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LITHOSTRATIGRAPHY, DEPOSITIONAL HISTORY AND CONSTRAINTS ON SEQUENCE STRATIGRAPHY OF THE KALLANKURICHCHI FORMATION (LOWER MAASTRICHTIAN) ARIYALUR GROUP, SOUTH INDIA

by

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The Kallankurichchi Formation of Ariyalur Group, South India has rich assemblage of micro, mega and ichno fauna and limited floral remains that enabled to establish biostratigraphic units and zones. As for as the lithologic documentation is concerned, this formation lacks such lucid publications. A collective analysis of lithic characteristics, their stratigraphic relationships, field and petrographic observations, sedimentary structures and fossils have enabled recognising five major lithologic types and transitionary varieties. They are grouped into four members viz., Arenaceous Member, Inoceramus limestone Member, Fragmental shell limestone Member and Gryphean limestone Member. Following the North American Stratigraphic Code (1983) and the keys and guidelines given by Eysinga (1970), systematic stratigraphy of these members is presented. On construction of detailed stratigraphic succession and analysing it with established depositional model, sequence stratigraphical constraints have been evolved and are presented in this paper.

Key words: Kallankurichchi Formation, Lower Maastrichtian, lithostratigraphy, depositional history, sea level changes, high resolution sequence stratigraphy, South India.

ЛИТОСТРАТИГРАФИЈА, ДЕПОЗИЦИОИА ИСТОРИЈА И ПРИМЕНА ОГРАНИЧЕНЕ СЕКВЕНЦИОНЕ СТРАТИГРАФИЈЕ ИА ФОРМАЦИЈУ КАЛАИКУРИЧИ (ДОЊИ МАСТРИХТ) ГРУПЕ АРИЈАЛУР, ЈУЖИА ИНДИЈА

Формација Калаикуричи групе Аријалур из јужне Индије садржи богату асоцијацију микро, макро и ихнофауне као и ређе биљне остатке, што омогућава установљавање биостратиграфских јединица и зона. О овој формацији недостају одговарајуће публикације када је у питању њена литолошка документација. Целокупна анализа литолошких карактеристика, њених стратиграфских односа, теренских и петрографских осматрања, седиментних структура и фосила, омогућила је да се у наведеној формацији издвоји пет главних литолошких типова и прелазних варијетета. Они су груписани у четири члана: песковити члан, члан иноцерамуског кречњака, члан кречњака са одломцима љуштура и члан грифејског кречњака. У складу са North American Stratigraphic Code (1983), упутствима и решењима које је дао

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Eysinga (1970) приказана је систематска стратиграфија тих чланова. У раду је приказана примена ограничене секвенционе стратиграфије што је остварено на основу конструкције детаљне стратиграфске сукцесије и њене анализе са установљеним депозиционим моделом.

Кључне речи: Формација Каланкуричи, доњи мастрихт, литостратиграфија, депозициона историја, колебање нивоа мора, секвенциона стратиграфија високе резолуције, јужна Индија.

INTRODUCTION

The Kallankurichchi Formation of Ariyalur Group, South India has been studied extensively in terms of its fossil content. Rich and diversified fossil assemblage of this formation led to the establishment of biostratigraphy and faunal zones. However, published data are limited on its lithologic characteristics. This paper deals with recognition of various lithounits, their extent etc., and their imlications on depositional environments and finally sequence stratigraphy.

PREVIOUS STUDY

The Kallankurichchi Formation consists of different limestone units, first described by Blanford (1962) as Inoceramus grit and Chokkanadhapuram Orbitoidal limestone. Its rich assemblage of fossils than any other litho unit of Upper Cretaceous deposits (Bhatia, 1984) of South India attracted the attention of geologists viz., Rao (1956; Foraminifera), Banerji (1972; Foraminifera), Govindhan (1977; Foraminifera), Sastry et al. (1977; Foraminifera and Palynofossils), Chiplonkar & Tapaswi (1979; Inoceramids), Guha (1980, 1987; Bryozoa), Guha & Senthil Nathan (1990; Bryozoa), Rasheed & Ravindran (1980; Foraminifera), Bhatia (1984; Ostracoda), Ayyasamy (1990; Ammonite), Ramamoorthy (1991; Brachiopoda), and Radulović & Ramamoorthy (1992; Brachiopoda). All these workers have paid attention towards biostratigraphy or recording occurrence of various taxa. Other studies carried out based on faunal characteristics of the formation are by Mitrović–Petrović & Ramamoorthy (1992; Functional morphology of *Stigmatophygus elatus* and its ecological adaptation), Chandrasekaran & Ramkumar (1994; Trace fossil and depositionaal environment) and Ramkumar & Chandrasekaran (1996a; Megafaunal assemblage and depositional environments). The sedimentologic and environmental interpretations of this formation was pioneered by Sastry et al. (1972), Nair (1974, 1978) and Sundaram (1977). Recent studies include elemental geochemistry (Ramkumar, 1996a) stable isotopes (Ramkumar et al. 1996), microfacies analysis (Ramkumar, 1998a), diagenesis (Ramkumar, 1998b) and sedimentary structures (Ramkumar, 1996b and 1998c).

From the foregoing review, it is evident that, most of the publications on this formation have had their concentration on paleontology and ecology and only recently, petrographic and geochemical characteristics are being documented. However, a detailed lithologic description that is prerequisite for any geological investigation is found to be lacking in the literature. In the absence of such detailed lithologic characterisation, the workers of this field often informally describe lithounits with loose terms viz., Gryphea bed (Rasheed & Ravindran, 1980), Periyanagalur limestone (Subbaraman, 1974), Reddipalaiyam limestone (Nagaraja & Gowda, 1976), Srinivasapuram limestone (Mallikarjun, 1992) and Maastrichtian horizon of Upper Ariyalur Group (Guha, 1987). These only imply different beds of Kallankurichchi Formation; but use various informal terminologies. Using varied terminologies introduce misidentifications and render difficulties while correlating them with equivalent sequences elsewhere.

GEOLOGIC SETTING

The Kallankurichchi Formation unconformably overlain the Sillakkudi Formation and underlain by Ottakoil and Kallamedu formations (Fig. 1). The general stratigraphic setup of the area (Table 1) is as follows (after Sastry et al. 1972 and Chandrasekaran & Ramkumar, 1995).

Table 1. – Табела 1.

