

Discrimination of tectonic dynamism, quiescence and third order relative sea level cycles of the Cauvery Basin, South India

MUTHUVAIRAVASAMY RAMKUMAR¹

Abstract. Application of integrated stratigraphic modeling of sedimentary basins with the help of sequence and chemostratigraphic methods for improved understanding on the relative roles of depositional pattern and history of a Barremian-Danian stratigraphic record of the Cauvery Basin, India was attempted. Through enumeration of facies characteristics, tectonic structures and geochemical characteristics of the sedimentary rocks the use of geochemical signatures in distinguishing the relative roles of major factors has been evaluated. The results indicate that the geochemical signatures of the sedimentary rocks accurately record the prevalent geological processes and an ability to distinguish them through employing stratigraphic variations of compositional values and discrimination diagrams help in understanding the basinal history better. In addition, predomination of relative sea level fluctuations and active nature of tectonic movements during few time slices, which in turn was overwhelmed by sea level fluctuations are also inferred.

Key Words: Barremian-Danian relative sea level, tectonic events, source area weathering, tectonic setting, Cauvery Basin, India.

Апстракт: У раду је покушана примена интегрисаних стратиграфских модела на седиментне басене уз помоћ секвенционих хемотратиграфских метода у циљу бољег разумевања одговарајућих улога депозиционих образаца и историје баремско-данског стратиграфског записа у Кувери басену. Путем класификације фацијалних карактеристика, тектонских структура и геохемијских особина седиментних стена извршена је процена употребе геохемијских показатеља за разликовање одговарајућих улога које су имали главни фактори. Резултати указују да геохемијска својства седиментних стена прецизно одражавају главне геолошке процесе као и да могућност њиховог препознавања путем употребе стратиграфских варијација композиционих вредности и дијаграма разврставања помаже бољем разумевању историје басена. Поред тога, разматране су и значајне промене нивоа мора као и тектонски покрети који су били активни током дужег временског периода а што је за последицу имало колебање нивоа мора.

Кључне речи: Баремско-дански релативни ниво мора, тектонски догађаји, површинско распадање у зони порекла материјала, тектонски услови, Каувери басен, Индија.

Introduction

The theory of sequence development defines the sedimentation system under the control of four major variables, namely, tectonic subsidence, eustatic sea level change, volume of sediment influx and climate (SARG 1988). The relative sea level cycles, first published by VAIL *et al.* (1977), revised by HAQ *et al.* (1987) espoused that the sedimentary sequences are produced principally under the influence of sea level cycles that vary between few tens of millions of years (1st order cycle) to few million years (3rd order cycle).

Successive studies have shown that distinct sedimentary sequences could be traced to sea level cycles up to infra seventh order (NELSON *et al.* 1985; WILLIAMS *et al.* 1988; CARTER *et al.* 1991). VAIL *et al.* (1977) stated that the sea level chart published by them is incomplete and cycles of varying order could be added, so that, more complete chart could be established. The aim behind this statement is to incorporate sea level cycles at Milankovitch scale, to which the response of the sedimentation system is proved beyond doubt (CARTER *et al.* 1991). RUBEN *et al.* (2012), HAQ (2014) and RUBAN (2015) have present-

¹ Department of Geology, Periyar University, Salem - 636011. India. E-mail: muramkumar@yahoo.co.in

* Present Address: South East Asia Carbonate Research Laboratory (SeaCarL), Universiti Teknologi Petronas, Tronoh, Malaysia.

ed the updates based on the progress made in this field of research so far.

HAYS *et al.* (1976) have convincingly demonstrated that climatic records were dominated by frequencies characteristic of variations in the Earth's tilt, precession and eccentricity relative to the Sun. In the years since, numerous studies have upheld the validity of the Milankovitch climatic cycles in terms of 100, 41, 23 Ka orbital periods that influence or control variations in global ice volume, thermohaline circulation, continental aridity and run off, sea surface temperature, deep ocean carbonate preservation and atmospheric CO₂ and methane concentrations (RAYMO *et al.* 1997; GALE *et al.* 2002, 2008; GALEOTTI *et al.* 2009). While examining the compiled data on the sediment volumes (mass) or sediment fluxes of the continental and marine subsystems to determine the complete routing in terms of mass conservation for specific time periods since Cenozoic, HINDERER (2012) reported that the response times of the large sedimentary systems are within the Milankovitch band. HILGEN *et al.* (2014) opined that despite fragmentary sedimentation, stratigraphic continuity as revealed by cyclostratigraphy unequivocally established the dominant role of depositional processes at the Milankovitch scale.

Global chemostratigraphic signals such as those carried by organic matter (MIDDLEBERG *et al.* 1991; PASLEY *et al.* 1993; MEYERS & SIMONEIT 1989; TU *et al.* 1999; CALVER 2000) oxygen isotope (ANDERSON *et al.* 1996; VEIZER *et al.* 1999) and strontium isotope (VEIZER 1985; VEIZER *et al.* 1999; MUTTERLOSE *et al.* 2014) and their relationships with sea level changes, and in turn, the climatic fluctuations are well known. The global carbon cycle varies on a million year time scale affecting the isotopic and chemical composition of the global carbon (WALLMANN 2001). The glacial intervals coincide with shifts in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. For the carbon isotope record, rate of burial of C_{Org} and thereby changes in atmospheric CO₂ and for the oxygen isotopic records, temperature and ice volume effects on the seawater reservoirs and thereby sea level changes may be linked (KAMPSCHULTE *et al.* 2001).

Spectral analysis of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ shows that their significant variances are concentrated at 100, 43, 23 and 19 Ka spans (OPPO *et al.* 1990; OPPO & FAIRBANKS 1989). While examining $\delta^{18}\text{O}$ of Phanerozoic seawater, VEIZER *et al.* (1997) observed high frequency cycles within first order cycle. STRAUSS (1997) recorded fourth order cycles of sulphur isotope that stack up to form 3rd order cycle fluctuations that in turn accommodated within 2nd order cycles. GOLDHAMMER *et al.* (1991) showed that the sequences of Paradox Basin exhibited a hierarchical stacking pattern of 5th order (80 Ka duration) shallowing upward cycles grouping into 4th order (400 Ka duration) cycles, which in turn stacked vertically into part of a 3rd order cycle. Large number of studies has docu-

mented the occurrences of high frequency sea level changes within major sea level cycles (for example, GIL *et al.* 2006; KULPECZ *et al.* 2009; ELRICK & SCOTT 2010; PELLENARD *et al.* 2014; ULIČNÝ *et al.* 2014). These abilities of sequence and chemostratigraphy helped successfully reinterpret the basinal history, and establish regional and global stratigraphic correlation and are being widely applied for petroleum exploration, inter-well correlation and reservoir characterization, etc. (RAMKUMAR *et al.* 2010, 2011). On the contrary, there are many studies that have questioned the veracity of the sequence stratigraphic concepts (MIALL 1991; 2009), especially the third order cycles (for example, CLOETING 1988; MIALL 1991; HISCOTT 2001; SPALLETTI *et al.* 2001; STEPHENS & SUMNER 2003) and the precision of the cycle durations and the applicability of such cycles on a global scale (MIALL & MIALL 2001).

Nevertheless, there are reports that have documented the occurrences of sedimentary records typical of high-frequency cycles deposited under the primary control of tectonics (for example, BHATTACHARYA & WILLIS 2001; VAKARELOV *et al.* 2006) though doubts have been raised over the rate at which the tectonic movements can mimic high-frequency cycles (GOLDHAMMER *et al.* 1987; MASETTI *et al.* 1991). Influence of regional-global plate movements over third order cycles has also been reported by BACHMANN *et al.* (2003) and VEIGA & SPALLETTI (2007). In an innovative study, VAN DER MEER *et al.* (2014) recently demonstrated the control exercised by tectonics over atmospheric CO₂ through a complex and intrinsically coupled chain of processes and thereby over climate–continental weathering and sea level fluctuations, and ensuing sedimentary records. HISCOTT (2001), SPALLETTI *et al.* (2001), BACHMANN *et al.* (2003) and BRETT *et al.* (2004) opined that it is a common phenomenon of sedimentary records to have sea level cycles affected by local tectonics either positively or negatively. Depending on the local, regional and global scale of processes, these cyclic changes may get preserved in the ensuing sedimentary strata, the temporal scale of which may vary from few thousand years to few or few tens of millions of years – a postulate widely utilized in sequence and chemostratigraphy.

Thus, the enigma of relative roles of tectonics–sea level fluctuations over depositional pattern remains to be there where it had all started when VAIL *et al.* (1977) proposed the sequence stratigraphic concepts. It has also raised questions on the very fundamentals of sequence and chemostratigraphic applications. At this juncture, it becomes essential to address the problem of discrimination relative influences of tectonics and relative sea level fluctuations over sedimentary records.

The Cauvery Basin (Fig. 1) is located in the southern part of Indian peninsula. It contains a near complete stratigraphic record of Barremian–Danian. It is

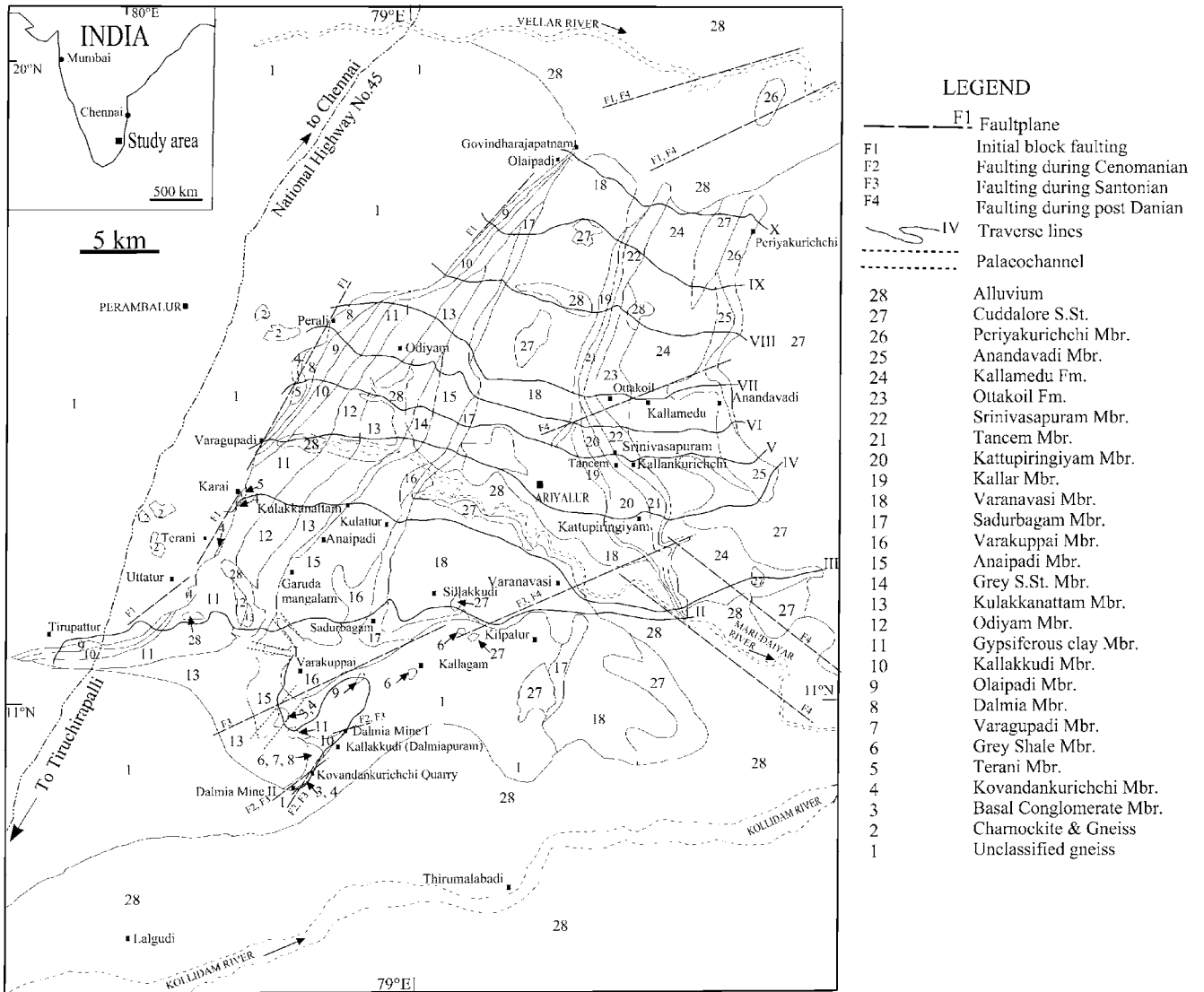


Fig. 1. Location and Geology of the study area (After RAMKUMAR *et al.* 2004a).

one of the most studied basins (ACHARYYA & LAHIRI 1991). In a first ever basin-scale temporally long range chemostratigraphic study, RAMKUMAR *et al.* (2011) recognized six major chemozones, separated by type 1 sequence boundaries and other correlative surfaces coeval with third order cycles of sea level, which in turn contained high frequency cycles, probably in the order of 10^4 – 10^6 years and found to be consistent with the timescale-sea level curve of GRADSTEIN *et al.* (2004). Though there are disagreements on the connectedness of Indian subcontinent with other continental plates during Barremian to Danian, (ALI & AITCHISON 2008), the enclosed nature of Indian subcontinent by sea and its behavior as an Island akin to the present day Australia was not questioned. As the climatic conditions of Island continents are predominantly controlled by the temperature of surrounding seawater and the Cretaceous Period had experienced extended greenhouse effect (VEIZER *et al.* 2000; BICE

& NORRIS 2002; COCCIONI & GALEOTTI 2003; HERRLE *et al.* 2003; NAJARRO *et al.* 2010), changes in seawater temperature would have affected the glaciers to retreat or advance, causing high-frequency sea level oscillations that in turn might have influenced the depositional system of the Cauvery Basin.

As the provenance area of the Cauvery basin sediments were confined to adjacently located horsts and hinterland (RAMKUMAR *et al.* 2004a, 2006) the sea level changes and the tectonic events might have been exacerbated (VEIGA & SPALLETI, 2007) and reflected in the sedimentary records. The basin fill shows textural immaturity all through its sedimentary history. In addition, high-frequency sea level cycles during Barremian–Santonian and Late Cretaceous–Danian, overlap of much older lithostratigraphic units by younger units and angular unconformity surfaces characterize the basin fill and indicate the involvement of certain amount of tectonism (VEIGA *et al.* 2005) over deposi-

Table 1. Lithostratigraphy of the exposed part of the Cauvery Basin (*after* RAMKUMAR *et al.* 2004a).

Age	Formation	Member	Thickness (m)	
Mio- Pliocene	Cuddalore S.St. Fm.		>150	
	----- Unconformity -----			
Danian	Niniyur Fm	Periyakurichchi biostromal Mbr	26	
		Anandavadi arenaceous Mbr	30	
Maastrichtian	----- Unconformity -----			
	Ariyalur Group	Kallamedu Fm.		100
		----- Unconformity -----		
	Ottakoil Fm.		40	
	----- Unconformity -----			
	Kallankurichchi Fm.	Srinivasapuram grypcean L.St. Mbr.		18
Tancem biostromal Mbr.			8	
Kattupiringiyam inoceramus L.St. Mbr.			8	
Kallar arenaceous Mbr.			6	
----- Unconformity -----				
Campanian	Sillakkudi Fm.	Varanavasi S.St. Mbr.	270	
Santonian		Sadurbagam pebbly S.St. Mbr.	80	
Coniacian	Garudamangalam Fm.	Varakuppai lithoclastic conglomerate Mbr.	45	
		----- Unconformity -----		
Turonian	Kara Fm.	Anaipadi S.St. Mbr.	215	
		Grey S.St. Mbr.	35	
Cenomanian	Dalmiapuram Fm.	Kulakkanattam S.St. Mbr.	123	
		----- Unconformity -----		
Albian	Sivaganga Fm.	Karai Fm.	175	
		Odiyam Sandy clay Mbr.	275	
Aptian	Sivaganga Fm.	Gypsiferous clay Mbr.		
		----- Unconformity -----		
Barremian	Sivaganga Fm.	Kallakkudi Calcareous S.St. Mbr.	60	
		Dalmiapuram Fm.	65	
Barremian	Sivaganga Fm.	Olaipadi conglomerate Mbr.	15	
		Dalmiya biohermal L.St. Mbr.	23	
Barremian	Sivaganga Fm.	Varagupadi biostromal L.St. Mbr.	7	
		Grey shale Mbr.		
----- Unconformity -----				
Barremian	Sivaganga Fm.	Terani clay Mbr.	30	
		Kovandankurichchi S.St. Mbr.	24	
Barremian	Sivaganga Fm.	Basal Conglomerate Mbr.	18	
		----- Unconformity -----		
Basement Rocks (Granitic gneiss, charnockite, pegmatite, etc.)				

tional history and creation of accommodation space. By these traits, the Cauvery Basin offers a test site to discriminate relative influences of tectonics and sea level fluctuations. As the stratigraphic record is the outcome of an exogenic system consisting of geological setting, changes in sea level, changes in geochemical reactions between the sea and earth and climate (SRINIVASAN 1989) and as the sedimentary geochemistry is a faithful recorder of provenance, tectonic setting and palaeoclimatic conditions prevalent (BHATIA 1983; BHATIA & CROOK 1986; ROSER & KORSCH 1986; TAYLOR & MCLENNAN 1985; MONGELLI *et al.* 1996; CINGOLANI *et al.* 2003), this paper attempts

understanding the dynamics of provenance, tectonic setting and sea level fluctuations of the Cauvery Basin and to discriminate them through geochemistry.

