Геолошки анали Балканскога полуострва Annales Géologiques de la Péninsule Balkanique	67	35–40	Београд, децембар 2006 Belgrade, December 2006

A storm event during the Maastrichtian in the Cauvery basin, south India

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Abstract. Sedimentary structures in the Kallankurichchi Formation of the Ariyalur Group, South India have been examined with a view of assessing the depositional setting of these rocks. Of the different sedimentary structures, such as cross bedding, cut and fill, etc., hummocky cross stratification is significant as it resulted from a major storm event. This paper deals with the recognized sedimentary structures, their genesis and environmental implications.

Key words: storm event, Maastrichtian, Kallankurichchi Formation, Ariyalur Group, South India.

Апстракт. Седиментне структуре формације Каланкуричи, Аријалур група, јужна Индија, проучаване су ради утврђивања депозиционог простора тих стена. Међу различитим седиментним структурама, као што су укрштена слојевитост, структура спирања итд., брежуљкаста коса слојевитост је значајна као последица деловања снажне олује. У овом раду се говори о утврђеним седиментним структурама, њиховом пореклу и утицајима на депозициону средину.

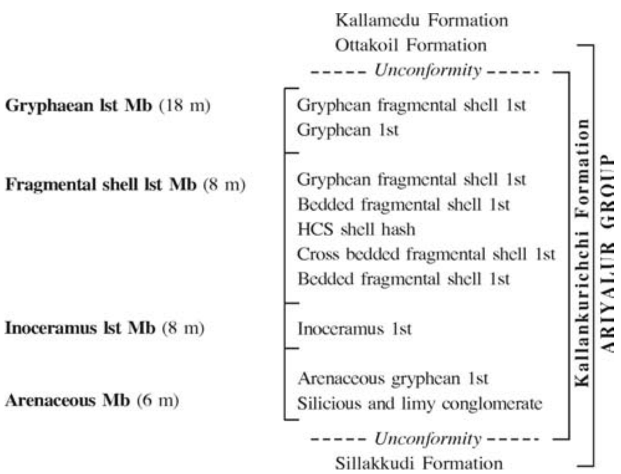
Кључне речи: утицај олуја, мастрихт, Каланкуричи формација, Аријалар група, јужна Индија.

Introduction

Sedimentary structures play a vital role in the interpretation of depositional conditions and hence an attempt was made to understand the depositional environment of the Kallankurichchi Formation of the Ariyalur Group, Tamil Nadu based on its sedimentary structures. The study area is situated east of the town Ariyalur and forms a part of the Kallankurichchi Formation (Fig. 1). The general stratigraphic setup is as follows (after Sastry *et al*., 1968; Chandrasekaran & Ramkumar, 1995).

	Age	Formation	Gross Lithology
Ariyalur Group	Maastrichtian	Kallamedu Formation	Sandstone
		Ottakoil Formation	Sandstone
		Kallankurichchi Formation	Limestone
		----- *Unconformity* -----	
	Campanian	Sillakkudi Formation	Sandstone
		----- *Unconformity* -----	
		Trichinopoly Group	

In the study area, the Kallankurichchi Formation is a prominent carbonate unit and is exposed as isolated outcrops (Guha & Senthilnathan, 1990). The formation is 40 m thick and has N–S extension of 35 kilometers with a width varying from 500–3500 m. Based on the faunal composition, Maastrichtian age has been assigned by Sastry *et al*. (1972) and later refined to Lower Maastrichtian by Ramamoorthy (1991) & Radulović and Ramamoorthy (1992). Hart *et al*. (2000) speculated the commencement of the deposition of this formation during the late Campanian–Earliest Maastrichtian. The generalized lithological succession of this formation was provided by Ramkumar (1999) and is presented herein.



