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CHAPTER 1

INTRODUCTION

1.1 ORIGIN AND RELEVANCE OF THE RESEARCH PROBLEM

Seismic stratigraphy, litho and biostratigraphy of sedimentary basins have been studied to understand the sea-level changes with time and space and its applications are widely used in petroleum industry in the last four decades (Payton 1977). The publication of AAPG memoir 26 in 1977 is initiated a tremendous interest in understanding sedimentary architectures of the rock record, which consists of unconformity and/or correlative conformities bound sequences and vertical successions with similar lateral variations. Sequence stratigraphy is born out of such efforts. Its importance lies in its ability to predict lateral and vertical litho facies variations. Vail and his school from erstwhile Exxon team have been the most influential in shaping the initial concept of sequence stratigraphy. It provides the architecture of a depositional sequence like the rate of sediment supply, rate of subsidence/accommodation volume and relative sea-level change. Sequence stratigraphy has developed into a powerful, predictive facies analysis tool for both the hydrocarbon industry and research work.

The chemical facies study is a useful dataset to understand the rock formation in response to the dynamics of the earth and to explore economic resources. In order to explain the strata system, the different methodology to be adopted to bring out the practical results. The sequence stratigraphy study
with an integrated approach like, field setting, lithostratigraphy, biostratigraphy records, petrophysical, mineralogical data, tectonic events, seismic data, isotope records etc., are the essential components to understand the sedimentary basin depositional system. Similarly the science of geochemical-sequence stratigraphy is important in evaluation of the outcrop and subsurface geology.

The geochemical-sequence stratigraphy offers improved resolution in barren and fossiliferous lithosections. The greatest significance of the technique is well suitable for lithosection where microfossil control precludes precise age. This method is allows the correlation of poorly dated or barren strata from different environments including continental settings. This technique couples with provenance; address the key strata surfaces such as marine flooding surfaces, transgression and regression surfaces through unique chemical signatures. The geochemical correlation is agrees with the biostratigraphic interpretation, and in addition, some of the lithological boundaries lie close to the geochemical unit boundaries. The strontium concentration, oxygen and carbon stable isotope is consistent with the biostratigraphy which confirms that an unconformity. The oxygen stable isotope data obtained from the whole rock samples analysis are used for calculation of palaeotemperature (Mabrouk et al 2005).

Using the reliable biostratigraphy correlation to sequence level, it is possible to chemically identify markers down to individual flooding surface/parasequence level. This information can be used to refine a sequence stratigraphy model, adding confidence to the identification of sequence boundaries, flooding surfaces, maximum flooding surfaces and condensed horizons. Integration of this information with a statistically significant means of testing the resultant correlations, and the result is a very potential technique.
1.2 GEOCHEMICAL-SEQUENCE STRATIGRAPHY

Peters et al (2000) applied the concept of geochemical-sequence stratigraphy to construct a geochemical-stratigraphy model for the Mahakam Delta and Makassar slope in Indonesia (AAPG) marks the key reference. The analogous concepts of references are; chemostratigraphy or chemical stratigraphy (Qin Zhengyong 1991, Liu Tuo 1994 and references therein), chemical-sequence stratigraphy (Zhou Yaoqi et al 1997, Lu Yongchao et al 1996). The chemical stratigraphy is based on the chemical elements in sedimentary rocks to divide and correlate the strata, analyze the sedimentary environment and depositional processes. The chemical elements frequently used are Na, K, Ca, Mg, Rb, Sr, Ba, S, B, P, Fe, Co, Ni. The chemical sequence stratigraphy deals with the chemical revolution of chrono-rock packages with genetic hiatus and their temporal and partial relationship through the study of the chemical depositional records in rocks. The traditional sequence stratigraphy describes the physical marks to understand tectonic activities, depositional process, global sea-level change and climate change (Li Meijun et al 2003). The geochemical-sequence stratigraphy is of great significance in the study of sequence boundary features, high resolution sequence division, and quantitative sea-level change. Altogether, both chemical stratigraphy and chemical sequence stratigraphy are based on the chemical method (inorganic chemical method) to divide and contrast the strata. The geochemical-sequence stratigraphy, however, is based on organic chemistry to study the occurrence, distribution and characters of source, reservoir and seal play elementals within a sequence framework. The integration with geological and geophysical data, predict and appraise the sediment characteristics of reservoirs.

