofacies known as the Andimadam Formation, described as coarse-fine grained sandstone and shale of mainly fluvial to marine origin. The stratigraphic relationships between regional continental strata in different part of A-P sub basin has only briefly been described and has locally been related to equivalent marine deposits. To address these problems, thr study focuses upon three main approaches viz. biostratigraphic details and the lithofacies variability of Andimadam Formation. A unified biochronostratigraphic framework for Late Jurassic - Early Cretaceous sediments and Paleoenvironmental and paleogeographic evolution to construct gross depositional environmental maps.

Sedimentological investigation by earlier workers has identified greater variation in lithofacies and depositional processes and sandstone is deposited under fluvio-lacustrine to shallow marine to deep marine setup. Lithostratigraphic correlation shows a fluvial system transported sediment into a wide fluvio-lacustrine-shallow marine-deep marine basin. Several episodes of marine transgression culminating in a distinct and regionally correlatable transgressive episode represented by Sattapadi Shale of Albian-Cenomanian age.

Building upon previous work and new insights from the Andimadam Formation a synthesis and re-interpretation of the spatial and temporal heterogeneity of sediments and depositional environments through-out the Late Jurassic - Early Cretaceous is presented. During the Oxfordian time the subbasin was dominated by fluvial and lacustrine regime with minor influence of marine transgression in the sub basin. During Kimmerdigian-Tithonian the sub basin experienced more marine influence resulting in the lacustrine setup encroached by marine water turning them into brackish water lakes and the coast line started moving inland. Since, Tithonian-Albian continuous rise in sea level resulted in the prevalence of open marine environment and the sediments deposited in overall transgressive mode and finally the deposition of Sattapadi Shale Formation considered as maximum flooding surface.

Introduction

The A-P Sub Basin a part of Cauvery Basin that represent a Meso-Cenozoic pericratonic basin located in southern part of Indian peninsula. The Late Jurassic - Lower Cretaceous rock succession comprised of fluvio-deltaic and marine sediments of Andimadam Formation. The principle aim of this study is to undertake an integrated sedimentological, biostratigraphic and regional stratigraphic study of the Andimadam and part of Tranquebar sub basin to improve the understanding of large-scale, sedimentary systems. In order to achieve this, detailed biostratigraphic and sedimentological analysis of the Andimadam Formation is presented and discussed in terms of paleo-environmental evolution and controls on lithofacies distributions and stratigraphic architecture. To further explore lithofacies variation within large-scale sedimentary systems, electolog motifs have also been used. The study attempt to explore the controls and environmental evolution in the sub basin.

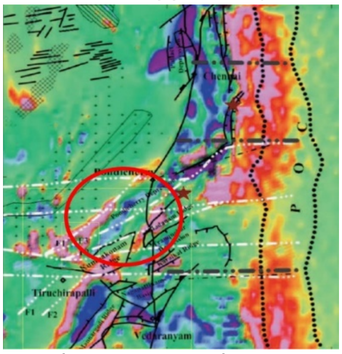
Objective

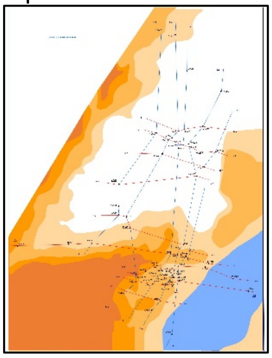
To provide stage wise Gross depositional environmental maps from Oxfordian (Late Jurassic) to Albian (Early Cretaceous) using forwards stratigraphic modeling approach in order to provide a probable distribution of expected reservoir facies.

Background

During the Late Jurassic-Early Cretaceous, the Ariyalur-Pondicherry sub basin developed an extensive cover of siliciclastic sediment. These sediments were transported East-South eastward by fluvial systems, where they accumulated with basin ward thickening and is known as the Andimadam Formation. Today, these sandstone-dominated deposits are of major economic interest in the subsurface as hydrocarbon source and reservoirs. This has inevitably led to over generalization of the sedimentological character of the Late Jurassic - Early Cretaceous clastic deposits and severely limited the understanding of these strata.