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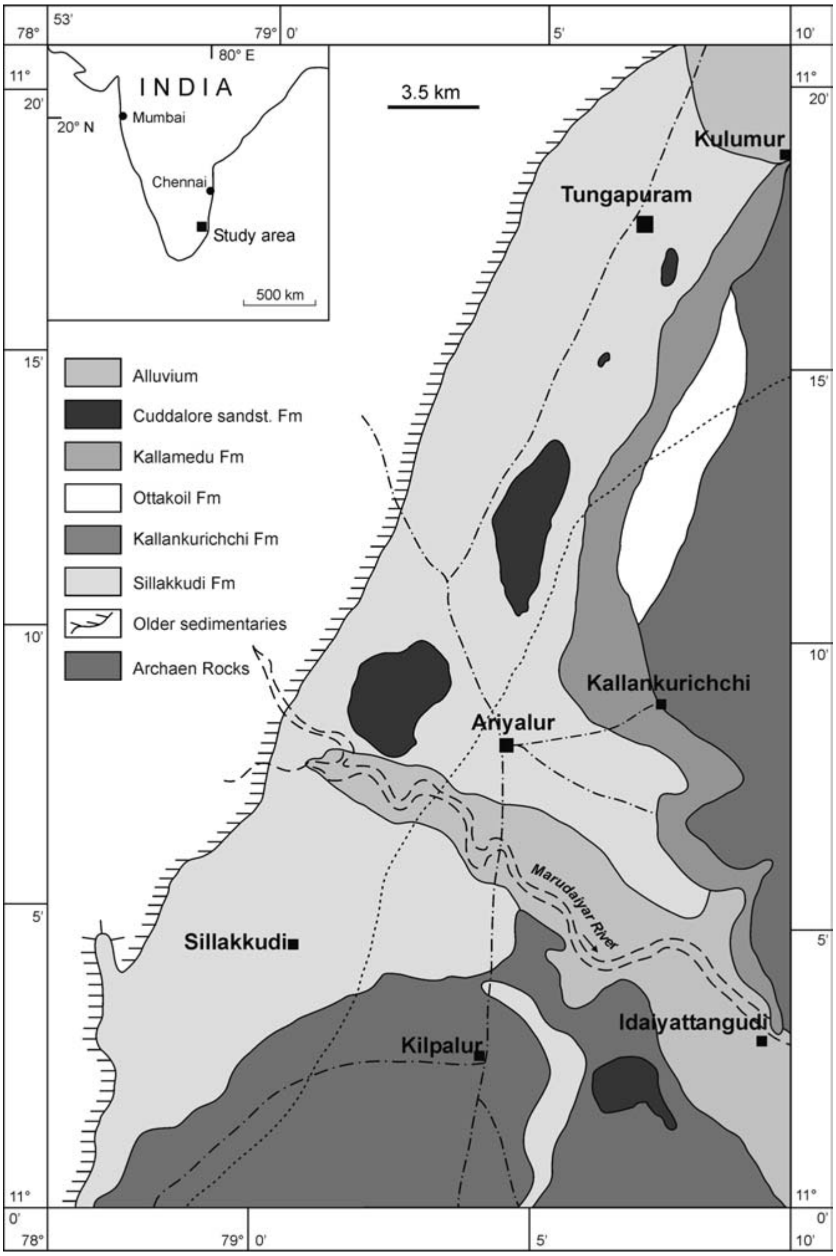

Fig. 1. Location map of the study area

The Kallankurichchi Formation commenced with a transgression during the Latest Campanian–Early Maastrichtian (HART *et al.*, 2000). Towards the top, the conglomeratic deposits show a reduction in proportion and size of siliciclastics which were increasingly replaced by gryphean colonies. In due course, the gryphean bank shifted towards shallower regions and the locations previously occupied by coastal conglomerate become middle shelf, wherein typical inoceramus limestone started developing. The break in the sedimentation of inoceramus limestone was associated with a regression of the sea level, resulting in the erosion of shell banks and middle shelf deposits and their redeposition into biostromal deposits. Again the sea level rose to create a marine flooding surface, as a result of which gryphaean shell banks started developing more widely than before. Towards the top, shell fragments and minor amounts of siliciclastics are observed, indicating the onset of regression and higher energy conditions. The occurrence of a non-depositional surface at the top of this formation and the deposition of shallow marine siliciclastics (Ottakoil Formation) immediately over the carbonates and a conformable offlap of much younger fluvial sand deposits (Kallamedu Formation) are all suggestive of a gradual regression associated with the establishment of a fluvial system during the end of the Cretaceous.