The Cauvery Basin contributes significantly towards development of hydrocarbon source rocks. These economic discoveries of hydrocarbons in
India demand organized thinking and classification of the Cretaceous sediments. Sequence stratigraphy studies necessitate the finer subdivision of the rock record and a refined higher resolution correlation from surface to subsurface sediment properties in each sub-basin. In framing of these depositional models the sufficient data input on the outcrop strata characteristics, faunal assemblages, effect of major tectonic events, sea-level changes, chemical facies and unconformity punctuated through major part of the Cretaceous are the essential data.

The Cretaceous succession of Tiruchirapalli, southeast India occupies a very critical geographical position in the Indo-Pacific region during the Cretaceous. It is a treasure house of rich and varied fauna, which helps in inter regional correlation of different Cretaceous sections across the globe. After the pioneering works of Blanford, Forbes, Stoliczka, Kossmat, Ramarao, Narayanan, Banerjee, Ramasamy, Mahavaraju, Govindan, Raju, Chidambaram, Reddy, Yadagiri, Ramamurthy, Ravindran, Hart, Watkinson, Tewari, Ramkumar, Sundaram, Nagendra and research contributions have appeared from time to time enhancing our knowledge on the lithostratigraphy, sedimentology, tectonostratigraphy, sequence stratigraphy, geochemistry, macrofossils, sea-level changes, paleoecology, paleontology of this area.

1.3 INTERDISCIPLINARY RELEVANCE

Earth process is a complex phenomenon and geological field sites are the product of exogenous and endogenous process. To understand the natural materials of physical and subsurface environment and its use in resource exploration, demands the scientific probe in a multidirectional approach. This thesis is to address the geochemical constituents of the sediments, particularly on the sequence surfaces, elemental concentration to equate to the earth process to bring out the sedimentary depositional system.
The systematic surface and subsurface lithology units, geochemical elements are provides the high resolution sequence stratigraphy model. The geochemical results are corroboration with geological, paleontological, and geophysical data is the complete practical sequence deposition model for the use in hydrocarbon exploration. This method of geochemical characterization of Campanian-Maastrichtian sediments of Cauvery Basin is a useful record for further hydrocarbon exploration activities.

1.4 REVIEW OF RESEARCH LITERATURE AND DEVELOPMENT IN THE SUBJECT OF GEOCHEMICAL-SEQUENCE STRATIGRAPHY

1.4.1 International Research Records

Sloss (1963) reported the concept of globally synchronous unconformities created by eustatic lowering of sea-level and the preservation of those unconformities across a continent. The development of sequence stratigraphy has been provided by the main protagonist. The publication of AAPG memoir 26 in 1977 marks a milestone in the evolution of sequence stratigraphy. Since then, this science is growing in universal acceptance as the most powerful tool of sedimentary basin analysis (Mitchum et al 1977, Vail et al 1977, Van Wagoner et al 1988, Van Wagoner 1995, Emery and Myers 1995 and Milton and Bertram 1995).

Vail (1977) refined the Sloss concept and developed a technique to identify the strata in virgin basins where only a seismic line was available. The publication of a memoir by the Exxon group in 1977 revealed the practical utility of the concepts for basin studies, regional and global correlation (Payton 1977). Over a period of decades in the 1960s and 1970s, Vail and his coworkers studied seismic reflection data, methods and interpretation of results published in AAPG Memoir 26.
Subsequently, Payton (1977) has contributed a pioneer work on seismic stratigraphy and its applications in hydrocarbon exploration (AAPG Memoir 26, Publ. AAPG, USA, 502p). Vail et al (1977) and Mitchum et al (1977) work on seismic stratigraphy and global changes of sea-level are of noteworthy references.

Vail et al (1981) have reported on the bounding unconformities of the depositional sequences and interpreted that the unconformities are produced by rapid falls in sea-level. Van Wagoner et al (1990) worked on sequence biostratigraphy in Cretaceous rocks of Book Cliffs, Colorado. Pomerol (1983) suggest that the major oxide, Mn and carbon isotope events are useful records in paleooceanographic reconstructions.

Hilbrecht and Hoefs (1986) discussed the foraminifera diversity and the occurrences of macrofossils. A shift to higher $\delta^{18}$O values coincident with the $\delta^{13}$C excursion is possibly a response to cooling of ocean water for which evidence is provided by a low diversity globular planktonic assemblage. The correlation of $\delta^{18}$O and foraminifera diversity is suggested to provide a tool for bathymetric interpretations of sections.

King et al (1987, 1989, 1990, and 1991) have contributed to the identification and correlation of depositional facies, eustatic history of the Jurassic and Upper Cretaceous of Central and Eastern Alabama on the basis of outcrop observations, well-log analysis and laboratory studies. King and Skotnicki (1992, 1994) have published on the relationship of facies stratigraphy and stratigraphy breaks to relative sea-level changes, and proposed depositional sequence stratigraphy of the Gulf coastal plain of Eastern and Central Alabama. They also correlated the depositional model from the study area with the global patterns of relative sea-level change.