Thus, the objectives of this paper are set to examine **a)** hierarchical variations of geochemical signatures (*sensu* RAMKUMAR, 2015) in tune with prominent controls of sequence-chemostratigraphic cycles, **b)** ability of geochemical signatures to distinguish the relative significances of various depositional agents, provenance and tectonic setting, etc. and **c)** utility of application of integrated chemo-sequence stratigraphic modeling for characterizing basin fill on a long-short term cycles.

Geological setting

Among the NE–SW trending Late Jurassic–Early Cretaceous pericratonic rift basins created all along east coast of the Indian peninsular shield (SASTRI *et al.* 1981; POWELL *et al.* 1988; CHARI *et al.* 1995; JAFAR 1996; CHATTERJEE *et al.* 2013), in response to the fragmentation of Gondwana super continent and rifting of Africa–India–Antarctica (LAL *et al.* 2009), the Cauvery Basin (Fig. 1) is located at the southern part of the Indian peninsula. The basin continued evolving till the end of Tertiary through rift, pull-apart, shelf sag and tilt phases (PRABAKAR & ZUTSHI, 1993). It lies between the latitudes 08°30'N and the longitudes 78°30'E and covers an exposed area of about 25,000 km² onland and 17,500 km² in the offshore (SASTRI *et al.* 1981) of the Bay of Bengal upto 200 m isobath. It is a structurally elongated basin with NE–SW trending half-graben morphology and a regional dip of 5–10° E and SE directions.

This basin is well differentiated into sub-basins and horsts (ACHARYA & LAHIRI, 1991; CHANDRA, 1991; PRABHAKAR & ZULCHI, 1993; Chari *et al.* 1995) namely, Ariyalur - Pondicherry sub-basin, Tanjore - Tranquebar - Nagapattinam sub-basin, Ramnad - Palk Bay sub-basin, Pattukottai - Mannargudi - Karaikal ridge, Kumbakonam - Mandanam ridge, and Mandapam - Delft ridge. The evolutionary (SASTRI *et al.* 1981; PRABHAKAR & ZUTCHI, 1993; CHARI *et al.* 1995; LAL *et al.* 2009), stratigraphic (RAMANATHAN, 1968; BANERJI, 1972; SUNDARAM & RAO, 1986, TEWARI *et al.* 1996; SUNDARAM *et al.* 2001; RAMKUMAR *et al.* 2004a, 2005a), palaeontologic (CHIPLONKAR, 1987; GOVINDHAN *et al.* 1996; BHATIA, 1984; JAFAR & RAI, 1989; KALE & PHANSALKAR, 1992; KALE *et al.* 2000; GUHA, 1987; GUHA & SENTHILNATHAN, 1990, 1996; RAMKUMAR & CHANDRASEKARAN, 1996; RAMKUMAR *et al.* 2010a; RAI *et al.* 2012), and geochemical (RAMKUMAR, 2007; RAMKUMAR *et al.* 2004b, 2005b, 2006, 2010b, 2010c, 2011) characteristics of this basin are well-documented. The sedimentary succession of this basin exceeds 5500 m in thickness (GOVINDAN *et al.* 2000). Lithofacies associations and fossil data indicate periodic sediment-starved nature and basin filling process of depositional pattern (AYYASAMY, 1990). Based on the facies characteristics, comprehensive lithostratigraphy of the onland part this basin was presented by TEWARI *et al.* (1996) and was modified by SUNDARAM *et al.* (2001) and later a systematic revision was made by RAMKUMAR *et al.* (2004a) following standard stratigraphic procedures and terminologies. The lithostratigraphic sub-divisions (Table 1; Fig. 1) are separated by sequence boundaries and other correlative surfaces (RAMKUMAR *et al.* 2011) and are geochemically distinct to the tune of 100% from each other (RAMKUMAR *et al.* 2010b). A brief description on facies characteristics of the Barremian–Danian sedimentary sequence is presented in the table 2.

Materials and methods

Systematic field mapping in the scale of 1:50,000 was conducted through ten traverses (Fig. 1) in which 308 locations were logged and sampled. At each location and along the traverses, information on lithofacies, contact relationships, sedimentary and tectonic structures and occurrences of mega and ichnofossil assemblages were recorded. For characterizing the strata for sequence analysis, the conceptual standard workflow of CATUNEANU (2006) and CATUNEANU *et al.* (2009, 2010, 2011) were followed. It included definition of type sections, recognition of sequence stratigraphic surfaces (among the seven types of surfaces), defining them into sequence boundaries, and relating them with any of the four events of the base-level cycle, and then with any of the three systems tracts (forced regression, normal regression and transgression) based on the outcrop, facies and other relevant criteria. The sequence model so developed was presented earlier (RAMKUMAR *et al.* 2004a).

Based on the field data, a composite stratigraphic profile of Barremian–Danian strata was constructed that allowed selection of 157 rock samples for analyzing trace elemental composition. From these 157 samples, 70 samples were further selected and analyzed by XRF for major elemental composition following the procedures discussed in KRAMAR (1997) and STÜBEN *et al.* (2002). Stable isotopic analyses were performed as per the procedures presented in KELLER *et al.* (2004). Analyses of 157 samples for petrography and whole-rock mineralogy, 70 samples for clay mineralogy were also performed. The geochemical data were interpreted with stratigraphic variation, plotting in established discrimination diagrams (for example, ROSER & KORSCH, 1986) and computation of weathering indices (NESBITT & YOUNG, 1982), and corroboration with major geological events. Collation of all these information along with the published data allowed elucidation of the prevalent changes in provenance, tectonic setting, and fluctuations in relative sea level with which, the relative influences of various processes were interpreted and discussed.

Results

Tectonic events

All along its western margin, basin margin faults are recognizable (Fig. 1) which separate the Archaean shield from the sedimentary deposits. Based on the field structural criteria, contact relationships, and lithological association and displacement, basin scale tectonic movements and their relative timings were interpreted viz., initial block faulting (F1 in Fig. 1), movement of fault blocks during Albian–Cenomanian boundary interval (F2 in Fig. 1), reactivation of older fault blocks and creation of new fault during Santonian (F3 in Fig. 1) and reactivation of fault blocks during post Danian–pre

Table 2. Lithofacies characteristics of the Barremian-Danian strata of the Cauvery Basin.

Formation	Member	Facies characteristics
Niniyur	Periyakurichchi	Thick arenaceous bioclastic limestone bed followed by medium to thick, parallel, even bedded recurrent biostromal limestone and marl typify this member. Regionally varying concentrations of shell fragments and whole shells of bivalve, gastropod and remains of amphibia, pisces, algae, foraminifera and ostracoda are also observed.
	Anandavadi	Isolated coral mounds, impure arenaceous limestone and lenses of sandstone and clay, deposited in a restricted marine regime under subtidal to intertidal regions. Occurrence of localized concentrations of shell fragments, coralline limestone and reef derived talus deposits are characteristics of this member. This member rests over the Kallamedu Formation with distinct unconformity. At top, an erosional surface is recognizable
Kallamedu		Unconsolidated, well rounded and poorly sorted barren sands with rare-scarce dinosaurian bone fragments. Towards top, these grade to medium to thin bedded, relatively highly argillaceous sandstones. Local occurrence of clays and silts with dispersed detrital quartz grains and sandy streaks, non-bedded nature, rare lamination and mud cracks in them indicate sedimentation as over bank deposits. Towards top, this formation has paleosol indicating return of continental conditions.
Ottakoil		The rocks are coarse to medium sized, well-sorted, fossiliferous, low angle cross-bedded and planar to massive bedded sandstones with regionally varying sparse calcareous cement. They also show recurrent fining upward sequences. Abundant <i>Stigmatophygus elatus</i> and few trace fossils indicative of shallow marine environment of deposition. This formation rests over Kallankurichchi Formation with unconformity and overlapped by Kallamedu Formation.
Kallankurichchi	Srinivasapuram	Uniform, parallel, thick-very thick-bedded grypcean shell banks with <i>Terebratulata</i> , <i>Exogyra</i> , bryozoa and sponge. Extensive boring in grypcean shells, syndepositional cementation, colonies of encrusting bryozoa over grypcean shells and micritization of bioclasts deposition of this member in inner shelf.
	Tancem	Biostromal limestone beds with thin to thick, parallel, even bedded nature, cross bedding, normal grading, hummocky cross stratification, feeding traces, escape structures and tidal channel structures. Local concentrations of various fossils, sporadic admixture of siliciclastics and intraclasts.
	Kattupiringiyam	Dusty brown friable carbonate sands with parallel, even and thick to very thick bedding that contains only <i>Inoceramus</i> and bryozoa. This member has diagenetic bedding and abundant geopetal structures filled with mm to cm sized dog tooth spars of low magnesian non-ferroan calcite. This member has non-depositional surface at bottom and has erosional surface at top.
	Kallar	Normal graded conglomerates in which well-rounded clasts of basement rocks, fresh feldspar, resedimented colonies of serpulids and other older sedimentary rocks that range in size from coarse sand to boulder are observed. Lower contact of this member is an erosional surface. The upper contact is non-depositional surface resulted from marine flooding.
Sillakkudi	Varanavasi	Featureless, massive, thick to very thick bedded, coarse to medium grained sandstones. Occasional very coarse sandstone lenses, pockets of shell hash, intraformational lithoclastic bounders in association with vertical cylindrical burrows and resedimented petrified wood logs are observed. The rocks rest over the pebbly sandstone member with non-depositional surface Upper surface of this member represents erosional surface associated with regression.

Table 2. continued.

Formation	Member	Facies characteristics
Sillakkudi	Sadurbagam	Coarse siliciclastics with abundant marine fauna, shell fragments and varying proportions of calcareous matrix. At the base, an erosional surface followed by distinct cobble-pebble quartzite conglomerate is observed. The rocks show normal grading, low angle cross bedding, massive, thick to medium, even and parallel bedding. At places, pockets of shell rich carbonate lenses with abundant siliciclastic admixture are found to occur. Load casts, slump folds, pillow structures and syneresis cracks, occasional development of algal mounds are also found.
	Varakuppai	It rests over older sedimentary rocks with typical erosional surface. The erosional intensity was such high that, the beds have direct contact with much older Karai Formation. Fluvial sandstones with well-rounded basement rocks, quartzite and older sedimentary rock boulders in addition to unsorted coarse sand-pebble sized siliciclastics constitute this member. These are typically reverse graded and show cyclic bedding, large scale cross bedding and lack any body fossils. Large scale cross bedding, mud drapes, fresh feldspar and sandstone clasts are also recorded. Towards top, <i>thalassinoid</i> burrows are reported, that indicate gradual submergence of the depocentre by rising sealevel.
Garuda mangalam	Anaipadi	Massive and thin-bedded claystones, silty claystones and clayey sandstones in south that gradually grade to silty clay in south center and thin down. Again, from there, thickness of these beds and sediment grain size increase and contain abundant large ammonites. Further north, these were observed to be clayey siltstones with abundant shell fragments and ammonites.
	Grey sandstone	Highly well cemented, sorted and rounded grains giving massive appearance. The beds are cyclic, parallel, even bedded alternative layers of barren and highly fossiliferous and sandy layers with regionally varying thicknesses. This member rests conformably over the Kulakkanattam member and has distinct erosional and non-depositional surface. Upper contact is non-depositional surface associated with marine flooding.
	Kulakkanattam	Massive, yellowish brown ferruginous sandstones with abundant admixture of silt and clay. Localized concentrations of shell fragments, bivalves and gastropods and ammonites are common. It also contains abundant wood fragments with extensive oyster boring. Cross bedding, channel courses, planar bedding and feeding traces are also common. The depositional surface was strongly bioturbated and riddled by roots. An angular erosional unconformity separates this member from underlying Karai Formation.
Karai	Odiyam sandy clay	Silty clays and sandy clays with abundant ammonites. Load structures and syndepositional slump folds are frequently observed. Upper portion of this member has localized pockets of fine sandstone along with ammonites. While the lower contact is conformable with underlying member, upper contact is erosional.
	Gypsiferous clay	Unconsolidated deep marine clays and silty clays. These beds contain thick population of belemnite rostrum and phosphate nodules. While a non-depositional unconformity surface separates this member from the underlying member, upper contact is non-depositional and erosional. From south to north, gradual reduction of thickness, population of belemnite and phosphate nodules and frequency of gypsum layers are observed. Repetitive occurrences of 1–3 cm thick red and green colored clay layers that can be traced for many kilometers are ubiquitous.

Table 2. continued.

Formation	Member	Facies characteristics
Dalmiapuram	Kallakkudi	Fine-coarse sandstones with alternate medium to thick beds of silty clay, calcareous siltstones, bioclastic arenaceous limestone and gypsiferous clay. In the southern region, these beds show recurrent bands of fining upward sequences of siliciclastics with calcareous cements. The intercalations are recurrent and show typical Bouma sequences, normal grading, load casts and channel and scour structures. Towards northern regions, this member grades to more silty and clayey, but gradation and gypsiferous bands are persistent with an addition of ferruginous silty clay bands.
	Olaipadi	Basinal silty clays and clays in which chaotic blocks are embedded. The beds contain large blocks of angular and subrounded basement rocks, coralline limestone blocks, claystones (lithoclasts of carbonates and greenish claystones typical of Karai Fm.) and lithoclasts of older conglomerates, etc. Towards the top, deep marine clays grade into calcareous siltstone and include granitic cobbles and minor amounts of siliciclastic sands.
	Dalmia	Pure algal and coral facies limestone beds that form reef core. Upper contact of this member is a forced regression surface.
	Varagupadi	Limestone beds typical of reef flank biostromal beds deposited under high-energy conditions. Thin to thick bedded, even to parallel, bioclastic limestone beds that have drawn their detritus from reefs predominate. These beds are found to be directly overlying the Grey shale member. The rocks show wackestone to rudstone fabric and have clasts of redeposited boundstones.
	Grey shale	Grey shale beds with frequent thickening upward interbeds of fossiliferous grey limestone and minor to significant admixture of silt sized siliciclastics. Lower contact of this member is an unconformity surface associated with marine flooding and the upper contact is non-depositional and erosional.
Sivaganga	Terani Clay	White to brownish colored clay and argillaceous siltstone that show transition from Kovandankurichchi member. Beds are massive to very thick in nature. Lower contact of this member is non-depositional surface.
	Kovandankurichchi	Grain supported coarsening upward cyclic beds (20-100cm thick each) of very coarse sandstones that show parallel, even and thin to thick bedding. Grains are well sorted within each lamina and show rounded-well rounded shape. These represent recurrent sheet flow deposits probably in a sub-aqueous fan deltaic environment.
	Basal conglomerate	Recurrent fining upward sequences of lithoclastic conglomerates of fluvial and coastal marine environments. Lithoclasts are of gneissic basement rocks. Rests over basement rocks with distinct erosional surface. Upper contact is a non-depositional surface.

Quaternary (F4 in Fig. 1). It is to be stated that, in addition to these major fault movements, there were minor and local scale tectonic movements, namely across Aptian–Albian boundary interval, during Cenomanian (during the deposition of Olaipadi member), and during Santonian (during the deposition of Varakuppai member) all of which were confined only to adjustment of fault blocks along the preexisted fault planes. There exists a difference in trends of post Danian fault movements (F4 in Fig.1) that have affected the Miocene to Pliocene sandstones, Danian Limestones, and Maas-

trichtian deposits by folding, fracturing and faulting (RAMKUMAR 2007). Enumeration of tectonic structures and depositional history of the Cauvery Basin indicated that after initial block faulting and inception of sedimentation during Late Jurassic–Early Cretaceous, intensity of tectonic control over sedimentation was diminutive (PRABAKAR & ZUTCHI 1993; RAMKUMAR 1996; RAMKUMAR *et al.* 2005a). WATKINSON *et al.* (2007) recognized three major tectonic stages and resultant stratigraphic groups for this basin; viz., syn-rift Gondwana Group (Early Cretaceous), syn-rift Uttatur Group (Al-

bian–Coniacian) and post-rift Ariyalur Group (Santonian–Maastrichtian) and are in conformity with the present observations.