The rocks of this formation consist predominantly of skeletal limestones and fragmental limestones analogous to the bank and bank-derived materials of NELSON *et al*. (1962). They contain whole shells and bioclasts of mollusca, bryozoa, foraminifera, brachiopoda, echinodermata, ostracoda and algae. Minor to significant amounts of peloid, quartz, lithoclasts and intraclasts are also observed. The six standard types of microfacies of WILSON (1975) are recognized from this formation (RAMKUMAR, 1995) and interpreted to have been deposited in a distally steepened carbonate ramp setting (RAMKUMAR, 1999). The depositional history of this formation was elucidated by RAMKUMAR (1995, 1999) and a brief note of it is presented herein.

Sedimentary structures

Cross Bedding

Tabular cross bedding is a common in fragmental limestone. The maximum thickness of the cross bedded unit is of the order of 1.8 meters. Due to the presence of shell fragments, the foreset beds do not exhibit well defined layers in the vertical section. However, they do appear as uniform layers on the surface (Fig. 2A). The cross bedding structure is found in a limited region within finely fragmented limestone and can be seen in the southwest wall of mine pit I of the Tancem mine (located west of Kallankurichchi Village and north of the Ariyalur–Kallankurichchi road – Fig. 1). This cross bedded unit can be termed as large scale cross bedding (REINECK & SINGH, 1986). The individual laminae have a more or less uniform thickness varying from 1.5–2.3 cm. The bounding surfaces of the foresets are sharp. The individual laminae can be traced throughout the length. The grains are well sorted irrespective of the nature of the clasts. High roundness is observed in both the bioclasts and peloids. Since this unit is bounded by bank deposits, the cross bedded deposits can be described as large underwater sand dunes developed in the shelf region which might have originated by shoaling waves (Chakraborty, personal communication). Like the carbonate sequence of the Middle Eocene of Peninsular Florida, described by RANDAZZO *et al*. (1990), this cross bedded unit also has abundant burrows.

Cut-and-Fill Structure

Cut-and-fill structures characterized by a shallow concave base and a flat top are common. These are observed in the Tancem mine I along the SW wall of bench I (located west of Kallankurichchi Village and north of the Ariyalur–Kallankurichchi road – Fig. 1). These have a maximum length of 150 cm and a height of 20 cm. These structures occur above the cross bedded strata and form the base of the hummocky cross bedding. The channel fill material does not show any cross bedding and the channels are filled up with fining upwards coarse grained carbonate sand. This carbonate sand consists of minor amounts of intraclasts, ferruginous matrix and fine quartz sand. These channel-fill structures gradually merge into hummocky cross stratification (HCS).

Hummocky Cross Stratification

Hummocky cross bedding is found near the location where cut-and-fill structures predominate. Its characteristics are described herein.

a. The laminae are curved both in hummocks (convex up) and swales (concave up) sectors.
b. The laminations dip at 12°; but the bed sets appear to meet at very low angles in such a way that, at times, they are parallel to the lower bounding surface.
c. Individual laminae have a maximum thickness of 4 cm at swales and 1.8 cm at hummocks, reflective of a thickening (at swales) and a thinning (at hummocks) nature. Maximum wave height is 97 cm and wave length 6 meters.
d. The laminations show no preferred orientation.
e. The rocks showing HCS structures are composed of polished fragmental shells (Fig. 2B, C). These are sandwiched between normal bedded and cross bedded carbonate sand. The upper contact of the hummocky cross stratification unit is also sharp.