Wiener (1989) dealt with a record of relative sea-level changes from Cretaceous of western interior, USA. The paper is discussed on identification of the regression of shoreline, depositing wide spread shallow marine sandstone and deposits that fill incised drainage, reflecting the sea-level and landward movement of the shoreline associated with coastal on lap.

The landmark publications on sea-level changes are an integrated approach by Wilgus et al (1988). Sarg (1988) has provide the detail insight to the carbonate sequence stratigraphy. Van Wagoner et al 1990 worked on siliciclastic sequence stratigraphy in well logs, cores and outcrops. Concepts for high resolution correlation of time and facies aspects were contributed by Van Wagoner et al (1990)

Haq (1991) publication on sequence stratigraphy, sea-level change and significance for deep sea is the significant reference. Vail et al (1991) updated the basic concepts of sequence stratigraphy in different settings in the paper the stratigraphy signatures of tectonics, eustasy and sedimentation. Haq et al (1992), infer the application of sequence stratigraphic concepts in a high sediment influx area-prodelta setting of Cenomanian.

Weimer and Posamentier (1993) established the relation between the eustatic curve and tectonic origin. The new sequence stratigraphy has the unique vitalizing force propelling researches in post-Pangaea stratigraphy, sedimentation and sedimentary tectonics.
Creaney and Passey (1993) recorded the principal controls on organic carbon accumulations. The maximum TOC in a vertical profile through a marine sequence probably correlates to the maximum flooding surface. TOC decreases above this surface due to increasing sediment dilution during highstand progradation and decreases below it with the higher sedimentation rate of the older transgressive systems tracts. Commensurate with TOC increase towards the maximum flooding surface, the organic matter type becomes more marine and increasingly oil prone.

Sequence stratigraphy of carbonate shelf with an example from mid Cretaceous of southeastern France reference by Hunt and Tucker (1993) discussed the carbonate shelf models and forced regression. Donovan (1993) established the lithostratigraphic, chronostratigraphic and biostratigraphic relationships within sequences in a paper on the use of sequence stratigraphy to gain new insights into stratigraphic relationship in Upper Cretaceous.


Aitken and Howell (1996) proposed high resolution sequence stratigraphy, its innovations, applications and future prospects in a special publication published by Geological Society of London and explain that the re-examination of sedimentary basins with a sequence stratigraphy approach is the vital role in resource evaluation.

Bohacs et al (1997) studied the distribution and characters of coal seams in a paralic environment under a sequence framework and pointed out that accommodation changes predictably throughout a depositional sequence, the distribution of coals may be predicted within a sequence stratigraphic framework. They inferred that the thickest, isolated coals occur in upper low
stand and basal transgressive systems tracts; the most continuous coal seams are found in middle lowstand and middle highstand system tracts; and minimal, very isolated coal seams are found in basal lowstand, middle transgressive, and upper highstand systems tracts. Thickest coal typically corresponds to the best conditions for organic preservation, and would commonly enhanced petroleum potential.

Mann and Stein (1997) studied the organic facies types and their source rock potential within a sequence stratigraphic framework. According to the organic-geochemical and microscopic analyses, they distinguished four organic facies types in Cretaceous black shale of the Quebrada Ocal, Upper Magdalena valley, Colombia. Different organic facies types are located in different positions of a sequence and have specific geochemical features.

In the past, sequence stratigraphy focused mainly on reservoir prediction and was less concern about the occurrence and geochemical characteristics of hydrocarbons accumulated in reservoirs. Geochemical sequence stratigraphy study is used to identify the possible hydrocarbon reservoir strata, by using source related geochemical parameters.

Peter et al (2000) recorded the four groups of source rocks within a sequence stratigraphy as; highstand systems tract coastal plain coals, lowstand systems tract coaly shale, transgressive systems tract source rocks according to their position in a sequence and their geochemical characters, recognized the importance of lowstand kitchens as the key contributors to deep water hydrocarbons in the offshore Mahakam Delta area, and the extending hydrocarbon discoveries also proved their geochemical sequence stratigraphic model.

Peter (2000) discussed the use of geochemistry to identify the source rock potential within a sequence stratigraphy framework and to
describe the characteristics of hydrocarbons accumulated in reservoirs, which were predicted by way of sequence stratigraphy.

Jarvis et al (2001) has published the event record on the Cenomanian- Turonian pelagic and hemipelagic carbonate succession of hydrothermal activity during the rapid sea floor spreading and oceanic plateau formation.

