Genesis and significance of shellbeds in terrigenous platform deposits: an example from the Ordovician of Sardinia

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Introduction

Shellbeds are dense accumulations of organic remains set in a variable amounts of matrix and cement. Their formation and distribution has been the subject of numerous investigations (Kidwell, 1985, 1986; Brett & Bordeaux, 1990; Kidwell & Bosence, 1991; Boyajian & Thayer, 1995; Li & Droser, 1997; Botquelen *et al*., 2001; etc.).

Kidwell *et al*. (1986) proposed a descriptive classification for shellbeds based on taxonomic composition, structure, geometry and internal complexity of these concentrations. Furthermore, they proposed a genetic classification of shellbeds with three end-member data-sets: biologic, sedimentologic and diagenetic. According to Kidwell (1991), in a third-order sequence, shellbeds are located along surfaces of strata convergence, e.g. onlap, backlap, downlap and toplap. Thus, shellbeds positions seem to be linked to the system tract architecture. Shellbeds, located as predicted by Kidwell, have been described in Cenozoic sedimentary piles (Naish & Kamp, 1997; Kondo *et al*., 1998; etc.).

The aim of the present work is to study the repartition of shellbeds on the scale of a genetic sequence along a cross-section situated in SW Sardinia. Sedimentologic and taphonomic analyses have been carried out to define the relationships between shellbeds, faunal associations and sequence architecture. A genetic model for shellbeds is proposed taking into account autocyclic and allocyclic constraints in a terrigenous platform.

Geological setting

During Ordovician times, SW Sardinia belonged to the North Gondwana province and was characterized by important terrigenous deposits, containing layers of carbonated sediments.

In the Sulcis-Iglesiente area, the upper Ordovician is represented by five formations (Leone *et al*., 1991; Laske *et al*., 1994). The Portixeddu Formation (Caradocian-Asghillian) is constituted by fine-grained sandstone, silstone and mudstone, affected by a weak metamorphism (greenschist facies). This formation contains a rich and diversified benthic fauna (Hamman & Leone, 1997 and cited references). According to the sedimentary structures, the Portixeddu Formation was laid down in a storm-dominated shelf, between the proximal and the distal part of the upper offshore (Loi, 1993).

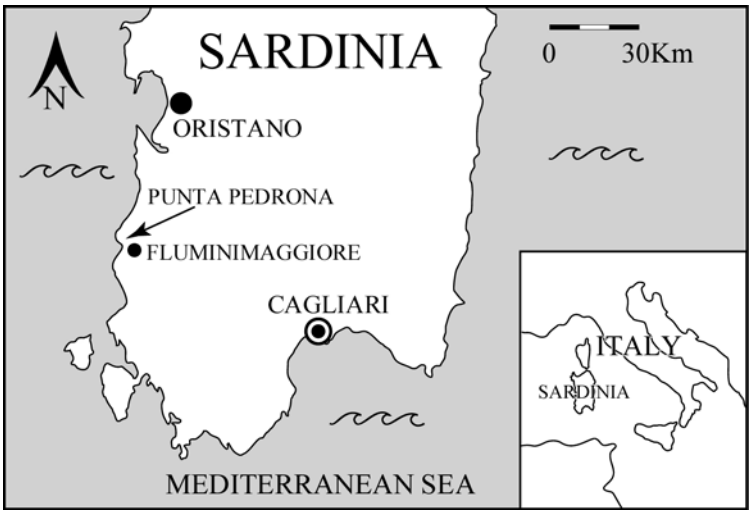


Fig. 1 - Location of the studied Punta Pedrona section (Portixeddu Formation) in SW of Sardinia.

The study was carried out along the Punta Pedrona cross-section (NW of Fluminimaggiore, Fig. 1). About 110 samples, 3 Kg each, have been collected, for a total of more than 18.000 bioclasts counted.

Sedimentary facies and taphonomy

In the studied cross-section, several facies have been recognized:

Facies 1: it is constituted by pluricentimetric to centimetric sandy strata with hummocky cross stratification (HCS), separated by centimetric argillaceous and silty layers. Pluricentimetric gutter casts and furrow casts are present in the basal part of HCS strata. This facies characterizes the proximal part of the upper offshore.

Facies 2: in this facies, sandy HCS strata are less thick (few centimeters) than in the facies 1 and silty/argillaceous strata are more important. Furrow casts are meter scale. This facies characterizes the median part of the upper offshore.