Group (група)	**Age** (старост)	**Formation** (формација)	**Lithology** (литологија)
Ariyalur Group	Maastrichtian	Kallamedu Formation	Sandsotne
		Ottakoil Formation	Sandstone
		Kallankurichchi Formation	Limestone
		--------------U.C.-------------------	
	Campanian	Sillakkudi Formation	Sandstone
		--------------U.C.-------------------	
		Trichinopoly Group	

The formation is assigned to Maastrichtian age on the basis of occurrence of *Orbitoides* (Sastry et al., 1972) and later precised into Lower Maastrichtian by Ramamoorthy (1991) and Radulovic & Ramamoorthy (1992). Exposed portion of this formation extends roughly N–S about 35 kilometers and dips due east. Width varies from 500–3500 meters. Except in few places, the beds are horizontally bedded. Sub-surface extensions (as revealed by bore hole cores collected by ONGC at down south and offshore regions due east) of this formation are also reported by Nair (1978). Thickness of the formation is 40 meters. The present study is confined with exposed part in and around Ariyalur (Fig. 1). These rocks are skeletal limestones and fragmental limestones analogues to bank and bank derived materials of Nelson et al. (1962). They contain bioclasts of mollusca, bryozoa, foraminifera, brachiopoda, echinodermata, ostracoda and algae. Minor to significant amounts of peloid, quartz, lithoclasts and intraclasts are also observed. Other than grains, the rocks consist of mictric matrix and cement spars. Analysis of these rocks with Dunham's (1962) classification modified by Embry & Klovan (1971) shows that these have wide textural spectrum ranging from wackstone to rudstone. On the basis of energy index classification (Plumley et al. 1962), these rocks are inferred to have been deposited under quite to moderate energy conditions with occasional

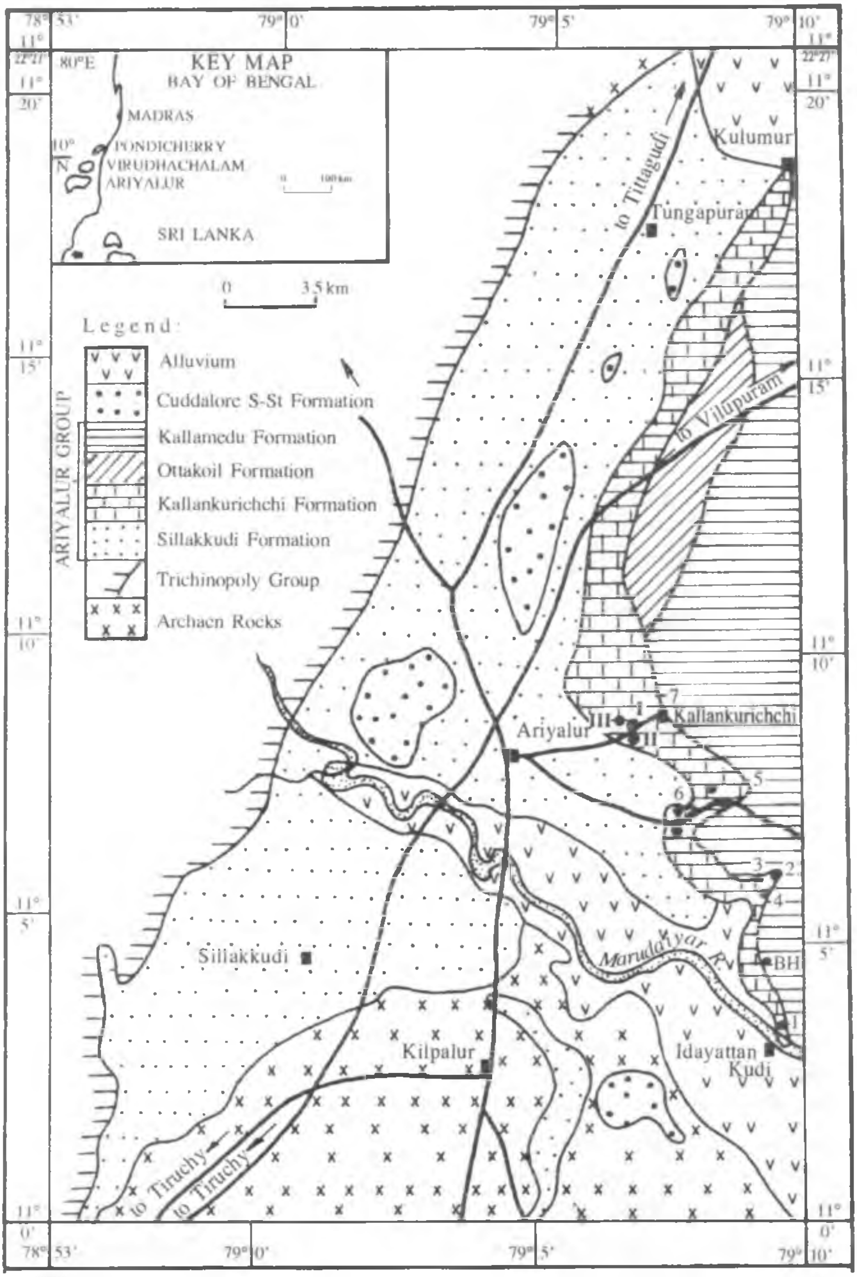

Fig. 1. Distribution of Formations of Ariyalur Group (after Chandrasekaran & Ramkumar, 1995). 1. Dharani Mine, 2. Viscose Mine, 3. Tan–India Mine, 4. Alagappa Mine, 5. Fixit Mine, 6. Tamin Mine, 7. Tancem Mine, • BH – Borehole locations.

Сл. 1. Распрострањење формација групе Аријалур (према Chandrasekaran & Ramkumar, 1995). Рудници: 1. Дарани, 2. Вискозе, 3. Тан–Индија, 4. Алагапа, 5. Фиксит, 6. Тамин, 7. Танцем, • BH – локација бушотина.

high energy conditions. Six standard microfacies types (Wilson, 1975) are recognised from this formation and interpreted to have been depossited in a carbonate ramp setting (Ramkumar, 1998a). Shallow marine, normal saline, warmer, well oxygenated and turbid free water conditions were prevalent during major part of deposition. Deposition took place essentially under photic region.

LITHOLOGY

Initially, a reconnaissance survey had benn conducted with 1:50,000 scale Survey of India toposheets (parts of 58 M/3 and M/4). It was followed by detailed study of the area with 1:10,000 scale base map (prepared by using the instrument Optical Reflecting Projector. 1:50,000 scale toposheet had been enlarged to five times and drawn). Field data, rock samples and fossils were collected from stream and river sections, exposures, well and mine sections. In addition, a set of bore hole core samples for a length of 30.30 meters covering the Kallankurichchi Formation and top portion of Sillakkudi Formation had been collected from Tancem mines core library (location of bore hole is indicated in Fig. 1). Compilation of data from field, paleontologic, megascopic and microscopic study enabled preparation of detailed lithological map. Then the base map with geological information had been reduced with instrument Optical Reflecting Projector and the reduced map is presented in Fig. 1.

This formation is named after Kallankurichchi, an important pilgrimage centre of Tamil Nadu wherein the famous Kaliyuga Shri Varadharaja Perumal Temple is situated. The village is located near the eastern boundary of the formation at about 6 km east of Ariyalur town. In the field, Kallankurichchi Formation is readily recognised by the development of thick kankar beds over its limestone beds (upto 3.5 meters thickness and extending to a length of about a kilometer) and distinct lithologic variation from adjacent formation. The rock types recognised are conglomerate, oyster limestone, inoceramus limestone, fragmental shell limestone and dolomitic limestone. These are described herein.