Meijun et al (2008) introduced their facies associations, organic geochemical features and geochemical-sequence stratigraphy focuses on the occurrence, distribution and characters of source rocks and reservoir hydrocarbons.

1.4.2 National Research Records

Banerjji (1966) carried out quantitative study of commonly occurring foraminifer species, used for interpretation of depositional characteristics of the sediment during lower Ariyalur times. His contributions during 1968, 1972 and 1973 reconstructed the paleoenvironment of the basin during the Late Cretaceous times in Pondicherry area using the foraminifer biostratigraphy.

Raju and Ravindran (1990) identified the sea-level cycles for the Upper Cretaceous of Cauvery Basin. Ramasamy and Banerji (1991) discussed the geology, petrography and systematic stratigraphy of the pre-Ariyalur sequence in Tiruchirapalli district. Rangaraju et al (1993) proposed that the Cauvery Basin is one of the pericratonic rift basins on the East coast of India. It came into existence as a consequence of dismemberment of Gondwana land.

Rangaraju et al (1993) published record on tectonostratigraphy, structural style, evolutionary model and hydrocarbon prospects of the Cauvery and Palar Basins. Raju et al (1994) proposed that the foraminifer data suggests that the oldest marine sediments are of Aptian and the sedimentation continued in the Cauvery Basin to the recent times, the paper infers that the basin interrupted by at least four major hiatuses.

Tewari et al (1996) proposed a revised a lithostratigraphy classification of the Cretaceous rocks of the Trichinopoly area, where they divided the Cretaceous rocks of the area into three Groups, seven formations and seventeen members.

Madhavaraju and Ramasamy (1999a) published a record on the upper Cretaceous geochemistry of Kallankurichchi Formation of the Ariyalur area. The paper discussed the rare earth element geochemistry of Ce positive anomalies and the trace element U- shows the sediments deposited under the oxic condition.

In India, Reddy et al (2000) were the first scientists who made an attempt to understand the application of sequence stratigraphy in oil industry and published record on sequence biostratigraphy -A case study from GS-15 structure, Krishna-Godavari offshore. Hart and Watkinson (2000) made a contribution on the occurrence of larger foraminifera from the upper


Nagendra et al (2002) identified the sequence stratigraphic surfaces based on field characters, foraminifer assemblages and microfacies data. They inferred the sequence boundary, drowning unconformity and TST in the Kallakudi quarry-II section and proposed the Dalmiapuram sequence with in sequence stratigraphy frame work. Nagendra et al (2003) published a paper on petrophysical characterization of Sillakkudi sandstone.

Ramkumar (2004) studied the Upper Cretaceous–Lower Tertiary deposits of the Cauvery Basin, which are shows the prominent geochemical and isotopic anomalies across the K/T boundary. The paper discusses the stratigraphic variations of whole rock elemental concentrations and stable isotopic compositions in revealing of sedimentation history. The petrography and mineralogy of the rocks revealed that these anomalies may be due to increased detrital influx caused by sea-level and climatic changes, Deccan volcanism and release of volatile gases from buried hydrocarbons, presumably gas hydrates.
Watkinson et al (2007) is proposed the Cretaceous exposed onshore, which have been interpreted as Albian reefs, are interpreted as irregularly shaped limestone olistoliths/olistostromes produced by intra-Cretaceous rifting and slumping within the Cauvery Basin.


Madhavaraju et al (2010) proposed the lower Cretaceous geochemistry of Dalmiapuram Formation of the Uttatur area. The depletions of trace elements and the rare earth element of Eu and Ce anomalies are shows the presence of plagioclase feldspar. The Dalmiapuram sediments are deposited in mixing, sea water end member and the reducing condition.


However, the detailed national and international literature review reveals that the research gap on geochemical characterization of sediments and its application in sequence stratigraphy of Cretaceous sections, Cauvery Basin, south India. The review of literature and for need based research is promoted this Ph.D thesis work and addressed the geochemical elemental characterization of Campanian-Maastrichtian sediments of Cauvery Basin. The geochemistry of siliclastics, carbonates and shale sediments, is in integration with the biostratigraphy, petrography and TOC, are used to decipher the sequence surfaces to establish the sediment depositional architecture during Late Cretaceous. This integrated study of Mesozoic sedimentary basin in India is the useful research records for practical studies in Cauvery Basin for hydrocarbon exploration.
1.5 SIGNIFICANCE OF THE STUDY

Geochemical-sequence stratigraphy provides;

1) The precise and predictive scientific data to recognize the key stratal surfaces, sequence boundaries, flooding surfaces, Maximum flooding surface, changes between progradation, transgressive surface, condensed horizons, erosion surfaces, change in the provenance and paleoslope.

