



**P-304**

## **Integrated Analysis of Late Albian to Middle Miocene Sediments in Gulf of Mannar Shallow Waters of the Cauvery Basin, India: A Sequence Stratigraphic Approach**

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### **Summary**

*Gulf of Mannar sub basin comprises of two syn-rift depocenters separated by southward plunging Mandapam-Delft ridge. The western part forms the present day shallow water area of Gulf of Mannar. Integrated sequence stratigraphic analysis was carried out on Late Albian to Middle Miocene sedimentary sections using seismics, electro logs, sediment sample analysis, FMI (formation micro imager) study and bio-stratigraphic data. By following sequence stratigraphic principles, sequence boundaries and/or their correlative conformities were identified based on stratal patterns and amplitude variations on seismics and correlating them with corresponding log markers close to those seismic signatures. Bio-stratigraphic studies aided in age control, identifying paleo bathymetry and recognising hiatuses. Eight major sequence boundaries close to Late Albian, Middle Turonian, Early Maastrichtian (K/T boundary), Early Eocene, Middle Eocene, Late Eocene, Early Oligocene and Middle Miocene ages are identified. These sequence boundaries closely correlate with the major sequence boundaries identified in the Cauvery Basin on regional scale. Nature and distribution of sedimentary facies in the study area was controlled by confined depositional setting in pre-Cretaceous times and unconfined setting during post-Cretaceous period deposited under varied depositional environments ranging from Lower Bathyal during Late Albian to Inner Shelf through Middle Miocene. Based on adsorbed gas analysis, matured oil prone source rock is predictable at deeper stratigraphic levels below Late Albian in this area. Core and FMI studies on the sand intervals shows that these were gravity driven slump deposits of low stand systems tracts deposited above Middle Turonian and Early Maastrichtian sequence boundaries. The study reveals that required elements of petroleum system exist in the area below Lower Eocene but younger stratigraphic levels above may not be interesting in hydrocarbon perspective.*

### **Introduction**

Gulf of Mannar Sub-Basin constitutes the south eastern offshore part of Cauvery Basin, the southern most of the Mesozoic rift basins along the east coast of India. Late Jurassic fragmentation of eastern Gondwanaland into India, Antarctica, and Australia had initiated the formation of Mesozoic rift basins on the eastern continental margin of India including Cauvery Basin. Numerous deep extensional faults developed in NE-SW direction during rifting had initiated active subsidence that resulted in the formation of graben and horst blocks which subdivided the Cauvery Basin into many sub-basins including Gulf Of Mannar (Fig.1).

The first documented hiatus from the sub-surface had been marked close to the top of Albian (Indian stage-Nallurian-Raju, 2008). The second major unconformity during Middle Turonian manifests itself in the absence of Late Turonian sediments in major parts of the basin. The third major hiatus marks the K/T boundary (Late Cretaceous). By the end of Cretaceous the rifted grabens were filled and prograding clinoforms of typical passive margin started emerging. During Tertiary period unconformities in the form of hiatuses were recorded at Oligocene and Middle Miocene times.



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Fig.1. Location Map of Cauvery Basin

The generalised litho stratigraphy of Cauvery Basin, representative lithology of the formations and sequence boundaries (PSSS, Cauvery Basin, KDMIPE, 2008) are shown in the Figure.2.

