GENESIS AND CLASSIFICATION OF SHELL BEDS - AN EXAMPLE FROM THE LATE CRETACEOUS OF ARIYALUR SUB-BASIN, TAMIL NADU.

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Abstract

Ever since the inception of Taphonomy (a new branch of palaeontology), the distortion/ incompleteness of the fossil record has been considered as an important tool for the palaeoenvironmental interpretations. The palaeontological information losses due to inadequate preservation of the fossils have now being used as additional evidences for overall preservational conditions. The taphonomic signatures are best found in the shell beds and the investigation of these shell beds has become an imperative means for the palaeoecological studies. The different mechanisms of the formation of the shell beds along with their classification have been discussed. The shell beds found in the Late Cretaceous sediments of Ariyalur sub-basin has been selected as an example to demonstrate their implication in palaeocology.

Key words

Taphonomy, shell beds, Late Cretaceous, Ariyalur, and Tamil Nadu.

Introduction

1. Fossils are the preserved remains of ancient organisms, therefore understanding of the different processes of preservation; recognition and identification of fossil remains after their discovery are integral part of palaeoecological studies. Protective cover (sediments) and stabilizing chemical environments are of prime importance in the preservation of once living organisms. Due to processes of aerobic decay and physical/chemical destruction, most animal leave no evidence of their existence. Not every organism that ever lived could be part of the fossil record. A large percentage of all biological entities end up as food for other organisms higher on the chain. This fact alone may prevent the preservation of these organisms. Even those organisms that avoid being eaten have a low probability of becoming fossilized because most of them under go decay and recycling of their chemical components.

2. The study of the post mortem history of fossil is one of the essential and critical aspects of the analytical methods and used to study fossil records under taphonomy (derived from Greek word "taphos" meaning death), a sub discipline of palaeontology. The term "Taphonomy" was first used by Efromov (1940), in search for principles, which govern the transit of organism from the biosphere to the lithosphere. Earlier, not much significance was given to this sub-discipline owing to its negative aspects, but now it has been found to make significant contributions to pin the studies of how fossil formed, where they occur and the amount of palaeontological information which can be extracted form them.

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Taphonomic Processes

Taphonomy is the study of what happened to an organism after its death and until its discovery as a fossil, which includes decomposition, post-mortem transport, burial, compaction and other chemical, biologic, or physical activity, which affected the remains of the organism. Being able to recognize taphonomic processes that have taken place can often lead to a better understanding of palaeoenvironment and even life history of the once living organism (Goldring, 1991). Since last few decades this sub-discipline is gaining much significance in the palaeoecology, because it encompasses the different processes responsible for bringing the organism as a part of fossil record and how these processes have influenced the different sources of information in the fossil record. The processes involved to bring these changes are necrolysis (death and decomposition of organism), biostratinomy (sedimentary history of remains up to the time of burial) and fossil diagenesis (the transformation responsible for any organism becoming part of the fossil record).

Tafo Facies

Fossiliferous sediments that have similar taphonomic histories are referred to as tapho facies (Brett & Baird, 1986, Speyer & Brett, 1986, 1988).

The common features of the different tapho facies are:

(a) The likelihood that the sediment may be reworked leading to dissociation and fragmentation.

(b) The potential of the sediment to infill cavities.

(c) The compaction potential.

3. (d) The dissolution and replacement potential of the minerals involved. The fossil may locally interfere with, and modify, this sequence and gradient because of their large size, porosity etc.

Taphonomy can also be used to distinguish between assemblages without necessarily identifying the species, a useful tool in facies analysis. It can be used in field identification and in loss of information. It incorporates all the processes operating in faunas from the moment of their death up to their recovery of fossils. Particularly important are the processes that operate to the point of final burial of organisms or their remains, the biostratinomy. The early history of palaeontological investigations, the negative impact of these processes which lead to an enormous loss of information (negative aspect) was mainly considered. But now, it has been established that such process like transport, breakage, abrasion, bio-erosion, dissolution etc. leave char acteristic marks on the hard parts and provide enormous information about the depositional environment (positive aspect). This information can be well demonstrated by shell beds, since they record a variety of physical and biological processes. They are ideal objects to illustrate the impact of such processes on organic hard parts, which ultimately could be used for the palaeoenvironmental interpretations.

