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ORIGINAL PAPER

Biodiversity and taphonomy of bivalve assemblages of the Pliocene of Algeria (Bas Chelif Basin)

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Abstract Similar to the Miocene, the Pliocene of the outcrops of Bas Chelif Basin delivered abundant and much diversified fossiliferous levels of malacofauna (bivalvia). The paleontological study of two typical Pliocene series, in the center (Sidi Brahim) and at the northwestern margin of the Bas Chelif Basin (Sassel Beach), permit the identification of 4 orders, 8 families, 15 genera, and 20 species among the bivalvia. The simultaneous study of autoecological and taphonomic features of the fauna contained in the Sidi Brahim geological section allowed distinguishing at once four fauna associations, in which each one characterizes a particular ecozone which is attributed to an environment: (1) the muddy deep environment association (*Cristatopecten cristatum*, *Pelecyroa brochii*, and *Tellina donacina*); (2) the muddy instable and frankly deep environment association (*Anadara diluvii*, *C. cristatum*, *P. brochii*, and *T. donacina*); (3) the association of the infralittoral environments, rich in sandy supplies; and (4) the association of the upper infralittoral sandy environment and three shell assemblages—the "3D census assemblage," "3D multihabitat time-averaged assemblage," and "3D allochthon assemblage"—where their spatiotemporal enchainment allowed making obvious four phases of transgressive–regressive oscillation in the general transgressive tendency of Sidi Brahim section, during the lower and average Pliocene. With a reduced thickness, the Sassel Beach section is characterized, on one hand, by the setup of two fauna associations of the infralittoral sandy environments (*Pecten benedictus* and *Ostrea lamellosa*) and infralittoral muddy environments (*Aequipecten opercularis*, *Aequipecten seniensis*, and *P. benedictus*), and of other parts by the piling up of three types of assemblages (3D allochthonous assemblage, 3D census assemblage, and 3D multihabitat time-averaged assemblage), defining three phases, comparatively less pronounced of the transgressive cycle of the Pliocene.

Keywords Bivalves · Pliocene · Sidi Brahim · Sassel Beach · Basin of Bas Chelif · Taphonomy · Paleoecology · Assemblage · Association

Introduction

The history of the Neogene biostratigraphy of the Bas Chelif Basin is closely related to bivalve mollusks studies. Indeed, this malacofauna (associated with other organisms such as gastropods, echinoderms, balanids, etc.) served as the basis for the first stratigraphic subdivisions of the Neogene lands of Algeria (Pomel 1892; Ficheur 1890; Brive 1897; Dalloni 1915), prior to use, more accurate microfauna (Mazzola 1971; Belkebir 1986; Belkebir et al. 1996, 2002, 2008. Other research (Freneix et al. 1974, 1987a, b, 1988; Rouchy and Freneix 1979) have brought about significant results on the paleoecological aspect or integrated in multidisciplinary synthesis (Perrodon 1957; Rouchy 1982). Few paleontological works have been devoted directly to the Pliocene mollusks. Taking as a basis the series of Sidi Brahim (center of Chelif Basin) and Sassel Beach (northwestern edge of the Chelif Basin), this study provides basically a systematic inventory and focuses on the analysis of the paleoenvironmental dynamics of bivalve associations and

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shell assemblages during the Pliocene and their integration within the eustatic cycle of the Pliocene sea, both in the center of the basin and in its northwestern margin.

Geological setting and field area

The Pliocene of Bas Chelif Basin corresponds to a complete sedimentary cycle (Perrodon 1957). It is generally transgressive on previous lands (Perrodon 1957; Rouchy 1982; Atif 2001): it started by azoic conglomeratic level (Bouzghaia), conglomeratic horizon (El Ghomri), or by bioturbated horizon (Djebel Meni).

The Pliocene deposits are characterized by white marls at the base (equivalent to *trubi* facies of the Italians authors) which are well represented in the northeastern regions. They became absent in the western and southern regions and showed sporadic occurrence in the northwestern regions (Repal 1952; Perrodon 1957). They reach their maximum of thickness in the axial parts of the basin with sandy marl or marl sandstone (Rouchy 1982).