The main limiting factor for the regional studies of the Late Jurassic - Early Cretaceous in the region is the lack of a robust biostratigraphic framework. The occurrence of stratigraphically useful microflora so far have been reported from the study area have not been used adequately and faunal occurrence is very poor to help in provides the opportunity to extrapolate them litho-stratigraphically.





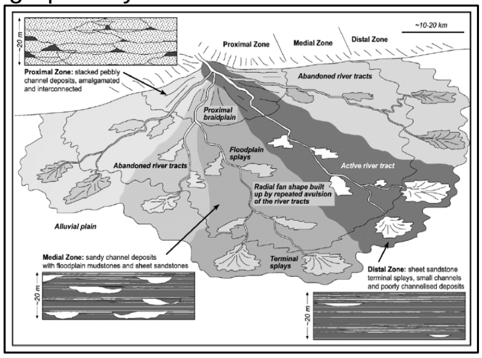


Fig. 1. The grabens representing Mesozoic sedimentary fill in the studied area is Ariyalur – Pondicherry Sub basin and part of Tranquebar depression separated by Kumbhakonam – Madnam ridge. Fig. 2. Well location along the selected profiles. Fig. 3. Fig. *Facies model for a distributary fluvial system (Nichols and Fisher, 2007)*

The term Andimadam Formation is introduced by Venkatarengan et al., (1993). The formation is not exposed in out crop areas of Cauvery Basin. In the subcrop the Andimadam Formation developed in the en-echelon grabens. The lower boundary of this formation is the Archean basement. The upper boundary is arbitrarily fixed at the base of an argillaceous section – the Sattapadi Shale, overlying this formation. The holostratotype comprises mainly of calcareous sandstone and minor shale alternations. The Sandstone is pale grey, moderately hard, fine to coarse grained, abundant pebbles and granules (conglomeratic) are seen at places, angular-sub rounded, garnet and abundant mica set in a clayey matrix, feebly calcareous. The Shale is grey, moderately hard, silty, abundant mica and non- calcareous, minor fissility seen at places. The thickness of this formation varies between 1000-1500m (+) in different subbasins. In rest of the areas, arenaceous facies is dominant. The serrated log response against the calcareous and tight sandstones and the intervening shale layers are the diagnostic features for recognizing this formation. From the lithological characters it could be inferred that sediments have been deposited in a very shallow marine high energy regime.

The detailed sedimentological studies of the Andimadam Formation has been carried out by Bharkatya et al., (2014). The sandstone is predominantly light grey and dirty white with occasional medium grey, fine to coarse, occasionally very coarse grained and floating sub angular to angular granules at places, moderately hard and compact, angular to subrounded grains are ill sorted and arkosic in composition. Argillaceous and also patchy ferruginous matrix is prominent with authigenic disseminated pyritisation at places. Heterogeneous patchy carbonate cementation is present. The other prominent minerals associated at places are mica and ferro magnesium minerals. Besides polymictic conglomerate and gritty sandstone has also been observed in the upper part of the formation. The interbedded shale is predominantly dark grey moderately hard and compact, well fissile, richly carbonaceous and associated with free Sulphur. Abundant organic debris and coaly matter present. Green colored chloritic micaceous shale observed at places. Massive sandstone bedding (thickness variation from 5cm to 220cm) observed with occasional normal and reverse grading cycles. Massive sandstone with occasional floating rip up claystone clasts have been observed. Horizontal bedding/ layers in medium to coarse grained high energy sandstone also observed. Laminated silt and shale alternations, crude irregular layers in argillaceous sandstone, poor cross laminations, wavy discontinuous shale parting are present with grain alignment to flow and the contact between two facies is normally sharp and inclined