2) Geochemical elemental correlation and chemical zonation.

3) This method is much significant in identification of origin, depositional system and organic maturation.

4) A tool for reservoir facies analysis.

1.6 OBJECTIVES

• To integrate the outcrop and subcrop sediment geochemistry of Campanian-Maastrichtian sediments of Cauvery Basin (Major elements; Si, Al, Na, Ca, Mg, Mn, P, Fe and Ti, Trace elements; Sc, Y, Co, Cr, Ni, Cu, Sr, Ba, Nb, Zr, Zn, V and Li and REE; La, Ce, Nd, Sm, Eu, Dy, Yb) to record classification, tectonic events, provenance history, paleoweathering and hydraulic sorting of Campanian- Maastrichtian sediments.

• To recognize the Transgressive-Regressive event records, (sequence surfaces) using geochemical records of Campanian-Maastrichtian sediments of Cauvery Basin.
1.7 STUDY AREA

The geochemical-sequence stratigraphy studies are carried out both in outcrop and subcrop Campanian-Maastrichtian sediments of Ariyalur Pondicherry sub-basin, Cauvery Basin, South India. The good outcrop exposures in Ariyalur district near Trichinopoly and subcrop well SS-1, SS-2 and SS-3 sedimentary section of Ariyalur–Pondicherry sub-basin sediments were selected for geochemical-sequence stratigraphy studies.

The Campanian-Maastrichtian sediments, Ariyalur Group of rocks are well exposed in Ariyalur district, TamilNadu, South India. The Ariyalur Group of sediments is exposed and covers in 200 sq.km area. The litho sections are studied in cement factories; India cement, TAIN, TANCEM, Dalmia cement, Birla cement, Chettinad cement etc situated in Kallankurichchi, Periyanagulr, Velliperinjium, Reddipalayam, Chokkanathapuram, Srinivasapuram and adjoining areas. The chief lithological units of Ariyalur Group are represented by four formations viz, Sillakkudi, Kallankurichchi, Ottakkovil and Kallamedu. The sandstone and calcareous sandstone with fossil assemblages is the chief rock type in the Campanian outcrops belongs to Sillakkudi Formation. The Kallankurichchi Formation represents by biostromal limestone, ferruginous limestone and arenaceous limestone of Maastrichtian age (Figure 1.1). The fresh sediment samples were used for major, trace, REE studies and isotope analysis. The biostratigraphy frame work of Ariyalur Group was used for integration with geochemistry to decipher the sequence depositional surfaces.
1.8 GEOLOGY OF THE STUDY AREA

The Cretaceous system of Cauvery Basin consists of shallow marine sequence with a rich faunal succession of Albian–Maastrichtian. Three main areas of exposure are represented on the coastal plain of TamilNadu; in the Ariyalur, Virdhachalam and Pondicherry districts. Of these, the Ariyalur area affords the best and complete representation of the Cretaceous litho succession, and has been the focus of the study (Figure 1.2).
1.8.1 Geology of Cauvery Basin

Cauvery Basin is located in the southeastern part of India and is a structurally elongated marginal basin located between 08°30’ and 12°30’ N and 78°30’ and 80°30’E. It has an area extent of 25,000 sq.km. Onshore and equivalent area in the offshore waters of Bay of Bengal (up to 200m isobaths). It is bordered towards west by steep, down to basin faults, which delineates the outcrops of igneous and metamorphic rocks of Peninsular India shield. Towards the east, the basin extends into the offshore area. The Precambrian igneous and metamorphic rocks forming the Ceylon massif mark the southern boundary. The basin forms a half-graben morphology trending NE-SW. It has a regional dip of 5°-10° towards east and southeast due to the continental rifting of India, Antarctica and Australia in the Late Jurassic and/or even Permian. It is essentially a part of a group of Mesozoic extensional basins formed all along the eastern continental margin of peninsular India, and
therefore it has been classified as pericratonic basin (Sastri et al 1981, Biswas et al 1993). The sedimentary successions onshore exceed 5500m in thickness with stratigraphic record from Barremian (135 Ma) to Recent.

1.8.2 **Tectonic History and Evolution of Cauvery Basin**

The Cretaceous–Paleogene sections of Cauvery Basin are closely related to the rifting and drifting phases of peninsular India. The basement is characterized by structural highs and lows, these being evidenced by strong tectonic activity affecting the basin since its inception. Two major tectonic and sedimentary phases are deciphered. The first is taphrogenic rifting and associated block movements along the dominant NE-SW trend during Late Jurassic, resulting in morphotectonic humps and deep slopes. The second phase signifies coastal progradational/deltaic sedimentation through a series of marine transgression and regression in response to the oscillatory tectonic movements. During Paleocene, the basin continued to tilt towards east and depocentres consequently shifted.