Hummocky cross stratification is commonly associated with storm deposits ("Tempstites" of AGER, 1973; KREISA & BAMBACH, 1982; LOOPE & WATKINS, 1989; MENG *et al*., 1997). It is observed on the continental shelf of the northwest Atlantic Ocean in water depths of 10–40 meters. It is also found in tidal flats (MUKHERJEE *et al.,* 1987; WEIDONG *et al.,* 1997). It has been reported from clastic sediments (Bose *et al.,* 1997), as well as from carbonate skeletal deposits (MENG *et al*., 1997; WEIDONG *et al*., 1997). The HCS is interpreted as being due to a combination of storm generated and geostrophic currents (SWIFT *et al*., 1983).

In the present area, reworked autochtonous fauna in the HCS with little lateral variation of texture and structures are found to occur. This suggests that this particular unit of the Kallankurichchi Formation did not receive material from distant sources during the storm. The absence of whole unabraded, well marked layering, edge-polished shell fragments of fossils (Fig. 2B, C), in addition to the occurrence of storm deposits as a single thick unit, etc., suggest that the prevalent major storm might have mobilized already deposited sediments on the bottoms (MENG *et al*., 1997; KROH & NEBELSICK, 2003). According to the descriptions of AIGNER (1982) and AIGNER & REINECK (1982), the exposures of HCS at Tancem mine I SW wall bench I represent a proximal storm bed in view of the following characteristics.

a. This storm depositional unit is a very thick bed.
b. The beds are composite and intermixed with various bedforms and materials.
c. It is composed of bioclasts which are coarse grained (Gravel to coarse sand).

These characteristics of this sequence are spread over short distances and die out towards the east where the size of the bioclasts decreases. Further east, thinly bedded, mud dominated rocks with unabraded fossils are observed, which may represent the distal end of storm beds (TUCKER & WRIGHT, 1990). BOUOUGRI & PORADA (2002) and MENG *et al*. (1997) also observed the deposition of mud and finer grain rich deposits after major storm event in the Neoproterozoic deposits of Morocco. As has been observed in storm associated deposits elsewhere (MENG *et al*., 1997; SAVRDA & NANSON, 2004), due to the reduction of intensity of the storm, the finer grade materials also started to settle and hence, this sequence shows fining upward gradation from gravel to sand. The grains were carried and settled from a suspension cloud. These interpretations are supported by the horizontality of platy shell material with reference to the original sedimentation surfaces. Comparison of these characteristics based on the criteria enlisted by GOFF *et al*. (2004) clearly affirms the storm generated nature to these deposits. This type of typical storm deposit and its distal expression (MARTINI & BANKS, 1989) are interpreted to be of inner and