Relative sea level fluctuations

Sedimentation in this basin took place in an epicontinental sea and the bathymetry was at shallow – modest levels (<50 m – as indicated by the linear curve in Fig. 2) although variations from supratidal to basinal levels were inferred. Based on the foraminifer data, RAJU & RAVINDRAN (1990) and RAJU *et al.* (1993) documented six 3rd order cycles of glacio-eustatic origin. RAMKUMAR *et al.* (2004a) constructed a sea level curve for this basin based on bathymetric trends of lithofacies data, which is similar to the curves presented by RAJU *et al.* (1993) except that it additionally recorded fourth and higher order sea level cycles (Fig.

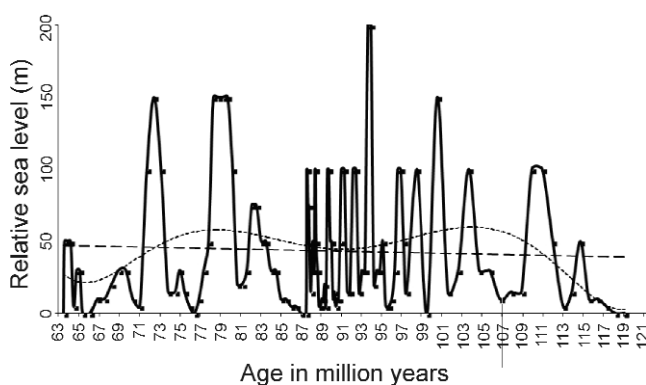


Fig. 2. Relative sea level fluctuations during Barremian–Danian in the Cauvery basin (after RAMKUMAR *et al.* 2004a). Solid line curve is indicative of absolute values of RSL; — linear trend; polynomial trend.

2). The global sea level peaks during 104 Ma (Early–Late Albian), 93.7 Ma (± 0.9 ; Middle to Late Cenomanian), 92.5 Ma (± 1 ; Early to middle Turonian), 86.9 Ma (± 0.5 ; Early to Late Coniacian), 85.5 Ma (± 1 ; Early to Late Santonian), 73 Ma (± 1 ; Late Campanian), 69.4 Ma (Early to Late Maastrichtian) and 63 Ma (± 0.5 ; Early to middle Danian) were observed to occur in this basin (RAJU & RAVINDRAN, 1990; RAJU *et al.* 1993; RAMKUMAR *et al.* 2004a). The 3rd order cycles are separated by type I sequence boundaries (recognized through shift of shoreline crossing shelf break as explicit in lithologic information, contact relationship between strata, evidences of subaerial exposure and erosion, advancement of fluvial channels over former offshore regions, etc.). The period from Barremian to Coniacian shows frequent occurrence of sea level lows and highs that may be interpreted as prevalent high frequency/higher order cycles. The period from Coniacian to Danian shows sea level rise and fall punctuated with lesser frequency of higher

order cycles. The sea level rise during Santonian–Early Campanian shows steadily increasing pattern.

Geochemical characteristics

Geochemical elemental data having predominant affiliation with detrital (Si, Ti, Zr), biogenic (Ca), and tectonic processes (Y) and computed values of plagioclase alteration index (PIA) as climatic indicator were plotted in stratigraphic profiles (Fig. 3). These profiles depict the occurrences of inverse relationships between detrital elements and biogenic element, six major enrichment-depletion cycles coeval with 3rd order sea level cycles within which many high-frequency enrichment-depletion cycles, significant change of the pattern across Santonian, sudden positive excursions of Y during Cenomanian and Santonian, and a major positive excursion of PIA during Turonian–Coniacian.

Plotting few selected oxides percentages against Al_2O_3 shows sympathetic nature of SiO_2 , TiO_2 , and K_2O , strongly anti-sympathetic nature of CaO , slightly positive yet scattered nature of MgO and Na_2O (Fig. 4). The plot of Al_2O_3 against CaO shows an interesting phenomenon of distinctly recognizable twin clusters. Other plots also show feebly recognizable but scattered twin clusters. Textural discrimination of the samples based on oxides percentages shows that most of the samples fall in the texturally immature fields viz., litharenite, wacke, arkose, subarkose, and only very few in the quartz arenite field (Fig. 5). Plotting the $\text{SiO}_2\text{--Al}_2\text{O}_3\text{*}5\text{--CaO}\text{*}2$ in ternary diagrams that have average shale, smectite, illite, kaolinite fields and enrichment indicators of detrital (significant sediment influx), biogenic (warm climate, sea level high), and clay (significant weathering in the provenance) fields show that all the samples fall either near siliciclastic or biogenic fields (Fig. 6). Ternary plot of CN–A–K also shows that most of the samples fall below the feldspar join and only a few fall above the join (Fig. 7). Plot of the data in tectonic setting discriminant diagram (SiO_2 Vs $\text{K}_2\text{O}/\text{Na}_2\text{O}$) shows that the samples fall in the Arc, active continental margin and passive continental margin (Fig. 8) fields. The tectonic discrimination diagrams of SiO_2 Vs $\text{K}_2\text{O}/\text{Na}_2\text{O}$ and $\text{SiO}_2/\text{Al}_2\text{O}_3$ Vs $\text{Na}_2\text{O}/\text{K}_2\text{O}$ show interesting phenomenon of plot of Barremian–Santonian samples in the active continental margin field, Campanian–Danian samples except few samples of Kallamedu Formation (Late Maastrichtian) in passive continental margin field and few samples of Kallamedu and Ottakoil formations in the island arc field (Fig. 8).

Discussion

Geological events and Depositional cycles of the Cauvery Basin

All along the western margin of the exposed area of the basin, the Precambrian basement rocks show the

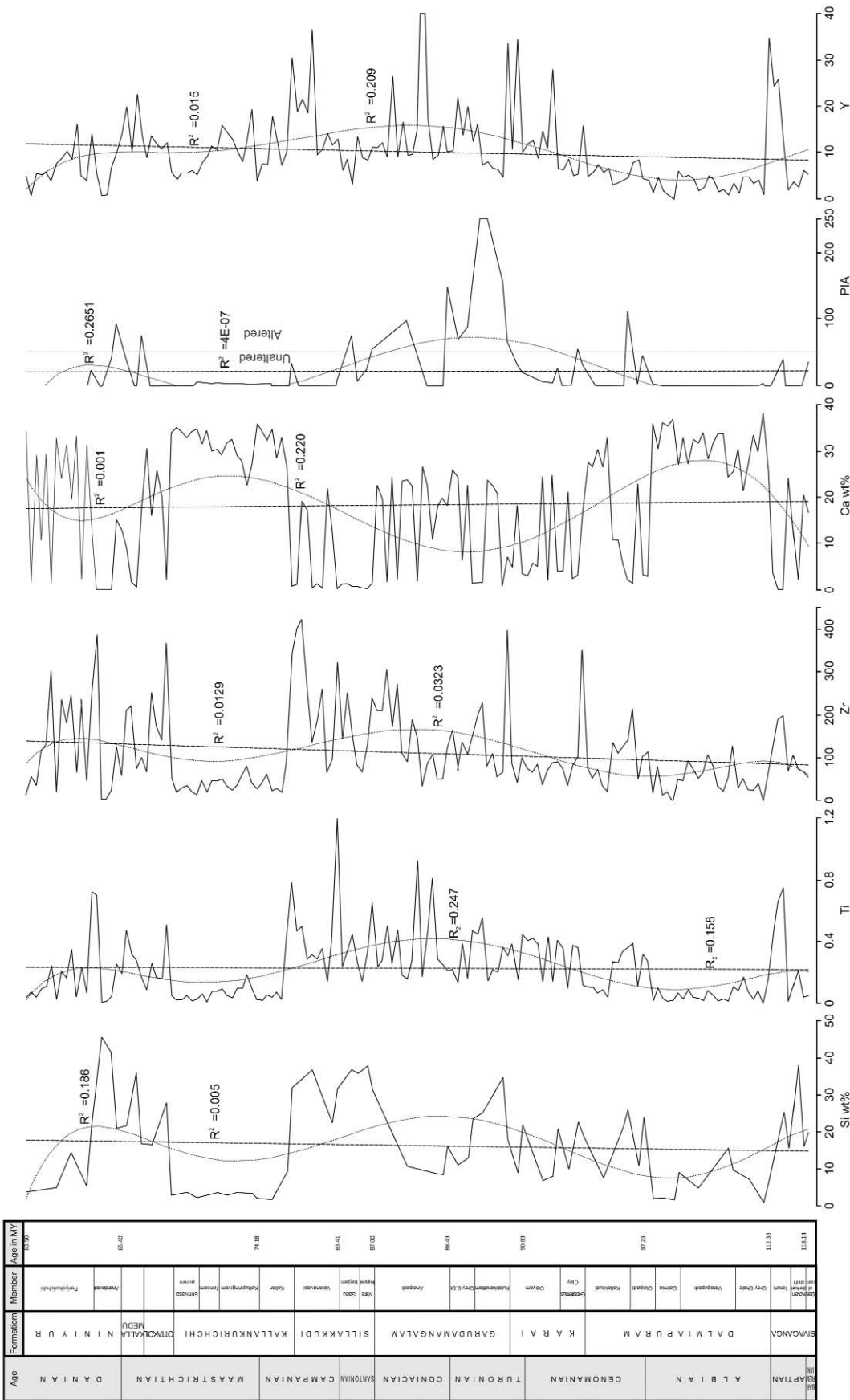


Fig. 3. Stratigraphic variations of selected elemental and alteration index values. The Si, Zr, Ti, and Ca are expressed in weight percentages, the Y is expressed in ppm and the PIA is expressed in index value.

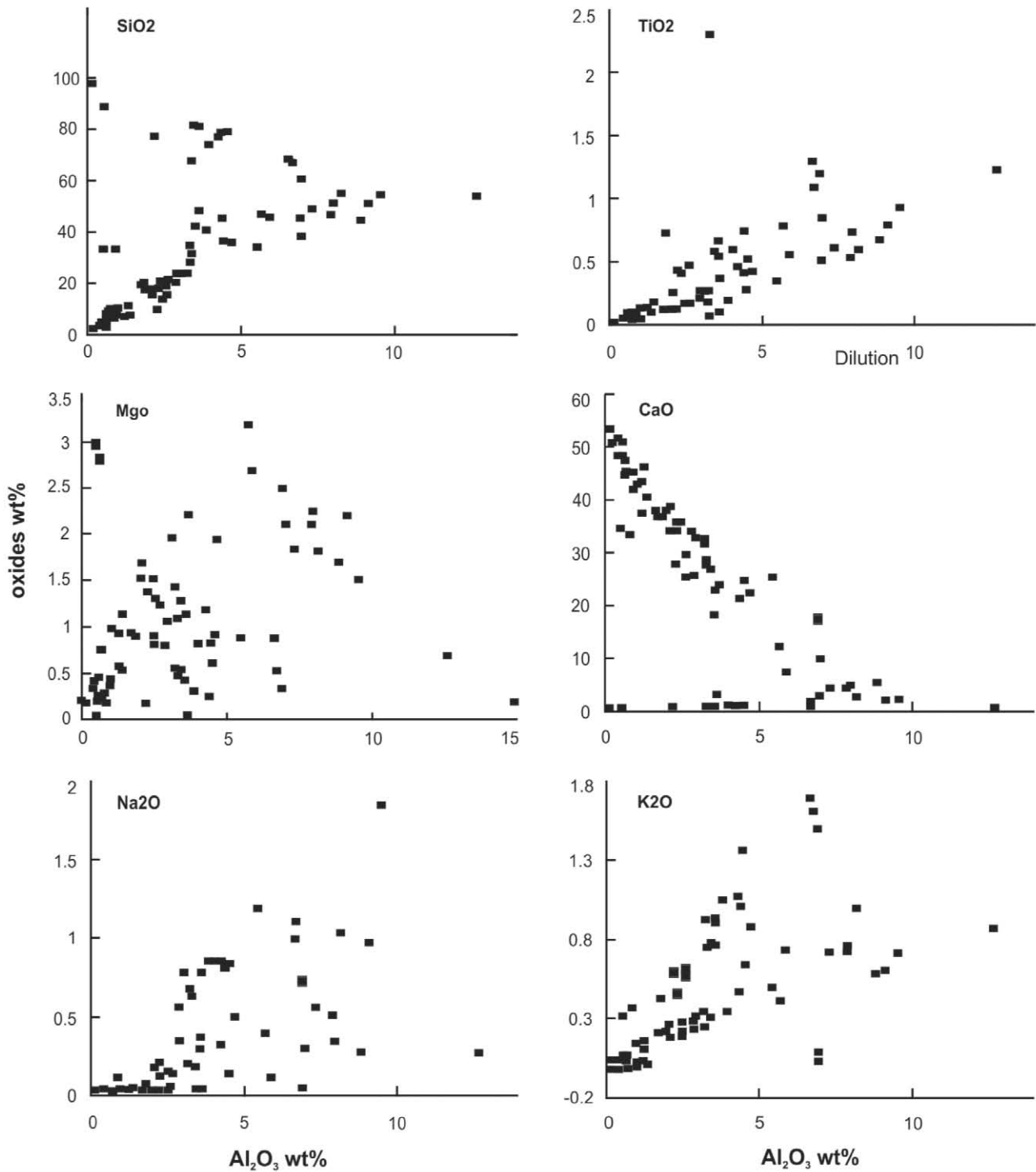


Fig. 4. Bivariate diagrams showing relationships among elemental oxides. Note the uniform dispersal pattern among detrital elemental oxides, distinct clustering of CaO and scattered yet recognizable similar clustering among other oxides. All these may be indicative of the existence of either siliciclastic or carbonate dominated depositional system at a given time period and climate-sea level fluctuation controlled nature of the depositional pattern.

occurrences of fault lines aligned NE–SW (F1 in Fig. 1; Plate 1.1) that mark the initial block faulting, perhaps during Barremian. This faulting had resulted in transgression and commencement of sedimentation of

the Sivaganga Formation. The basement rocks located at west of the basin margin were severely eroded and transported to the depocenter before inheriting alteration and maturity and thus fresh, angular to sub-

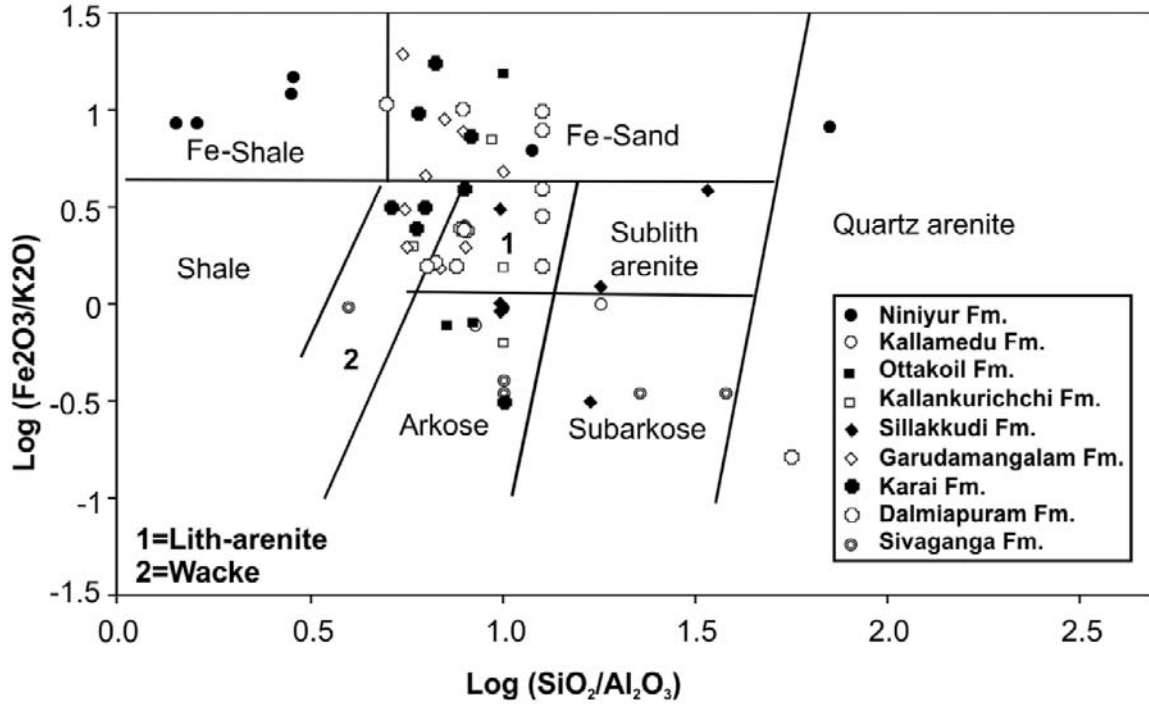


Fig. 5. Discriminant diagram showing textural maturity of the rocks studied. Note that most of the samples fall in the fields of litharenite, wacke, arkose and subarkose suggestive of predominance of mechanical weathering, and subdued nature of chemical weathering. Among these also, litharenite dominates, suggestive of recurrent erosion of basement as well as former marine regions and recycling of sediments. It also suggests sediment starved nature of the basin.