Present Study

During the Late Jurassic - Early Cretaceous a large-scale fluvio-lacustrine system drained the interior of the Ariyalur-Pondicherry Sub basin which continuously changed to open marine environment in Albian-Cenomanian resulted in deposition of Andimadam Formation in fluvio-lacustrine to deep marine environment during which maximum of 1500m thick alternating finer and coarser clastic sediments deposited in Cauvery Basin. The distribution of fluvial, lacustrine and marine facies are interpreted to be controlled by a combination of accommodation availability, repeated relative sea-level rises, and auto cyclic fluvial processes. Facies relationships illustrate how repeated relative sea-level rise was able to rapidly inundate large parts of the A-P sub basin due to the high angle and facies distribution and preservation were restricted due to the balance between sediment supply and accommodation/subsidence.

To understand the A-P sub basin eight dip and five strike profiles have been constructed to illustrate the variability and complexity in structural and sedimentary architecture since the Breakup Unconformity (Basement top). Rift tectonics is the key feature as it controls the majority of the fault systems, as well as sediment distribution and the resulting architecture due to subsidence. In summary, the study area can be divided into three distinct rift phases viz. Rift, Rift-Drift and Sag. These sections show the typical chrono-stratigraphic succession of the A-P Sub-basin. The sections shows the basement wash/basal clastic identified above the basement as early synrift sediments. Towards the end of Jurassic around Tithonian (152-145Ma) rift phase ceases and the basin enters in to rift-drift phase Hauterivian (132.9-129.4Ma). From Barremian (129.4-125Ma) the basin begins to subside and continued till Albian (113.0-100.5Ma) in the subsidence phase. The sediments deposited during rift phase starts to be overloaded by early Cretaceous sediment.

The dip sections show thick early Cretaceous succession but sediment thickness varies basin ward along with differential subsidence due to presence of basement highs and lows. These sections show the typical lithostratigraphic succession of the A-P Sub-basin. The entire synrift sediments are essentially composed of finer and coarser clastic sediments. The coarser clastic portion corresponding to the progradation of alluvial fan sediments with proximal fan facies debouching in marine realm with increasing marine influence in the sub basin. The sediment transfer from uplands to basin correspond to a simple model of direct and classic source to sink system, with widespread fan systems. In the early part of Late Jurassic, the sedimentation is dominated by fluvial clastic sediments and lacustrine shale related to the initial drift related highs and lows, the highs represents the positive/source areas while the lows represent the sink areas. The basin is dominated by coarser clastic sediments during the period Tithonian – Hauterivian, in the rift drift phase while the marine shales are representative of marine influence and increasing sea level. During the period Barremian – Albian, with the basin entering into the sag phase due to increasing sediment load along with the flight of Indian plate towards N-NW, continuous rise in sea level resulted in increase in marine shales with secondary coarser clastics and the basin finally witnesses basin wide marine transgression.

The output of forward stratigraphic modeling is typically the properties of d*epositional environment, lithological information, sediment concentrations, facies model/maps, and Reservoir/seal properties.*

Methodology

Gross Depositional Environment maps have been drawn for each stage from Oxfordian - Albian. GDE maps allow more reliable prediction of reservoir distribution than correlation between sparsely distributed wells and a better representation of sediment distribution systems from high lands to deep water. The wells are considered representative of the study area. Reservoir facies and characteristics were obtained from the integration of biostratigraphy and lithostratigraphic breakdown from the 83 wells logs signature and interpreted lithological columns. Vertical facies distribution from the wells for each stage in reservoir and non-reservoir units (Gross reservoir and Gross shale results). Porosity results from previous petrophysical studies and Reservoir characteristics from key wells. The methodology used for making the GDE maps is depicted below.