Conglomerate

The deposition of Kallankurichchi Formation started with conglomerates attaining 4 meters thickness. These are divisible in to two viz., siliceous and limy conglomerates. The silicious conglomerates are recognised by their sugary texture and friable nature. Comparatively these are devoid of any whole mega fossil taxa. These are lenticular in geometry and can be traced up to 100 meters continuously. Good exposures are found to occur in northwestern and middle portions of the study area. The major constituents of this unit are quartz and quartzite grains. Size range from fine sand to gravel. Roundness varies from very angular to sub–angular. Though this is general nature, well rounded monocrystalline quartz sand–pebble are also forming significant proportions. This lithounit is generally unsorted and immature. Matrix is of clay, silt and lime mud in the order of decreasing dominancy. These are loosely packed and cementation had been manifested by calcareous matter. Grains range from 60–90%, matrix 25–30% and cement 0–15%.

Towards south, the quartz conglomerate gradually grade into limy conglomerate showing simple compositional variation. The limy conglomerates are dusty brown to honey yellow coloured owing to the presence of iron oxides. This unit is recognisable in the field by its mottled texture. This consists of boulder to coarse sand sized clastic grains of quartz, quartzite, potash feldspar and few hypersthene. The cresentic shaped impact marks found in coarser clastics of this unit suggest that they have been made during high velocity flows (Canybeare & Crook, 1968). The characteristics feature of this lithounit is the presence of irregular shaped boulders of sandstone of older formation (derived from the Sillakkudi Formation as revealed from megascopic and microscopic study of lithic boulders of this conglomerate and samples from underlying Sillakkudi Formation). It also contains fragments of burrow fills derived from older sedimentaries. Among the grains, fragments of molluscan shells ranging in size from very fine sand to 120 mm are also forming significant proportion. All these bioclasts show evidences of abrasion. The grains are moderately packed. Sorting is poor. The limy conglomerate show distinct size gradation in terms of fining up of sequence. Towards top, among the clastics, increase in percentage of smaller sized grains is observed along with increased roundness. Matrix of this unit is of lime mud, clay and minor amounts of iron oxside patches. Clastic grains range upto 50%, bioclasts 20%, matrix 5–20% and cement 10–15%. However, the percentage of clastics is getting reduced along with increase of bioclast proportion towards top. This unit is devoid of any sedimentary structure except grain size gradation.

The form, extent, geometry, structure and petrographic characteristics of these conglomeratic beds suggest that these are channel deposits and coastal conglomerates (Hart & Plint, 1995). The content of lithic boulders of older sedimentaries and other rocks suggests initial torrential stormy floods that have caused widespread erosion of older formations. The source materials were brought into the depositional site by sudden flooding through suspension cloud and got settled (Ramkumar, 1995).

Oyster limestone

This limestone contains thick walled *Gryphea* that lived in thick population and formed reef like lime body. These are termed as gryphean banks according to Nelson et al. (1962) classification. This is the well developed lithounit of Kallankurichchi Formation. Tipical sections of this unit can be observed in northern and north western walls of Fixit mines and mine III of Tancem mines. The gryphean limestone bed found in lower part of this formation is rich in siliciclastics. It is overlain by succeeding inoceramus limestone and fragmental shell limestone beds. The top portion of Kallankurichchi Formation contains gryphean limestone beds that from 18 meters in thickness. They can be divided into two, namely gryphean limestone bed that contains exclusively gryphea and gryphean limestone bed with other fossils (shells of bryozoa, *Exogyra*, *Alectryonia* and *Terebratula*), fossil fragments, sand–silt sized siliciclastics and fragmental shell limestone patch etc. In all the mapped areas, a distinct, sharp erosional and or non depositional surface is found to separate these two units. The pure gryphean limestone is 10 meters in thickness whereas the other unit ranges upto 8 meters in thickness. This unit is well cemented and shows feeble bedding.

Inoceramus limestone

From Dharani mine in south to Tancem mine II in north, a distinct lithounit that contains exclusively whole shells of large, thick ribbed inoceramus fossils is found to occur. Next to gryphean limestone, this is the well developed whole fossil limestone of this formation. This is lenticular in geometry and the rocks are dusty brown in colour. This has maximum measured thickness of 8 meters at Fixit mines. This unit overlies the gryphean limestone of lower part of Kallankurichchi Formation. It thins down towards north of mine II, Tancem mines and is not met in the regions further north. Matrix is of lime mud. This lithounit is massive and does not shows any primary bedding. This unit shows the development of diagenetic bedding (sensu Bathurst, 1987). Another characteristic of this unit is, its content of clear, vug filling dog tooth spar mosaics occupying the voids of shell chambers and cavities.

Fragmental shell limestone

This is the next dominant limestone in aerial extent. Its maximum thickness is 8 meters. It is underlain by upper gryphean limestone units and overlain inoceramus limestone. The lower contact is very sharp and the upper contact is gradational and/or non depositional. This unit contains fragmented shell materials of *Inoceramus*, *Gryphea*, *Exogyra*, bryozoa, *Stigmatophygus*, *Terebratula* and *Alectryonia* in the order of decreasing dominancy. Sorting is poor and roundness varies from very angular to well rounded. Matrix is composed of fine silt to fine sand sized shell fragments, monocrystalline quartz and minor amounts of clay. Grain size gradation is also observed. *Stigmatophygus* and *Alectryonia* are dominant fossils than any other limestone beds of this formation. The fragmental shell limestone is divisible in to four broad categories viz.,

a. Shell hash – limestone beds that contain gravel sized fragments of *Inoceramus* with poor sorting and limited matrix;
b. Well developed hummocky cross stratified (HCS) beds that contain well rounded shell fragments, whole unabraded fossils of *Stigmatophygus* and internal sedimentary structures viz., channels and escape structures;
c. Well sorted cross bedded coarse sandy limestone beds typical of shoals, and
d. Horizontally bedded, coarse sandy limestone beds that well sorted peloid, ostracod, foraminiferal graistone typical of tidal channels (Wilson, 1975).

The lithological association, composition and intertongueing nature of these units suggests that these have received source materials from adjacent gryphean banks and underlying inoceramus limestone beds.

Dolomitic limestone

Another type of limestone unit that contain abundant thick shelled *Gryphea* and fragmented shells is found to occur only in Viscose mine. It is having maximum length of 800 meters (east – west) and width of 200 meters (north – south). The mine sections situated just north (Tan – India mine) and west (Alagappa mine) of the Viscose mine have not shown any lateral continuity of this unit. This limestone unit is very hard and black in colour. The field characteristics and structural elements suggest that this is gryphean limestone and fragmental shell limestone of Kallankurichchi Formation (Ramkumar, 1995). This particular unit had undergone folding and faulting and experienced semi closed system of diagenesis that had produced dolomitisation (Ramkumar, 1997) and this look like a different type.