The studied areas

Sidi Brahim section

Known as "Telegraph of Sidi Brahim," this section is located on the southwestern edge of the massif of the Dahra, about 40 km east of the city of Mostaganem (Fig. 1). The geology of this region is a part of the Neogene basin of Chelif. Locally, the Pliocene consists of thick series of blue marl ("Tahria" formation; Anderson 1936), which is gradually loaded with sand often rich in glauconite to the top (Perrodon 1957). This marl facies is superposed by the "astiens" sandstone, corresponding to the formation of "Slama" (Anderson 1936).

However, Perrodon (1957) noted that most pelagic fauna of the Upper Miocene continued during the Pliocene. This has made the distinction between the two epochs often delicate. Macrofauna is represented principally by molluscs (bivalves and gastropods) and echinoids, while the microfauna are characterized by the coexistence of abundant planktonic and benthic foraminifera. Detailed biostratigraphy based on foraminifera, established by Mazzola (1971) has identified four distinct biozones: three for the Upper Messinian-Lower Pliocene where the formation of Tahria is assigned and one for the middle Pliocene. The overlying formation Slama, composed essentially by sandy marl deposits, has marked the beginning of the middle Pliocene.

To follow the frequent lateral and vertical variations of thickness and lithology of the different facies containing bivalves outcrops, two main sections were realized in the study area showing the synthetic facies arrangement upwards (Fig. 2):

Tahria formation This unit shows unconformable contact on the gypsum and calcareous units of the Messinian stage and is dominated by soft to weakly indurate marl (Atif et al. 2008). The difference on colors of the encountered facies makes