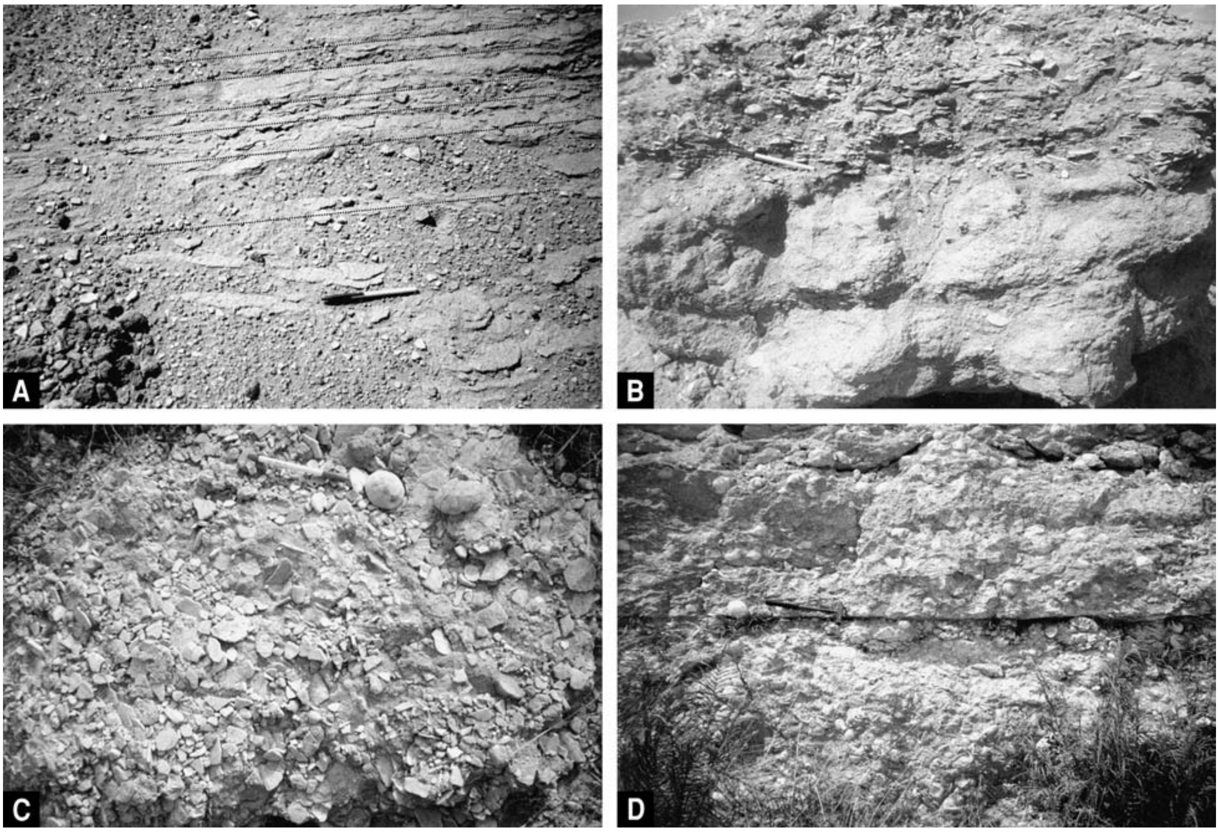

Fig. 2. **A**, Field photograph of planar cross bedded limestone exposed in a mine floor. Due to low dip and planar bedding, the exposure at the mine floor depicts only feeble bedding planes, indicated by dashed lines; **B**, Field photograph showing the nature of the HCS sequence in a mine section. The shoal facies is superposed by HCS beds. Note the sudden change from shoal facies limestone (lower) to edge polished fragmental limestone (HCS bed) as reflected by the sudden change in skeletal composition. Differential compaction of the shoal facies limestone and the HCS limestone has obliterated the sharp erosional bedding plane (indicated by pen in the photograph) between these two units; **C**, Close-up view of the HCS bed showing fragmented and rounded shell material. Also note the presence of Stigmatophygus in life position (indicated by pen in the photograph); **D**, Typical gryphean limestone deposit of the Kallankurichchi Formation. Occurrence of these gryphean colonies over the HCS unit denotes the return of normal depositional conditions after a major storm event.

middle shelf in origin respectively (DROSER & BOTTJER, 1988; BURCHELL *et al*., 1990).

Since the storm bed with HCS is found to occur in between normal bedded and cross bedded deposits, the energy of the shoaling waves is presumed to have been short lived. The gradual change of the storm beds to cross bedded, well sorted carbonate sands is indicative of the waning period of the storm. The escape structure in a 'V'-shaped burrow at the base of the storm deposit (HECKEL, 1972) suggests the sudden appearance of storms. Oyster beds above the bedded and cross bedded carbonate deposits suggest that the colonization of oysters (Fig. 2D) started after the major storm event.

Conclusion

From the nature and sequence of the sedimentary structures, particularly the hummocky cross beds, it can be concluded that during the deposition of the Kallankurichchi Formation, there were storm events, which contributed to the continuous and homogenous deposition of bank deposits and middle shelf deposits. The intensity of the storm event was very high in the deposition of 1.8 meters thick fragmental shell beds. From the change in the nature of sediments within the storm bed, an easterly storm condition has been inferred. The storm deposits of the Kallankurichchi Formation show similarities in broader terms with that of the Cretaceous Mzamba Formation of South Africa, as reported by LIU & GREYLING (1996).