Gross depositional environment

Andimadam Formation-Lithological charcterstics

According to Venkataraman *et al.,* (1993), the lower boundary of this formation is the Archean basement and the upper boundary is arbitrarily fixed at the base of an argillaceous section – the Sattapadi Shale, overlying this formation. The holostratotype comprises mainly of calcareous sandstone and minor shale alternations. Sandstone is pale grey, moderately hard, fine to coarse grained, abundant pebbles and granules (conglomeratic) are seen at places, angular to sub rounded, garnet and abundant mica set in a clayey matrix, feebly calcareous. The Shale is grey, moderately hard, silty, abundant mica and non-calcareous, minor fissility seen at places. The lithology of hypo stratotype is comparable to the holostratotype. The thickness of this formation varies between 1000 – 1500m (+) in different subbasins. The serrated log response against the calcareous and tight sandstones and the intervening shale layers are the diagnostic features for recognizing this formation. From the lithological characters it is inferred that the sediments have been deposited in a very shallow marine high energy regime.

Massive sandstone bedding (thickness variation from 5cm to 220cm) observed with occasional normal and reverse grading cycles. Massive sandstone with occasional floating rip up claystone clasts have been observed. Horizontal bedding/layers in medium to coarse grained high energy sandstone also observed. Laminated silt and shale alternations, crude irregular layers in argillaceous sandstone, poor cross laminations, wavy discontinuous shale parting are present with grain alignment to flow and the contact between two facies is normally sharp and inclined. The cores are marked with dominantly arenaceous facies than the argillaceous facies. The sandstone is predominantly light grey and dirty white with occasional medium grey, fine to coarse, occasionally very coarse grained and floating angular to sub angular feldspar granules, moderately hard and compact, angular to sub-rounded grains are ill sorted and highly arkosic in composition. Generally argillaceous matrix is carbonaceous and micaceous and has patchy ferruginous cement in prominence with authigenic disseminated pyritisation at places. Heterogeneous patchy calcite cementation is observed. The other prominent minerals commonly associated at places are mica and ferro-magnesium minerals. The interbedded shale is predominantly dark grey, moderately hard and compact, well fissile, richly carbonaceous and associated with free Sulphur. Abundant organic debris and sapropilic matters present. Green colored chloritic micaceous shale observed at places. Texturally the grains are angular to sub-rounded, coarse - fine with floating granules, predominantly ill-sorted and texturally immature. The sedimentary structures represented by Massive sandstone with floating granules / claystone clasts (25 to 200cm thickness). Massive sandstone with reverse and normal grading cycles. Gently dipping (up to 20°), crude/hazy layers and beds. Horizontal layers of coarse and fine grained sands. Poorly developed cross beddings. Intercalations of claystone and fine grained sandstone.

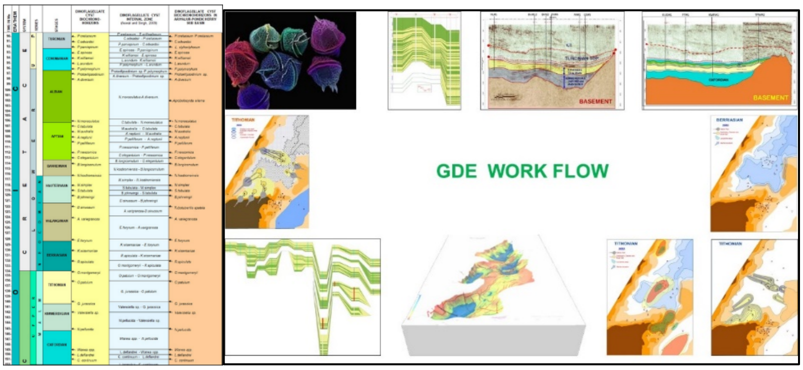


Fig. The methodology used for GDE maps

Results

Main sedimentary pathways driving sediments from the high lands towards the basin are through the alluvial fan systems debouching in marine realm. Deposition of sediments is thus localized along these fan delta systems and localized lows or mini basins. High sedimentation rates are mainly localized in the mini basins formed during the rift and rift drift phase tectonics. The highest rates of sediment accommodation occurs around the rapidly prograding proximal fan deltas as well as around the mini basins. The diversion of sedimentary pathways between alluvial fan systems leads to a further sediment transfer into the deeper basin. The paleoenvironment modeling generated from the forward stratigraphic simulations supports the proposed geological model with alluvial fan-lacustrine to shallow marine settings towards the margin that develops rapidly into deep marine settings. The sand content diminishes along the slope as it increases towards the fan axis does the connectivity of the reservoir facies (Sand, mixed sand, shale and silt).