SYSTEMATIC STRATIGRAPHY

From the foregoing descriptions, it is clear that though the Kallankurichchi Formation is primarly composed of limestone beds, there are many discrete, mappable and different lithologic types. In this context, it is necessary to group the individual beds and lithologies in to organised manner. For this, widely practiced (stated by Walker, 1995; Tewari et al., 1996) North American Stratigraphic Code (1983) and the keys and guidelines given by Eysinga (1970) have been followed. This led to recognition of four distinct, mappable members viz., Arenaceous member, Inoceramus limestone member, Fragmental shell limestone member and Gryphean limestone member. The names of these members have been assigned to represent their salient features so as to use them with ease moreover to avoid complications/difficulties that may arise by any other nomenclature. Further, it is a practice to name members according to rock types they possess (for example see Ramasamy & Banerji, 1991).

Arenaceous Member

Nomenclature. Newly proposed.

Strato–type. River section located ≈500 meters NE of Idaiyattangudi village – Northern bank of Marudaiyar River.

Geographic extension. This member is best developed is southern region of this formation but traceable elsewhere from south (Idaiyattangudi to North (Kulumur). The basal portion marks the beginning of the Kallankurichchi Formation.

Lithology. Lithologically this member is made up of silicious conglomerate and limy conglomerate that finally grade to arenaceous gryphean limestone without any break in sedimentation. The conglomerates and limestone show typical size gradation in terrigenous clastics and are termed as type II grading/normal grading (Ramkumar, 1998a,b) according to the classification of Pettijohn (1975). The continuous gradation from boulder–cobble–pebble–rudite–arenaceous gryphean limestone is best developed at the type section of this member. It is also noted that each successive reduction of size and amount of terrigenous clastics is equalised by successive increase in bioclasts and whole shells of *Gryphea*. Insitu nature of gryphean shells and absence of abrasion characters in them suggest that though this formation started with sedimentation from suspension cloud, in due course, colonisation of *Gryphea* occurred under favourable conditions.

Contacts. The lower contact is an unconformable one that overlain the Sillakkudi Formation with pronounced erosional surface. Upper side is having non depositional surface contact with inoceramus limestone member. In the field, both these contacts are explicit in view of distinct change in terms of colour, lithology, fossils, sedimentary structures on either sides.

Fossils. The *Orbitoides* and *Siderolites* constitute dominant microfaunal composition whereas *Gryphea* and *Alectryonia* are abundant mega fauna.

Thickness. 6 meters.

Equivalent units from other areas. Based on the study of sub–surface borehole samples, Nair (1974, 1978) reported the conglomerate and arenaceous gryphean limestone from Ayyampettai area that is located ≈50 kilometers down south of Ariyalur town. Examination of borehole core samples recoverd from NE of Dharani mine also reveal their occurrence.

Inoceramus limestone Member

Nomenclature. Newly proposed.

Strato–type. NE wall Bench I (abandoned) of Fixit mine.

Geographic extension. This member is best developed between Dharani mine (south) and Tancem mine II (north). It shows typical lenticular shape and pinching out nature.

Lithology. This member is characterised by dusty brown coloured, friable, thick bedded limestone of uniform composition throughout its lateral and vertical extensions in the exposed area. Distinctly it has thick population of inoceramus shells. Diagenetic bedding present in the rocks readily distinguishes this member in the field. The lenticular, even, parallel and thick – very thick bedded nature suggests that this lithology typically belong to middle shelf deposits (Wilson, 1975; Collinson & Thompson, 1989).

Contacts. Non – depositional surface at its lower contact with arenaceous gryphean limestone. At top, it has highly pronounced erosional surface conctact with overlying fragmental shell limestone member.

Fossils. Except thick population of *Inoceramus*, there seems to be no other mega fossil found to occur. Bryozoan fronds are frequent.

Thickness. 8 meters.

Equivalent units from other areas. It extends towards east and also in sub–surface as revealed by study of borehole core samples recovered from NE of Dharani mine.

Fragmental shell limestone Member

Nomenclature. Newly proposed.

Strato–type. Exposures at mine I Bench I and II (both abandoned) of Tancem mine.

Geographic extension. These are distributed all over the Kallankurichchi Formation and are traced in sub–surface sections also.

Lithology. This member consists of a variety of limestone beds that have fragments of *Inoceramus*, *Gryphea*, *Exogyra*, bryozoa, *Stigmatophygus*, *Terebratula* and *Alectryonia* shells in varying amounts. These develop locally concetrated patches of either one or two types of fossil fragments. All these have had source materials from adjacently located whole fossil limestone beds and are orginated by periodic and long lasted high energy conditions (Ramkumar & Chandrasekaran, 1996a; Ramkumar, 1998c). The Hummocky Cross Stratification (HCS) and associated structures have been studied by Ramkumar & Chandrasekaran (1996b) and reported to have originated as strom deposits associated with sudden fall in sea lavel and erosion of former shelf regions of sea. Periodic movement of coastline towards east and resultant wave and tidal impact over shallow water deposits that had also brought erosion during every initial phase of sea–level fall and resedimentation of eroded materials is suggested as mechanism for genesis of these limestone beds (Ramkumar, 1995, 1998c; Ramkumar & Chandrasekaran, 1996b).

Fossils. In general, these have limited whole, unabraded fossil content. However, local exclusive concentrations of *Gryphea*, *Exogyra*, *Stigmatophygus* and ostracodes are found to occur.

Contacts. The lower contact is always erosional and the upper is represented by non–depositional–gradational and less frequently erosional surfaces.

Thickness. 8 meters.

Equivalent rocks in other areas. These are the fragmental limestone of Nair (1974, 1978) who has reported their occurrence in Ayyampettai and in offshore (sub––surface) regions also.

Gryphean limestone Member

Nomenclature. Newly proposed.

Strato–type. Northern walls of Bench I and II of mine II, Tancem mines.

Geographic extension. Except few places, these are found to occur all over the formation. They occur in sub–surface extensions at in land (Ayyampettai) and offshore regions also (Nair, 1974, 1978).

Lithology. Except in places associated with fragmental shell limestone beds, this member looks homogenous all through its extent. The very thick population of thick shelled gryphea distinctly differentiates this member from other members as well as from other formations. The beds are uniform, parallel, even and thick – very thick bedded characterising shelf deposits. The insitu nature of *Gryphea*, intimate association of bryozoans, intense boring in gryphean shells and micritisation of bioclasts are all suggestive of photic zone of deposition for these beds (Ramkumar, 1996b).

Contacts. The lower contact is non–depositional and at places gradational. Upper contact is unconformable with overlying Ottakoil Formation and offlap of Kallamedu Formation.