Shell concentrations have been defined by Kidwell (1991), as a concentration of biomineralized remains more than 2 mm in size from any invertebrate animal. The more familiar term shell bed refers to a particular geometric arrangement of shell concentrations and is therefore less broadly applicable. Still more general term skeletal concentration (or fossil concentration, Kidwell et al. 1986) refers to a concentration of all biogenic hard parts regardless of their size and taxonomic origin.

Although wide spread in the sedimentary record, shell concentrations have received relatively little attention till recently. The pioneer works carried out by the Wilhelmshaven School since the 1920s (summarized by Schäfer, 1966) was only taken up in the last two decades in the context of the resurgent interest in taphonomy. Recently, the state of the art has been extensively reviewed and the concern literatures comprehensively compiled by Kidwell (1991).

Descriptive Classification of Shell Concentration

Classifying shell concentrations in a descriptive way not only facilitates scientific communication, but also some basic factors, closely related to genesis of the shell concentrations. From the numerous possibilities of descriptive classification, those based

4. on taxonomic composition, the biofabric, and the geometry of concentration and on its complexity are particularly promising, as they reveal a variety of ecological, hydrodynamic, and the topographic information (Fig.1). For example, from the taxonomic composition of shell concentrations we get a glimpse of the communities, which contributed hard parts and therefore, obtain information on the ecological framework. In many cases, the ecological information has been filtrated by various taphonomic processes such as sorting according to size or shape. This provides information also on the hydrodynamic setting under which the deposit formed. As a result we can distinguish between mono-, pauci- and polyspecific shell concentrations (Kidwell et al. 1986). Similarly the biofabric that is the three-dimensional arrangement of skeletal elements yields information on the hydrodynamic regime and, to a lesser degree, on compaction or ecology by using orientation pattern, packing density and degree of sorting. Simple descriptive classification on biofabrics that can be easily used in the

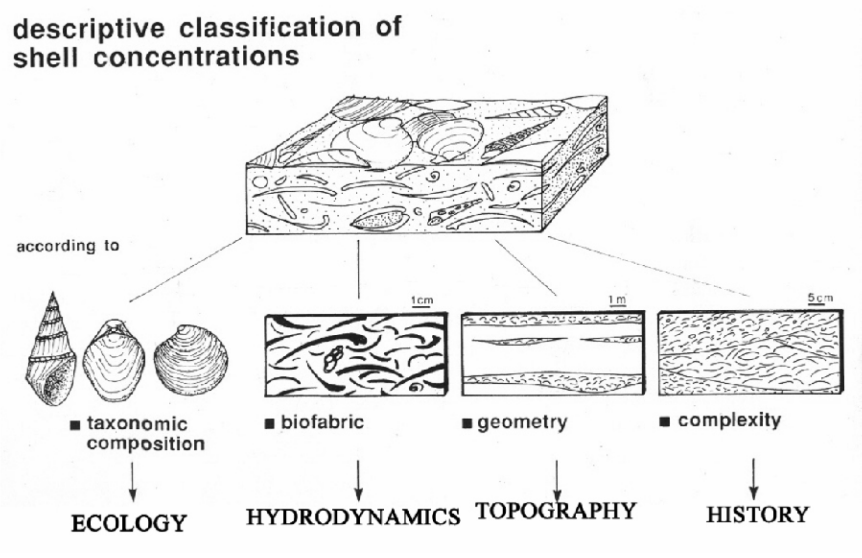

Fig. 1. Descriptive classification of shell concentration (after Fürsich, 1995)

field was put forward by Kidwell & Holland (1991). The geometry of shell concentration (Kidwell et al. 1986) provides information of the topography and, to some extent, all on the concentration agents (organism, waves or currents). Finally, the complexity of the internal structure of a shell concentration, the lateral and vertical changes in taxonomic composition, biofabric and matrix tells us something about the history of the concentration processes.

Formation of Shell Concentration

Three factors play on an essential role in the formation of the shell concentration i.e. biological processes, physico-chemical processes, and time (Fig.2). Shell concentration may be produced by the organism whose remains are found in the concentration. Examples are gregarious-settling behavior (*Mytilus edulis* beds on modern tidal flats), high population densities opportunistic life strategies (Levinton, 1970), high population densities due to optimal ecological condition and gregarious spawning behavior (Doyle & Macdonald, 1993). Another example is mass mortality of organisms, which is caused by variety of biogenic or biotic factor such as red tides, changes in water chemistry or temperature, or rapid sedimentation and which is ultimately a biological response to changing environmental conditions (Arntz, 1985; Speyer & Brett, 1985; Steimle & Sindermann, 1978).