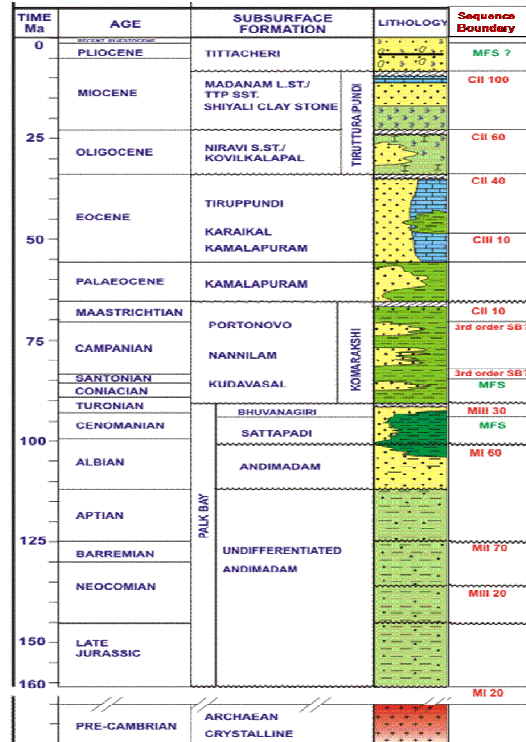


Fig.2. Generalised Stratigraphy of Cauvery Basin

## Area

Gulf of Mannar sub basin comprises of two cretaceous depocenters separated by the southward plunging NE-SW aligned Mandapam-Delft ridge. The western part forms the shallow water area of Gulf of Mannar, subject of the present study (Fig.3). This part of sub basin is geologically contiguous with hydrocarbon producing Ramnad sub-basin located onland towards NNE. The eastern part of Gulf of Mannar lying between India and Sri Lanka is one of the deepest depositional troughs of Cauvery Basin.



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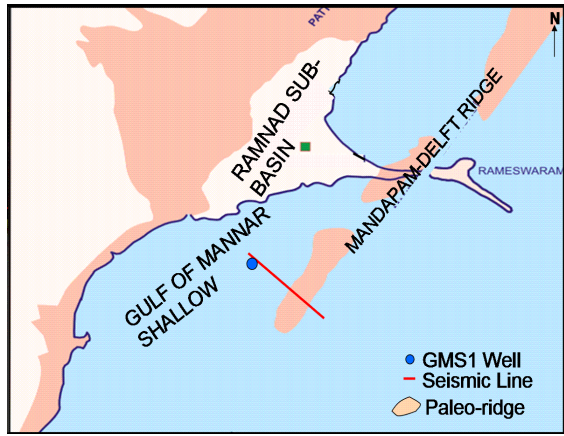


Fig.3. Map showing Gulf Of Mannar Shallow area with seismic line and well.

The Albian and post Albian stratigraphic record of Gulf of Mannar shallow area consists of various sedimentary sequences that are bounded by unconformity or their correlative conformity surfaces representing different depositional environments. Two distinct depositional settings, pre-cretaceous confined and post-cretaceous unconfined, together with their associated sedimentary processes had controlled the distribution of sedimentary facies throughout the area.

The Gulf of Mannar shallow area remained in confined setting till end of Cretaceous by which time it got filled up and sediments started depositing over Mandapam-Delft ridge (Fig.4). A well drilled on the Mandapam-Delft ridge in NE direction in the area had encountered a very thin Late Cretaceous sedimentary cover deposited directly over granitic basement.

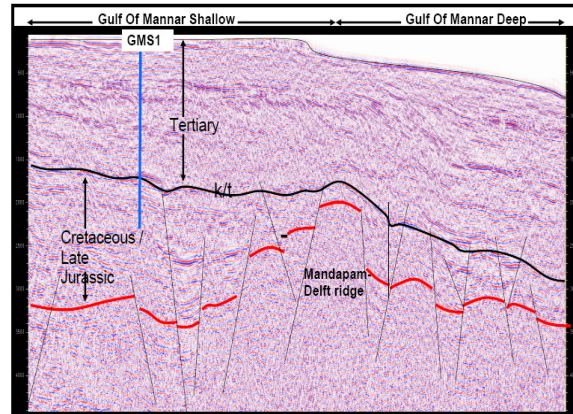


Fig.4. Seismic section from NW to SE across Gulf Of Mannar shallow through the well GMS1.

This area attained unconfined depositional setting thereafter and gradually shallowed up shifting the depocenter towards east of Delft ridge (Gulf Of Mannar Deep).

## Present Study

An attempt was made to identify and define sequence boundaries and associated systems tracts by integrating seismic and well data in Gulf of Mannar shallow area following sequence stratigraphic principals; analyse depositional environments of sedimentary sections and understand their role in petroleum system of the area.

## Data

Part of Gulf of Mannar shallow area had been covered by 2D seismic survey. 3D seismic survey in limited area was also carried out. Few wells were drilled in and around this area but hydrocarbon occurrence however, is yet to be established.

In the present study, a 2D seismic line in dip direction (NW-SE) crossing the Mandapam-Delft ridge which passes through a drilled well located at deeper part of the study area named as GMS1 drilled upto 3500m was considered to represent the interpretation.

The electro logs including FMI, Bio-stratigraphy, sedimentological and Geo-chemical analysis of the well GMS1 were integrated. Since bio-stratigraphic control at younger stratigraphic levels in the well GSM1 was poor,



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near by well data was considered for age control and in arriving at paleobathymetry by extending correlation.