Fossils. Thick population of *Gryphea* is discernible all over this member. In addition, negligible to abundant population of bryozoa, foraminifera, red algae, *Alectryonia*, *Terebratula* and *Exogyra* are also present.

Thickness. 18 meters.

Equivalent rocks in other areas. This member is found to occur in all the areas wherein Kallankurichchi Formation is reported.

With all these descriptions, detailed succession is constructed and is given in Table 2.

Table 2. Stratigraphic succesion and contact relationships.
Табела 2. Редослед у стубу и контактни односи.

	Kallamedu Formation		
	Ottakoil Formation		
	-------------Unconformity--------------------		
Gryphean limestone member	Gryphean fragmental shell limestone	} 8m	⇦a
	Gryphean limestone	} 10m	⇦b
Fragmental shell limestone member	Gryphean fragmental shell limestone	} 1m	⇦c
	Bedded fragmental shell limestone	} 1m	⇦d
	HCS shell hash	} 2m	⇦e
	Cross bedded fragmental shell limestone	} 2m	⇦f
	Bedded fragmental shell limestone	} 2m	⇦g
Inoceramus limestone member	Inoceramus limestone	} 8m	⇦h
Arenaceous member	Arenaceous gryphean limestone	} 2m	⇦i
	Silicious and limy conglomerate	} 4m	⇦j
	-------------Unconformity--------------------		
	Sillakkudi Formation		

Legend. a. Non–deposition and erosional surface; b. Non–depositional surface; c. Gradational contact; d.–g. Erosional surface; h. Non–depositional surface; i–j. Gradational contact.

Легенда. a. Ерозиона и површ без депозиције; b. Површ без депозиције; c. Градациони контакт; d.–g. Ерозиона површ; i.–j. Градациони контакт.

DEPOSITIONAL HISTORY

Compilation of data from depositional model (Ramkumar, 1995) and present study have provided newer insights on depositional history of the Kallankurichchi Formation and are presented herein.

Entire deposition of this formation took place in a "*distally steepened ramp*" setting. Depositional environments varied from tidal flat to outer shelf and the sub–surface extensions suggest basinal conditions also. Initiation of deposition of this formation took place with widespread erosion of older sedimentaries and also drew source materials from distally located igneous and metamorphic terrains. This erosional event was followed by the deposition of graded conglomeratic and arenaceous limestone beds. As the intensity of influx of sediment plume reduced, environmental conditions were favourable to support colonisation of *Gryphea* and thus the arenaceous gryphean limestone directly overlies the basal conglomeratic beds without any major break in sedimentation. The arenaceous gryphean limestone is overlain by inoceramus limestone member that is a typical middle shelf deposit (relatively deeper water deposit). Occurrence of it directly over gryphean limestone with non-depositional contact indicate flooding over former shallower regions of shelf and thereby indicate prevalent increase in relative sea-level. It is quite common that there would always be a period of non-deposition soon after increase in relative sea-level (Anderson et al., 1996). This increased sea-level lasted for quite long time and produced 8 meters thick inoceramus limestone member without any break in sedimentation. The highly uniform nature of these beds all through their lateral and vertical extents suggest constant nature of environmental parameters.

Unlike other whole fossil limestone beds of this formation, the inoceramus limestone is devoid of any other fossil taxa except fragments of bryozoan fronds. It is reported that periods of highstands of sea are associated with increase in salinity (Martinsen et al., 1995) and the lowstands seem to develop hypersalinity only when there is no river discharge (Thunell et al., 1988). Since the deposition of inoceramus limestone has been initiated with relative increase in sea-level (thereby waters with high salinity), the *Gryphea* and other stenohaline organisms were not able to keep pace with this higher salinity and is why exclusive occurrence of *Inoceramus* and only a few bryozonas are found to occur in this member. This member is overlain by fragmental shell limestone member with distinct erosional surface contact. Occurrence of fragmental shell limestone beds immediately over inoceramus limestone indicates sudden change in sea-level, possibly lowering (as observed by Grammer et al., 1996 in Paradox basin) that brought the impact of waves and tides over previous below fair-weather wave base (middle shelf) deposits. Occurrence of individual fragmental shell limestone beds that contain exclusively the fragments of inoceramus shells ranging in thickness upto 2 meters give clear evidences for the intensity and duration of prevalent high energy erosional and resedimentation processes that inturn have been brought in to the depositional basin by lowering of sea--level (Ramkumar & Chandrasekaran, 1996b). The statements of Walker (1995) "*extensive erosional surface in a rock unit is a result of relative sea-level fluctuation*" and Heckel (1972) "*it is common that in shallow marine sedimentary environments, frequent changes will result in environmental settings influenced by change in relative sea-level*" are also adding support to this interpretation. During the erosional and redepositional process, tidal channels have been originated (represented by lenticular, peloid ostracod grainstone beds).

Later, in view of effective restriction of influx of terrigenous clastics and lowering the impact of waves and tides towards further east by shoal structures, highly favourable conditions for *Gryphea* had been introduced along with increase of sea-level. Thus, with gradational contact, pure gryphean limestone started developing all over the shelf. The colonisation kept pace with slowly and steadily increased sea-level and is why retrograding (movement of gryphean bank towards shoreline) had occurred (Tewari et al., 1996). These conditions were prevalent for a long time and produced 10 meters thick gryphean limestone bed. Finally, these gryphean banks have reached near shore regions and started receiving higher energy and resultant production of erosional contact and thin patches of fragmental shells. Above this contact, gryphean limestone bed of 8 meters thickness is present. However, mixing og terrigenous clastics and fragmental shell materials were plenty. In addition, wide range of other organisms accompanied grypheans showing open conditions of sea.

Study of structural grains of this area (Sundaram, 1977; Sastry et al., 1977; Prabhakar & Zutshi, 1993; Ramkumar, 1996c, 1997) demonstrated that during deposition of this formation, there has been no any syndepositional tectonic influence that may have caused sinking or any other criteria. By this, it can safely be concluded that sea-level oscillations were the causative mechanisms behind the deposition of different lithologies of this formation. This conclusion is in conformity with views of Sarg (1988) who has reviewed primary controls on carbonate deposition world over.

SEQUENCE STRATIGRAPHY

It is generally accepted and followed fact that the Kallankurichchi Formation, the Ottakoil Formation and the Kallamedu Formation are all deposited during Maastrichtian. The Kallankurichchi Formation has been further specifically designated to Lower Maastrichtian by Radulović & Ramamoorthy (1992). The Ariyalur – Pondicherry depresion of Cauvery Basin has been stated to possess a complete record of marine Maastrichtian (Govindhan & Ravindran, 1996). The biostratigraphic studies have demonstrated that the Kallankurichchi Formation can be grouped as *Hauriceras rembda* ammonite biozone and as *Globotruncana stuartiformis* (Rasheed & Ravindran, 1978) and *Globotruncana gansseri* (Raju, 1995) planktonic foraminiferal zones. Govindhan & Ravindran (1996) have recorded flooding surface at the base of this formation. Under these circumstances, and other technique, if it could provide further insights, would be of high resolution (stratigraphic intervals of fourth order and above) and also would demonstrate its ability to probe microlevel environmental changes.