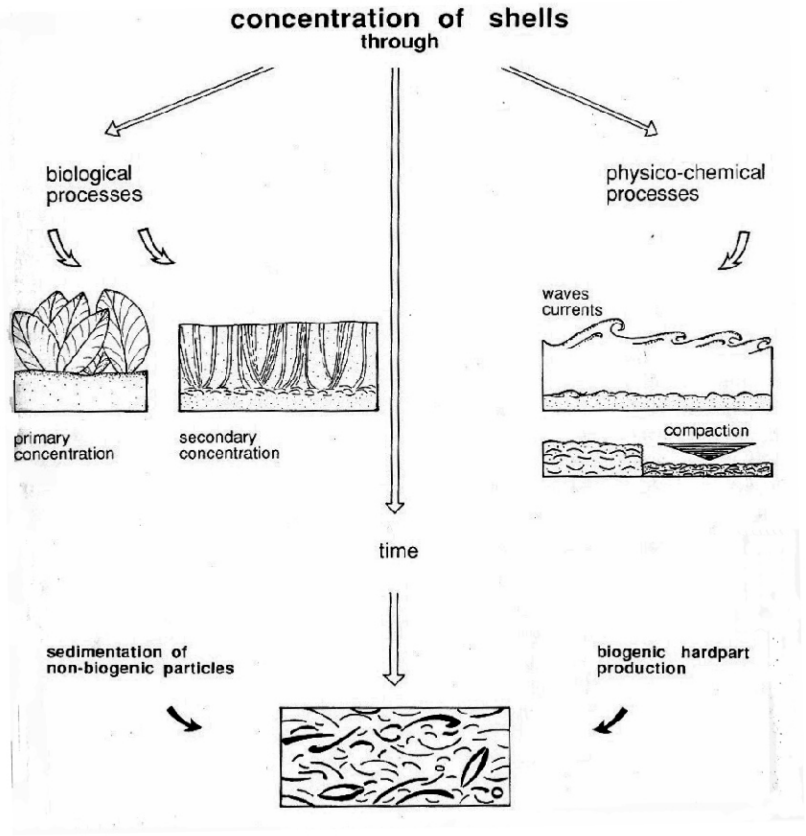

Fig.2. Processes of formation of shell concentration.

Therefore, shell concentrations are formed by organism that actively concentrate skeletal remains of others organisms (Fürsich, 1995). It is reflected by their particular feeding behavior such as shell pockets formed by rays (Gregory et al. 1979) or other behavior patterns (e.g. shell concentrations as back fills or used for wall construction made of burrows). Physical processes play most significant role for the concentration of biogenic hard parts, whereas chemical processes, more or less restricted to compaction, play only a subordinate role (Fürsich, 1995). The main physical processes are waves, currents and turbidity currents, which may concentrate skeletal material either by winnowing the finer material or by selective transport. The hydraulic processes affect the skeletal elements before final burial, and there after, compaction and pressure solution are the main components of the diagenetic processes responsible for the formation of shell concentration (Fürsich, 1995). Time is also one of the most influencing factors in their formation, evidenced directly by the duration of the concentration process, or represented by the sedimentation of non-biogenic particles or else via production of biogenic hard parts

Information loss /information gain

Since, shell concentrations are finally formed due to reworking or rearrangement of the skeletal element, there is considerable loss of biological information e.g. autecological informations- about growth position, fauna-substrate relations; and synecological information- about the composition of former communities. Since most of the shell concentrations are influenced by condensation of the time axis, a similar loss may be there to the biostragraphic information. Sometimes shells of different age either accumulate together due to non-sedimentation or due to reworking of layers of different ages, the resulting concentrations will be highly time-averaged and ecological attributes such as species diversity, species composition, or trophic group composition will no longer carry much significance (e.g. Fürsich & Aberhan, 1990; Kidwell & Bosence, 1991; Fig. 3). In spite of these information losses, shell concentrations entails enormous amount of

