The evolution of a coastal lagoon system: hydrodynamics determined by ostracofauna and sediments— The Bonne-Anse Bay (Pointe de la Coubre, France)

P. CARBONEL, J. M. JOUANNEAU

Institut de Géologie du Bassin d'Aquitaine
Université de Bordeaux I
351, cours de la libération
33405 Talence Cedex, France

ABSTRACT

The coastal system of the Bonne-Anse is evolving rapidly from a cuspate foreland to a recurve spit system and embayment. The evolutionary changes in morphology can be noted from an old map sequence and from changes in vertical sequence of sediments and microfauna. A model defining the relationship between water circulation, sediments and ostracofauna was made which has potential use for the analogue interpretation of more ancient environments. By determining the transported ostracofauna's place of origin and relating this to the deposited sediments, we have succeeded in tracing both the evolution of the water circulation and the morphology of the lagoonal system.

INTRODUCTION

The Bonne-Anse Bay is located at the northwest corner of the entrance to Gironde estuary. It is a small lagoon (5, 7 km^2), adjacent to the Pointe de la Coubre and forms the extreme northwestern end of the estuary's right bank. Present entrance to the lagoon is only possible through a 100 m passage, because the bay is isolated from the Bay of Biscay by a 6 km sandy spit (Fig. 1). Fairly precise maps of this important light house site from 1677 onward plus aerial photography (Fig. 1) enabled us to make precision analyses of the evolution of the cuspate foreland of 1677 to the modern recurve spit-embayment system. The first phase of this transition corresponds with the beginning of the formation of a recurved spit in 1892 and ending with the first recurve terminating around 1955. This was followed by the second phase leading to the development of the present 6 km sandy spit which has almost totally enclosed the small Bonne-Anse Bay today. Initially the sandy spit protruded southward as a simple spit. Accordingly, the present "bay area" was subject to open Atlantic swells and fine sedimentation could not occur. From approximately 1948 onwards one can note the formation of the latest recurved sandy spit toward the northeast. At that time, the bay began to fill up with fine sediments at an increased rate of sedimentation.

Between 1955 and 1958 the old hook or spit began to erode from tidal waves. Then a new recurve formed more to the east which turned northeasterly, progressively shutting off the bay from the Atlantic swell and enlarging the surface area of the embayment as we know it today. Thus the tidal flat to the north of the bay corresponds to the oldest part of the bay and was initially very much influenced by the marine environment. However, this marine influence diminished as the old recurve began advancing to the northeast. The resultant consequence of narrowing of the bay and creation of a sheltered body of water favorable to suspension increased rates of deposition to approximately 20 cm per year. With continuing erosion, and partial dismantling of the first recurve and the development of the last segment of the recurve spit, the present new tidal flat was formed.

It is essential to understand the geomorphic evolution of the embayment in order to understand changes in fauna in the sediment. Further, the coastal hydrodynamic system changed with great rapidity and effected the microfauna sequence. The best evidence for interpretation of sedimentary events in the bay is from autochthonous and displaced ostracods. This is because of their quantity and the constancy they give with respect to the changes in hydrologic and sedimentary environments. Thus the aim of this study is twofold:

1. To utilize evidence from the ostracod microfauna and the sediments to determine the present bay environment and water mass circulation.

Geo-Marine Letters Vol. 2, 065–070(1982)

0276-0460/82/0201&2-0065$01.75

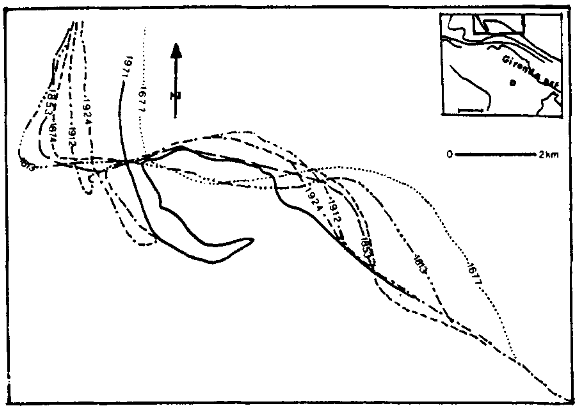

Figure 1. Evolution of the sand spit and the flexure of Pointe de la Coubre.