Since deposition of different and varied lithounits of this formation had resulted by relative sea-level changes, it is found relevant to have insights through sequence stratigraphy. Current research on sedimentary facies development related to sea-level variations focuses on two models – the global sea-level model (GSM) and the sequence stratigraphic model (SSM). The SSM is flexible enough to characterise delicate depositional features and it summarises the stratigraphic architecture of sediments deposited during a sea-level cycle recognising three major facies assemblages grouped in to lowstand, transgressive and highstand systems tracts (Carter et al., 1991). Appraisal of sequence stratigraphic analysis can be best expressed in areas where biostratigraphic and sedimentological characteristics are well constrained (Martinsen et al., 1995).

The sequence boundaries of any given stratigraphic section are selected by analysing outcrop profile and vertical succession of lithofacies (Olsson, 1988; Baum & Vail, 1988) at surface bounded by unconformities and their correlative conformities (Singh & Singh, 1997). The correlative conformities are erosion surfaces, condensed or zero deposition surfaces, firm grounds or hard grounds (Van Wagoner et al., 1990). Table 2 shows that the contact relationships between various lithounits and members barring few, are either erosional or non-depositional that imply the sea-level associated depositional and/or erosional pattern. In view of these factors, it is expected that this formation will serve well to be divided into different systems tracts (sensu – Walker, 1990, 1995).

In terms of changes in relative sea–level, deposition of this formation can be summarised as follows.

Deposition of Kallankurichchi Formation started with major flooding and the sea–level was increasing steadily up to the time of end of deposition of inoceramus limestone. It was followed by sudden lowering of sea–level. Again, another increase of sea–level was introduced leading to deposition of the upper gryphean limestone beds. Steady increase of sea–level during this time has been indicated by retrograding movement of gryphean banks towards land. After a stage, the sea–level started declining which led to the development of fluvio–marine sands and non–marine sands. Thus the sea–level rise, fall, gradual rise and gradual final fall indicate a single cycle of third order (Carter et al., 1991). Sea–level variation of this duration is attributed to eustasy of unknown type according to Vail et al. (1977) and Haq et al. (1987). With in this major cycle, there were many distinct changes that have producted high–resolution sequence boundaries. These boundaries match with the lithostratigraphic boundaries also. Figure 2 illustrates the division of the Kallankurichchi Formation in to various systems tracts.

Figure 2a depicts the transgressive systems tract – represented by initial flooding and gradual increase in sea–level that led to deposition of basal conglomerate, arenaceous gryphean limestone and finally inoceramus limestone without any indication on fall of sea–level. The gradual increase of sea–level has also been substantiated by lack of any erosional except non–depositional surface which in turn indicate prevalent increase of sea–level and resultant non–depositional phase. Similar extensive erosional unconformity ovelain by shallow marine deposit that contain gravel–sand–mud gradation and transported fossils has been interpreted respectively as sequence boundary and transgressive systems tract by Carter et al. (1991). The sudden flooding influenced deposition of conglomerate, slow increase in sea–level causing grypheans to colonise and a non–depositional phase followed by another increased sea–level and its stability to produce uniform beds of inoceramus limestone indicate the fact that normally the periods of rapid rise in sea–level will always be followed by slow rise and stillstand (Anderson et al., 1996).

Figure 2b depicts the lowstand systems tract, which has been brought in to this depositional basin in view of sudden lowering of sea–level. This event represents *type I Exxon Sequence Boundary* that had been created by fall of sea–level beneath contemporary "*shelf edge*" there by produced a shelf wide erosional surface. The eroded materials have been recycled and deposited by later stage minor oscillations of relative sea–level and these oscillations seem to have not crossed newly created contemporary shelf edge and fall with in *type 2 sequence* of Vail & Todd (1981) and Posamentier & Vail (1988). The varied lithic content, geometry and many episodes of minor oscillacions observed in this systems tract is similar to that reported by Grammer et al. (1996). They have also related to higher frequency (5^{th} and 6^{th} order cycles) and interpreted them as primarily facies controlled.

Figure 2c shows development of gryphean limestone immediately over former very shallow water deposits indicating rapid increase in sea–level and introduction of favourable conditions for *Gryphea* colonisation in vast extent of shelf. Even in the event of limited magnitude of rise, the gryphean banks have manifested dramatic landward shift similar to that of facies shift observed in Texas shelf by Anderson et al. (1996). Such offshore facies shell bed with insitu fossils has been interpreted as maximum flooding surface of highstand systems tract by Anderson et al. (1996) and Carter et al. (1991). Carbonate banks associated with sea–level highstands are characterised by shift in their facies locations and are bounded above by a sequence boundary (Sarg, 1988). Sarg has further observed progradation of banks at initial phases of highstands and falling sea–level at the end of highstand as present in Kallankurichchi Formation. The shallowing upward nature shown by the gryphean banks parallel the observations of Grammer et al. (1996) where in they interpreted such carbonate banks as deposition during typical highstand systems tract.

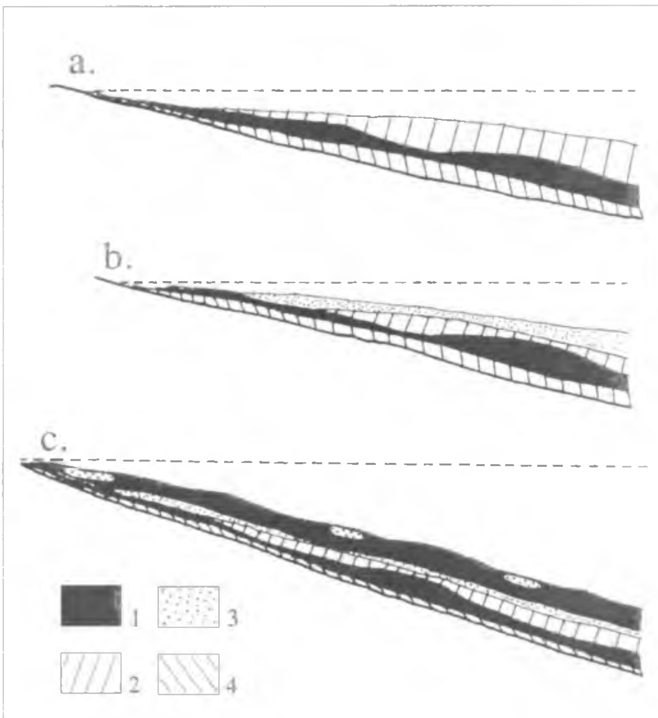

Fig. 2. Sequence Stratigraphic Model. a. Transgressive systems tract; b. Lowstand systems tract; c. Highstand system tract. Legend. 1 Gryphean Limestone, 2. Inoceramus Limestone, 3. Fragmental Shell Limestone, 4. Conglomerate.