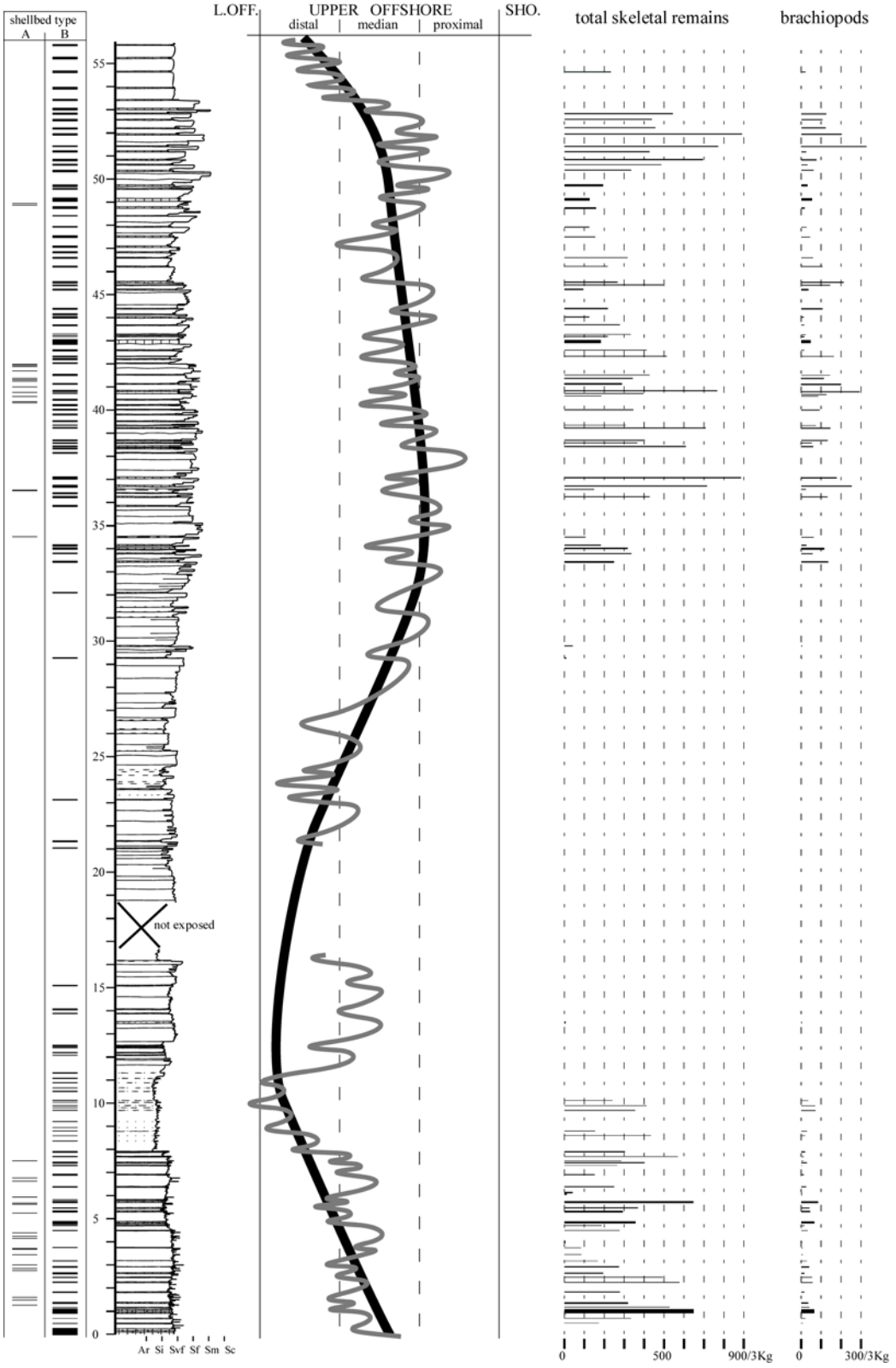
Facies 3: it consists of mudstones containing silty laminae, interbedded with some centimetric sandy/silty strata with HCS. Furrow casts are scarce and decameter scale. This facies characterizes the distal part of the upper offshore.

Facies 4: in this argillaceous complex, silty lamina get scarce and siliceous nodules are present. This facies characterizes the transition between upper and lower offshore (Loi & Dabard, 2000, 2002).