2. To indicate the effect of morphological changes of the bay and adjacent coastal barrier on the sedimentology, biotic environment and water circulation.

FACIES, FAUNA AND PRESENT WATER CIRCULATION

Facies. Surficial sediments can be differentiated in three groups: sands, mixed sandy mud facies and muds. The sandy facies (Fig. 2) covers the narrow entrance to the bay and part of the tidal channels. It plays a prevailing role in the formation of sandy banks, tidal lobes and banks linked to the end of the sandy spit.

The mixed sandy mud facies (Fig. 2) is comprised of interbedded sand, clay and muddy sands. It is well represented along the interior borderline within the sandy spit, indicating that tidal flats are not predominant. This facies is also found on a part of the older recurve spit and in the bottom of tidal channels that extend to the center of the bay.

The mud facies (Fig. 2) is developed in the center and western portion of the bay where it forms extensive tidal flats.

Fauna. Surficial ostracods are relatively abundant and of great variety. The number of living fauna allowed us to distinguish two major areas within the bay (Fig. 3). In the North Tidal Flat area bioceonosis is at least less than 30 ostracods per

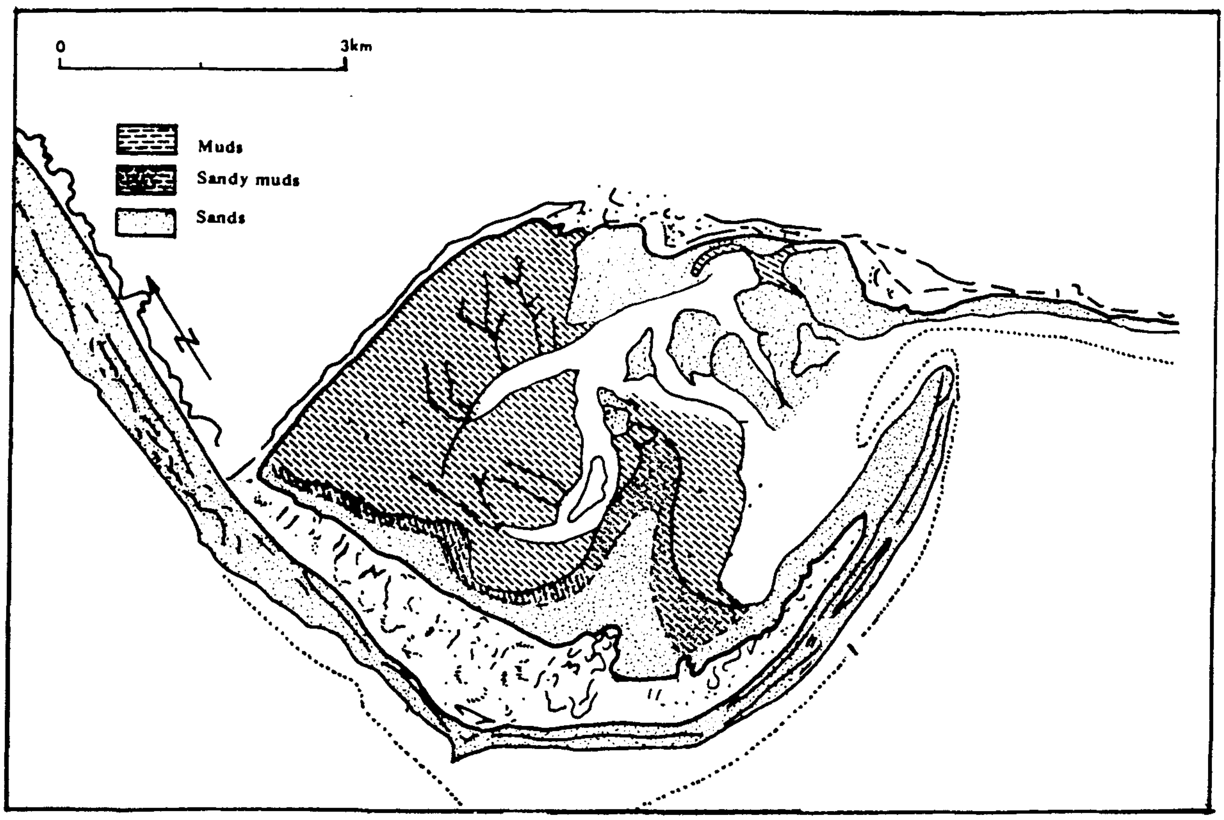

Figure 2: Sedimentary facies in the Bay of Bonne-Anse.

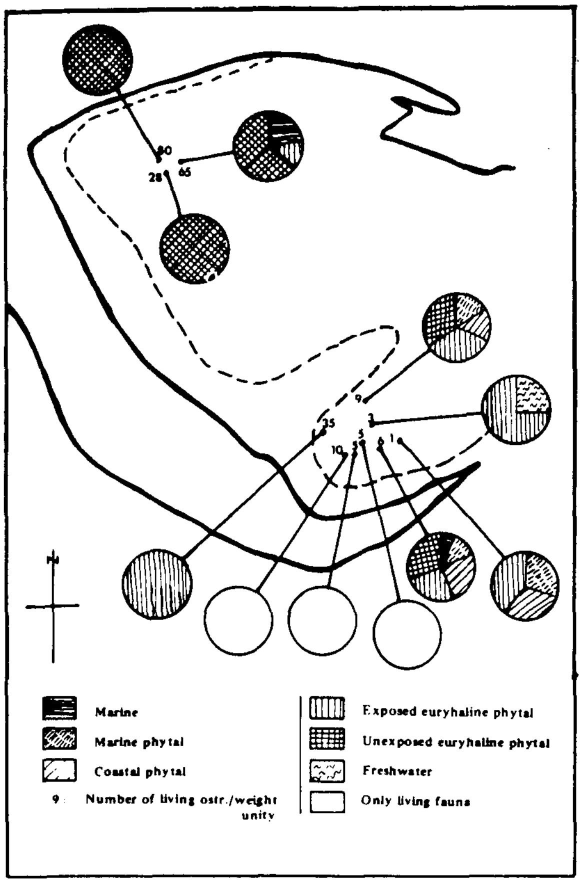

Figure 3. Bay of Bonne-Anse: distribution of ostracods in surficial sediments.

100 gr (average 120) of bulk sediment. The presently active tidal flat located between the recurve spits can be subdivided into two zones: 1. the base of the tidal flats and around the edge of the old recurved spit with an average of 10 ostracofauna, and 2. the middle of the tidal flat and its southern edge where the number of ostracods does not exceed five per sample.

Thus the living fauna is three times greater in the northwestern and calmer part of the bay. This area is emerged for a significantly longer part than the remainder of the bay. Inversely, living ostracods are rare in the southern part of the bay which has only a short time of emersion. The surficial pellicle of the sediments is saturated with water (more than 180%) [1] and consequently the structure is more diluted and the stability of the pellicle is weaker.

As in other domains where it has been recognized that emersion plays a role in the quantitative distribution of ostracods [2,3] the Bonne-Anse Bay demonstrates a clear contrast between environments of long emersion and freshly emerged biotopes. Today, biocoenosis is represented only by *Loxoconcha elliptica*. In the northeast areas of the bay where there are many schorre plants (Fig. 4), one can also find *Cytherois*. On the *Fucus* of mussle-hurdlers, that lay about the principal channel, one can gather *Paradoxostoma*. The last two shells are easily displaced. The poor diversity of living ostracofauna may be caused by a slightly euryhaline tendency of the bay [3].