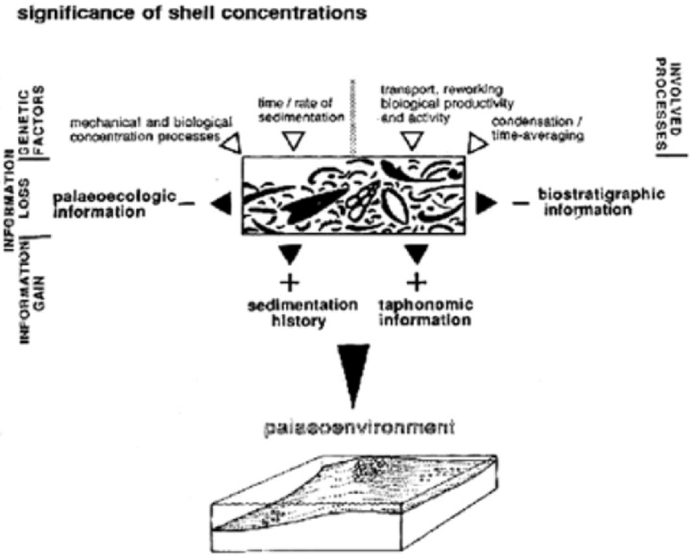

Fig.3. Information loss/information gain.

information, not only about the final concentration process, but also about preceding biological and physical parameters of the environment. Although such studies of retrieving information have been practiced on the modern environments (Callender et al. 1990, Davies et al. 1989; Feige & Fürsich, 1991), of late has been used for fossils also (Beckvar & Kidwell, 1988; Doyle & Macdonald, 1993; Speyer & Brett, 1988; Fürsich & Pandey, 1998). The biological activities can be interpreted through the orientation of shells, variability of the shell grading pattern, modal distribution of skeletal elements and matrix. The nature of physical parameters can be obtained from the various hydrodynamic processes such as storm waves, storm flows, long shore currents etc. (Fürsich, 1995). The taphonomic signatures imprinted on the individual skeletal elements (Davies et al. 1989) may depict the nature of the original environment in which organism lived and records, though in a fragmentary way, the history of their concentration. This includes information on the hydrodynamic regime, on the bathymetric setting, the residence time of skeletal elements on the sea floor and on the biological activities, which affected them. Thus biofabric and taphonomic signatures together with the taxonomic composition as a rudimentary ecological source, considerably contribute to the reconstruction of the physical and biological properties of ancient environments. Thus in spite of the information loss, much could be known about palaeoenvironmental conditions prevailing during the lifetime of the organisms through the taphonomic studies.

Genetic Classification of Shell Concentrations

The different biological and physical processes responsible for shell concentrations are more explicitly illustrated by the genetic behavior of the organisms. Hence the genetic classification of the shell concentration appears to be more promising than the descriptive ones especially in the case of palaeoenvironmental applications. Broadly shell concentrations can be genetically classified in ternary diagrams according to the relative importance of biological, sedimentological and diagenetic processes (Kidwell et al. 1986). Such classification depicts the relationship between the shell concentration and allied environments. Kidwell (1991) further proposed a more refined scheme of classification by distinguishing i. event concentration, caused ecologically brief concentration episodes and preserved as discrete events, ii. composite concentrations, characterized by amalgamation or accretion of multiple events, iii. hiatal concentrations in which slow net accumulation is the prominent feature, and iv. lag concentration, in which erosion and/or corrosion play the decisive role and significant stratigraphic truncation occurs (Fig. 4). These four types of shell concentration too exhibits characteristic trends along onshore offshore transects and within depositional sequences (Kidwell, 1991).