Modeling

The sandstone facies extends from high lands to basin and preferentially accumulated in depocenters formed by active faulting and rift architecture. Sandstone rich lobes appear to be present in the basin, primarily filling mini-basins and corridors between proximal and distal fan facies. Finally, the thickness trends also support the hypothesis of three main trapping domains viz. Major alluvial fan progradation, Mini basin development due to rift architecture (basement highs and lows) and sediment transfer in the deeper basinal setting.

Gross depositional environments (GDE)

GDE maps have been drawn for each interval from Oxfordian to Albian.

Oxfordian There are very few wells which have penetrated in these sediments. Along with the available well data, to come to the conclusion about the GDE during the Oxfordian time, relief map at the top of the basement has been taken in to account for extension of the lows as well as to understand the limit of marine influence. The sediments of the Oxfordian age corresponds to the basal part of synrift sediment. The depositional environment prevailed during the period is mainly the fluvial setup while the sediments from the alluvial fan axis are transported to the initial lows formed with the rift tectonics where dominantly a lacustrine setup was prevailing. The marginal marine setup appears only in the north-eastern part of the basin.

Kimmeridgian

During the Kimmeridgian, sediments begin to infill the inherited mini basins. The thickness map shows thick accumulations of reservoir facies towards the proximal part (PN wells viz. F, G, AA) and in the axis (BV-I, VL-A) of alluvial fan systems. The lacustrine environment prevailed during the Oxfordian time turned in to brackish set up during the Kimmeridgian due to rise in sea level. The sediment distribution and transportation is controlled by distributary channels of alluvial fan system.

Tithonian

Tithonian witnessed further filling of the inherited mini rift basins. In both viz. Bhuvanagiri and Pandanallur-Andimadam area the shift in the fan axis is clearly evident as well PN#G and BV#I shows maximum sand thickness. During Tithonian the marine realm extended further in the basin encompassing all the lows which were acting as inland lakes. This is for the first time the alluvial fan systems further extended and started debouching in the marine realm in shore face to inner shelf environment.

Berriasian

During the Berriasian time the coast line further moved inland engulfing more areas in A-P sub basin. Due to the continuous rise in sea level the alluvial fan facies paved the way for foreshore to shore face environmental set up especially in Pandanallur area. In Bhuvanagiri area the alluvial fan system continued to prograde in the fore shore- shore face environment due to unabated sediment supply. The Bhuvanagiri fan prograded almost to the well CD#EA. For this fan system two models have been proposed as the location represented by CD#E well was getting the sediment supply from the adjoining Madnam high from Oxfordian - Tithonian. The sand models of Berriasian suggests, due to the high sediment supply in Bhuvanagiri fan the proximal fan facies extended to the CD location, however, the same location, sediment supply from Madnam high cannot be ruled out as the seismic line passing through this area suggest bimodal sediment supply.

Valanginian

The Valanginian period corresponds to global sea level fall due to opening of northern Atlantic with the separation between Europe and Newfoundland characterized by major regressive sequence due to which the fan system started receiving the more sediment input while the deeper part of the basin has low sediment accumulation suggested by the presence of low sand percentage in the proximal part of the fan while the mid fan complex accumulated more sand. The fan architecture suggest more widening then the progradation in comparison to the Berriasian fan architecture in Bhuvanagiri and Pandanallur area while in Komarakshi area the fan progradation is observed. In the basin dominantly foreshore to shore face environment prevailed.

Hauterivian

During the Hauterivian period, the sediment input increases drastically as reflected by the increase in sand percentage in all the alluvial fan system since Oxfordian. Another evidence of the increase in sand percentage is from north where another fan develops in Chattaram area with approximately 87 percent sand deposited during the period. The change is sediment supply may be attributed to the basin entering in sag phase of rift tectonics. The rapidly increasing sediment load and development of additional alluvial fan system. With the rising sea level and coast line moving landward the Bhuvanagiri fan system instead of prograding started increasing laterally as the ever rising sea level hinders the sediment supply to the deeper part.