Facies 5: it comprises bioclastic limestone and marlstone and it is probably related to a distal environment.

Shellbeds are abundant in the whole formation and are associated with proximal, as well as distal facies (Fig. 2). Phosphatic nodules and crusts are present in the more proximal facies (1 and 2).

Fig. 2 - Distribution of shellbed types and relative abundance of total skeletal and brachiopods in the Punta Pedrona section (Portixeddu Formation) versus sea-level variations.


shellbed type
A
B
L.OFF.
UPPER OFFSHORE
distal
median
proximal
SHO.
total skeletal remains
brachiopods
55
50
45
40
35
30
25
20
15
10
5
0
not exposed
Ar Si Svf Sf Sm Sc
0
500
900/3Kg
0
300/3Kg

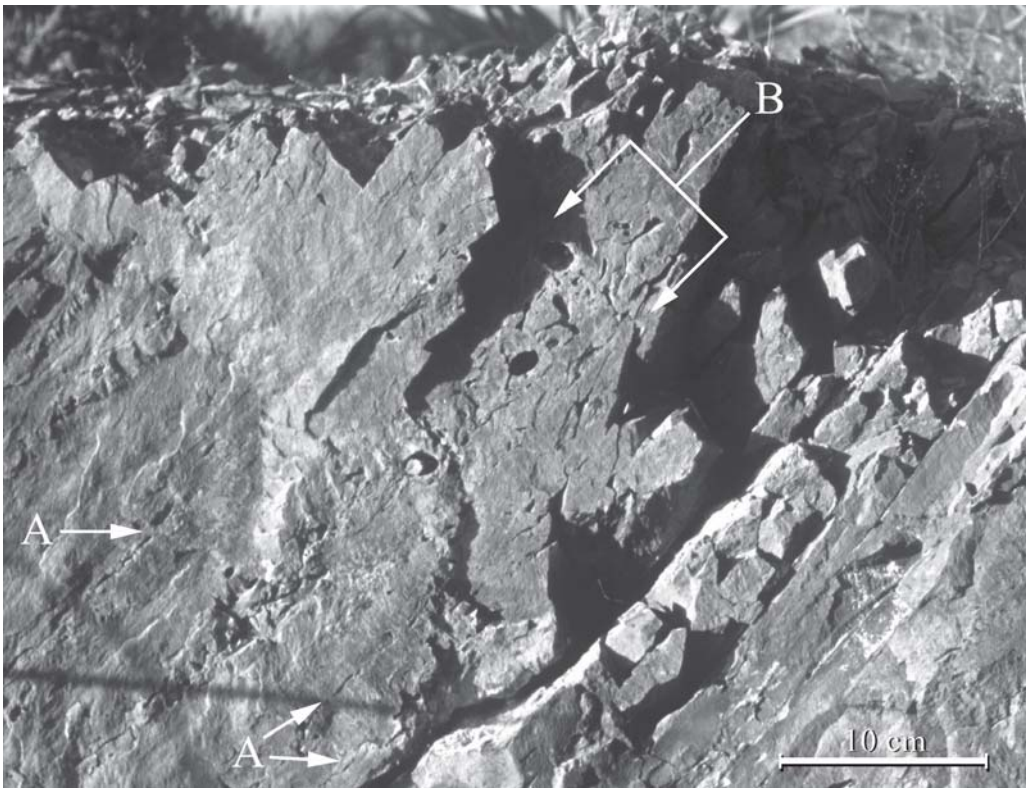


Fig. 3 - Typical aspect of shellbeds in the Portixeddu Formation. A: type A shellbed; B: type B shellbed.

Description of shellbeds:

The fauna collected in the Portixeddu Formation mainly consists of bryozoans, brachiopods, crinoïds, cystoïds. Gastropods, cornulitids and some bivalves and trilobites can also be observed. These epibenthic organisms belong to the platform domain and constitute associations of which the study is now in progress.

Shellbeds thickness can vary from less than one centimeter to several centimeters. Two types of shellbeds have been distinguished (Fig. 3).

Type A: The shellbeds of this type are lenticular and made of only one coquina level, which thickness depends of the size of the bioclasts (a few mm to 1 cm). The shells are concentrated parallel to the bedding ("concordance" according to Kidwell *et al*., 1986) without imbrication and are scattered in a sandy to silty matrix (A in Fig. 3). The density of the skeletal remains is weak to moderate (shellbeds are generally loosely packed).