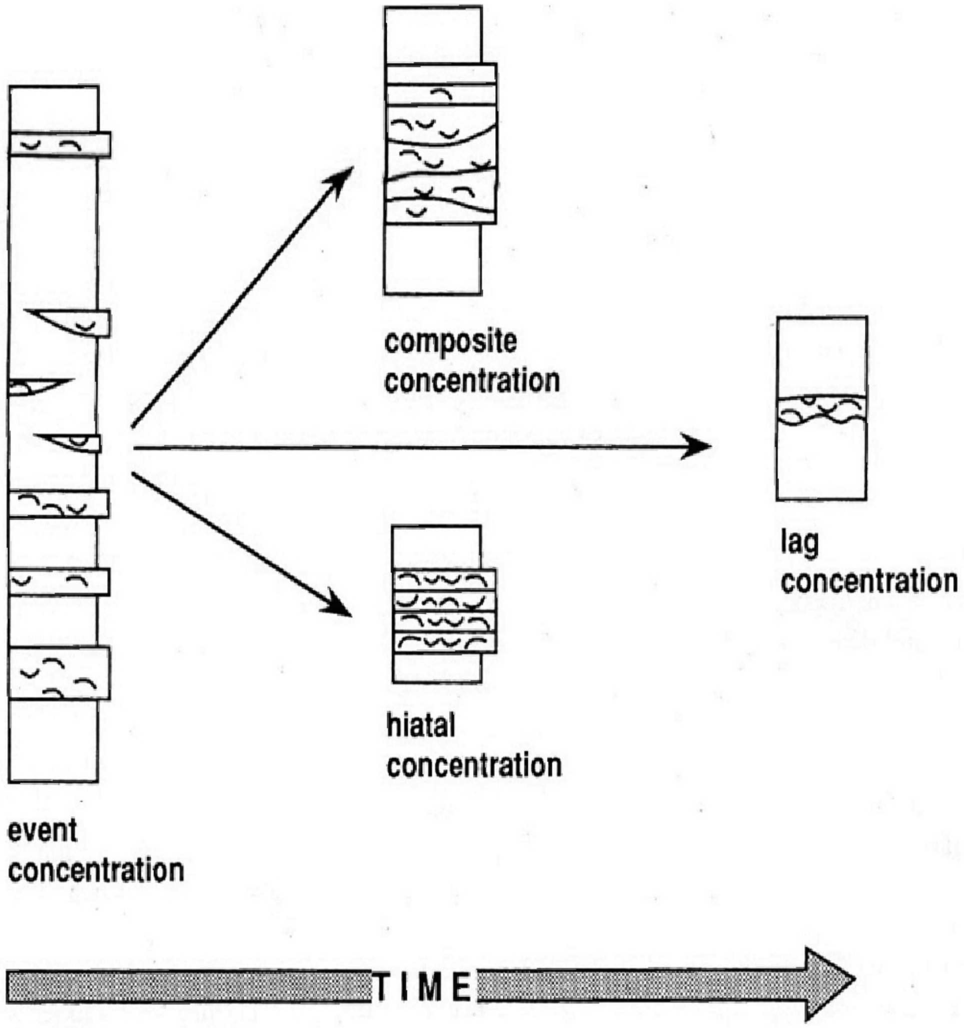

Fig. 4. Categories of shell concentration (after Kidwell, 19991).

Fürsich & Oschmann (1993) further proposed a more resolution in the classification of the shell concentration, developed for sequences in the Jurassic of Kachchh basin (western India), but they emphasized that is applicable to epicontinental seas in general (Fig. 5). Nine genetic types of shell concentrations, related to the relative importance of the main concentration of processes (waves, currents, biological productivity, biological activity, net sedimentation, and time), can be distinguished. These types exhibit distinct bathymetric trends and thus serve as excellent tools in basin analysis (Fürsich & Oschmann, 1993). This refined classification of the shell concentration proposed by Fürsich, 1995) has been summarized in the Table 1. The high taphonomic signatures and biofabric correspond to the wide range of environments represented by these skeletal elements and thus, shell beds are indeed

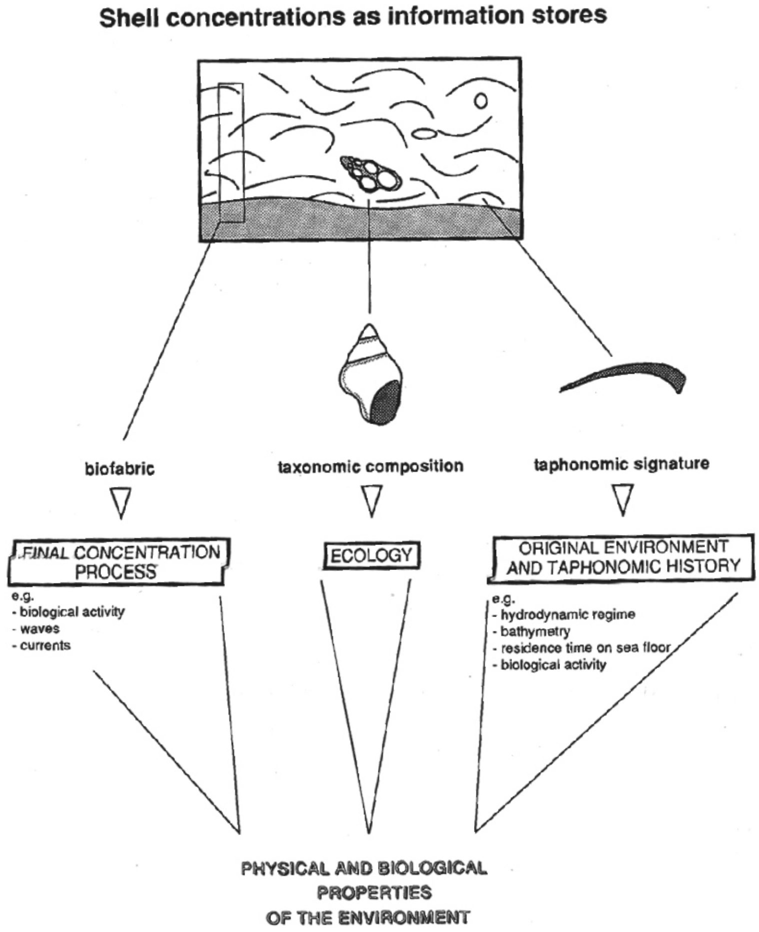

Fig. 5. Shell concentration as information stores.