Сл. 2. Модел секвенционе стратиграфије. a. Трансгресивни систем тракт; b. Тракт систем ниског нивоа; c. Тракт систем високог нивоа. Легенда. 1. Грифејски кречњак, 2. Иноцерамски кречњак, 3. Кречњак са одломцима љуштура, 4. Конгломерат.

Thus, the base of Kallankurichchi Formation (unconformity surface), erosional surface between inoceramus limestone member and fragmental shell limestone member, non–depositional surface between fragmental shell limestone member and gryphean limestone member and the unconformable contact between the Kallankurichchi Formation and the overlying formations serve as sequence boundaries. The whole duration of deposition of this formation, bounded between unconformable contacts is representative of a complete third order sea–level cycle (1–5 Ma – Vail et al., 1977; Haq et al., 1987; Carter et al., 1991). With in this major cycle, there are many fourth or still higher frequency cycles.

The development of theory of sequence analysis has proceeded from higher to lower level orders of sea–level changes. The first Exxon sea–level chart of Vail et al. (1977) dealt with third order cycles and later major revision by Haq et al. (1987) incorporated some fourth order cycles. However, the work of Carter et al. (1991) provided ample evidences for the consideration of even the infra seventh order (sensu Boyd et al., 1988) as basic building blocks of this sea–level chart. At each stage in the development of SSM, the term parasequence has been used to refer minor sedimentary rhythms with in a sequence. Thus parasequences are sub–divisions of higher order (i.e., finer sequences of the next higher order as stated by Carter et al., 1991). Studies of Goldhammer et al. (1991) in Desert Creek, Lower and Upper Ismay sequences of Paradox basin, U.S.A. had shown that 5th order shallowing upward cycles are grouped into 4th order sequences which in turn stack vertically into part of a 3rd order accommodation trend. In this context, the minor cycles of sea–level variations with in the observed third order cycle of Kallankurichchi Formation could well be attributed for inferences on parasequences. In the absence of microscale chronologic information, it would not be feasible to assing orders for them. The major (3rd order) and minor (4th or 5th) cycles are attributed to eustacy of unknown type by various authors (Kidwell, 1984; Plint, 1988; Fulthorpe & Carter, 1989). Facies architecture in relation to sequence stratigraphy of this formation is comparable with the Neogene deposits of New Zealand as studied by Carter et al. (1991).

SUMMARY AND CONCLUSION

Systematic analysis of field, petrographic, taphonomic and paleontologic data had revealed the following in the light of recent developments in sedimentology.

a. The Kallankurichchi Formation is divisible in to four distinct, mappable lithostratigraphic members.
b. The depositional process was mainly controlled by eustatic sea–level changes of unknown type. As precisely reviewed by Sarg (1988), this formation also illustrates that relative sea–level changes were the major controls on the depositional stratal patterns and facies architecture.
c. Excepting the contact between arenaceous gryphean limestone and inoceramus limestone, the contacts of lithostratigraphic members are sequence boundaries. This demonstrates that careful and systematic documentation of lithologic details holds good.
d. Microscale chronologic informations are needed to fine tune the sequence stratigraphic model developed.

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PLATE I ТАБЛА

Fig. (Сл.) 1. Field photograph showing exposure of basal limy conglomerate with large gravel sized and quartzite grains (arrow). Pen (15 cm length) is placed for scale. Location of the photograph: Marudaiyar river section described in text.
Изданак базалног кречњачког конгломерата са крупним облуцима кварца и зрнима кварцита (стрелица). Размерник је писаљка дужине 15 cm. Локалитет: профил реке Марудаијар (описан у тексту).

Fig. (Сл.) 2. Field photograph showing exposure of basal limy conglomerate with boulder sized orthoclase feldspar grain (arrow). Pen (15 cm length) is placed for scale. Location of the photograph: Kallar river section located just south of mine II Tancem mines – from where type section of the Kallankurichchi Formation is described by Sastry et al. (1972).
Изданак базалног кречњачког конгломерата са крупним валуцима ортокласа (стрелица). Размерник је писаљка дужине 15 cm. Локалитет: профил реке Калар непосредно јужно од рудника II у оквиру групе рудника Танцем где је типски профил формације Каланкуричи описан од стране Sastry et al. (1972).

Fig. (Сл.) 3. Field photograph showing thick population of *Gryphea*. Oyster encrused surface – hard ground. Location of the photograph: Kallar river section located just south of Tancem mine II. Scale bar is 25 cm length.
Густо нагомилање грифеја. Површ енкрустрирана љуштурама – хардграунд. Локалитет: профил реке Калар непосредно јужно од Танцем рудника II. Размерник је дужине 15 cm.

Fig. (Сл.) 4. Field photograph showing thick population of *Inoceramus*. Location of the photograph: Fixit mine. Geological hammer (32 cm length) is placed for scale.
Густо нагомилање иноцерамуса. Локалитет: рудник Фиксит. Размерник је геолошки чекић дужине 32 cm.

Fig. (Сл.) 5. Field photograph showing exposure of dolomitic limestone. Rock is black in colour and look uniform. Geological hammer (32 cm length) is placed for scale. Location of the photograph: North western corner of Viscose mine.
Изданак доломитичног кречњака. Стена је црне боје и монотоног је изгледа. Размерник је геолошки чекић дужине 32 cm. Локалитет: СЗ део рудника Вискозе.

Fig. (Сл.) 6. Field photograph showing the occurrence of shell hash bed with edge polished broken fragments of *Inoceramus* along with whole unabraded shells of *Stigmatophygus elatus* (Top centre of the photograph). Pen (15 cm length) is placed for scale. Planar surface view of the exposure illustrated in Pl. II, Fig. 1. Location of the photograph: Tancem mine I described in text.
Слој састављен од обрађених (исполираних) одломака иноцерамуса заједно са целим необрађеним љуштурама *Stigmatophygus elatus* (централни горњи део фотографије). Размерник је писаљка дужине 15 cm. Изглед површи изданка је приказан на Таб. II, сл. 1. Локалитет: Танцем рудник I (описан у тексту).

PLATE II ТАБЛА

Fig. (Сл.) 1. Field photograph showing the sharp erosional surface contact between cross bedded carbonate sand bed (below) and hummocky cross stratified fragmental shell bed. Note the sharp contrast on either side of the pen (15 cm length – placed at left side of the arrow). Location of the photograph: Tancem I described in text.

Оштар ерозиони контакт између косо слојевитог слоја карбонатног песка (доле) и брежуљкастог косо слојевитог слоја са одломцима љуштура. Уочљив је оштар контраст са обе стране писаљке (дужине 15 cm која је постављена лево од стрелице). Локалитет: Танцем рудник I (описан у тексту).