Near areas of biocoenosis a homogeneous and variable thanatocoenosis is developed, represented by empty, well preserved valves transported to place of deposition.

These ostracods represent several faunic groups. The different species listing is indicated in references 4 and 5. We have given only the genera to simplify the text:

1. Displaced ostracods within the bay such as *Cytherois* and *Paradoxostoma*;
2. Fresh water ostracods—ostracods usually living in the peripheral biotopes of the bay such as *Ilyocypris*, and *Candona*;
3. Coastal ostracods—*Aurila*, *Heterocythereis*, *Urocythereis*, and *Cushmanidea;* and
4. Salt water ostracods—*Semicytherura*, *Neocytherideis*, *Carinocythereis carinata*, *Loxoconcha guttata.*

In the northern tidal flat, thanatocoenosis rarely exceeds 10% of the total and is almost exclusively composed of local species. The remainder of the displaced fauna is marine in origin (Fig. 3). In the south and center of the tidal flat, the local transported fauna predominates. The southern border is mostly inhabited by a fauna transported from outside of the bay. Allothanatocoenosis is more abundant and exceeds 30% of the total; sometimes it predominates (Fig. 3). Although the predominant fauna is local, depending on the place from which the samples were taken, the fauna are neither qualitatively nor quantitatively the same. Thus it is most important to know where these displaced fauna come from and to trace their transport paths in order to determine water circulation patterns within the bay.

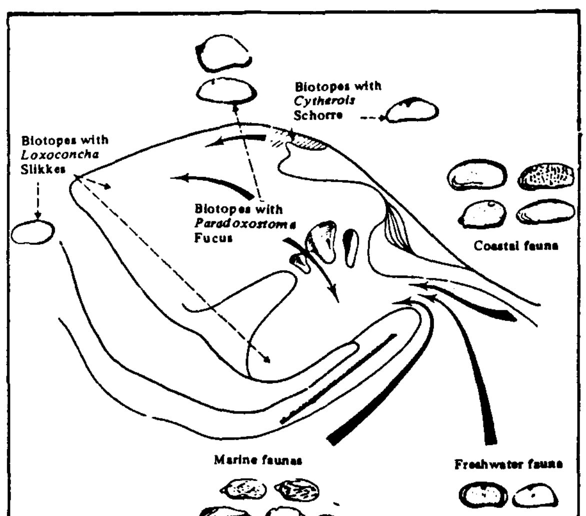

Figure 4. Origin of displaced faunas in Bonne-Anse Bay.

Present water circulation. Suspended matter in the bay is brought in by the flood tide, a portion of which is removed at the time of the turbidity maximum and oscillates at the inlet [6]. The source of the clay and suspension is the Gironde estuary [1,7]. This turbid water enters the bay on the middle of the flood tide. By the end or the ebb and at the very begining of the flood tide, a large quantity of marine water (higher salinity, lower turbidity) enters the bay [7].

Given this complicated circulation system, the flood tide moves and mixes estuarine turbid waters as well as introduces open marine water. In the Bonne-Anse Bay, the flood tide first penetrates the median channel and its principal tributaries and thereafter covers the mud flat. Therefore open marine waters enter through the channels, mix with the estuarine waters and cover the intertidal muddy zones. Our knowledge of the shifting water circulation patterns of the bay and our use of fauna transport diagrams in the Gironde estuary [8] helped us to trace the path of the transported ostracods into the Bonne-Anse estuary.

Origin and transport of displaced ostracods. The marine fauna is transported from the continental shelf whereas the periphytal marine fauna is derived from seaweed found on rocky shoals. Coastal periphytal fauna is transported from the upper intertidal seaweed, the same shoals, or from the coastal zone between the Gironde inlet and Bonne-Anse Bay. The "protected" euryhaline and phytal fauna (*Cytherois*) probably originated from the schorres in the bottom of the bay (Fig. 4) but also from the Gironde estuary. Its abundance in the bay suggests that the local source (from the schorres) is more important. The "exposed" euryhaline and phytal fauna (*Paradoxostoma* sp. div.) is no doubt local in origin.