The fossils associations are monotypic (one taxa dominating) or polytypic (several taxa dominating).

Organisms are preserved as internal or external moulds, and are often disarticulated. Articulated specimen are very scarce**.** Neither size-sorting nor shape-sorting have been observed. Fragmentation and "corrasion" (*sensu* Brett & Baird, 1986) are variable.

Type B: This type represents the thickest concentrations (> 3 cm) and single shellbeds have a constant thickness. These shellbeds are composed of several superposed coquina

levels, amalgamated or intercalated with thin terrigenous layers (B in Fig. 3). In these shellbeds, the density of bioclasts is variable and the orientation of shells is from concordant to isotropic. A sandy, silty or marly matrix is generally present.

The bioclastic associations are monotypic to polytypic. The organisms are usually disarticulated. A few specimens of brachiopods are preserved with valves in connexion. Crinoïds are present as stems. Neither size-sorting nor shape-sorting have been observed. The organisms are preserved as moulds and fragmentation is very variable. In some case, abrasion is important, and ornament and muscle scars are not preserved. Some shellbeds are bioturbated (vertical burrows). Bioerosion marks by perforating worms (*Trypanites*) and trepostomes can be observed on internal moulds of brachiopods implying post-mortem bioactivity. In some strata, a sheet of bryozoans can be observed at the base of the concentration where it constitutes a hard substratum for some epibenthic communities (brachiopods, cornulitids, cystoids, etc.). These live/dead organisms interactions underline the reality of taphonomic feedback (Kidwell & Jablonsky, 1983).

In silty facies, some shellbeds are associated with siliceous and/or phosphatic nodules, and sometimes with phosphatic crusts.

Genetic sequence and shellbeds distribution

Genetic sequence (very high frequence sequence) is the smallest scale stratigraphic unit identified in outcrop. It is related to a sea-level variation cycle and is limited by the two more distal facies, corresponding to the maximum flooding surfaces (MFS). In terrigenous environments, genetic sequence is made of superposition of coarsening and thickening upward layers (Fig. 4). In the genetic sequences identified in the Portixeddu Formation, type A shellbeds are ubiquitous, while type B shellbeds are only present in the uppermost part of the genetic sequences.

The genetic sequences architecture is controlled by the sediment volume partitioning (Homewood *et al*., 1992). According to Cross (1988) and Cross & Lessenger (1998) the volume of sediment accumulated in an environment changes through space and time because of the accommodation (total space available for storing sediments) variations.

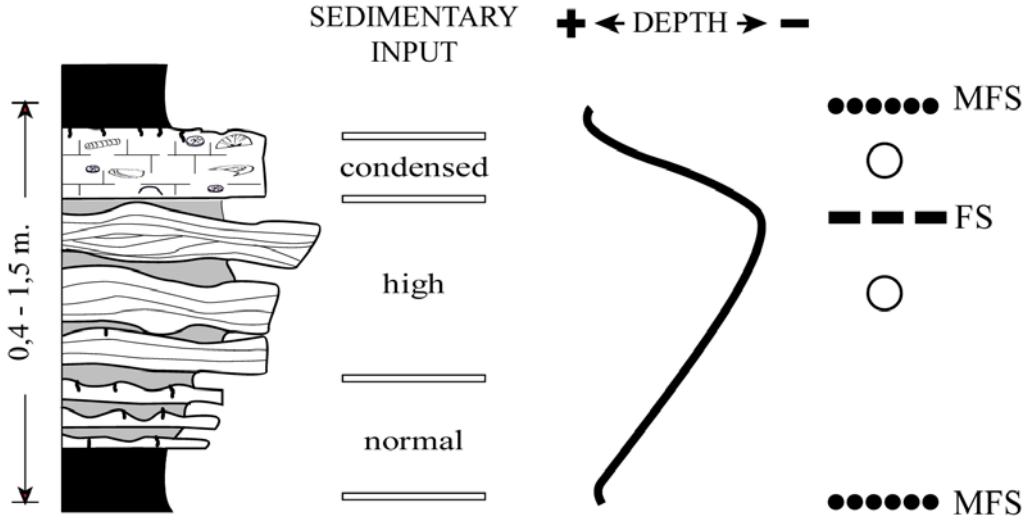


Fig. 4 - Genetic sequence and stratigraphic reponse to very-high-frequency sea-level variation cycle.