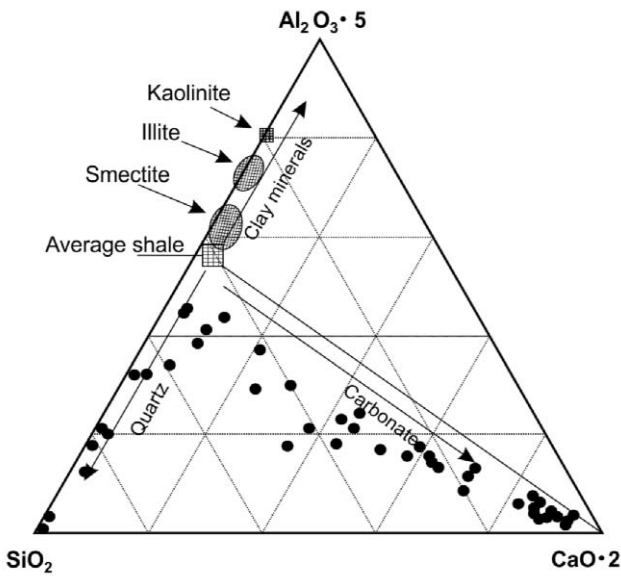


Fig. 6. Discriminant diagram showing the absence of any significant weathering as all the samples fall far below the average shale discriminant line. In addition, the diagram shows a grouping of the samples studied either with siliciclastic or carbonate dominated nature, suggestive of the predominance of relative sea level fluctuation controlled nature of the depositional cycles/pattern.

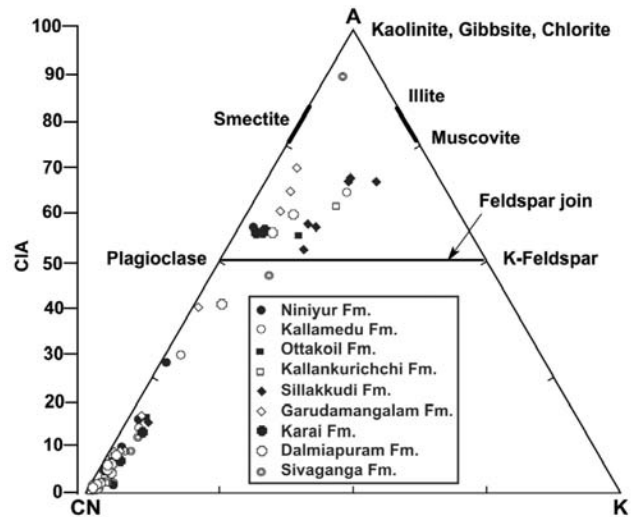


Fig. 7. Discriminant diagram of CN-A-K showing the subdued nature of chemical weathering. Note that most of the samples fall below the feldspar join. Few samples of the Dalmiapuram Formation, Karai Formation, Garudamangalam Formation, the Sillakkudi Formation are found above this join, indicative of episodes of chemical weathering too.

angular basement rock boulder-cobble sized clasts and feldspar pebbles typify this formation (Plate 1.2).

As the intensity of energy conditions reduced, sediment grain size also got reduced. Significant sedimentation commenced with the establishment of fluvial

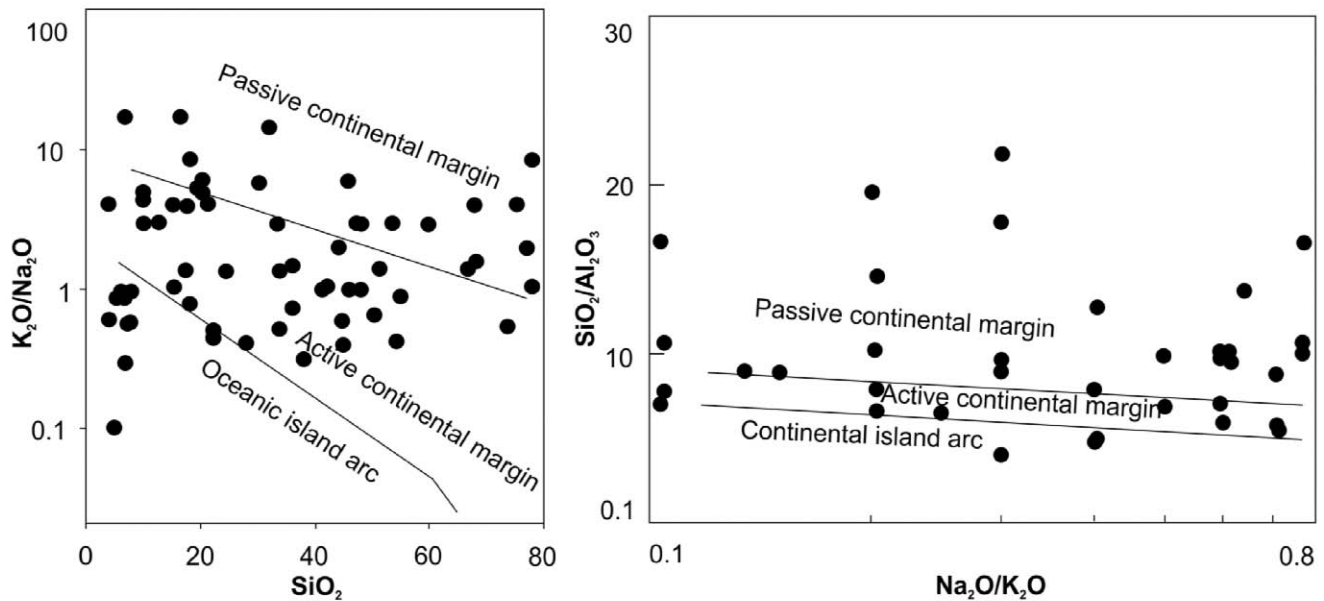


Fig. 8. Discriminant showing tectonic setting of the samples studied. Most of the samples in the Active continental margin field are of Barremian–Santonian while most of the samples in the Passive continental margin field are of Campanian–Danian and the samples found in the Oceanic island arc are from the late Maastrichtian, particularly from the Kallamedu and Ottakoil Formations.

source onland and submarine fan delta in the basin (represented by the Kovandankurichchi sandstone member). Gradation of this sandstone member into deep marine claystone-siltstone member (Terani member) indicates prevalence of stabilized environmental conditions until the end of deposition of the Terani member. It was brought to an end due to renewed faulting introducing an angular unconformity associated with erosion and redeposition of older sedimentary rocks.

The rejuvenated sedimentation was through deposition of shale and shale-limestone alternate beds of the Grey shale member of the Dalmiapuram Formation. The depocenter was partially and periodically closed, while grey shale was deposited. Whenever open conditions of sea circulation were prevalent, bioclastic limestone beds were deposited. These limestone interbeds show thickening upward character indicating increase in durations of openness of the sea that culminated in the development of biostromal member over the Grey shale member. The biostromal member contains principally coral clasts and algal fragments with varying proportions of bioclasts of bryozoa, bivalvia and gastropoda in addition to reef dwelling microfauna. Siliciclastic admixture is significant to minor in proportion and varies randomly. Beds of this member are parallel, even to uneven, thin to thick and have frequent erosional surfaces in between. All these signify deposition in subtidal to storm weather wave base regions under photic zone. Typical coral reef deposits developed over this member that moved gradually towards offshore regions owing to fall of sea

level. At the top of this biohermal limestone member, major erosional surface associated with faulting (F2 in Fig. 1; Plate 1.3, 1.4, 1.5) and regression is observed.

This faulting had exposed the subtidal-storm weather wave base deposits to subaerial conditions that led to karstification. It also paved way for the deposition of the Olapadi conglomerate member which contains large boulders (many of which are more than 10 m in diameter) of basement rocks, and lithoclasts of similar size, drawn from underlying bioclastic and coral limestone, Terani claystone and lithoclasts of older sedimentary conglomerates, all embedded in basinal clay sediments! Angular to sub rounded nature of the boulders, presence of basement as well as lithoclasts of older sedimentary rocks in basinal sediments clearly indicate a major faulting event, creation of steep slope and short distance of transportation. Presence of argillaceous siltstone over these boulders with lamination parallel to the boulder boundaries indicates restoration of normal depositional conditions and gradual increase of sea level. A detailed facies and sequence analysis of these deposits suggested (RAMKUMAR, 2008) the prevalence of turbiditic current controlled depositional pattern coeval with seismicity related mechanical erosion and gravity driven deposition that acted independently. Deposition of argillaceous sediments was brought to an end by rejuvenation of fluvial source resulting in influx of coarse-finer clastics and suspended sediment load. This new set of environmental conditions led to the deposition of the Kallakkudi calcareous sandstone member. This member is sandy in southern region and clayey in northern region. Occurrence of recurrent

Bouma sequences that always top with a gypsiferous layer followed by an erosional surface and again by another Bouma sequence in this member indicates deposition under the influence of turbidity currents and gradual facies change from near shore to deep sea. On the whole, it could be interpreted that, deposition of this member took place in a slowly sinking basin and/or deposition with episodic sea level rise and fall coupled with active fault block adjustment (in minor scale) after major movement.

With due sinking of the coastal basin and/or sea level rise, deep marine conditions were established and thick pile of Karai Formation clays were deposited. Deposition of about 450 m thick clay alternated with ferruginous silty clays and gypsiferous layers suggests well developed fluvial system onland that supplied suspended sediment load continuously to deep marine regions. Thick population of belemnites, silty admixture, alternate thin-thick lamina of ferruginous silty clay and gypsiferous clay bands are frequent in the southern region indicative of deposition also in shallower regions of paleosea. These shallower regions were periodically exposed subaerially due to minor sea level oscillations to produce evaporites. The top surface of this formation is marked by a pronounced erosional surface that suggests major regression at the end of the deposition. This erosional surface is overlain immediately by subtidal-supratidal ferruginous sandstones along with shell banks typical of estuary and shell hash typical of shallow water shoals/distributary mouth bars that represent Kulakkanattam and Grey sandstone members of the Garuda-mangalam Formation. Together, their occurrences indicate shoreline retreat and associated advancement of fluvial system over former offshore areas. This inference is substantiated by sudden appearance of large tree trunks in these sandstones. Although the boundary between the Karai clays and the Kulakkanattam sandstones is an erosional unconformity, presence of conformable relationship and near parallel bedding planes of rocks between them suggests simple sea level variation and introduction of newer environmental conditions rather than fault controlled environmental change across the boundary. The deep-water conditions were restored again in this part of the basin with the introduction of deposition of the Anaipadi sandstone member that shows gradual increase of sea level. Break in sedimentation, probably influenced by major regression was witnessed at the end of deposition of the Anaipadi sandstone member.

Renewed transgression initiated during the Middle Santonian covered the regions located north and south that were not transgressed previously. This widespread transgression, associated with downwarping of fault blocks, had submerged the coastal tracts up to Pondicherry in the north resulting in generation of Archaen–Santonian and Archaen–Campanian contact (faultline located north of Kilpalur – refer F3 in Fig.

1; Plate 1.6, 1.7, 1.8, 1.9). This period was associated with widespread erosion of basement rocks and older sedimentary rocks and their redeposition in the newly created depocenters. The Sillakkudi Formation of the Ariyalur Group, which has been the product of this widespread transgression, has three members. The lowermost member is a fluvial unit and shows transition to deposition under marine influence towards top. Major channels with a width of more than a kilometer and 30 m deep that incised older sedimentary rocks (Fig.1), were recognized in the field. The strata of this member have reverse graded basement boulder and lithoclastic conglomerates (Plate 1.6, 1.7, 1.8). They also show large scale advancing cross beds (Plate 1.7), alternate with ferruginous sandstone foresets. From the detailed facies and sequence analysis and tectonic structural information recognized in the field, RAMKUMAR *et al.* (2005a) interpreted overwhelming influence of sea level fluctuations over the depositional pattern, and continued seismicity influenced mechanical erosion and gravity assisted fluvial transport until the deposition of the Sadurbagam member. Continued rise of sea level had submerged the fluvial/estuarine mouth sediments and deposition in subtidal to intertidal environments occurred. This sea level rise has been overwhelming and covered large tracts of western part of the basin that remained positive since inception of the basin, as indicated by the contact between Archaen–Varanavasi member of the Sillakkudi Formation (Plate 1.9). Towards top, the Varanavasi member shows frequent occurrences of pebbly sandstone layers may be as a result of prevalent periodic higher energy conditions (RADULOVIC *et al.* 2015) and/or seismic aftershocks, erosional surfaces and reworked fauna. Localized occurrences of serpulid colonies at the top of this member indicate cessation of sediment supply, reducing sea level, reduced circulation and lower energy conditions. A major erosional unconformity separates this formation from overlying Kallankurichchi Formation.

The renewed transgression during the Latest Campanian–Early Maastrichtian was marked with widespread erosion of basement rocks and older sedimentary rocks. However, the size of the basement boulders and lithoclasts of older sedimentaries in the basal conglomerate member of this formation, rarely exceed 30 cm and are more rounded than their older counter parts. These clasts seem to be recycled from older sedimentary rocks rather than sourced fresh from basement rocks. Thus, the Kallar arenaceous member has lithoclastic conglomerate deposits at its base and rests over the Sillakkudi Formation (Plate 1.10) with distinct angular erosional unconformity. Biohermal and biostromal deposits constitute the Kallankurichchi Formation and denote cessation of Santonian–Campanian fluvial sediment supply. As the initial marine flooding started to wane out, the deposits show reduction in proportion and size of siliciclastics

that were increasingly replaced by *gryphea* colonies. As the sea level was gradually increasing, the *gryphea* bank shifted towards shallower regions and the locations previously occupied by coastal conglomerate became middle shelf wherein typical *inoceramus* limestone started developing. Break in sedimentation of this member was associated with regression of sea level that had transformed the middle - outer shelf regions into intertidal - fair weather wave base regions.

These newer depositional conditions resulted in erosion of shell banks and middle shelf deposits and redeposition of them into biostromal deposits (Tancem biostromal member). As the energy conditions were high and deposition took place in shallower regions, frequent non-depositional and erosional surfaces, punctuated with cross bedded carbonate sand beds and tidal channel grainstones and storm deposits with hummocky cross stratification were deposited. Again, the sea level rose to create marine flooding surface and as a result of which, *gryphea* shell banks started developing more widely than before that represent the Srinivasapuram gryphea limestone member. Towards top of this member, shell fragments and minor amounts of siliciclastics are observed that indicate onset of regression and associated introduction of higher energy conditions and detrital influx. The occurrence of non-depositional surface at the top of this formation and deposition of shallow marine siliciclastics (Ottakoil Formation) in a restricted region immediately over the predominantly carbonate depocenter and conformable offlap of much younger fluvial sand deposits (Kallamedu Formation) are all suggestive of gradual regression associated with re-establishment of fluvial system (Plate 1.11) at the end of Cretaceous Period. Towards top of the Kallamedu Formation, paleosols are recorded implying abandonment of river system and restoration of continental conditions at the end of the Cretaceous Period.

At the beginning of Danian, transgression took place that covered only the eastern part of the Kallamedu Formation. Presence of conformable contact between the Anandavadi member and the Kallamedu Formation and initiation of carbonate deposition from the beginning of Danian are indicative of absence of any major tectonic activity and fluvial sediment supply at this time. Increase in sea level and establishment of shallow, wide shelf with open circulation paved way for the deposition of the Periyakurichchi member with cyclic marl-limestone couplets (Plate 1.12). At the top, this member has distinct erosional unconformity, which in turn, when interpreted along with the presence of huge thickness of continental sandstone (>4000 m thick Miocene-Pliocene Cuddalore sandstone Formation), indicates restoration of continental conditions in this basin. Absence of any other marine strata over the Cuddalore sandstone Formation suggests that the sea regressed at the end of Danian had never returned to this part of the Cauvery Basin.

The depositional cycles in the light of lithofacies characteristics (table 2) and succession (table 1) and geological events described above are summarized in the table 3. From these tables, it follows that, under favorable climatic and other conditions, significant influx of detrital materials (either with or without chemical weathering in the provenance area) to the depositional basin and resultant reduction in carbonate accumulation during sea level lowstands and conversely, reduction of detrital influx owing to the limited availability of terrestrial areas, shortening and/or drowning of fluvial channels and significant carbonate accumulation during sea level highstands, which are considered to be the fundamental processes of sequence development were in operation in this basin for the whole of its depositional history except during the major tectonic events. From the tables 2 and 3, it could also be observed that at each change (either tectonic or sea level fluctuation), there were significant erosion (either the provenance area or former marine regions or both) and sediment recycling events, that have removed former sedimentary records partially or completely and obliterated the depositional continuum.