Fig. (Сл.) 2. Erosional surface contact between pure gryphean limestone and gryphean fragmental shell limestone beds. Note more or less uniform nature of them. Hammer (32 cm length) is placed for scale. Location of the photograph: Tancem mine III Bench I.

Ерозиони контакт између правог грифејског кречњака и кречњака са одломцима грифејских љуштура. Уочљива је њихова више или мање једнообразна природа. Размерник је чекић дужине 32 cm. Локалитет: Танцем рудник III, ниво I.

Fig. (Сл.) 3. Channel deposit. Note the concave bottom and flat top (parallel to the pen). Erosional bottom surface contact with cross bedded carbonate sands is also indicated (arrows). Towards top, it is having gradational contact. The channel fill is coarse grained mixed shell material that is also visible in the photograph. Location of the photograph: Tancem mine I described in the text. Pen (15 cm length) is placed for scale.

Каналски седимент. Уочљиво је конкавно дно и равна горња површ (паралелна са писаљком). Такође је уочљив (стрелице) и контакт ерозионе површи дна са косо слојевитим карбонатним песковима. Повлатни контакт је градациони. Канал је запуњен крупнозрним мешовитим љуштурама што је такође видљиво на фотографији. Локалитет: Танцем рудник I описан у тексту. Размерник је писаљка дужине 15 cm.

Fig. (Сл.) 4. Thin section photomicrograph showing large (rudite sized) rounded molluscan grains (a) embedded in micrite (b) that represent distal expression of storm beds (Ramkumar & Chandrasekaran, 1996b). The hummocky stratified beds (molluscan rudites) grade towards east in this way. In view of intense later stage meteoric neomorphism, the grain boundaries seem to have blurred contact with micritic matrix. Scale bar is 1 mm length.

Микрофотографија препарата са крупним (величине рудита) заобљеним кластитима мекушаца (а) у микриту (б) који представљају дистални део темпестита (Ramkumar & Chandrasekaran, 1996b). Брежуљкасто стратификовани слојеви (шкољчани рудити) према истоку постепено прелазе у претходне стене. Због интензивног каснијег степена атмосферског неоморфизма границе зрна имају нејасне контакте са микритским матриксом. Размерник је дужине 1 mm.

Fig. (Сл.) 5. Thin section photomicrograph showing peloid ostracod grain–rudstone. a. completely micritised foraminiferal shell (peloid); b. ostracod shell; c. completely micritised molluscan shell (peloid). These are typical of tidal channels (Wilson, 1975). Scale bar is 1.5 mm.

Микрофотографија пелоидног остракодског грејнстона до рудстона (GS–RS). a. потпуно микритисана фораминиферска љуштурица (пелоид), b. љуштурица остракода, c. потпуно микритисана љуштура мекушца (пелоид). Фација типична за тајдалне канале (Wilson, 1975). Размерник је 1.5 mm.

Fig. (Сл.) 6. Thin section photomicrograph showing dolomite rhombs. Scale bar is 20 microns.

Микрофотографија са уочљивим доломитским ромбовима. Размерник је 20 микрона.

PLATE I ТАБЛА

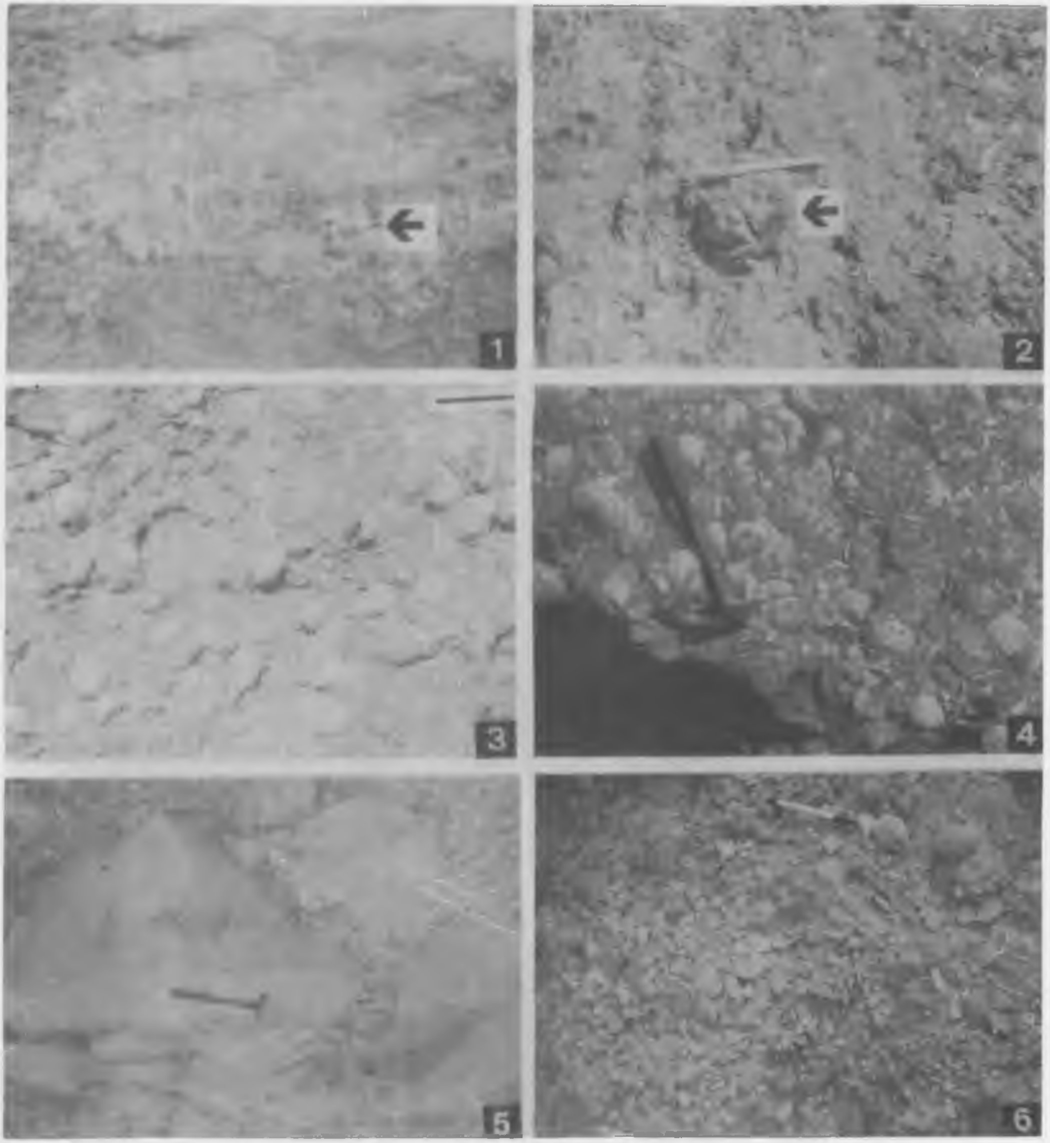

PLATE II ТАБЛА