useful environmental indicators, particularly in bathymetry, energy level and rates of sedimentation (e.g. Aigner, 1983; 1985; Fürsich & Oschmann, 1986, 1993; Norris, 1986). The exemplary use of the shell concentration has also been done in the sequence stratigraphy since these appear to occupy characteristic positions within the sequence stratigraphic frameworks. Banerjee & Kidwell (1991) found the shell beds at the top and base of the parasequences in the Lower Cretaceous Manville Group of Canada; Fürsich & Oschmann (1993) recognized parasequences based on types of shell concentrations in the Jurassic of western India and were able to correlate basin-wide shallowing-deepening large-scale trends in the geological events. Kidwell & Brenchley (1994) found that the

concentrations	Characteristic Features
Weather wave concentration	The elements of fair weather wave concentration exhibit signs of abrasion and fragmentation and due tothe persistent wave exposure. Shells are invariably disarticulated; sorting is conspicuous. In plan view, a bimodal orientation pattern will be characteristic.
Storm wave concentration	Storm wave concentration differs in being much better preserved, as reworking is only a brief event. Articulated shells may dominate, if a life assemblage is reworked. Signs of sorting are usually absent. Infaunal elements will lack signs of boring or encrustation.
Proximal tempestites	Proximal tempestites share many features with storm wave concentrations, but in addition exhibit signs of transport. As a rule, they consist of reasonably preserved shells. Proximal tempestites have a sharp erosive base and grading is common. Disarticulated shells are preferentially in a convex-up orientation.
Distal tempestites	Distal tempestites differ from proximal ones in being thinner and in the smaller size of their components. In addition they are graded and very well sorted.
Current concentrations	In current concentrations (5) caused by tidal currents, long shore currents or any other type of shelf current, skeletal elements show a wide range of preservation qualities, depending on their residence time within the current regime, but poorly preserved shells prevail. Again most shells are convex-up oriented.
Primary biogenic concentrations	Primary biogenic concentrations are the result of gregarious settling behavior of larvae, but may also reflect low rates of sedimentation. Some shells may be preserved in lifeposition and original colonization pattern, (e.g.nests) may be preserved.
Winnowed concentrations	Winnowed concentrations (7) are pavements or thin accumulations of relatively well-preserved shells, which formed by gentle winnowing of finer matrix due to currents too weakto transport larger skeletal elements.
Transgressive lag concentrations	In transgressive lag concentrations the time factorbecomes more prominent. As in Kidwell's (1991) lagconcentrations, several phases of reworking and erosion are usually involved in addition to low net rates of sedimentation. Inepicontinental seas, this scenario is characteristic of transgressive phases,during which exposure of formerly more restrictedenvironments to open shelf currents and heavy storms lead to repeated reworking, while the sediment source retreats. Transgressive lag concentrations are therefore characteristically multi-event products and characterized by shells witha long residence time on the sea floor, complex taphonomic signatures and with moderate to poor preservation quality. Above all, many shells are bored and encrusted or at least show residual signs of such biogenic degradation.
Condensed concentrations	Condensed concentrations represent the longest timeinterval. Due to their long exposure time on the sea floor, the shells are often bored, encrusted, or corroded; The faunal composition may be heavily biased in favor of large, thick, sturdy shells because small and thin shells have been removed bybioerosion or chemical erosion. On the other hand,as fresh material is constantly added, some shells usually exhibit a very high preservation quality.

Table - 1 Genetic Classification of shell concentrations (after Fürsich 1995).

cycles with the help of these shell beds. These shell concentrations have also recorded increase in the thickness of the shell concentrations through the Phanerozoic reflects evolutionary changes such as increase in the reproductive and metabolic output in benthic ommunities over time.