The sedimentation system is dominated by cyclic processes that operate on a hierarchy of temporal and spatial scales on which short-lived events are superimposed (VEIZER *et al.* 1997). As a consequence, only a net result of cycles and events could be recognized in rock records. Cyclic sedimentation has been documented in several sedimentary basins and there are many lines of evidences that relate those cycles to short-term (Milankovitch band) glacio-eustatic pulses (GRAMMER *et al.* 1996). At this juncture, report of occurrences of all the six global sea level peaks of eustatic in origin, occurrences of 100% distinct six chemozones (RAMKUMAR *et al.* 2010b, 2011) in tune with third order sea level cycles, pristine nature of geochemical characteristics of the rocks (RAMKUMAR *et al.* 2006) are all suggestive of predominance of climate-sea level cycle controlled depositional pattern in this basin. However, the major faulting during Barremian and reactivation of faults during depositional history, as observed from field and lithofacies characteristics necessitates examining the impact of these events over the depositional system.

Relative influences of tectonics and sea level fluctuations over the depositional cycles

The general knowledge about a geochemical system allows establishing a definite number of processes governing the sedimentary system namely, the redox conditions, detrital input, changes in provenance and quantum of sediment influx and climate, etc, (PINTO *et al.* 2004; MONTERO-SERRANO *et al.* 2010). The occurrences of inverse relationships between the Si, Ti, Zr and Ca, (Fig. 3), when corroborated with the lithofacies alternations between siliciclastics and carbonates (table 2) and

Table 3. Geological events of the Cauvery Basin as inferred from the exposed area.

	AGE	FORMATION	MEMBER	EVENTS
Tertiary	Mio-Pliocene	Cuddalore S.st. Fm.		Continental deposition, tropic climate Total regression, sequence boundary
	Danian	Niniyur Fm.	Periyakurichchi biostromal Mbr.	Marine flooding
			Anandavadi arenaceous Mbr.	
Upper Cretaceous	Maastrichtian	Kallamedu Fm.		Major transgression, K-T boundary
			Ottakoil Fm.	Total regression
	Campanian	Kallankurichchi Fm.		Sealevel fall, cessation of carbonate deposition
			Srinivasapuram grypcean L.st. Mbr.	Marine flooding
			Tancem biostromal Mbr.	Regression, tidal channel & storm deposits
Kattupiringiyam inoceramus L.st. Mbr.			Marine flooding	
Santonian	Sillakkudi Fm.		Sequence boundary, regression & transgression	
		Varanavasi S.st. Mbr.	Marine flooding	
Coniacian	Garudamangalam Fm.		Transgression	
		Sadurbagam pebbly S.st. Mbr.	Fluvial, estuarine & coastal deposition	
Lower Cretaceous	Turonian	Karai Fm.	Varakuppai lithoclastic conglomerate Mbr.	Faulting, regression, sequence boundary
				Major sequence boundary, regression
	Cenomanian	Dalmiapuram Fm.	Anaipadi S.st. Mbr.	Marine flooding
			Grey S.st. Mbr.	Regression
	Albian	Sivaganga Fm.		Major flooding surface
			Sealevel fall, fluvial influx increase	
Aptian	Sivaganga Fm.		Major flooding surface	
			Sealevel fall, fluvial influx increase	
Barremian	Sivaganga Fm.		Major flooding surface	
			Sealevel fall, fluvial influx increase	

Archaen granitic gneiss

their synchronicity with sea level lows and highs respectively (Fig. 2), allow interpretation of sea level controlled depositional pattern in this basin. Decrease in Si and many metals typical of heavy minerals are observed from these profiles (Fig. 3) and can be interpreted as the result of transgressions (HILD & BRUMSACK, 1998). Similarly, the reduction of Ca content is found to be associated with regressions. As could be observed elsewhere (RACHOLD & BRUMSACK, 2001; HOFMANN *et al.* 2001; BOULILA *et al.* 2010), whenever siliciclastic deposition ceased, carbonate deposition was initiated (WARZESKI *et al.* 1996) in this basin. From the Falcon Basin, northwestern Venezuela, MONTERO-SERRANO *et al.* (2010) reported similar geochemical elemental grouping in terms of either detrital or carbonate as a result of siliciclastic-carbonate lithofacies alternations. SARG (1988) observed that, sedimentary basins starve for detrital sediments during high stands that lead to development of carbonates. A recent review of previously published information on evolutionary stages and sequence development in the Cauvery Basin (KALE 2011) suggested the availability of larger accommodation space than the sediment influx all through its evolutionary history. It also means that there might be climatic control over the observed lithofacies-geochemical grouping alternations.

RUFFEL & RAWSON (1994) and SOREGHAN (1997) opined that dry periods might cause a deficit in detrital supply and favor deposition of carbonates. It supports the interpretation of occurrences of sea level highstands during interglacial periods (warmer than glacial periods) and resultant general aridity and deprivation of clastic sediment supply. The glacial periods promote enhanced terrigenous supply to the depocenters in view of shelf erosion (KAMPSCHULTE *et al.* 2001) and fluvial system advancement (SARG, 1988; CARTER *et al.* 1991). Occurrences of paleochannel courses (Fig. 1) and their association with siliciclastic deposits, erosion during the periods of lower sea level, influenced also by the proximity to source rocks and adequate slope could be inferred from the configuration of the Cauvery Basin. Occurrences of unaltered lithoclasts and feldspar clasts in rocks that immediately follow regressive surfaces also suggest the prevalent mechanical erosion, rapid and short duration of transport and quick burial. Such rapid physical erosion and textural immaturity of ensuing sediments could have produced the co-variation of Si and other elements associated with quartz, feldspar and other silicates. Based on the occurrences of all the six global sea level peaks, recognized independently

through foraminifer (RAJU & RAVINDRAN, 1990; RAJU *et al.* 1993) and geochemical data (RAMKUMAR *et al.* 2005b; 2010b; 2011), influence of climate controlled eustatic sea level changes, over the depositional pattern of the basin is affirmed.

The element Y shows a peculiar polynomial peak across Aptian–Albian boundary (Fig. 3), subdued nature during most of the successive period until latter part of middle Albian and gradual increase then onward, a significant peak during Coniacian and finally a gradual decrease. In magnitude and scale, it mimics Zr (Fig. 3). As the element Y undergoes little or no diagenetic alterations (ANDREW *et al.* 1996; DAS 1997; PINTO *et al.* 2004; MONTERO-SERRANO *et al.* 2010), presence of its short and significantly prominent peaks exactly coinciding faulting events (Fig. 1) and associated change in sedimentation pattern (Table 2) indicates influx of Y immediately after major tectonic movements and resultant change in nature, quantum and composition of detrital influx into the basin. Sedimentation pattern and nature of sediments of the periods between Barremian–Coniacian and Santonian–Danian were different and are reflected in the patterns of Y and Zr during these two time spans. The differences between these elements in terms of temporal resolution may be a consequence of their differential response (WHITFORD *et al.* 1996) to prevalent depositional environmental conditions as enforced/introduced by the major tectonic event. DUBICKA *et al.* (2014) also observed significant changes in environmental conditions due to Subhercynian tectonic movements in Ukraine during Coniacian–Santonian. Enrichment of these elements up to Coniacian and their subdued nature after Coniacian could be attributed to the changes brought in by major tectonic activity occurred during Santonian, across which significant changes in proximity of sediment source and nature and quantum of detrital influx were witnessed (SUNDARAM & RAO, 1986).

The abundance of Zr in clastic rocks was interpreted to be the result of detrital influx as well as sediment recycling (SPALLETTI *et al.* 2008). Occurrences of generally higher levels of Zr all through the Barremian–Danian with the exception of latest Campanian–middle Maastrichtian (Kallankurichchi Formation) and many episodes of positive excursions over this general trend suggest sediment starved nature of the basin and significant recycling of older sedimentary rocks. Ti and Zr are generally assumed to represent detrital inputs into a sedimentary basin and their variations should be related with changes in weathering conditions in the hinterland or changes of provenance (BELLANCA *et al.* 2002). Zr and Ti are considered to be effective in discriminating volcanoclastic sediments and also sediments of different diagenetic and tectonic histories (ANDREOZZI *et al.* 1997). Zirconium is mostly concentrated in zircons, which accumulate during sedimentation while less resistant

phases are preferentially destroyed (ALVAREZ & ROSER, 2007). Peak enrichments of Zr during middle Cenomanian (Gypsiferous clay member), latest Cenomanian (Oidium member), middle Campanian (Varakuppai member), middle-late Maastrichtian (Ottakoil Formation), early Danian (Anandavadi member) are observed and interpreted as the durations of influx and cessation of terrigenous materials which in turn might have been controlled by variations in source area weathering and/or a change from more humid to more arid conditions or tectonic movements (MUNNECKE & WESTPHAL, 2004). SANDULLI & RASPINI (2004) interpreted the elemental cycles as the precession and obliquity periodicities, the bundles and superbundles into short and long eccentricity cycles and similar inference could be made to the rocks under study.

The source area consists of granitic gneisses in low lying plains and massive hills of charnockite. These rocks consist of very coarse grained plagioclase, smaller grains of quartz, hypersthene, and amphibole as major minerals, magnetite, garnet, and biotite as minor minerals and zircon, rutile and apatite as accessory phases (SHARMA & RAJAMANI, 2001). Cutting across the granitic gneiss, pegmatite veins composed of large to very large feldspar crystals (at places ranging upto many tens of centimeters) occur frequently. The nature and extent of source rock weathering, physical sorting during transport and environmental conditions during deposition at the depocenters exert significant control over sediment geochemistry (SHARMA & RAJAMANI, 2001). The samples under study show that the period from Cenomanian–Coniacian have very high PIA values with a peak value during middle Turonian meaning that the plagioclase was almost totally destroyed by source area weathering during Cenomanian–Coniacian and during other periods, there was no such wholesome alteration. This observation, when compared with the conditions of chemical weathering at lower latitudes listed by BOUCOT & GREY (2001), and with paleogeographic location of the Cauvery Basin in the lower latitudes during Barremian–Maastrichtian, limited extent of the provenance and the configurations of the depositional basin and provenance, support the inference of weaker chemical weathering. SINGH & RAJAMANI (2001) studied the floodplain sediments of the modern (present day) Kaveri River and observed striking similarity of trace elemental and REE patterns between the rocks of the source area and the modern floodplain sediments. SHARMA & RAJAMANI (2000) reported weaker chemical weathering, exposure of fresh unaltered rocks in the provenance and interpreted these phenomena as the result of continued tectonic movements, due to which, only limited weathering profiles are exposed at the provenance. Taking clue from this, occurrences of unaltered basement rock clasts in rocks deposited during Barremian, Cenomanian, Aptian–Albian, Coniacian–Santonian, are interpreted as

the durations of tectonic activity in this basin. These durations are also accompanied by significant positive excursions of Si, Ti, Zr and Y. This inference necessitates checking the consistency and dynamism of provenance and tectonic setting of these rocks.

The geochemical characteristics of clastic rocks have been used to decipher the provenance (TAYLOR & MCLENNAN 1985; PINTO *et al.* 2004). The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio is sensitive to sediment recycling and the weathering process and can be used as an indicator of sediment maturity (ROSER & KORSCH, 1986). The average $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios in unaltered igneous rocks range from ~3.0 (basic) to ~5.0 (acidic), while values >5.0–6.0 in sediments are an indication of progressive maturity (ROSER *et al.* 1996). Examination of the rocks under study in the light of these precepts and by plotting the data in established discrimination diagrams of textural maturity, and tectonic setting have revealed the following.

The plots of two distinct clusters in the bivariate diagrams of oxide percentages (Fig. 4), most of the samples in the texturally immature fields (Fig. 5) namely, (litharenite, wacke, arkose, subarkose etc), all the samples below the average shale discriminant line, existence of two-cluster nature (Fig. 6), all the samples below the feldspar join together with selective samples of Dalmiapuram, Karai, Garudamangalam and Sillakkudi formations above the feldspar join (Fig. 7) are all supportive of the inferences of limited extent of provenance, proximity to provenance, sediment starved nature of the sedimentary basin, prevalence of less significant chemical weathering, and predominance of siliciclastic-carbonate alternate cycles under the influences of relative sea level fluctuations.

The Indian subcontinent was located at the southern latitudes during the deposition of the Ottakoil and Kallamedu formations (RAI *et al.* 2012). The studies of LAL *et al.* (2009), KALE (2011), CHATTERJEE *et al.* (2013), have shown that the Indian subcontinent was on a flight at various rates and directions since its breakup from Africa-Antarctica and was above the Reunion hotspot (MORGAN 1981; SHETH & CHANDRASEKHARAM 1997; CHATTERJEE *et al.* 2013) or the Vishnu Fracture (SHETH 1999) during the late Cretaceous. The present observations of plot of Barremian–Santonian samples in the active continental margin field, Campanian–Danian samples in the passive continental margin field and plot of few samples of Ottakoil and Kallamedu formations (Late Maastrichtian) in the island arc field (Fig. 8) are all supportive of changing palaeogeographic positions and tectonic dynamism of the Indian plate. The change of depositional pattern across Santonian as indicated by lithofacies and geochemical characteristics are also supported by the change of tectonic setting across Santonian (from active to passive continental margin), suggestive of the sensitivity of geochemical parameters to climate-sea level fluctuations, tectonic movements, rates of sediment influx and chemical weathering.

The recognition of island arc setting in the sedimentary records of the Kallamedu Formation is important from the point of Cretaceous–Tertiary transitional environmental conditions in this part of the country. Though previous studies have either presumed or suggested the influence of Deccan volcanism and the presence of vitrified volcanic ash deposits in this formation, due to the inherent lithological characteristics (thin lamina of fine grained and also diagenetically altered sediments amidst coarse, recycled sediments of varying bed thicknesses which in turn were cut across by calcrete and silcrete veins), and scattered and weathered nature of the exposures, usually thwarted characterizing these deposits so far. This is the first time, the affinity of argillaceous siltstone beds of the Kallamedu Formation are unequivocally affiliated with volcanogenic sediment source. ANDREZZI *et al.* (1997) commented that distinctive beds, particularly volcaniclastic layers which may be useful for stratigraphic and environmental reconstruction, may escape field identification because their recognition generally depends on a marked lithological contrast with the surrounding sediments. Because of several factors such as fine grain size, intense diagenetic modifications, and selective weathering may hinder their identification. This statement stands true to the case of Kallamedu Formation.

Conclusions

The Barremian–Danian strata of the Cauvery Basin record all the six third order sea level cycles within which many high-frequency cycles could be recognized. These are reflected in the lithofacies and enrichment-depletion patterns of sensitive geochemical proxies.

The northward flight of the Indian subcontinent, in which the Cauvery Basin is located has experienced active and passive nature of the tectonic setting and passed through active volcanic plume, all of which are explicitly shown by the geochemical characteristics of the rocks contained in the Cauvery Basin.

The depositional system was under the predominant influence of climate-sea level fluctuations despite the recurrent major tectonic movements of fault blocks. Few of the tectonic fault movements have coincided with sequence boundaries (Barremian, Aptian–Albian, Coniacian–Santonian, Maastrichtian–Danian) and may have contributed to exacerbation of sea level cycles, particularly during the deposition of the Olaipadi, Varakuppai and Sadurbagam members. Thus, the present study supports the influence of tectonics, to the development of third order cycles of depositional system.

The predominance of mechanical weathering, prevalence of insignificant chemical weathering of the source rocks as indicated by textural immaturity and the occurrences of high-frequency cycles in the

Barremian–Coniacian deposits that have experienced syndepositional tectonic events and the prevalence of relatively stable environmental conditions during the period of tectonic quiescence (Campanian–Danian) are all suggestive of dominant role played by climate-relative sea level fluctuations.

While the recurrent sediment recycling events suggest reduced rates of subsidence (BUCHBINDER *et al.* 2000), the predominance of textural immaturity and mechanical erosion suggest dynamic nature of tectonism (SHARMA & RAJAMANI, 2000) suggesting the existences of balance between eustatic sea level fluctuations by tectonic events.

Acknowledgements

The study was initiated with the financial grants from Alexander von Humboldt Foundation, Germany, to MR. Prof. Dr. DORIS STÜEBEN, Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology, Germany is thanked for her invitation to MR to conduct collaborative research. Dr. ZSOLT BERNER, Head of Laboratories, Institute of Mineralogy, is thanked for scientific support and lively discussions. Thanks are due to the scientific personnel of the Institute namely, Dr. UTZ KRAMAR for XRF analytical facilities, Dr. KAROTKE and Mrs. OETZEL for XRD analyses, Mr. PREDRAG ZRINJSAK for carbon and sulphur analyses and Dr. G. OTT for computing facilities. Partial funding to this work in the form of Research Associateship and Senior Research Associateship was provided to MR by Council of Scientific and Industrial Research, New Delhi, and University Grants Commission, New Delhi in the form of research project (Maastrichtian–Danian part of the study area). SHRI. T. SREEKUMAR, Geologist, OFI, Mumbai, is thanked for assistance during the field work. Permission to collect samples was accorded by the mines managers and geologists of Messers. Alagappa cements, Chettiyar mines, Dalmia Cements, Fixit Mines, Pvt. Ltd, Nataraj Ceramics Ltd., Parveen mines and Minerals Ltd., Ramco Cements, Rasi cements, TANCEM Mines, TAMIN mines, Tan-India Mines and Vijay Cements. SHRI T. SUGANTHA, Research Student, Department of Geology, Periyar University helped in final drawing of the profiles. The journal reviewers Dr. DMITRY A. RUBAN, Southern Federal University, Rostovna-Donu, Russia and Dr. JYOTSANA RAI, Birbal Sahni Institute of Paleobotany, Lucknow, India are thanked for constructive comments and relevant literature, that helped the author to improve the content and style of the paper. Editor of the journal Prof. VLADAN J. RADULOVIĆ, is thanked for the supply of recent publication on the Cauvery Basin, and for provision of Serbian abstract.