Barremian

During this time, the sedimentary system has started to evolve with a continuous increase in shale content in the shore face to fore shore areas of the period. The widening of the alluvial fan system continues during Barremian also. The depositional environment is more open to marine influences. In order to better understand sands distribution from distal part of the fan system to the basinal part during this time frame, a sand depositional model has been constructed. Results show a broad distribution of sandstone across the basin. A major transgressive event occurs during the Barremian period leading to the increase of shale content in overall lithofacies. This event is related to global Barremian transgression and with the basin entering in the sag phase of rifting due to the heavy sediment supply during Hauterivian period resulting in overall mechanical compaction of early cretaceous –Late Jurassic sediments and overall subsidence of the basin.

Aptian

The period witnessed the global regression which commenced in Barremian and continued till Aptian, but in A-P sub basin due to the sagging of the basin resulting in differential subsidence the sea level continued to rise. Due to this rise due to subsidence the area in and around the CD#E, KMR#A, the high shale percentage i.e. 100% in CD#E suggest this area continued to subside more and may represent inner to middle shelf conditions where dominantly the finer clastics are deposited. There is overall increase in shale percentage throughout the basin since Barremian.

Albian

This period in the sub basin experienced the widespread marine transgression throughout the basin which has brought most highs or positive areas in the basin under marine realm. This transgression in the basin is in conformity to the eustatic sea level rise. The extent of this transgression was so wide spread that the coastline crossed the basinal boundaries and deposited a continuous sequence of calcareous and siliciclastic sediments in the outcrop area of Trichinapalli. The dominant lithology deposited during this period in the basin is mainly shales and siltstone/claystone represented by Sattapadi Shale Formation, considered as MFS.

Conclusions

1. The sediments of the Oxfordian age corresponds to the basal part of synrift sediment is deposited in fluvial- fluvio lacustrine setup. The sediments are transported to the initial lows formed with the rift tectonics where dominantly a lacustrine setup was prevailing through alluvial fan system.
2. During Kimmeridgian sediments begin to infill the mini basins. Sediment distribution and transportation is controlled by distributary channels of alluvial fan system.
3. Tithonian witnessed the shift in the fan axis and marine realm extended further in the basin encompassing all the lows which were acting as inland lakes. The alluvial fan systems further extended and started debouching in the marine realm.
4. During Berriasian the coast line further moved inland. With continuous rise in sea level the alluvial fan facies paved the way for foreshore to shore face environmental setup. The sand models suggest that due to the high sediment supply in Bhuvanagiri fan the proximal fan facies reached up to the CD location along with the supply from the Madnam high cannot be ruled out as the seismic line suggest bimodal sediment supply.
5. The Valanginian period corresponds to global relative sea level fall suggested by presence of low sand % in proximal fan, the mid fan complex accumulated more sand. The fan architecture suggest more widening in comparison to the Berriasian fan architecture in Bhuvanagiri and Pandanallur area while in Komarakshi area fan progradation is observed in foreshore to shore face environmental setup.
6. During the Hauterivian period, the sediment input increases drastically as reflected by the increase in sand percentage. In Barremian, sedimentary system started to evolve with continuous increase in shale content in the shore face to fore shore areas of the period. The widening of the alluvial fan system continues during Barremian also.
7. The Aptian period witnessed the regressive phase which commenced in Barremian and continued till Aptian, but due to differential subsidence the sea level continued to rise reflected by overall increase in shale percentage throughout the basin.
8. The Albian period experienced the widespread marine transgression throughout the basin which has brought most highs or positive areas in the basin under marine realm.
9. The dominant lithology deposited during this period in the basin is mainly shales and siltstone/claystone represented by Sattapadi Shale Formation, which is considered as MFS.

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