The freshwater fauna appears to come from the Gironde estuary, following the pathways mentioned previously. However, we have never found any living freshwater fauna in the Bonne-Anse Bay. These valves must, therefore, be derived from the fluvial Gironde or from the schorres drainage channels [3]. The uniformity of the size of these valves indicates lengthly transport, probably by tidal waters [3].

Thus freshwater fauna enters the bay through the middle of the flood tide and is of estuarine origin. Other fauna enter the bay at the beginning of the flood tide with the salt water intrusion. Moreover, the distribution of various allothanatocoenosis indicates the importance of the channel's distributative role. For instance, the majority of the marine ostracods, as opposed to the euryhaline ostracods, are deposited at close proximity to the channel (Fig. 4). Thus the allothanatocoenosis transport is always the same whether long or short. Two water masses of different density transport several forms of fauna, using the tide as a driving force and the bottom morphology, i.e., the channels as distributative axes.

DEVELOPMENT OF THE BAY: CORE STUDIES

The 2 to 4 m cores analyzed in this study were samples from the tidal flat areas and the border of the bay where sandy sediments form the bottom.

Sediments. The sediments of the bay may be divided into two domains. *The North Tidal Flat Domain* core sediments are reduced soft muds with numerous silty and sandy laminations. Lamellibranch shells are abundant. Water content in these muds varies from 70% to a slurry of 100%. The vertical sequence of sediment grain size includes an increase of the silty fraction (45-60%) and a decrease of the clay fraction towards the surface (50-35%). Clay minerals are composed of 40% illite, 33% kaolinite, 20% smectite and 7% chlorite. *The Active Tidal Flat Domain* includes sediment cores of very soft mud, almost fluid in the surface decimeters. The sediments are very homogeneous and silty layers are very thin and shell layers extremely rare. Water concentration in these muds varies from 110 to 140%. Sediment size analysis indicates that the silty fraction changes very little and does not exceed 40%. The clay fraction, in greater quantity, varies between 60 and 70%. The clay mineral components are identical to those in the *North Tidal Flat Domain.* Thus the difference between these two sediment domains does not lie in their mineralogical composition but in the percentage of their various components. It is obvious that the *Active Tidal Flat* sediments are deposited in a calmer environment than the sediments of the *North Tidal Flat*, in which sand is more frequent.

One can find ostracods throughout the cores. However the faunal characteristics differ with respect to the domain study. In the *Active Tidal Flat*, the fauna remains practically the same along the cores except for sporadic freshwater fauna influxes caused by seasonal transport linked to times of floodwaters (Fig. 5). *North Tidal Flat* cores show a gradational change from the base to the top. Allothanatocoenosis is less towards the top.

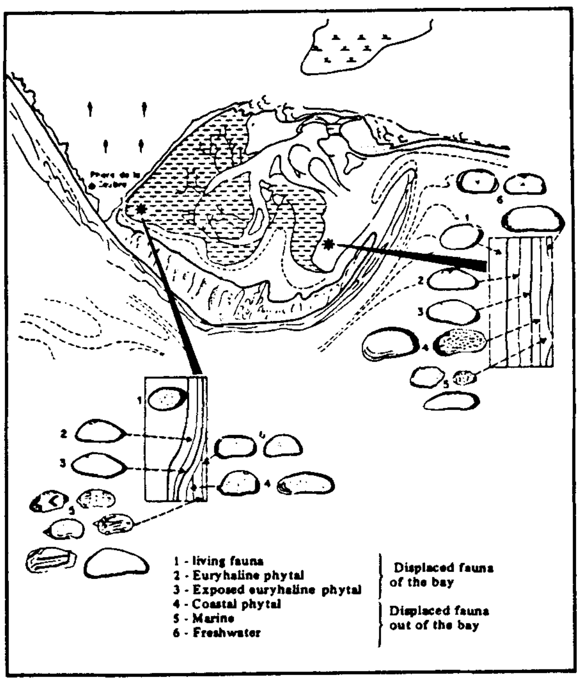

Figure 5. Distribution of ostracods in cores.