References

ACHARYYA, S.K. & LAHIRI, T.C. 1991. Cretaceous palaeogeography of the Indian subcontinent: A review. *Cretaceous Research*, 12: 3–26.

- Ali, J.R. & Aitchison, J.C. 2008. Gondwana to Asia: Plate tectonics, paleogeography and the biological connectivity of the Indian sub-continent from the Middle Jurassic through latest Eocene (166–35 Ma). *Earth Science Reviews*, 88: 145–166.
- ALVAREZ, N.O.C. & B.P. ROSER, B.P. 2007. Geochemistry of black shales from the Lower Cretaceous Paja Formation, Eastern Cordillera, Colombia: Source weathering, provenance, and tectonic setting. *Journal of South American Earth Sciences*, 23: 271–289.
- ANDERSON, J.B., ABDULAH, K. & SARZALEJO, S. 1996. Late Quaternary sedimentation and high-resolution sequence stratigraphy of the east Texas shelf. In: DE BATIST, M. & JACOBS, P. (Eds), *Geology of siliciclastic shelf seas*, 95–124. Geological Society Special Publication, 117.
- ANDREW, A.S., WHITFORD, D.J., HAMILTON, P.J., SCARANO, S. & BUCKLEY, M. 1996. Application of chemostratigraphy to petroleum exploration and field appraisal. An example from the Surat basin. *Proceedings of Seminar on Asia Pacific Oil and Gas*, 421–429.
- ANDREOZZI, M., DINELLI, E. & TATEO, F. 1997. Geochemical and mineralogical criteria for the identification of ash layers in the stratigraphic framework of a foredeep: The Early Miocene Mt. Cervarola sandstones, northern Italy. *Chemical Geology*, 137: 23–39.
- AYYASAMY, K. 1990. Cretaceous heteromorph ammonoid biostratigraphy of southern India. *Newsletters in Stratigraphy*, 22: 111–118.
- BACHMANN, M., AMIN, M., BASSIOUNI, A. & KUSS, J. 2003. Timing of mid-Cretaceous carbonate platform depositional cycles, northern Sinai, Egypt. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 200: 131–162.
- BANERJI, R.K. 1972. Stratigraphy and micropalaeontology of the Cauvery basin. Part I, exposed area. *Journal of the Palaeontological Society of India*, 17: 1–24.
- BELLANCA, A., ERBA, E., NERI, R., SILVA, I.P., SPROVIERI, M., TREMOLADA, F. & VERGA, D. 2002. Palaeoceanographic significance of the Tethyan ‘Livello Selli’ (Early Aptian) from the Hybla Formation, northwestern Sicily: Biostratigraphy and high-resolution chemostratigraphic records. *Palaeogeography Palaeoclimatology Palaeoecology*, 185: 175–196.
- BHATIA, M.R. 1983. Plate tectonics and geochemical composition of sandstones. *Geology*, 91: 611–627.
- BHATIA, S.B. 1984. Ostracode faunas of the Indian subcontinent—their palaeozoogeographic and palaeoecologic implications. *Journal of the Palaeontological Society of India*, 20: 1–8.
- BHATIA, M.R. & CROOK, K.A.W. 1986. Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins. *Contributions to Mineralogy and Petrology*, 92: 181–193.
- Bhattacharya, J.P., & Willis, B.J. 2001. Lowstand Deltas in the Frontier Formation, Powder River Basin, Wyoming: Implications for sequence stratigraphic models, U.S.A. *American Association of Petroleum Geologists Bulletin*, 85: 261–294.
- BICE, K.L. & NORRIS, R.D. 2002. Possible atmospheric CO₂

- extremes of the Middle Cretaceous (late Albian-Turonian). *Palaeoceanography*, v.17. doi:10.1029/2002PA000778.
- BOULILA, S., DE RAFÉLIS, M., HINNOV, L.A., GARDIN, S., GALBRUN, B. & COLLIN, P. 2010. Orbitally forced climate and sea-level changes in the Paleoeceanic Tethyan domain (marl–limestone alternations, Lower Kimmeridgian, SE France). *Palaeogeography Palaeoclimatology Palaeoecology*, 292: 7–70.
- BRETT, C.E., MCLAUGHLIN, P.I., CORNELL, S.R. & BAIRD, G.C. 2004. Comparative sequence stratigraphy of two classic Upper Ordovician successions, Trenton Shelf (New York–Ontario) and Lexington Platform (Kentucky–Ohio): implications for eustasy and local tectonism in eastern Laurentia. *Palaeogeography Palaeoclimatology Palaeoecology*, 210: 295–329.
- BUCHBINDER, B., BENJAMINI, C. & LIPSON-BENITAH, S. 2000. Sequence development of Late Cenomanian–Turonian carbonate ramps, platforms and basins in Israel. *Cretaceous Research*, 21: 813–843.
- CALVER, C.R. 2000. Isotope stratigraphy of the Ediacarian (Neoproterozoic III) of the Adelaide rift complex, Australia and the overprint of water column stratification. *PRECAMBRIAN RESEARCH*, 100: 121–150.
- CARTER, R.M., ABBOTT, S.T., FULTHORPE, C.S., HAYWICK, D.W. & HENDERSON, R.A. 1991. Application of global sea level and sequence stratigraphic models on Southern hemisphere Neogene strata from New Zealand. *International Association of Sedimentologists Special Publication*, 12: 41–65.
- CATUNEANU, O. 2006. Principles of Sequence Stratigraphy. Elsevier B.V.
- CATUNEANU, O., GALLOWAY, W.E., KENDALL, C.G.St.C., MIAL, A.D., POSAMENTIER, H.W., & STRASSER, A. 2011. Sequence Stratigraphy: Methodology and Nomenclature. *Newsletters in Stratigraphy*, 44: 173–245.
- CATUNEANU, O., ABREU, V., BHATTACHARYA, J.P., BLUM, M.D., DALRYMPLE, R.W., ERIKSSON, P.G., FIELDING, C.R., FISHER, W.L., GALLOWAY, W.E., GIBLING, M.R., GILES, K.A., HOLBROOK, J.M., JORDAN, R., KENDALL, C.G.St.C., MACURDA, B., MARTINSEN, O.J., MIAL, A.D., NEAL, J.E., NUMMEDAL, D., POMAR, L., POSAMENTIER, H.W., PRATT, B.R., SARG, J.F., SHANLEY, K.W., STEEL, R.J., STRASSER, A., TUCKER, M.E. & WINKER, C. 2009. Towards the standardization of sequence stratigraphy. *Earth Science Reviews*, 92: 1–33.
- CATUNEANU, O., BHATTACHARYA, J. P., BLUM, M. D., DALRYMPLE, R.W., ERIKSSON, P.G., FIELDING, C.R., FISHER, W.L., GALLOWAY, W.E., GIANOLLA, P., GIBLING, M.R., GILES, K.A., HOLBROOK, J.M., JORDAN, R., KENDALL, C.G.St.C., MACURDA, B., MARTINSEN, O.J., MIAL, A.D., NUMMEDAL, D., POSAMENTIER, H.W., PRATT, B.R., SHANLEY, K.W., STEEL, R. J., STRASSER, A. & TUCKER, M.E., 2010. Sequence stratigraphy: Common ground after three decades of development. *First Break*, 28: 21–34.
- CHARI, M. V. N., SAHU, J. N., BANERJEE, B., ZUTSHI, P. L. & CHANDRA, K. 1995. Evolution of the Cauvery Basin, India from subsidence modeling. *Marine and Petroleum Geology*, 12: 667–675.
- CHANDRA, P.K. 1991. Sedimentary basins of India. Presidential address of VIII Convention of Indian Geological Congress, 1–31.
- CHATTERJEE, S., GOSWAMI, A. & SCOTSE, C. R. 2013. The longest voyage: Tectonic, magmatic, and paleoclimatic evolution of the Indian plate during its northward flight from Gondwana to Asia. *Gondwana Research*, 23: 238–267.
- CHIPLONKAR, G.W. 1987. Three decades of invertebrate palaeontology and biostratigraphy of marine Cretaceous rocks of India. Geological Survey of India Special Publication, 11: 305–339.
- CINGOLANI, C.A., MANASSERO, M. & ABRE, P. 2003. Coposition, provenance, and tectonic setting of Ordovician siliciclastic rocks in the San Rafael block: Southern extension of the Precordillera crustal fragment, Argentina. *Journal of South American Earth Sciences*, 16: 91–106.
- CLOETING, S. 1988. Intraplate stress: A tectonic cause for third order cycles in apparent sealevel? In: WILGUS, C.K., HASTINGS, B.S., KENDAL, C.G.St.C., POSAMENTIER, H.W., ROSS, C.A. & VAN WAGONER, J.C. (Eds), Sea level changes – An integrated approach, 19–29. SEPM Special Publication 42.
- COCCIONI, R. & GALEOTTI, S. 2003. The mid-Cenomanian event: prelude to OAE 2. *Palaeogeography Palaeoclimatology Palaeoecology*, 190: 427–440.
- DAS, N. 1997. Chemostratigraphy of sedimentary sequences: A review of the state of the art. *Journal of the Geological Society of India*, 49: 621–628.
- DUBICKA, Z., PERYT, D. & SZUSZKIEWICZ, M. 2014. Foraminiferal evidence for paleogeographic and paleoenvironmental changes across the Coniacian-Santonian boundary in western Ukraine. *Palaeogeography Palaeoclimatology Palaeoecology*, 401: 43–56.
- ELRICK, M. & SCOTT, L.A. 2010. Carbon and oxygen isotope evidence for high-frequency (10^4 – 10^5 yr) and Myscale glacio-eustasy in Middle Pennsylvanian cyclic carbonates (Gray Mesa Formation), central New Mexico. *Palaeogeography Palaeoclimatology Palaeoecology*, 285: 307–320.
- GALE, A.S., HARDENBOL, J., HATHWAY, B., KENNEDY, W.J., YOUNG, J.R. & PHANSALKAR, V. 2002. Global correlation of Cenomanian (Upper Cretaceous) sequences: Evidence for Milankovitch control on sea level. *Geology*, 30: 291–294.
- GALE, A.S., VOIGT, S., SAGEMAN, B.B. & KENNEDY, W.J. 2008. Eustatic sea level record for the Cenomanian (Late Cretaceous)—Extension to the Western Interior Basin, USA. *Geology*, 36: 859–862.
- GALEOTTI, S., RUSCIADELLI, G., SPROVIERI, M., LANCI, L., GAUDIO, A. & PEKAR, S. 2009. Sea level control on facies architecture in the Cenomanian–Coniacian Apulian margin (Western Tethys): A record of glacio-eustatic fluctuations during the Cretaceous greenhouse? *Palaeogeography Palaeoclimatology Palaeoecology*, 276: 196–205.
- GIL, J., GARCÍA-HIDALGO, J.F., SEGURA, M., GARCÍA, A. & CARENAS, B. 2006. Stratigraphic architecture, palaeogeography and sea-level changes of a third order deposi-

- tional sequence: The late Turonian–early Coniacian in the northern Iberian Ranges and Central System (Spain). *Sedimentary Geology*, 191: 191–225.
- GOLDHAMMER, R.K., DUNN, P.A., & HARDIE, L.A. 1987. High-frequency glacio-eustatic sea level oscillations with Milankovitch characteristics recorded in Middle Triassic platform carbonates in northern Italy. *American Journal of Science*, 287: 853–892.
- GOLDHAMMER R.K., OSWALD E.J. & DUNN P.A. 1991. Hierarchy of stratigraphic forcing: Example from Middle Pennsylvanian shelf carbonates of the Paradox basin. In: FRANSEEN, E.K., WATNEY, W.L. & KENDALL, C.G.St.C., (Eds.), *Sedimentary modeling*, 361–413. Kansas Geological Survey Bulletin, 233.
- GOVINDHAN, A., RAVINDRAN, C.N. & RANGARAJU, M.K.R. 1996. Cretaceous stratigraphy and planktonic foraminiferal zonation of Cauvery basin, South India. In: SAHNI, A. (Ed.), *Cretaceous stratigraphy and palaeoenvironments*, 155–187. Memoirs of Geological Society of India, 37.
- GOVINDAN, A., ANANTHANARAYANAN, S. & VIJAYALAKSHMI, K.G. 2000. Cretaceous petroleum system in Cauvery basin, India. In: GOVINDHAN, A. (Ed), *Cretaceous stratigraphy - An update*, 365–382. Memoirs of Geological Society of India, 46.
- GRAMMER, G.M., EBERLI, G.P. & VAN BUCHEM, F.S.P. 1996. Application of high resolution sequence stratigraphy to evaluate lateral variability in outcrop and subsurface – Desert Creek and Ismay intervals, Paradox basin. In: LONGMAN, M. W. & SONNELFELD, M. D., (Eds.), *Paleozoic systems of the Rocky mountain region, Rocky mountain section*, 235–266. SEPM.
- GUHA, A.K. 1987. Palaeoecology of some upper Cretaceous sediments of India—an approach based on bryozoa. *Geological Survey of India Special Publication*, 11: 419–429.
- GUHA, A.K. & SENTHILNATHAN, D. 1990. Onychocellids (Bryozoa: Cheilostomata) from the Ariyalur carbonate sediments of south India. *Journal of the Palaeontological Society of India*, 35: 41–51.
- GUHA, A.K. & SENTHILNATHAN, D. 1996. Bryozoan fauna of the Ariyalur Group (Late Cretaceous) Tamil Nadu and Pondicherry, India. *Palaeontologica Indica*, 49: 2–17.
- GRADSTEIN, F.M., OGG, J.G., SMITH, A.G. (Eds.), 2004. A new geologic time scale 2004. Cambridge University Press, Cambridge. 464p.
- HAQ, B.U. 2014. Cretaceous eustasy revisited. *Global and Planetary Change*, 113: 44–58.
- HAQ, B.U., HARDENBOL, J. & VAIL, P.R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235, 1156–1167.
- HAYS, J.D., IMBRIE, J. & SHACKLETON, N.J. 1976. Variations in the earth's orbit: Pacemaker of the ice ages. *Science*, 194: 1121–1132.
- HERRLE, J.O., PROSS, J., FRIEDRICH, O., KOSSLER, P. & HEMLEBEN, C. 2003. Forcing mechanisms for mid-Cretaceous black shale formation: evidence from the Upper Aptian and Lower Albian of the Vocontian Basin (SE France). *Palaeogeography Palaeoclimatology Palaeoecology*, 190: 399–426.
- HILD, E. & BRUMSACK, H.J. 1998. Major and minor element geochemistry of Lower Aptian sediments from the NW German basin (core Hoheneggelsen KB 40). *Cretaceous Research*, 19: 615–633.
- HINDERER, M. 2012. From gullies to mountain belts: A review of sediment budgets at various scales. *Sedimentary Geology*, 280: 21–59.
- HILGEN, F.J., HINNOV, L.A., AZIZ, H.A., ABELS, H.A., BATENBURG, S., BOSMANS, J.H.C., DE BOER, B., HÜSING, S.K., KUIPER, K.F., LOURENS, L.J., RIVERA, T., TUENTER, E., VAN DE WAL, R.S.W., WOTZLAW, J. & ZEEDEEN, C. 2014. Stratigraphic continuity and fragmentary sedimentation: the success of cyclostratigraphy as part of integrated stratigraphy. *Geological Society Special Publication*, 404. doi 10.1144/SP404.12.
- HISCOTT, R.N. 2001. Depositional sequences controlled by high rates of sediment supply, sea level variations and growth faulting: The Quaternary Baram delta of north-western Borneo. *Inter. Journal of Marine Geology Geochemistry Geophysics*, 175: 67–102.
- HOFMANN, P., RICKEN, W., SCHWARK, L. & LEYTHAEUSER, D. 2001. Geochemical signature and related climatic-oceanographic processes for early Albian black shales: Site 417D, North Atlantic Ocean. *Cretaceous Research*, 22: 243–257.
- JAFAR, S.A. 1996. The evolution of marine Cretaceous basins of India: calibration with nannofossil zones. In: SAHNI, A. (ed.), *Cretaceous stratigraphy and palaeoenvironments*, 121–134. Memoirs of the Geological Society of India, 37.
- JAFAR, S.A. & RAI, J. 1989. Discovery of Albian nannoflora from type Dalmiapuram Formation, Cauvery basin, India—Palaeoceanographic remarks. *Current Science*, 58: 358–363.
- KALE, A.S. 2011. Comments on ‘Sequence surfaces and paleobathymetric trends in Albian to Maastrichtian sediments of Ariyalur area, Cauvery Basin, India’ from Nagendra, Kannan, Sen, Gilbert, Bakkiaraj, Reddy, and Jaiprakash. *Marine and Petroleum Geology*, 2010, 1–8. doi:10.1016/j.marpetgeo.2010.04.002.
- KALE, A.S. & PHANSALKAR, V.G. 1992. Calcareous nannofossils from the Uttatur Group, Trichinopoly District, Tamil Nadu, India. *Journal of the Palaeontological Society of India*, 37: 85–102.
- KALE, A.S., LOTFALIKANI, A. & PHANSALKAR, V.G. 2000. Calcareous nanofossils from the Uttatur group of Trichinopoly Cretaceous, South India. In: GOVINDAN, A. (Ed.), *Cretaceous stratigraphy-an update*, 213–227. Memoirs of the Geological Society of India, 46.
- KAMPSCHULTE, A., BRUCKSCHEN, P. & STRAUSS, H. 2001. The sulphur isotope composition of trace sulphates in Carboniferous brachiopods: Implications for coeval seawater correlation with other geochemical cycles and isotope stratigraphy. *Chemical Geology*, 175: 149–173.
- KELLER, G., BERNER, Z., ADATTE, T. & STUEBEN, D. 2004. Cenomanian–Turonian and $\delta^{13}\text{C}$, and $\delta^{18}\text{O}$, sea level and