Cauvery Basin comprises of depressions separated from one another by subsurface ridges; these structural elements extend into the offshore area. The structural elements from north-south are, (1) Ariyalur-Pondicherry depression, (2)Kumbakonam–Madnam-Shiyali ridge (3) Tanjore-Tranquibar–Nagapattinam depression (4) Pattukottai–Mannargudi ridge (5) Ramnad–Palk Bay depression (6) Mandapam–Delft ridge.

The first marine transgression occurred during the close of Late Jurassic. The marine environments of sedimentation continued till Cretaceous although a series of minor transgressions and regressions. A major regression occurred during the close of Cretaceous. The basin underwent an easterly tilt and the depocentres shifted due east prior to marine transgression during the beginning of Paleogene.
The evolution of Cauvery Basin is largely controlled by dominant trends in the Precambrian crystalline basement as is evident from the similarity between the alignment of the basinal structural elements and the major trends in the adjoining peninsular shield. The NE-SW Eastern Ghats trends are by far the most dominant and taphrogenic movements along these basement trends resulted in a series of elongated depressions that were separated from one another by intra-depression ridges (Figure 1.3).

![Tectonic map of Cauvery Basin](image)

**Figure 1.3** Tectonic map of Cauvery Basin with the locations of subsurface sections, SS-1, SS-2 and SS-3 and outcrop exposures in Ariyalur-Pondicherry sub-basin (after Govindan et al 1998)
1.8.3 Lithostratigraphic Classification

Blanford (1862) has classified the Cretaceous sediments of Cauvery Basin into: Uttatur plant beds, Uttatur and Trichinopoly Groups. Krishnan (1943) classified the Cretaceous sections into four stages: Uttatur (Cenomanian to Uppermost Albian), Trichinopoly (Mid-Cenomanian to Mid-Turonian), Ariyalur (Maastrichtian to Mid-Cenomanian) and Niniyur (Danian to Maastrichtian). Ramanathan (1968) has divided the Upper Jurassic to Cretaceous sections of Cauvery Basin into three formations: Upper Gondwana (Bathonian to Neocomian), Uttatur (Barremian to Albian) and Trichinopoly (Turonian to Upper Cenomanian). Nair (1974) introduced two

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groups for the Cretaceous sections: Ariyalur for Maastrichtian age and Uttatur for the rest part of the Cretaceous age. Sundaram and Rao (1976) proposed three groups for Cretaceous of Cauvery Basin: Uttatur, Trichinopoly and Ariyalur. Govindan (1998) complied the outcrop and subcrop sediments are proposed the sediments classification (Table 1.1).

1.8.4 Cretaceous Outcrop Exposures

Ariyalur-Pondicherry sub-basin depression is located in the northern part of the Cauvery Basin. This is a linear feature, aligned NE-SW and extends into the offshore. It is delineated to the west by Archean granites and gneisses, in the south by subsurface Kumbakonam–Shiyali ridge and on the east lays the offshore area. Thick Cretaceous outcrops, near the western fringe of the Ariyalur–Pondicherry depression occur discontinuously.

1.9 CAMPANIAN SEDIMENTARY SECTION; SILLAKKUDI FORMATION

The outcrops of Sillakkudi Formation are well exposed in Mettol (11°04'54.9"N:79°02'3.1"E), Nochikkulam (11°07'55.8"N:79°03'01"E), Vayalpadi (11°20'2.5"N:79°07'9.1"E). The Vayalpadi sandstone exposure of Sillakkudi Formation is a quartz arenites with calcareous cement and clay. Glauconitic pellets are known to occur in Nochikkulam sandstone of Sillakkudi Formation. The Sillakkudi sandstone sequence becomes fluvial and is topped by conglomerate bed. The Kilpalvur grain stone which is considered to be the base of Sillakkudi sandstone is resting over Archaean basement in open well sections are facies variants of Sillakkudi sandstone.
1.10 MAASTRICHTIAN SEDIMENTARY SECTION;
KALLANKURICHCHI FORMATION

Kallankurichchi Formation follows the Sillakkudi Formation unconformably. At a stream section, near Kaller (11°08.246′N and 79°06.965′E) pebbly grain stone with abundant sub-angular to angular, pink to white quartz and feldspar pebbles to cobbles is exposed. The presence of Kaller conglomerate between the Sillakkudi and Kallankurichchi Formations indicates a break in the deposition in the Mid-Campanian. The Kaller conglomerate unit is non-calcareous indicating a sub-aerial depositional regime.