Taphonomic Signatures (Shell Concentration) in the Ariyalur Sub-Basin

In the Ariyalur sub-basin, the evidences of shell concentrations are best preserved in the different horizons of the Kallankurichchi Formation, where shells are quite abundant (for location and geology, see Jaitly & Mishra, 2001, 2007). It is also visible in the lower Sillakkuddi Formation, but the concentration is not so thick while in Ottakkovil Formation shell concentrations are very poor. The different characteristic features (thickness, matrix, bioturbation, species composition, diversity, packing density and

Formation	Thickness (cm)	Substrate	Matrix	Faunal Diversity	Packing	Density	Contact
SILLAKUDI	225	Quartzwacke (calcareous)	Matrix supported	*Hyotissa* ***Protocardia*** Oysters	Low	Low	erosional
	100	bioclastic grainstone	Matrix supported	*Hyotissa*	Low	Low	erosional
	40	bioclastic grainstone	Matrix supported	*Hyotissa* Oysters	Low	Low	erosional
KALLANKURICHCHI	350	bivalvian packstone	Matrix-clast supported	***Phygraea*** *Inoceramus* *Plicatula*	Moderate	Moderate	Sharp, erosional
	600	molluscan grainstone	Matrix-clast supported	***Phygraea*** *Inoceramus* *Plicatula*	Moderate	Moderate	erosional
	100	Foraminiferal molluscan packstone	Matrix-clast supported	***Phygraea*** *Rastellum*	Moderate	Moderate	Sharp, erosional
	300	Foraminiferal molluscan packstone	Matrix supported	***Agerostrea*** *Phygraea* *Rastellum*	Low	Low-high	Sharp, erosional
	300	Bryozoan foraminiferal packstone	Matrix-supported	***Inoceramus*** *Rastellum*	Moderate	Moderate	erosional
	500	Foraminiferal packstone	Matrix-clast supported	*Phygraea* *Ceratostreon* *Rastellum*	High	Low- high	Sharp, erosional
	250	Foraminiferal wackstone	Clast supported	***Glycymeris*** *Frenguelliella*	high	High	Sharp, erosional
	100	Molluscan packstone	Matrix-clast supported	*Phygraea*	moderate	Moderate	erosional
	150	Molluscan packstone	Matrix-clast supported	*Phygraea*	moderate	Moderate	erosional
	200	Echinodermal packstone	Matrix-clast supported	*Phygraea*	moderate	Moderate	erosional
	300	Feldspathic quartzwacke	Matrix	*Phygraea*	moderata	Low	erosional

Table - 2 Characteristic features of shell concentrations from the Sillakkudi and Kallankurichchi formations.

contacts) are quite variable in these shell concentrations. The taphonomic signatures visible as shell fragmentation, disarticulation, abrasion, boring and encrustation. This will help in finding out the process responsible for their concentration. The names of the different concentration have been adapted from the name of the genus /species, whose shells are dominating or forming a bulk of the shell concentration. The characteristic features of the shell concentration are shown in the Table 2.

Hyotissa **concentration**

This type is found only in the Sillakkudi Formation. The thickness ranges from 40 cm to 225 cm. *Hyotissa* is occurring in both lower and upper part as shell pavements. The shells are randomly distributed. There is also no preference of orientation. Large shells at places show convex upside orientation. The packing densities is poor, grain to clast supported and occur as loosely packed shell beds, may be reminiscent of closely adjacent pavements. The contact is erosional. No sign of boring as well encrustation is visible. In the lower part cross bedding is seen, while the upper part is bioturbated. Shell fragments are rare and the most of the shells are abraded to a variable degree. Additional bivalve elements are represented by oysters (only muscle scars are present), *Protocardia* and *Chlamys*. The muscle scars of the oysters are bored.

Phygraea **(*Phygraea*)** ***vesicularis*** **concentration**

This shell concentration predominates in the whole of Kallankurichchi Formation. It ranges in thickness from 100 cm to 600 cm. Through out the shells of *Phygraea* (*Phygraea*) *vesicularis* laterally form a continuous layer. But in most cases, shells are either randomly distributed or forming shell pavements. Majority of the shells showing preferred convex down orientation especially where the articulated shells are common (Fig. 6 A). Convex up orientation has also been observed at few places (Fig. 6 B). But the majority of the shells are disarticulated in nature. Articulated valves are less common. Nesting of shells is also common. Boring and encrustation though not frequent but more or less common. Packing density variable (matrix to clast supported) with maximum (clast supported) in upper part. The contact in most of the cases is erosional. Bioturbation common. *Ceratostreon*, *Agerostrea*, *Rastellum*, *Inoceramus* and *Plicatula* are the other bivalves, whose shells/shell fragments, are also found with the shells of *Phygraea* 14 (*Phygraea*) *vesicularis*. On the whole the complete bivalve shells are exceeding the shell fragments.