Below 80 cm, transported fauna from outside of the depositional area become predominant. In other words, a repartition of facies similar to those in cores of the *Active Tidal Flat* (Fig. 5) appears in the lower part of the core. Inversely, *Loxoconcha elliptica*, which always represents biocoenosis, are more numerous at the top of the core rather than at the base. Two similar sequences therefore occur, both faunal and sedimentary, and are displaced in time and space. The second is found only in the *North Tidal Flat*, which is the oldest depositional area.

HISTORICAL INTERPRETATION

Sediments in the base of the North Tidal Flat cores were deposited in the 1950's. At that time, the bay had the same hydrodynamic processes noted today in the active tidal flat. A sandy hook blocked the entrance to the bay, leaving only a narrow channel through which floodwaters entered, carrying suspended matter including ostracod valves from both the Gironde estuary and from other external biotopes. Transported fauna were distributed through this channel throughout the bottom bay (Fig. 6a). Local transported fauna was evident but not *Cytherois*. Bottom schorres did not exist at that time and the resultant agitating water precluded ostracods. Proximity of the early channel is marked by the presence of a greater proportion of fauna transported from outside Bonne-Anse Bay. Finally, *Loxoconcha elliptica* which represented biocoenosis, were few in number (never more than 50%) as in the present active tidal flat.

After 1955, the North Tidal Flat became more distant from the regular tidal waters flooding the bay. By this time almost no exterior fauna was transported to the area. The old recurve and tidal banks played a "blocking" role. A new mud flat was formed between the present sandy spit and the old recurve spit. This new mud flat was inhabited by transported fauna from outside of the bay, distributed with respect to the channel's proximity. In this present active tidal flat (Fig. 6b) the same hydrodynamic conditions as those present during the deposition of the base of the cores in the northern area occur. At the same time, the older tidal flat has become more and more isolated. Its higher evaluation results in longer emersion at low tide, thus encouraging a biocoenosis proliferation [3]. During this second stage, schorres were set up in the northeastern part of the bay which explains the arrival and subsequent persistence of *Cytherois* (Fig. 6b).

Reference to the morphological data and in particular to the evolution of the coastal land forms as shown on aerial photography (1950, 1955, 1971 maps) suggests that changes noted in the ostracofauna are in agreement with our observations.

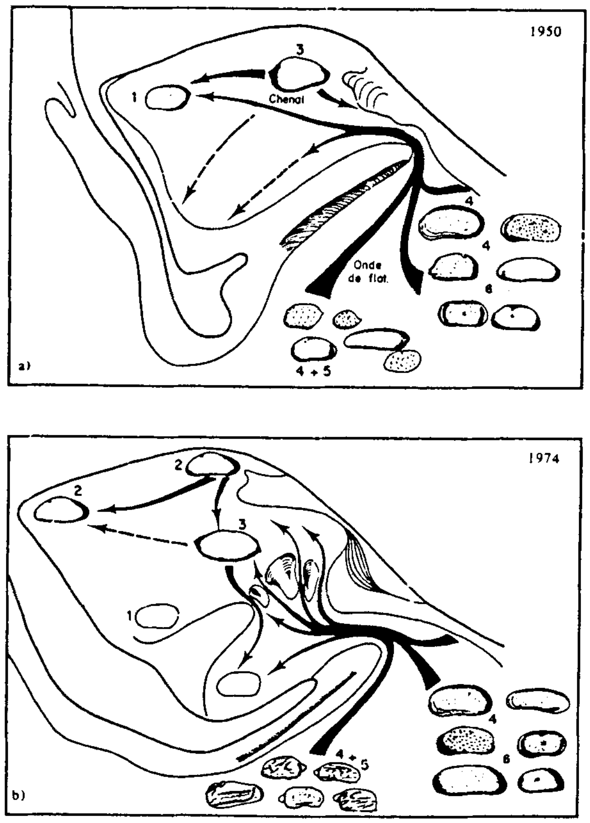

Figure 6. Evolution of water circulation in Bonne-Anse Bay by the evolution of distribution of displaced ostracods. For legend, see Figure 5.