The Kallankurichchi Formation consists of dominantly marine carbonates. It begins with beach conglomerates and ends with increased amounts of quartz sands into the marine environment from the shore. The presence of 0.5 m thick cobble conglomerate at 40 m depth from the surface of the mine resting on the Sillakkudi Formation indicates a break in the sedimentation.

The ferruginous limestone forms the lowermost unit of the Kallankurichchi Formation, which are directly overlying the Kaller conglomerate bed (5 m thickness). The 2.5 m thick lower arenaceous limestone directly overlies the ferruginous limestone. It is yellowish, massive, highly compacted and rich in silica content. The limestone has yielded macrofossils represented by *Gryphaea, Alectryonia, Exogyra, and Inoceramus*.

The Gryphaea limestones overlying the lower arenaceous limestone are rich in *Gryphaea, Alectryonia* and *Exogyra* fossils, which are well preserved in the exposed section. It is reddish brown in colour, fine to medium grained and rich in lime content. The upper arenaceous limestone litho unit directly overlies Gryphaea limestone. It is poor in both macro- and
microfossils and is rich in terrigenous input. The Kallankurichchi Formation is rich in *Gryphaea*, *Bryozoa*, *Gastropods* and *Exogyra* macrofossils. The Ottakkovil sandstone of Kallamedu sandstone exhibits burrowed structures with macrofossils indicating the termination of a shallow marine high energy environment. The cross lamination structures in sandstone of the Kallamedu sandstone is indication of fluvial channel deposits, and mark the Cretaceous termination in Ariyalur area.

1.11 LITHO AND BIOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT OF THE CAMPANIAN-MAASTRICHTIAN SEDIMENTARY SECTION OF STUDY AREA

Ariyalur Group of sediments of Campanian to Maastrichtian age (83.5-65.0 Ma) represents the upper Cretaceous in the geological time scale. Ariyalur Group consists of Sillakkudi and Kallankurichchi Formations.

The Sillakkudi Formation of Campanian age consists of Kilpalvur grain stone which is a facies variant of Sillakkudi sandstone. A major unconformity exists between Garudamangalam Formation and Sillakkudi Formation. The formation has the larger areal extent than other formation. The Sillakkudi Formation outcrops are well exposed in Ariyalur area. This formation is characterized by medium to coarse, off-white to grey, green glauconitic, calcareous friable and hard calcareous sandstones. The beds are layered parallel and commonly burrowed in many beds with scattered molluscans shells. Inoceramus shells are preserved along railway cutting section and occurrences of *nautilus, echinoids, rhynchonellids, pentacrinus* and *ammonites* etc. The distributions of fauna are diversified in these horizons. The occurrence of *Globotruncana arca* foraminifera suggests a Campanian age (Tewari et al 1996). Rasheed and Ravindran (1978) have reported a rich foraminiferal assemblage from subsurface section of
Sillakkudi Formation. The Sillakkudi Formation contains ammonites assigned to the *Karapadites karapadense* zone by Sastry et al (1968), which is of Campanian age (Henderson, 1970). Fossiliferous sections of calcareous ocherous silts, argillaceous limestone and hard sandy limestone is intercalated (Banerji, 1973). The Vayalpadi sandstone exposure of Sillakkudi Formation is dominantly quartz arenites with calcareous cement. The sedimentological parameters are attribute that these rock types are mineralogical, texturally immature and poorly sorted. The occurrence of poorly marked sandstones indicates their deposition below wave base. The Vayalpadi sandstone exposure of Sillakkudi Formation is a quartz arenites with calcareous cement and 15% clay, which supports an environment nearer the wave base. The presence of glauconite pellets in Nocchikkulam sandstone of Sillakkudi Formation indicates that they were formed under a transgressive episode in moderate water depth. Abundance of plagioclase especially, acid plagioclase of Sillakkudi railway cutting and Vayalapadi indicates rapid deposition from a nearby granitic provenance. Since the sandstone was formed below wave base, the pore spaces are filled with clay and the porosities are uniformly poor. The presence of angular to sub angular grains point towards short distance transport from a nearby provenance. Therefore, it is infers that the Sillakkudi Formation were deposited in inner shelf conditions below wave base forming part of transgressive episode (Nagendra et al 2003). The presence of glauconite pellets in sandstones attribute that they are formed under a transgressive episode in moderate water depth (Emery, 1996).