During base-level rise time, the accommodation increase in basin-margin leads to sediment storage on the shoreface and costal plain. That reduces sediment accumulation in the internal parts of basin. During base-level fall time, the accommodation decrease leads to increase volume of sediment transported toward the basin center (Cross & Lessenger, 1998). So, the sediment volume partitioning leads to differential preservation of the sediment volume within facies tracts during base-level cycles and controls the sedimentation rate (Fig. 4).

In the Portixeddu Formation, shellbeds distribution in the genetic sequence seems to be linked to sediment supply fluctuations. Type A shellbeds are associated to high or moderate supply episods during sea-level fall, while type B are related to low supply episods during sea-level rise. On the other hand, the analysis of the whole section (Fig. 2) evidences the scarcity of shellbeds during progradation of the third order sequence in comparison with retrogradation and aggradation times.

Shellbeds genesis

In a context of terrigenous shell environment dominated by storm wave action, a model of shellbeds genesis can be proposed in relation with autocyclic and allocyclic factors.

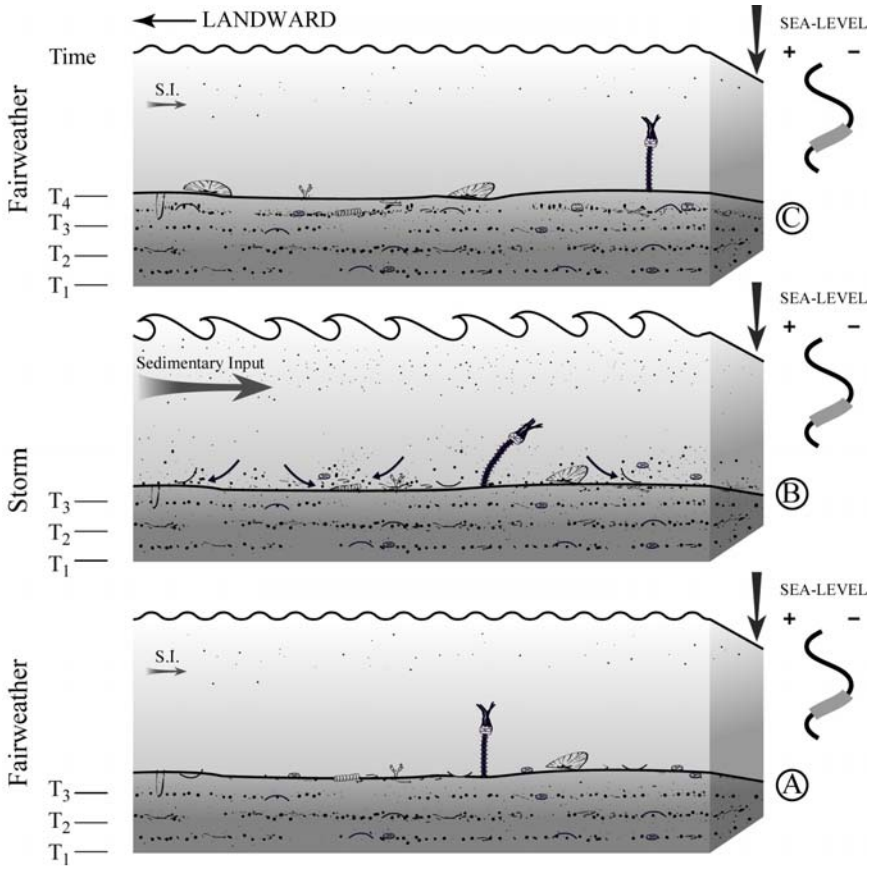


Fig. 5 - Sketch diagram illustrating deposition of type A shellbed during sea-level fall. A and C: fairweather time during falling sea-level. B: storm time during falling sea-level. Time: constant time increments. S.I.: sedimentary input.

The sea-level falls are characterized by high sedimentation rates, inducing the dilution of the skeletal remains by the terrigenous supply (Fig. 5). Under the influence of storm waves, the bioclasts undergo local reworking leading to the formation of type A-shellbeds (Fig. 5B). Then, these accumulations are rapidly covered by terrigenous particles in suspension and other fine material carried in by storm-related and/or nepheloid currents (Fig. 5C). These type A shellbeds are storm-related and correspond to "event concentrations" (*sensu* Kidwell, 1991).