### Methodology

Sequence boundaries or their correlative conformities were identified mainly based on stratal terminations supported by amplitude variations and erosional appearance of the surfaces on seismics and matching them with corresponding log markers close to those seismic signatures upto drilled depth (3500m) of well GSM1 which terminated in Albian sediments.

Systems tracts of each sedimentary sequence were identified based on coarsening and fining up trends on electro log and change in amplitude of seismic reflections. In this area sandy facies show high GR, for better control a combination of GR, Resistivity and DT logs was used.

Stratigraphic position i.e. age of sequence boundaries and indicative paleo bathymetry of each sedimentary sequence were derived from bio-stratigraphic studies considering the FDO (first downhole observation) of index planktic taxa.

Sedimentological studies of cutting samples, core analysis aided with FMI log studies were also integrated in describing the nature and sedimentation pattern of different sequences.

### Analysis

Eight sequence boundaries, three within Cretaceous SB10 to SB30 and five in Tertiary period SB40 to SB80 were identified (Fig.5). Sequence boundaries SB20, SB30, and SB70 appear erosional in nature with change in amplitude on seismics. SB60 is placed above prograding HST which was clearly seen on seismics. SB10 was placed mainly based on bio-stratigraphic control (absence of Late Albian forams above this depth) at the base of a dolerite injection marked on logs corresponding to amplitude change on seismics. SB40 was placed on top of prograding seismic reflections observed towards west of well location. SB50, placed on a downlap of clinoform was followed by LST represented by thin transported limestone. In the absence of any other control SB80 was placed based on change of seismic reflections from sub parallel-discontinuous to parallel-continuous.

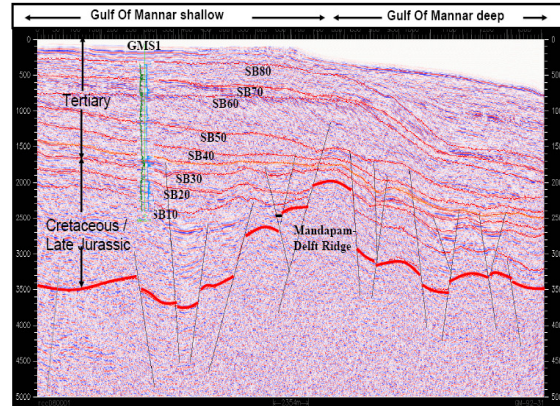


Fig.5. Seismic section showing well GSM1 and Sequence Boundaries

Based on bio-stratigraphic studies the stratigraphic position of these sequence boundaries from SB10 to SB80 were placed close to end of Albian, Middle Turonian, Early Maastrichtian (K/T boundary), Early Eocene, Middle Eocene, Late Eocene, Early Oligocene and Middle Miocene respectively (Fig.6).



Fig.6. Seismic section and Well Logs showing Sequence Boundaries and Systems Tracts.

The sequence boundaries SB10, SB20 and SB30 were within Cretaceous and correspond close to 3283m, 2927m and 2400m depths on logs.

**Sequence-I** from 3500m (DD) to SB10 (3283m), with the presence of planktic forams *Hedbergella planispira*, *Ticinella* sp., and *Globigerinelloides* sp. was assigned Late Albian age which was deposited under Lower Bathyal (1000-2000m) environment. The dominant lithology of this sequence is shale with minor siltstone.

Source rock analysis of a core sample in this sequence had shown that though organic carbon content was fair (TOC 0.5%, dominantly Type-III) and the Tmax 473°C was high the generation potential was low (S1 0.44 mg/g rock S2 0.31 mg/g rock HI 96mg/g TOC). The adsorbed gas analysis of the core indicates that adsorbed hydrocarbons were from an oil prone source rock.

**Sequence-II** between SB10 and SB20 (3283m to 2927m) yielded benthic forams *Ammobaculites* sp., *Lenticulina* sp.,

*Nodosaria* sp., *Hormosina ovulum*, *Glomospira* sp., *Saccammina* sp., *Haplophragmoides* sp. and indicate Upper Bathyal (200-500m) environment. Based on stratigraphic position this sequence was assigned Coniacian and Older (?) age in absence of index planktics. However, based on absence of Late Turonian sediments in many parts of the Cauvery Basin and recorded hiatus at this level the upper boundary of this sequence (SB20) was placed at the top of Middle Turonian. Shale and siltstone/silty sandstone constitute the main lithology of the sediments.