- salinity variations at Pueblo, Colorado. *Palaeogeography Palaeoclimatology Palaeoecology* 211, 19–43.
- KRAMAR, U., 1997. Advances in energy-dispersive X-ray fluorescence. *Journal of Geochemical Exploration*, 58: 73–80.
- KULPECZ, A.A., MILLER, K.G., BROWNING, J.V., EDWARDS, L.E., POWARS, D.S., MCLAUGHLIN, P.P., JR., HARRIS, A.D., & FEIGENSON, M.D. 2009. Postimpact deposition in the Chesapeake Bay impact structure: Variations in eustasy, compaction, sediment supply, and passive-aggressive tectonism. *In: Gohn, G.S., KOEBERL, C., MILLER, K.G., & REIMOLD, W.U. (eds.) The ICDP-USGS Deep Drilling Project in the Chesapeake Bay Impact Structure: Results from the Eyreville Core Holes*, 813–839. Geological Society of America Special Paper, 458.
- LAL, N.K., SIWAL, A. & KAUL, A.K. 2009. *Evolution of East Coast of India-A Plate Tectonic Reconstruction. Journal of the Geological Society of India*, 73: 249–260.
- MONGELLI, G., CULLERS, R.L. & MUELHEISEN, S. 1996. Geochemistry of Late Cretaceous-Oligocene shales from the Varicolori Formation, Southern Apennines Italy: implications for mineralogical, grain-size control and provenance. *European Journal of Mineralogy*, 8: 733–754.
- MASETTI, D., NERI, C., & BOSELLINI, A. 1991. Deep-water asymmetric cycles and progradation of carbonate platforms governed by high-frequency eustatic oscillations (Triassic of the Dolomites, Italy). *Geology*, 19: 336–339.
- MEYERS, P. A. & SIMONEIT, B.R.T. 1989. Global comparisons of organic matter in sediments across the Cretaceous/Tertiary boundary. *Advances in Organic Geochemistry*, 16: 641–648.
- MIAL, A.D. 1991. Stratigraphic sequences and their chronostratigraphic correlation. *Journal of Sedimentary Petrology*, 61: 497–505.
- MIAL, A.D. 2009. Correlation of Sequences and the Global Eustasy Paradigm: A Review of Current Data. CSPG CSEG CWLS convention, Frontiers + Innovation. Alberta, Canada, 123–126.
- MIAL, A.D. & MIAL, C.E. 2001. Sequence stratigraphy as a scientific enterprise: the evolution and persistence of conflicting paradigms. *Earth Science Reviews*, 54: 321–348.
- MIDDLEBERG, J., CALVERT, S. & KARLIN, R. 1991. Organic-rich transitional facies in silled basins: response to sea level change. *Geology*, 19: 679–682.
- MONTERO-SERRANO, J.C., PALAREA-ALBALADEJO, J., MARTÍN-FERNÁNDEZ, J.A., MARTÍNEZ-SANTANA, M. & GUTIÉRREZ-MARTÍN, J.V. 2010. Sedimentary chemofacies characterization by means of multivariate analysis. *Sedimentary Geology*, 228: 218–228.
- MORGAN, W.J. 1981. Hotspot tracks and the opening of the Atlantic and Indian Oceans. *In: EMILIANI, C. (ed.), The Sea*, 443–475. Wiley Interscience, New York, 7.
- MUNNECKE, A. & WESTPHAL, H. 2004. Shallow water aragonite recorded in bundles of limestone-marl alternations – the Upper Jurassic of SW Germany. *Sedimentary Geology*, 164: 191–202.
- MUTTERLOSE, J., BODIN, S. & FÄHNRIK, L. 2014. Strontium-isotope stratigraphy of the Early Cretaceous (Valanginian-Barremian): Implications for Boreal-Tethys correlation and paleoclimate. *Cretaceous Research*, 50: 252–263.
- NAJARRO, M., ROSALES, I. & MARTIN-CHIVELET, J. 2010. Major palaeoenvironmental perturbation in an Early Aptian carbonate platform: prelude of the Oceanic anoxic event 1a? *Sedimentary Geology*, 235 (1): 50–71. doi:10.1016/j.sedgeo.2010.03.011.
- NELSON, C.S., HENDRY, C.H. & JARRETT, G.R. 1985. Near-synchronicity of New Zealand Alpine glaciations during the past 750 Kyr. *Nature*, 318: 361–363.
- NESBITT, H.W. & YOUNG, G.M. 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, 299: 715–717.
- OPPO, D.W. & FAIRBANKS, R.G. 1989. Carbon isotope composition of tropical surface water during the past 22,000 years. *Paleoceanography*, 4: 333–351.
- OPPO, D. W., FAIRBANKS, R. G. & GORDON, A. L., 1990. Late Pleistocene southern ocean $d^{13}C$ variability. *Paleoceanography* 5, 43–54.
- PASLEY, M., RILEY, G. & NUMMEDAL, D. 1993. Sequence stratigraphic significance of organic matter variations: example from the upper Cretaceous Mancos shale of the San Juan basin, New Mexico. *In: KABZ, B. & PRATT, L. (Eds.), Source rocks in a sequence stratigraphic framework*, 221–241. AAPG Studies in Geology, 37.
- PELLENARD, P., TRAMOY, R., PUCÉAT, E., HURET, E., MARTINEZ, M., BRUNEAU, L. & THIERRY, J. 2014. Carbon cycle and sea-water palaeotemperature evolution at the Middle-Late Jurassic transition, eastern Paris Basin (France). *Marine and Petroleum Geology*, 53: 30–43.
- PINTO, L., HERAIL, G., MOINE, B., FONTAN, F., CHARRIER, R. & DUPRE, B. 2004. Using geochemistry to establish the igneous provenances of the Neogene continental sedimentary rocks in the Central Depression and Altiplano, Central Andes. *Sedimentary Geology*, 166: 157–183.
- POWELL, C.Mc.A., ROOTS, S.R. & VEEVERS, J.J. 1988. Pre-break up continental extension in east Gondwanaland and the early opening of the Indian Ocean. *Tectonophysics*, 155: 261–283.
- PRABHAKAR, K.N. & ZUTSHI, P.L. 1993. Evolution of southern part of Indian east coast basins. *Journal of the Geological Society of India*. 41: 215–230.
- RACHOLD, V. & BRUMSACK, H.-J. 2001. Inorganic geochemistry of Albian sediments from the Lower Saxony Basin, NW Germany: Palaeoenvironmental constraints and orbital cycles. *Palaeogeography Palaeoclimatology Palaeoecology*, 174: 121–143.
- RAI, R., RAMKUMAR, M. & SUGANTHA, T. 2012. Calcareous nannofossils from the Ottakoil Formation, Cauvery basin, South India: Implications on age, Biostratigraphic correlation and palaeobiogeography. *In: RAMKUMAR, M. (Ed.), On the sustenance of Earth's resources*, 109–122. Springer-Verlag, Heidelberg.
- RADULOVIC, B.V., AYOUB-HANNA, RADULOVIC, V.J. & BANJAC, N.J. 2015 *Sillakkudihynchia* gen. nov. (Rhynchonellida, Brachiopoda) from the Upper Cretaceous (Campanian) of the Cauvery Basin, southern India: Ta-

- xonomy, palaeoecology and palaeobiogeography. *Nuer Jahrbuch Geologie und Palaeontologie Abhandlung*, 276, 63–78.
- RAJU, D.S.N. & RAVINDRAN, C.N. 1990. Cretaceous sea level changes and transgressive/regressive phases in India – A review. *Proceedings on Cretaceous event stratigraphy and the correlation of Indian non-marine strata, Contributions to Seminar cum Workshop on IGCP-216*, Chandigarh, 38–46.
- RAJU, D.S.N., RAVINDRAN, C.N. & KALYANSUNDAR, R. 1993. Cretaceous cycles of sea level changes in Cauvery basin, India – A first revision. *Oil and Natural Gas Corporation Bulletin*, 30: 101–113.
- RAMANATHAN, S 1968. Stratigraphy of the Cauvery basin with reference to its oil prospects. *In: Cretaceous-Tertiary of south India. Memoirs of the Geological Society of India*, 2: 153–167.
- RAMKUMAR, M. 1996. Evolution of Cauvery basin and tectonic stabilization of parts of south Indian shield – Insights from structural and sedimentologic data. *Journal of the Geological Association and Research Centre*, 4: 1–15.
- RAMKUMAR, M. 2007. Dolomitic limestone in the Kallankurichchi Formation (Lower Maastrichtian) Ariyalur Group, South India. *Journal of Earth Science*, 1: 7–21.
- RAMKUMAR, M. 2008. Cyclic fine-grained deposits with polymict boulders in Olaijadi member of the Dalmiapuram Formation, Cauvery basin, south India: Plausible causes and sedimentation model. *Journal of Earth Science*, 2: 7–27.
- RAMKUMAR, M. 2015. Toward standardization of terminologies and recognition of chemostratigraphy as a formal stratigraphic method. *In: RAMKUMAR, M., (Ed.), Chemostratigraphy: Concepts, techniques and applications*. 1–21. Elsevier. <http://dx.doi.org/10.1016/B978-0-12-419968-2.00001-7>.
- RAMKUMAR, M. & CHANDRASEKARAN, V.A. 1996. Mega-fauna and environmental conditions of Kallankurichchi Formation (Lower Maestrichtian), Ariyalur Group, Tiruchy district, south India. *Journal of the Geological Association and Research Centre*, 4: 38–45.
- RAMKUMAR, M., STÜBEN, D. & BERNER, Z. 2004a. Lithostratigraphy, depositional history and sea level changes of the Cauvery basin, South India. *Annales Geologiques de la Peninsule Balkanique*, 65: 1–27.
- RAMKUMAR, M., STÜBEN, D., BERNER, Z. & SCHNEIDER, J. 2004b. Geochemical and isotopic anomalies preceding K/T boundary in the Cauvery basin, south India: Implications for the end Cretaceous events. *Current Science*, 87:1738–1747.
- RAMKUMAR, M., SUBRAMANIAN, V. & STÜBEN, D. 2005a. Deltaic sedimentation during Cretaceous Period in the Northern Cauvery basin, South India: Facies architecture, depositional history and sequence stratigraphy. *Journal of the Geological Society of India*, 66: 81–94.
- RAMKUMAR, M., HARTING, M. & STÜBEN, D. 2005b. Barium anomaly preceding K/T boundary: Plausible causes and implications on end Cretaceous events of K/T sections in Cauvery basin (India), Israel, NE-Mexico and Guatemala. *International Journal of Earth Sciences*, 94: 475–489.
- RAMKUMAR, M., STÜBEN, D. & BERNER, Z. 2006. Elemental interrelationships and depositional controls of Barremian–Danian strata of the Cauvery basin, South India: Implications on scales of chemostratigraphic modelling. *Indian Journal of Geochemistry*, 21: 341–367.
- RAMKUMAR, M., ANBARASU, K., SUGANTHA, T., JYOTSANA RAI., SATHISH, G. & SURESH, R. 2010a. Occurrences of KTB exposures and dinosaur nesting site near Sendurai, India: An initial report. *International Journal of Physical Sciences*, 22: 573–584.
- RAMKUMAR, M., BERNER, Z. & STÜBEN, D. 2010b. Hierarchical delineation and multivariate statistical discrimination of chemozones of the Cauvery Basin, south India: Implications on spatio-temporal scales of stratigraphic correlation. *Petroleum Science*, 7: 435–447.
- RAMKUMAR, M., STÜBEN, D., BERNER, Z. & SCHNEIDER, J. 2010c. $^{87}\text{Sr}/^{86}\text{Sr}$ anomalies in Late Cretaceous–Early Tertiary strata of the Cauvery Basin, south India: Constraints on nature and rate of environmental changes across K-T boundary. *Journal of Earth System Sciences*, 119: 1–17.
- RAMKUMAR, M., STÜBEN, D. & BERNER, Z. 2011. Barremian–Danian chemostratigraphic sequences of the Cauvery Basin, India: Implications on scales of stratigraphic correlation. *Gondwana Research*, 19: 291–309.
- RAYMO, E., OPPO, D.W. & CURRY, W. 1997. The mid-Pleistocene climate transition: A deepsea carbon isotopic perspective. *Paleoceanography*, 12: 546–559.
- ROSER, B.P., COOPER, R.A., NATHAN, S. & TULLOCH, A.J. 1996. Reconnaissance sandstone geochemistry, provenance and tectonic setting of the lower Paleozoic terranes of the West Coast and Nelson, New Zealand. *New Zealand Journal of Geology and Geophysics*, 39: 1–16.
- ROSER, B.P. & KORSCH, R.J. 1986. Determination of tectonic setting of sandstone-mudstone suites using SiO_2 content and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio. *Journal of Geology*, 94: 635–650.
- RUBAN, D.A. 2015. Mesozoic long-term eustatic cycles and their uncertain hierarchy. *Geoscience Frontiers*, 6: 503–511.
- Ruban, D.A., Zorina, S.O., Conrad, C.P. & Afanasieva, N.I. 2012. In quest of Paleocene global-scale transgressions and regressions: constraints from a synthesis of regional trends. *Proceedings of the Geologists' Association*, 123: 7–18.
- RUFFEL, A.H. & RAWSON, P.F. 1994. Paleoclimate control on sequence stratigraphic patterns in the Late Jurassic to Mid-Cretaceous, with a case study from eastern England. *Palaeogeography Palaeoclimatology Palaeoecology*, 110: 43–54.
- SANDULLI, R. & RASPINI, A. 2004. Regional to global correlation of lower Cretaceous (Hauterivian–Barremian) shallow-water carbonates of the southern Apennines (Italy) and Dinarides (Montenegro), southern Tethyan margin. *Sedimentary Geology*, 65: 117–153.