A open well section at Kilpalvur consists of bioclastic oolitic grainstone facies of Sillakkudi sandstone which is light brown, moderately compact, broken prisms of *Inoceramus* alternate with oolitic framework; other fauna are echinoid fragments, rare bivalves and foraminifera, wherein the oolites consists of 90 % allochems rest with *Inoceramid* debris (Govindan et al, 1998). Sporadic quartzose pebbles are reported by Sundaram et al 2001.
Upper and lower contacts of the formation are conformable except in the south where the Kilpalvur member onlaps basement (Sundaram et al 2000). The calcareous facies of the Kilpalvur member was developed under conditions of local transgression and represents a littoral to shallow sub-tidal assemblage (Sundaram et al 2000). The depositional environment could be agitated high energy transgressive tidal bars or grain stone shoals. This member rests over the Archaean basement and exposed are exposed in open well sections.

The Sillakkudi Formation is followed unconformably by Kallankurichchi Formation. At a stream section, near Kaller (11°08.246’N and 79°06.965’E), orange yellow, pebbly grain stone (Kallankurichchi limestone) with abundant subangular to angular, pink to white quartz and feldspar pebbles to cobbles, some to which are 10 cm in diameter is exposed. This lithologic unit is named as Kaller conglomerate.

Stratigraphically Kallankurichchi Formation is overlain by Ottakovil sandstone and Kallamedu sandstone underlain by Sillakudi Formation. There is a well marked unconformity that separates Kallankurichchi from the older Sillakkudi Formation. Lithologically these rudist bivalve carbonates are white, orange, yellow, and massive to thick bedded couplets of biostromal limestone/marl mainly of bioclastic packstone, grainstone facies with bryozoa, rudist bivalves, Terebratula, echinoids and larger foraminifera like, *Lepidorbitoids* and *Orbitoids*. Faunal distribution is not uniform as 80–90 % bioclasts at mine sections comprises larger foraminifera with reduced bryozoa and rudist bivalves.

Kaller conglomerate beds range from 1-2 m thickness comprises abundant pink to white quartz, feldspars, pebbles and cobbles of 10 cm diameter across, together with yellowish brown pebbly grain stone fabric
separates the Kallankurichchi Formation from the older Sillakkudi Formation. The Kaller conglomerate beds are overlain by ferrugenous limestone (5 m thick), which are yellowish orange in colour, fine to medium grain size and fossiliferous zone, rich in ferrous content and massive in structure. The lithotypes are biomicritic form and overlies conglomerate and underlain by arenaceous limestone. The ferruginous limestone are overlain by lower arenaceous limestone which are massive, rich in silica, highly compacted and pale yellowish in colour. It has a varied thickness with low lime content. The lower arenaceous limestone is overlain by Gryphaea limestone. It is rich in well preserved Gryphaea, Alectryonia and Exogyra megafossils. The Gryphaea limestone is overlain by upper arenaceous limestone having a thickness of 1.6 m and is well exposed in mine section. This limestone has more terrigenous input and low fossil content.

The ferruginous limestone samples have Quinqueloculina sp., Gavelinella plummerae, Gavelinella danica, Gavelinella sp., Cibicides sp., Gavelinopsis bembix, Gavelinopsis sp., Alabamina dorsoplan a, and Gyroidinoides sp. These species are benthic in nature and their tests are highly ferrugenised. The abundance of the above mentioned benthic foraminifera indicates a rise in sea-level during formation of these sediments. Bivalves are poorly preserved and highly ferrugenised foraminifer test infers the oxidation environment. The lower arenaceous limestone has benthic foraminifers like Textularia sp., Cibicides harperi, Cibicides sp., Gavelinella plummerae, Gavelinella sp., Gavelinopsis bembix, Praestorrsella sp., Lingulogavelinella sp., Osangularia sp., which gives evidence of rise in sea-level accompanied by occurrence of brachiopods like Lingula sp., and bryozoans like Onchycellids, Rectoporina kulmurensis, and bivalves like Inoceramus, Alectryonia and Gryphaea. The Gryphaea limestone has benthic foraminifer like Gavelinella plummerae, Gavelinopsis bembix, Textularia sp., Gyroidinoides sp., Saracenaria sp., Cibicides sp., Gavelinopsis sp..
Figure 1.4 Vertical litho section, macro and micro fauna of Kallankurichchi Formation
Lingulogavelinella sp., and Osangularia sp., which indicative of rise in sea-level during the depositional period. This bed occurs as condensed section having massive quantity of Gryphaea, Alectryonia and Lopha molluscans shell. The foraminifer occurrences in this formation infer that Kallankurichchi Formation has been formed during Maastrichtian age.