Geo-chemical analysis of the shales, TOC ~0.9%, Tmax 430-441°C, S2 ~0.5mg HC/g rock and HI ~77mg HC/g TOC, in this sequence shows that these are immature poor source rocks.

Igneous intrusion in the interval 3283 to 3251m encountered in the well GMS1 was interpreted as dolerite. Similar intrusions were also reported from other nearby wells drilled in the area. Age dating of these dolerites was from ~88ma. to 61ma. indicating multiple intrusions at different times. On seismic data intrusives are characterised by high acoustic impedance and very high amplitudes.

**Sequence-III** between SB20 and SB30 (2927m to 2400m) was assigned Coniacian to Early Maastrichtian age based on presence of forams like *Marginotruncana renzi*, *M.coronata*, *M.pseudolinneiana*, *Globotruncana arca*, *G.bulloides*, *Globotruncanites stuartiformis* and *G.elevata*. Late Maastrichtian forams were absent indicating a hiatus of ~4my at SB30 (K/T boundary). These sediments composed of sandstones and shales were deposited under Middle (500-1000m) to Upper Bathyal environments

The sands encountered in the intervals of 2901.5-2747m & 2712-2723m (Bhuvanagiri sands) in this sequence were placed under LST deposits. These massive sandstone sections were shaly and calcareous. High resistivity areas on image indicate highly calcareous sands. The high resistive sub rounded features noticed on images probably correspond to pebbles? Some sand intervals show few parallel and cross beddings indicating turbidity flows (Fig.7).



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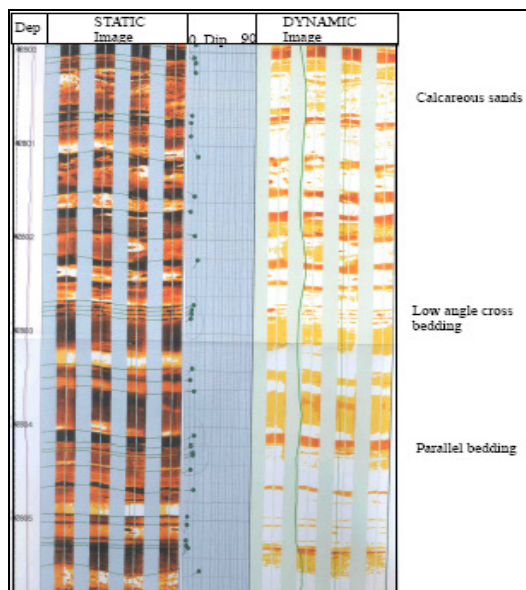


Fig.7.FMI Log from 2806m to 2800m

Other units were with sparse dips, few bedding planes and blank zones indicating debris flows (Fig.8).

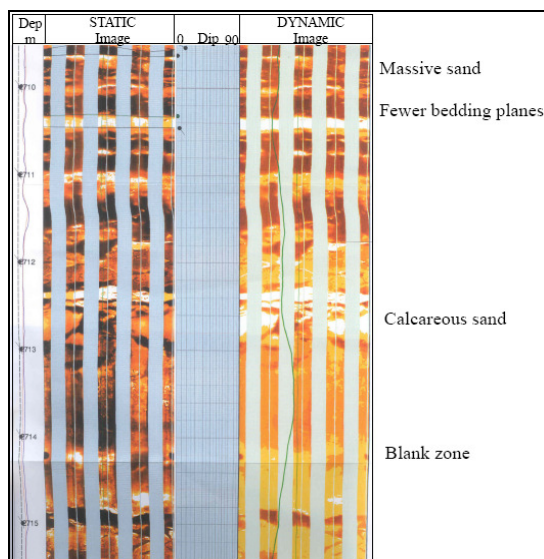


Fig.8.FMI Log from 2715m to 2710m

Finer clastic sediments in this sequence are inferred as immature poor source rocks based on geo-chemical analysis (TOC ~0.7% Tmax 420-430°C, S2 ~0.3 mg HC/g rock and HI ~56mg HC/g TOC).

The sequence boundaries SB40, SB50, SB60, SB70 and SB80 occur within Tertiary period and correspond to 2013m, 1472m, 1020m, 710m and 518m log depths respectively.