- SARG, J.F. 1988. Carbonate sequence stratigraphy. *In: Sea level changes – An integrated approach*. SEPM Special Publication, 42: 155–181.
- SASTRI, V.V., VENKATACHALA, B.S. & NARAYANAN, V. 1981. The evolution of the east coast of India. *Palaeogeography Palaeoclimatology Palaeoecology*, 36: 23–54.
- SHARMA, A. & RAJAMANI, V. 2000. Weathering of gneissic rocks in the upper reaches of Cauvery River, south India: implications to neotectonics of the region. *Chemical Geology*, 166: 203–223.
- SHARMA, A. & RAJAMANI, V. 2001. Weathering of charnockites and sediment production in the catchment area of the Cauvery River, southern India. *Sedimentary Geology*, 43: 169–184.
- SHETH, H.C. 1999. Flood basalts and large igneous provinces from deep mantle plumes: Fact, fiction, and fallacy. *Tectonophysics*, 311: 1–29.
- SHETH, H.C. & CHANDRASHEKARAM, D. 1997. Plume-rift interaction in the Deccan volcanic province. *Physics of the Earth and Planetary Interior*, 99: 179–187.
- SINGH, P. & RAJAMANI, V. 2001. Geochemistry of Kaveri flood plain sediments, southern India. *Journal of Sedimentary Research*, 71: 50–60.
- SOREGHAN, G.S. 1997. Walther's law, climate changes and upper Palaeozoic cyclostratigraphy in the ancestral Rocky mountains. *Journal of Sedimentary Research*, 67: 1002–1004.
- SPALLETTI, L.A., POIRE, D.G., SCHWARZ, E. & VEIGA, G.D. 2001. Sedimentologic and sequence stratigraphic model of a Neocomian marine carbonate-siliciclastic ramp: Neuquen basin, Argentina. *Journal of the South American Earth Sciences*, 14: 609–624.
- SPALLETTI, L.A., QUERALT, I., MATHEOS, S.D., COLOMBO, F. & MAGGI, J. 2008. Sedimentary petrology and geochemistry of siliciclastic rocks from the upper Jurassic Tordillo Formation (Neuquén Basin, western Argentina): Implications for provenance and tectonic setting. *Journal of the South American Earth Sciences*, 25: 440–463.
- Srinivasan, M.S. 1989. Recent advances in Neogene planktonic foraminiferal biostratigraphy, Chemostratigraphy and paleoceanography, Northern Indian Ocean. *Journal of the Palaeontological Society of India*, 34: 1–18.
- STEPHENS, N.P. & SUMNER, D.Y. 2003. Late Devonian carbon isotope stratigraphy and sea level fluctuations, Canning Basin, Western Australia. *Palaeogeography Palaeoclimatology Palaeoecology*, 191: 203–219.
- STRAUSS, H. 1997. The isotopic composition of sedimentary sulphur through time. *Palaeogeography Palaeoclimatology Palaeoecology*, 132: 97–118.
- SUNDARAM, R. & RAO, P.S. 1986. Lithostratigraphy of Cretaceous and Palaeocene rocks of Tiruchirapalli district, Tamil Nadu, South India. *Records of the Geological Survey of India*, 115: 9–23.
- SUNDARAM, R., HENDERSON, R.A., AYYASAMI, K. & STILWELL, J.D. 2001. A lithostratigraphic revision and palaeoenvironmental assessment of the Cretaceous System exposed in the onshore Cauvery Basin, southern India. *Cretaceous Research*, 22: 743–762.
- STÜBEN, D., KRAMAR, U., BERNER, Z., STINNESBECK, W., KELLER, G. & ADATTE, T. 2002. Trace elements, stable isotopes and clay mineralogy of the Elles II K/T boundary section in Tunisia: Indications for sea level fluctuations and primary productivity. *Palaeogeography Palaeoclimatology Palaeoecology*, 178: 321–345.
- TAYLOR, S.R. & MCLENNAN, S.M., 1985. The continental crust; its composition and evolution. *Blackwell, Oxford*, 312 p.
- TEWARI, A., HART, M.B. & WATKINSON, M.P. 1996. A revised lithostratigraphic classification of the Cretaceous rocks of the Trichinopoly district, Cauvery basin, Southeast India. *In: PANDEY, J., AZMI, R.J., BHANDARI A. & DAVE, A. (Eds), Contributions to the XV Indian Colloquium on Micropalaeontology and Stratigraphy*. 789–800.
- TU, T.T.N., BOCHERENS, H., MARIOTTI, A., BAUDIN, F., PONS, D., BROUTIN, J., DERENNE, S. & LARGEAU, C. 1999. Ecological distribution of Cenomanian terrestrial plants based on $\delta^{13}\text{C}/\delta^{12}\text{C}$ ratios. *Palaeogeography Palaeoclimatology Palaeoecology*, 145: 79–93.
- ULIČNÝ, D., JARVIS, I., GRÖCKE, D.R., ČECH, S., LAURIN, J., OLDE, K., TRABUCHO-ALEXANDRE, J., ŠVÁBENICKÁ, L. & PEDENTCHOUK, N. 2014. A high-resolution carbon-isotope record of the Turonian stage correlated to a siliciclastic basin fill: Implications for mid-Cretaceous sea level change. *Palaeogeography Palaeoclimatology Palaeoecology*, 405: 42–58.
- VAIL, P.R., MITCHUM, R.M. & THOMPSON, S. 1977. Seismic stratigraphy and global changes of sea level. Part 4 Global cycles of relative changes of sea level. *In: Payton, C.E. (Ed.), Seismic stratigraphy - Applications to hydrocarbon exploration*, 83–97. *Memoirs of the American Association of Petroleum Geologists*, 26.
- VAKARELOV, B.K., BHATTACHARYA, J.P., & NEBRIGIC, D.D. 2006. Importance of high-frequency tectonic sequences during Greenhouse times of Earth history. *Geology*, 34: 797–800.
- VAN DER MEER, D.G., ZEEBE, R.E., VAN HINSBERGEN, D.J.J., Sluijs, A., Spakman, W. & TORSWIK, T.H. 2014. Plate tectonic controls on atmospheric CO₂ levels since Triassic. www.pnas.org/cgi/doi/10.1073/pnas.1315657111.
- VEIGA, G.D. & SPALLETTI, L.A. 2007. The Upper Jurassic (Kimmeridgian) fluvial–aeolian systems of the southern Neuquén Basin, Argentina. *Gondwana Research*, 11: 286–302.
- VEIGA, G.D., HOWELL, J.A. & STÖRMBACK, A. 2005. Anatomy of a mixed marine–non-marine lowstand wedge in a ramp setting. The record of a Barremian–Aptian complex relative sea-level fall in the central Neuquen Basin, Argentina. *In: VEIGA, G. D., SPALLETTI, L. A., HOWELL, J.A. & SCHWARZ, E. (Eds.), The Neuquen Basin, Argentina: A Case Study in Sequence Stratigraphy and Basin Dynamics*, 139–162. Geological Society of London Special Publication, 252.
- VEIZER, J. 1985. Carbonates and ancient oceans: Isotopic and chemical record on timescales of 10⁷ – 10⁹ years. *In: SUNQUIST, E.T. & BROECKER, W.S. (Eds.), The carbon cycle and*

- atmospheric CO₂: Natural variations - Archaen to Present*, 595–601. American Geophysical Union Monograph, 32.
- VEIZER, J., BRUCKSCHEN, P., PAWELLEK, F., DIENER, A., PODLAHA, O.G., CARDEN, G.A.F., JASPER, T., KORTE, C., STRAUSS, H., AZMY, K. & ALA, D. 1997. Oxygen isotope evolution of Phanerozoic seawater. *Palaeogeography Palaeoclimatology Palaeoecology*, 132: 59–172.
- VEIZER, J., ALA, D. & AZMY, K. 1999. ⁸⁷Sr/⁸⁶Sr, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ evolution of Phanerozoic seawater. *Chemical Geology*, 161: 59–88.
- VEIZER, J., GODDERIS, Y. & FRANCOIS, L.M. 2000. Evidence for decoupling of atmospheric CO₂ and global climate during the Phanerozoic eon. *Nature*, 408: 698–701.
- WALLMANN, K. 2001. Controls on the Cretaceous and Cenozoic evolution of seawater composition, atmospheric CO₂ and climate. *Geochimica et Cosmochimica Acta*, 65: 3005–3025.
- WARZESKI, E.R., CUNNINGHAM, K.J., GINSBURG, R.N., ANDERSON, J.B. & DING, Z. 1996. A Neogene mixed siliciclastic and carbonate foundation for the Quaternary carbonate shelf, Florida Keys. *Journal of Sedimentary Research*, 66: 788–800.
- WATKINSON, M.P., HART, M.B. & JOSHI, A. 2007. Cretaceous tectonostratigraphy and the development of the Cauvery Basin, southeast India. *Petroleum Geoscience*, 13: 181–191.
- WHITFORD, D.J., ALLAN, T.L., ANDREW, A.S., CRAVEN, S.J., HAMILTON, P.J., KORSCH, M.J., TROTTER, J.A. & VALENTI, G.L. 1996. Strontium isotope chronostratigraphy and geochemistry of the Darai limestone: Juha 1 X well, Papua New Guinea. *Proceedings of III PNG convention*. 369–380.
- WILLIAMS, D.F., THUNELL, R.C. & TAPPA, E. 1988. Chronology of the Pleistocene oxygen isotope record 0–1.88 MY BP. *Palaeogeography Palaeoclimatology Palaeoecology*, 64: 221–240.

Резиме

Распознавање између активне тектонике, фаза мировања и циклуса релативног нивоа мора трећег реда у Каувери басену, јужна Индија

Теорија о секвенционом развоју дефинише седиментни систем који се налази под утицајем четири главне промене вредности, а то су тектонско тоњење, глобална еустатичка промена нивоа мора, количина приноса седимената и клима. Узастопна истраживања су показала да поједине седиментне секвенце могу бити повезане са циклусима промена нивоа мора на Миланковићевој скали и то до седмог степена. Ипак, постоје извештаји који документују појављивање седиментних записа типичних за високо фреквентне циклусе који су депоновани под примарном контролом тектонике, мада постоји сумња везана за степен

под којим тектонски покрети могу да имитирају високо фреквентне циклусе. Тако да питање које се односи на значај које имају тектоника и колебања нивоа мора на депозиционе образце остаје тамо где је практично и започето када су предложени концепти секвенционе стратиграфије. Такође се поставља и питање основних принципа у примени секвенционе и хемотратиграфије. Тренутно је од кључног значаја указати на проблем разликовања одвојеног утицаја тектонике и релативног колебања нивоа мора у седиментном запису.

Каувери басен се налази у јужном делу Индијског полуострва и садржи готово комплетан стратиграфски запис за интервал барем–даниан. Досадашњим истраживањима издвојено је шест хемозона које су међусобно раздвојене секвенционим границама типа 1 и осталим површинама које су корелативне са циклусима трећег реда, који се састоје од високофреквентних циклуса са вероватним интервалима од 10⁴ до 10⁶ година. Према томе, Каувери басен може да буде место за тестирање утицаја тектонике и варирања нивоа мора.

Стратиграфски запис је резултат егзогеног система који је подређен геолошким условима, колебањима нивоа мора и променама геохемијских реакција између мора, копна и климе. Узимајући у обзир да је геохемија седимената веродостојан показатељ порекла седимената, тектонских и палеоклиматских услова, овај рад покушава да појасни динамику порекла, тектонских односа и промене нивоа мора у Каувери басену, уз покушај да их расчлани помоћу геохемијских метода. Извршено је систематско картирање у размери 1 : 50 000 које је обављено на десет попречних профила на којима је описано и узорковано 308 локалитета. На свакој локацији и уздуж профила забележене су информације о литофацијама, односи на контактима, седиментационе и тектонске структуре и појављивање заједница мега- и ихнофосила. Укључено је дефинисање типских профила, препознавање секвенционих стратиграфских површина (између седам типова површи) и њихово дефинисање у оквиру секвенционих граница. Након тога је извршено повезивање са неким од четири догађаја циклуса базног нивоа, а затим са било којом од три системске групе (условљена регресија, нормална регресија и трансгресија).

Овако развијен секвенциони модел је раније представљен. На основу теренских података начињен је целовит стратиграфски профил баремско-данских творевина што је омогућило избор 157 узорака стена за анализу састава ретких елемената. Од поменутих 157 проба, 70 је издвојено ради даље анализе путем ХРФ за одредивање састава главних елемената. Такође су извршене и петрографска и минералозна анализа на 157 проба, а на 70 извршена је анализа минералног састава глина. Геохемијски подаци су разматрани заједно са страти-

графским варијацијама, затим су приказани на успостављеним дијаграмима разврставања, узимајући у обзир услове површинског raspadaња што је све заједно потврдило главне геолошке догађаје.

Поређење свих ових података као и публиковани радови дозвољавају да се ове промене објасне пореклом, тектонским условима и колебањем нивоа мора, а такође је интерпретиран и продискутован и релативни утицај различитих процеса. Резултати показују да је депозициони систем Куавери басена био под доминантним утицајем колебања нивоа мора узрокованог климом, упркос значајним периодичним кретањима раседнутих блокова. Неколико раседних тектонских покрета временски се поклапају са секвенционим границама (током барема, апт–алба, конијак–сантона, мастрихт–даниана) и могли су допринети поремећају циклуса нивоа мора.

Подаци изнешени овом приликом подржавају утицај тектонике на развој циклуса трећег реда депозиционог система. Учесталост механичког raspadaња, занемарљиво хемијско raspadaње матичних стена на шта указује незрелост текстура, појаве високофреквентних циклуса у баремско–конијакским наслагама које су прошле кроз синдепозиционе тектонске догађаје као и постојаност стабилности средине током периода тектонског мировања (кампан–даниан) заједно потврђују главну улогу климе у колебању релативног нивоа мора. Иако појаве узастопне прераде седимената указују на низак степен тоњења, учесталост незрелости текстура и механичка ерозија могу означавати динамичну природу тектонских процеса и постојање уравнотежене промене еустатичког нивоа мора услед тектонских догађаја.

Б. Р.

Plate 1

- Fig. 1. Intensively fractured and weathered nature of the basement rock. All along the basin margin, the basement rocks located in the vicinity of the F1 fault lines (Fig. 1) show such characteristics. Location of the photograph: Near Kalpalayam village north of Uttatur.
- Fig. 2. Lithoclastic conglomerates of the Sivaganga Formation containing angular, cobble-boulder sized basement clasts. Note the random orientation and fresh nature of the clasts and the unsorted calcareous matrix with fossil fragments.
- Fig. 3. Large (>2 m dia) boulders found embedded in the Olaijadi member. The boulders are of basement rocks (dark grey colored boulder at the bottom right of the photograph) and typical coral reef limestones (light yellowish pink colored boulder at the bottom centre of the photograph) and show angular nature. Angular nature of the clasts suggests little or no significant transportation. Fresh nature of these clasts suggests mechanical erosion, rapid transport, immediate burial and faster rate of deposition. These are embedded in parallel bedded Bouma sequences. The bedding planes of individual Bouma sequences follow the periphery of these large clasts and suggest syndepositional tectonic activity and erosion of basement as well as former marine regions. Location of the photograph: Quarry section located near Tirupattur.
- Fig. 4. Field photograph showing large (>10 m dia) angular limestone boulder embedded in the Bouma sequences. Note that the bedding planes of the Bouma sequences follow the boundary surface of the clast signifying syndepositional tectonic event that might have eroded the coral reef located at fault margin en masse and dumped it at the adjacently located deeper regions of the basin wherein typical Bouma sequences were being deposited under the influence of turbidity currents. Location of the photograph: Quarry section located near Tirupattur.
- Fig. 5. Close-up view of the coralalgal reef facies limestone boulder found embedded in the Bouma sequences. It is to be noted that these constitute typical reef-core and are not at all found anywhere in the basin, signifying, their development only in the former offshore regions of the paleo-sea, complete denudation during the syndepositional tectonic movements.
- Fig. 6. Erosional and angular unconformity surface contact between the Odiyam sandyclay member (Early Turonian) of the Karai Formation and the Varakuppai member (Santonian) of the Sillakkudi Formation (Santonian) exposed at northwest of Varakuppai Village. The intervening Garudamangalam Formation is entirely either eroded and or missing. The major faulting across Coniacian-Santonian had brought down the previously positive areas under the influence of marine forces and the event was accompanied by intense erosion of continental and former offshore regions alike.
- Fig. 7. The major faulting event was associated with the development of major fluvial channels that debouched at the fault margin coastlines of paleo-sea. The field photograph showing the development of climbing ripples consisting of large angular-subangular basement clasts and lithoclasts of older sedimentary rocks and unsorted granule-very coarse sand matrix. Location of the Photograph: Northwest of Varakuppai Village.
- Fig. 8. Close-up view of the previous photograph showing the occurrences of recycled pebble-gravel sized clasts with angular and sub-rounded nature. Many a times, they show reverse grading, suggestive of increase in energy conditions, perhaps associated with syndepositional seismicity (aftershocks?).
- Fig. 9. Field photograph showing the erosional offlap contact between Odiyam sandyclay member of the Karai Formation and the Sadurbagam member of the Sillakkudi Formation. The Sadurbagam member was deposited under middle shelf conditions and its occurrence over the Karai Formation signifies, differential depositional topography created by the faulting event and return of sea level fluctuation controlled depositional pattern after major faulting event and fluvial deposition.
- Fig. 10. Field photograph showing the erosional contact between Varanavasi member of the Sillakkudi Formation and Kallar member of the Kallankurichchi Formation. In addition, the beds on both the sides show parallel bedding, signifying simple sea level fall and rise across this boundary. Location of the photograph: Kallar river section near Tancem quarry I.
- Fig. 11. Field photograph showing conformable offlap between the Srinivasapuram member of the Kallankurichchi Formation and the Kallamedu Formation. Though conformable, the depositional topography might have been variable due to the development of shallow ephemeral river channels that cut through paleosurface and over flown frequently. Location of the photograph: Quarry section located southeast of Kallankurichchi Village.
- Fig. 12. Field photograph showing the alternate cyclic development of Marl-Limestone couplets of Periyakurichchi member of Niniyur Formation as a result of high-frequency sea level cycles during Danian. Location of the Photograph: Quarry section located north of Periyakurichchi Village.