CONCLUSIONS

The Bonne-Anse Bay is an example of a relatively stable physicochemical environment. Indeed, both the living fauna in situ, and the incoming minerals underwent very few if any modifications. However, this similarity is misleading for it does not take into account the great morphologic changes within the area of the present Bonne-Anse Bay. The evolution of the bay has strongly influenced water circulation and changed the abundance of the fine sediment fraction and of the transported fauna. A lateral and vertical displacement of the sediment-faunal facies have therefore occurred. The transported ostracods are therefore excellent indicators of lagoonal systems undergoing rapid evolution as is shown by this model applied at the entrance of the Gironde estuary. The geologist interpretating the ancient sedimentary and biologic record should therefore be aware of the concepts herein discussed in making paleoenvironmental interpretations.

ACKNOWLEDGMENTS

We are very grateful to Dr. J. C. Kraft (University of Delaware) for his in-depth review and major rewriting. We thank Mrs. D. Morel (IGBA) for translating our original text.

REFERENCES

[1] Tauzin, P., 1974. Etude des relations entre les caractéristiques physcio-chimiques et chimiques des milieux de dépôt et la distribution de quelques éléments métalliques dans l'ensemble de divers environnements du Golfe de Gascogne. Thèse Doct. 3e cycle, Université de Bordeaux 1, n° 1131, 116 p.

[2] Carbonel, P., 1978. Densités fauniques d'ostracodes en milieu intertidal euryhalin; rôle de l'émersion. Bulletin Institut Géologique Bassin d'Aquitaine, Bordeaux, n°23, p.165-171.

[3] Carbonel, P., 1980. Les ostracodes et leur intérêt dans la définition des écosystémes estuariens et de plateforme continentale. Essais d'application à des domaines anciens. Thèse Doct. ès-Sciences, Université de Bordeaux I, n° 646, 348 p.

[4] Carbonel, P., and Jouanneau, J. M., 1975. Relations entre les phénomènes hydrodynamiques et les thanatocoenoses d'ostracodes à Bonne-Anse (embouchure de la Gironde) au cours de histoire de la baie, Bulletin Institut Géologique Bassin d'Aquitaine, Bordeaux, n° 17, p. 3–16.

[5] Carbonel, P., Moyes, J., and Peypouquet, J. P., 1972. Ostracodes du domaine phytal intertidal dans la partie aval de l'estuaire de la Gironde et dans la zone Nord-Ouest de l'île d'Oléron. Bulletin Institut Géologique Bassin d'Aquitaine, Bordeaux, n° 12, p. 191-194.

[6] Allen, G. P., 1972. Etude des processus sédimentaires dans l'estuaire de la Gironde. Thèse Doct. ès-Sciences, Université de Bordeaux I, n° 369, 390 p.

[7] Jouanneau, J. M., 1974. Etude sédimentologique d'un système côtier évolutif: la Pointe de la Coubre (embouchure de la Gironde, France). Thèse Doct. 3e cycle, Université de Bordeaux I, n° 1136, 161 p.

[8] Carbonel, P., Moyes, J., and Vigneaux, M., 1971. La répartition des thanatocoenoses d'ostracodes dans l'estuaire de la Gironde et ses relations avec les courants. Compte Rendu Académie Sciences, Paris, v. 273, sér. D, p. 1679-1682.

Manuscript received 6 January 1982; revision received 12 June 1982.