**Sequence-IV** between SB30 and SB40 (2400m to 2013m) represented by sandstones and shales, consisting of forams like *Subbotina triloculinoidea*, *S.wilcoxensis*, *Planorotalites compressa*, *Morozovella aragonensis*, *M.formosa*, and *Acarinina pentacamerata*, suggest Paleocene to Early Eocene age. This sequence was deposited under Upper to Lower Bathyal environment.

The sands occurring between 2207m-2149m (Kamalapuram sands) in this sequence were placed under LST deposits. This unit was characterised by sharp and sub planar upper and lower contacts with low dip spread. The High resistive (white colour) beds seen on images correspond to calcareous silty sands. High resistive sub rounded features may correspond to pebbles? Short blue patterns at 2152m indicate probable direction of current from NW to SE.

Core study in the interval of 2150-2157m shows that this was a massive, medium to very fine grained, occasionally coarse grained calcareous sand with sub-angular and poorly sorted grains. The rock was classified as Arkose with kaolinite matrix. Alteration of orthoclase feldspar to kaolinite led to pore filling and reduction of porosity. Kaolinite changing to illite was noticed at few places.

Core segments matched with FMI log shows that the selective calcareous cementation correspond to high resistivity bands, cross laminations to low angle cross bedding and clay rafts as black sub rounded conductive features on images (Fig.9).

Shales in this sequence, TOC ~0.6%, Tmax 414-433°C, S2 ~0.3mg HC/g rock and HI ~43mg HC/g TOC, are inferred as immature poor source rocks.



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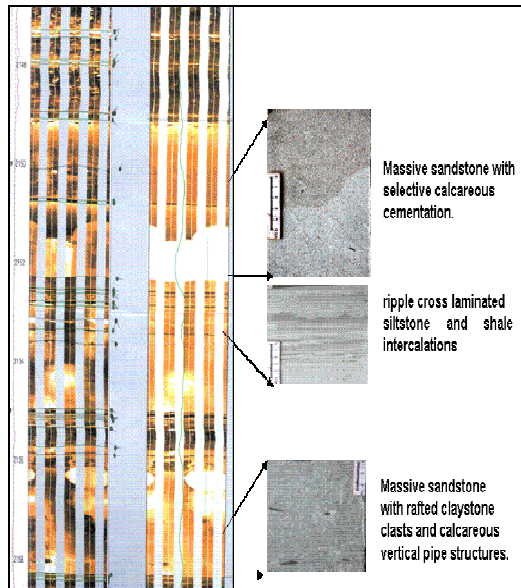


Fig.9.FMI Log from 2158m to 2148m and core segments from core 2150-2157m

**Sequence-V** between SB40 and SB50 (2013m to 1472m) with *Truncorotaloides rohri*, *T.topilensis*, and *Morozovella spinulosa*, was assigned Middle Eocene age and was deposited under Upper to Middle Bathyal environment. Dominant lithology of this sequence was Clst/shale and silty shale.

Source facies with TOC ~0.7% and poor values of Tmax 420-430°C, S2 ~0.3mg HC/g rock and HI ~39mg HC/g TOC are inferred as immature poor source rocks.

**Sequence-VI** between SB50 and SB60 (1472m to 1020m) with *Turborotalia cerroazulensis*, *T.cocoaensis*, and *Gavelinella* sp, belongs to Late Eocene age and was deposited under Middle Bathyal to Outer Shelf environment. The dominant lithology of this sequence was Clst/shale and silty shale with minor limestone.

Geo-chemical analysis of the Clst/shales in this sedimentary sequence shows that these are dominantly Type-III potential source rocks with TOC ~2.4% but poor values of Tmax 420-430, S2 ~2.4 and HI ~109 indicate that they are immature.

**Sequence-VII** between SB60 and SB70 (1020m to 710m) the presence of *Globigerina selli*, *G.opima*, *G.ampliapertura* and *Nannulites fichteli* indicate Early

Oligocene age. Late Oligocene marked with a hiatus. This sequence which composed of dominantly limestone with minor sands was deposited under Inner Shelf to Outer Shelf environment.

**Sequence-VIII** between SB70 and SB80 (710m to 520m) contains *Miogypsina* sp., *Lepidocyclina* sp., *Operculina* sp., *Spiroclypeus* sp. of Early to Middle Miocene age which deposited under Shallow Inner Shelf environment. The dominant lithology of this sequence was limestone with minor sands.