The type B shellbeds are emplaced under hydrodynamic conditions similar to those producing storm-related shellbeds, but with a deficit in terrigenous supply mainly related to the sea-level rise (Fig. 6). This deficit explains the absence of thick terrigenous intercalations between storm-related shellbeds (Fig. 6B-C). The stability of the water-sediment interface allows the perforation and incrustation of some shells by organisms colonizing the sea bottom (taphonomic feedback). The amalgamation of several coquina storm beds results in these shell accumulations. They can thus be regarded as condensed beds generated by a decrease or by an interruption of the terrigenous supply.

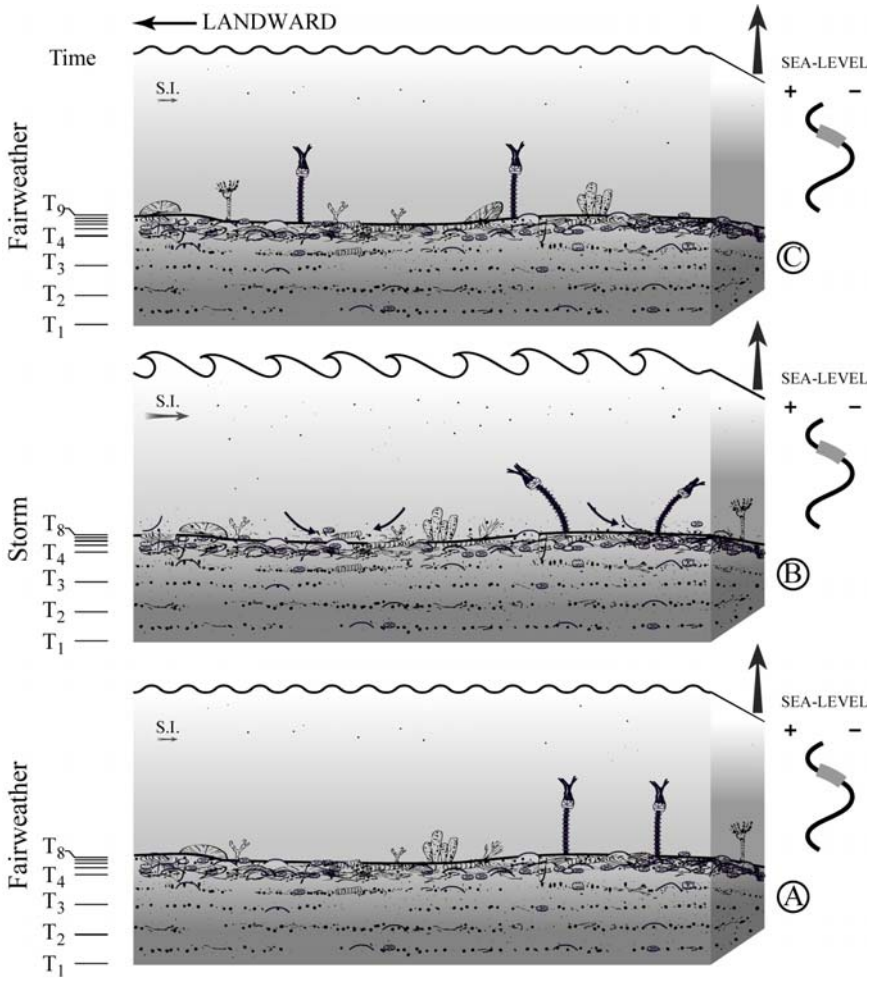


Fig. 6 - Sketch diagram illustrating deposition of type B shellbed during sea-level rise. A and C: fairweather time during rising sea-level. B: storm time during rising sea-level. Time: constant time increments. S.I.: sedimentary input.

Conclusion

This study shows that, in the Portixeddu Formation, shellbeds are present from the proximal part of the upper offshore to the transition zone with the lower offshore. In every environments, they are linked to storm processes. Differences between the two distinguished types are related to variations of the sedimentation rate, controlled by sea-level fluctuations. Type-B accumulations can be associated to episodes of condensation in very high frequency eustatic signal. On the other hand, shellbeds distribution seems to be governed by the place they occupy within the third order signal, they are abundant during retrogradation and aggradation times and rare during progradation times.

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