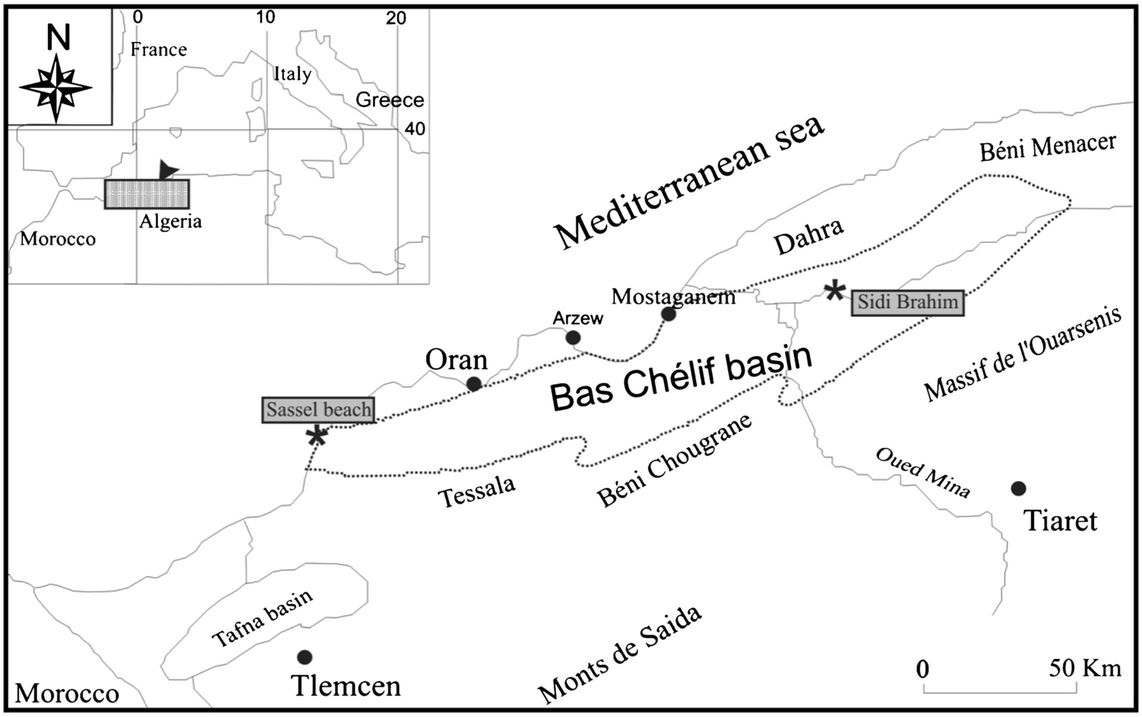
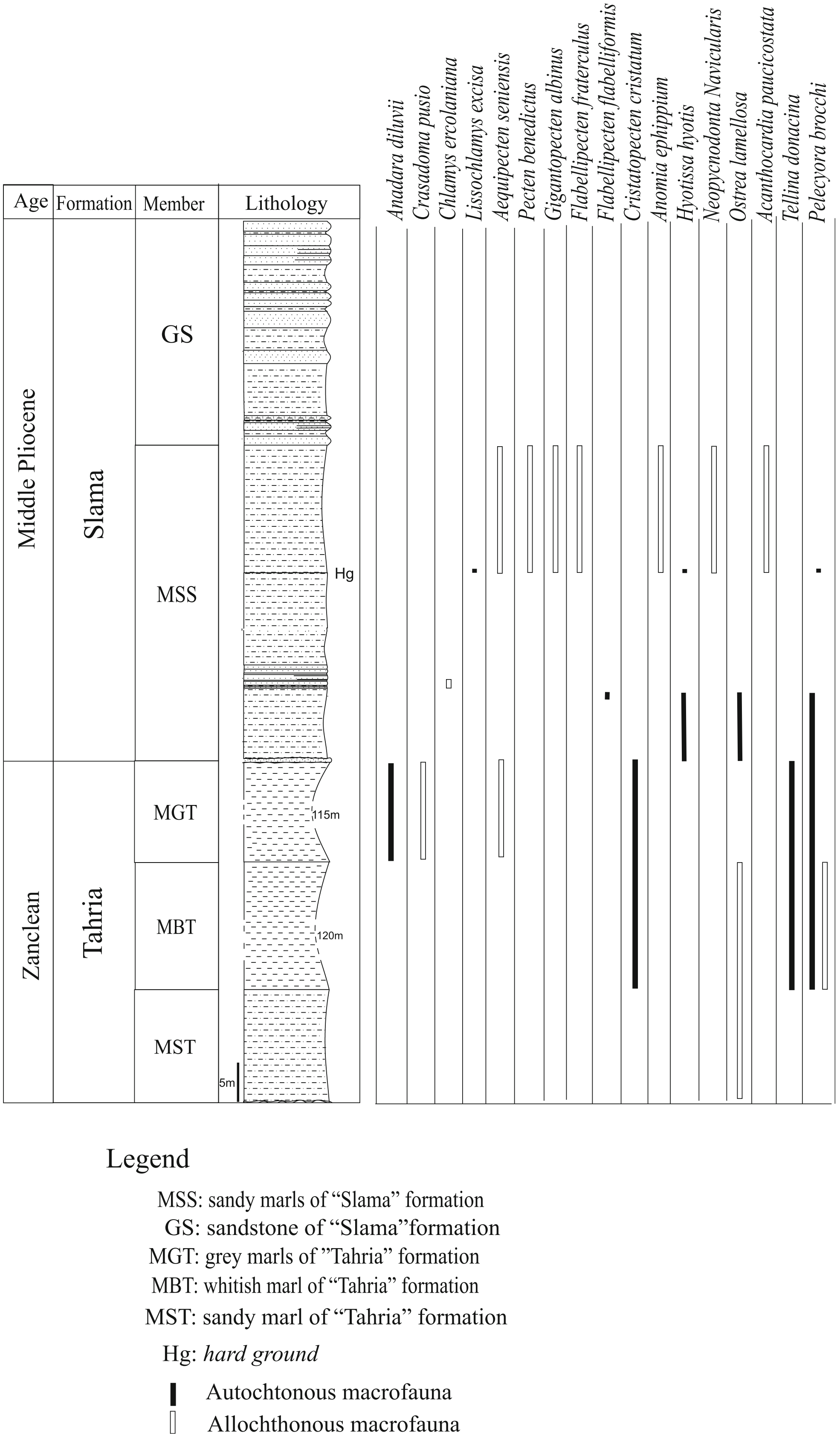


Fig. 1 Geographic localization of the studied fossiliferous sites (map of Perrodon 1957 (adapted)). The *Asterisks* denote the studied fossiliferous outcrops