### Discussions

During Late Albian i.e 3500m to SB10, Gulf Of Mannar Shallow area was experiencing Lower Bathyal environment. Since the drilled well was located at deeper part of the sub basin it received finer clastic sediments in the form of shales/silty shales representing bulk lithology of this interval.

From Late Albian to Middle Turonian (SB20) the area shallowed up from Lower Bathyal to Upper Bathyal. This was due to exhumation of basin by Marion hotspot activity which led to the separation of Madagascar from India at this time (Abramovich et al, 2002). During this period this area received silty sands and sands interspersed within shales. The fall of sea level by SB20 initiated gravity driven episodic sediment flows resulting in both debris and turbidite flows depositing massive sands above this sequence boundary during LST of sequence between SB20 and SB30. Later with subsidence and sea level rise bathymetry started increasing and finer clastic sediments were deposited till end of the sequence at SB30 the K/T boundary.

Lowering of sea level during K/T (Raju et al, 1994) had resulted in shelf bypass and massive sands in the form of gravity flows in pulses started depositing in this part of sub basin which were placed under LST of sequence between SB30 and SB40. During the post Cretaceous period basin gradually filled up and bathymetry started falling from Upper Bathyal at SB40 (Early Eocene) to Outer Shelf environment at SB60 (Late Eocene) shallowing the area. Prograding clinoforms of the sequences which filled up the area carried finer clastic sediments to this part of sub basin from SB40 to SB60 by which time this area attained shelf environment giving rise to limestone deposition during TST and HST. Subsequent sea level falls at SB70 (Early Oligocene) and SB80 (Middle Miocene) hampered limestone development and brought in coarser clastic sediments during later part of HST and following LST as seen from the lithology and log responses.



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Presence of source rock in the undrilled Albian and older sediments was inferred from adsorbed gas analysis. Occurrence of reservoir facies mostly in the form of slump deposits of debris and turbidite flows as interpreted from the FMI and core study mainly during Turonian-Campanian and Paleocene-Lower Eocene times had been established. Deposition of shale over slumped sands/silty sands act as effective seal and restricted nature of these sand/siltysand bodies could provide entrapment. Faults seen extending upto end of cretaceous could act as conduits for charging. However, in post cretaceous tectonic activity was very minimal. Peak generation worked out from modeling in this area ranges from ~80-20ma. for deepest to youngest hypothetical source rocks in sediments above basement to Albian top.

Another phenomenon which would have influenced the maturation, generation and entrapment of hydrocarbons in this area was igneous intrusions. Considerable thickness of dolerite injections of multi episodic origin from Late Turonian to Late Maastrichtian age were encountered in the wells drilled in this area. Though early maturation of source rocks was envisaged in this area due to these igneous intrusions, their role in entrapment is not fully understood.

### **Conclusions**

The area Gulf Of Mannar shallow was a sediment depocenter in confined depositional setting till Late Cretaceous receiving clastic sediment input both from basin margin towards west and Mandapam-Delft ridge towards east. Unconfined setting emerged post Cretaceous shifted depocenter to east of Mandapam-Delft ridge.

Sedimentary processes in this area were controlled by varied depositional environments ranging from Lower Bathyal during Late Albian to Inner Shelf through Middle Miocene times.

Eight sequence boundaries were identified in this area. Seven of them correlate well with the sequence boundaries identified regionally in the Cauvery Basin (PSSS, Cauvery Basin, KDMIPE, 2008), except sequence boundary SB50 at Middle Eocene identified based on reworked limestone (LST) above.

The study area received coarser clastic sediments mainly during LST times above SB20 (Middle Turonian) and SB30 (Early Maastrichtian) in the form of debris and turbidity flows.

Effective source rock in this area was not encountered in the drilled wells. Geo-chemical analysis shows that finer clastic sediments in the well GSM1 contain sufficient organic matter but are immature. Adsorbed gas analysis of core sample from Late Albian indicates oil prone source rock at deeper levels.

Elements of petroleum system in the area exist below Lower Eocene. However, the impact of volcanic intrusions observed in this area in respect of generation and entrapment of hydrocarbons needs to be understood for successful exploratory efforts.

Younger stratigraphic levels above SB60 (Late Eocene), with thin sediment cover deposited under shelf environment having immature poor source rocks without significant fault system may not be interesting targets for hydrocarbon exploration.

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