Inoceramus **concentration**

It is represented by five species of *Inoceramus,* having thickness of about 300 cm. The clastic sediments are grading upward into coarser sediments. The density of packing is moderate (matrix supported). The complete shells abundant, shell fragments less common. The shell size is variable between 6 cm to 11 cm and in some cases even more than it (6C). The articulated shells are less in number. Bryozoan encrustation quite common. *Inoceramus* (*Cataceramus*) *intrepidus* dominates over the shells of other four species of *Inoceramus*. The other shell fragments belong to *Rastellum* & *Chlamys*. This bed is bioturbated having erosional contact. The distribution of shell fragments is random and in some case shows convex upward orientation.

Glycymeris **(*Glycymerita*)** **concentration**

Shells of ecologically mixed epifaunal and infaunal bivalves occur together. The Shell bed is about 250 cm thick, usually matrix is clast supported. The density of packing is moderate to high. The shells are randomly distributed with disarticulated component dominated (6D). The most common sedimentary structure is cross bedding. The sorting of shells is poor. There is no preferred orientation evidenced in the shell population. Six species belonging to *Glycymeris* (*Glycymerita*) dominating, which exhibit signs of abrasion. Additional bivalve elements include *Frenguelliella*, *Ceratostreon* and *Chlamys*. Boring and encrustation are common.

Polyspecific concentration

This type of shell concentration is marked by the abundance of many species of bivalves. The thickness of such polyspecific concentration beds varies between 40 cm to 300 cm. They include *Phygraea*, *Ceratostreon*, *Agerostrea*, *Rastellum*, *Chlamys* and *Incoeramus* (6E). Sorting is poor. Shells are unevenly oriented. At places nesting of shells is visible due to bioturbation. Density of packing is variable. The majority of the large disarticulated shells of *Phygraea* and *Inoceramus* are having convex upward orientation. Bryozoan and serpulid encrustations common. Only the shells of *Phygraea* are bored. Fragmented shells are quite common (6F). These lack sharp boundaries. Shell abrasion quite common.

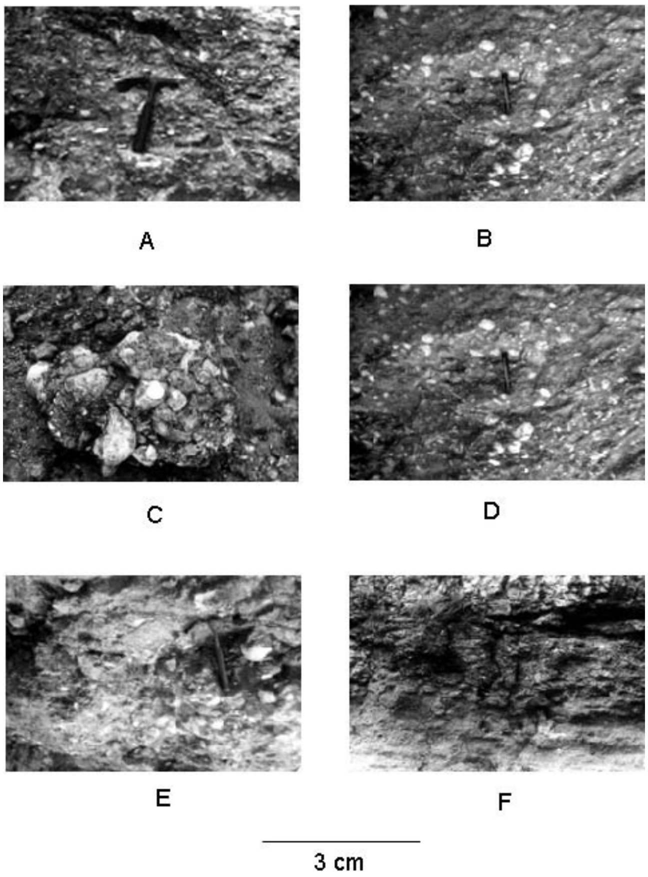

Fig. 6. Shell beds of Ariyalur.

Acknowledgements

Authors are thankful to the Head, Department of Geology for providing necessary facilities in the department to carry out the present work. The financial support provided by UGC, New Delhi to carry out the field work is thankfully acknowledged.

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