Acknowledgement

Prof. A. CHAKRABORTY, Department of Geology and Geophysics, IIT-Kharagpur is thanked for reading an earlier version of this manuscript. Prof. P.K. SARASWATI and Prof. H.S. PAN-

DALAI, Head, Department of Earth Sciences, IIT-Bombay, are thanked for the laboratory facilities, as well as academic and administrative support. Anonymous reviewers are thanked for critical suggestions and modifications that have helped the author to improve the manuscript.

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Резиме

Олујна појава за време мастрихта у басену Каувери, јужна Индија

Кречњачке наслаге формације Каланкуричи, Аријалур групе у јужној Индији, садрже карактеристичну асоцијацију седиментних структура ограничених на одређену област у близини села Каланкуричи. Како су седиментне структуре битне за тумачење палеосредине, учињен је покушај да се упознају главни услови таложења, а тиме се дошло и до доказа појава снажне олује током мастрихта у басену Каувери у јужној Индији.

Формација Каланкуручи се састоји претежно од скелетних кречњака и фрагментарних кречњака што одговара обалским и пореклом обалским материјалима. Запажене су мање до знатне количине пелоида, кварца, литокласта и интракласта. Утврђено је шест стандардних типова микрофација ове формације и њихово таложење у средини доњег краја стрме карбонатне рампе.

Табуларна коса слојевитост је честа код слојева поломљених кречњака формације Каланкуручи. Максималне дебљина косо услојених кречњака је реда 1,8 метара. Због присуства одломака шкољака, коси слојеви не показују јасно дефинисане слојеве у вертикалном профилу. Међутим, на површини слојеви изгледају уједначено. Ова косо услојена јединица се може узети да представља косу услојеност већих размера. Како је ова јединица ограничена обалским наслагама, косо услојене наслаге се могу описати као подводне велике пешчане дине највероватније формиране таласима у области оплићалог шелфа.

Структуре спирања (накнадно запуњене вододерине) су честе у проучаваној области и карактеришу се плитком конкавном основом и заравњеним врхом. Те структуре се јављају изнад укрштених слојева и формирају основу брежуљкасте слојевитости. Материјал и испуне вододерина не показују никакву косу слојевитост, већ су вододерине испуњене крупнозрним карбонатним песком који се навише уситњава. Те структуре спирања постепено прелазе у брежуљкасту косу стратификацију (БКС).

На брежуљкасту косу слојевитост се наилази у близини места где преовлађују структуре спирања. Брежуљкаста коса стратификација се обично доводи у везу са олујним наносима. БКС се објашњава да потиче од комбинованог дејства олујне и геострофне струје. Сада су у тој области нађене појаве преталожене аутохтоне фауне у БКС са малом бочном разликом у структури и текстури. Та структура указује да за време олује није стигао материјал са веће удаљености нарочито у ову јединицу формације Каланкуричи. Одсуство читавих, изражено слојевитих, фрагмената фосила школьки углачаних ивица поред појаве олујних наслага у виду једне дебеле јединице и друго указује да је доминантна, већа олуја можда покренула седименте већ наталожене на дну. На основу тога што је појава олујног слоја са БКС нађена између нормално услојених и косо услојених наслага, претпоставља се да је енергија таласа у оплићалој средини кратко трајала. Постепени прелаз олујних слојева у косо услојене наслаге, добро сортирани карбонатни пескови, указују на период слабљења олује. Структура испирања у бразди у облику слова "V" у бази олујне наслаге указује на наглу појаву олуја. Слојеви острига изнад слојевитих и косо услојених карбонатних наслага указују да је колонизација острига почела пре главне олује.

На основу природе и секвенце седиментних структура, нарочито брежуљкасто-косих слојева, може се закључити да су се за време таложења Каланкуричи формације јављале олује које су допринеле сталном и уједначеном таложењу обаских наслага и наслага средњег шелфа. Олује су биле врло великог интензитета кад су се наталожили слојеви одломака школьки дебљине 1,8 метара. Из промене природе седимената унутар олујног слоја закључује се да је олују стварао источни ветар. Олујне наслаге формације Каланкуричи показују сличност у ширем смислу са кредним олујним наслагама формације Мзамба у Јужној Африци.