Fig. 2 Lithostratigraphic distribution of bivalves of Sidi Brahim cutting (basin of Bas Chelif)



possible to distinguish tree members: (a) sandy marls (15 m), (b) whitish marl (120 m), and (c) grey marls (115 m). The first member exhibiting many polygenic and heterometric rollers (gypsum, limestone, etc.) and rare bivalve shells is often in fragmentary state. The second more marly member with whitish and more indurate marls contains macrofauna represented by few diverse assemblages of very small specimens scattered in the marl and often occurs in chalky state for most collected valves. The third member, with grey marls, delivered very rich and diverse macrofauna looking for several specimens of bivalves, gastropods, and scaphopods.

In some places (south section), the higher part of the member becomes more sandy and shows abundant oysters. It is divided into four horizontal fossiliferous levels clearly visible in the two last upper meters. Their thickness is variable between 0.1 and 0.15 m, and they are landmarked approximately at 0.2, 0.3, and 0.5 m below an azoic nodular sandstone bench. The fourth level consists of the basis of several traces of bioturbation associated with many recorded burrows vertical and/or horizontal. At this level, Mazzola (1971) had confirmed the beginning of the Middle Pliocene.

Slama formation The Slama formation is conformably overlaid with the previous deposits and the transition between the two items making through the first sandstone pseudo-nodule bench (northern section) in which the base is covered by oyster valves (south section), marking the start of the Slama formation (Perrodon 1957).

Outcrops of this formation are much less thicker than the previous and feature mainly to members as follows: (a) sandy marl lower member (35 m in thickness) and (b) sandstone upper member (25 m in thickness). They correspond to shallow coastal environment (Perrodon 1957).

At the top, a yellowish gritty bar clearly remarkable in outcrop contained at its base several taxa of bivalves and gastropods, with either their complete shell or as prints. Others are less common: complete specimens and/or fragmented left valves or just fragments. To the north, the sandstone beds have a lower dip, but are a little bit thick (0.1 to 0.2 m). Sometimes, they showed fine horizontal laminations that evolve upward to cross-bedding. These deposits are recovered by a large deposit of yellowish sandy clays (25 m). At about 3.5 m from its base, we note the presence of a sandstone bench, lined by a hard ground ferruginous surface. Several fossil remains are present, showing various states of preservation of the shells. This level is topped by second deposit of sandy marl (5 m). The second bar is marked by yellowish brown sandstone benches (thickness is variable between 1 and 5 m). Sometimes, they have rolled to a clear stratification, alternating with fine sandy marl levels. The fauna is absent in this facies, and the series ends with a 20-m intercalation of azoic yellowish sandy clays and fine sandstone.

Sassel Beach section

This section is located in the beach bay village of Sassel which lies about 60 km west of Oran (Fig. 1). The lithology and micropaleontological content allowed the identification of two main units (Fig. 3):

- The stromatolitic limestone (5 m thickness): They consist of a succession of several levels of stromatolitic domes (Saint Martin et al. 1995a). A lamellar pronounced appearance at the base tends to disappear into the top. The marly levels are gradually interspersed and become larger and more continuous upward. The upper surface is marked by a fairly clear gully surface. This set is characteristic of post-Messinian platform reef facies.
- The sandy clays (20 m): They unconformably lie on stromatolithic limestone. The presence of *Globorotalia margaritae* (Bolli and Bermudez) has to assign Zanclean age (Atif et al. 2008). They showed rich interbedded fauna, essentially of bivalve test, which are associated with some internal molds of gastropods and very small fragments of echinoderms.

Material and methods

The principal abbreviations used in the text are as follows: MNHN, Natural National History Museum of Paris; LPSP, Laboratory of Paleontology and Stratigraphic Paleoenvironments of Oran; Dup, umbono-palleal diameter; Dap, antero-posterior diameter; LV, left valve; and RV, right valve.

Equipment and sampling method

The material that was the basis for this study is preserved in the fossil collections of the MNHN Paris, for the majority of specimens (Sidi Brahim), additional specimens (Sidi Brahim, Sassel Beach) are included in the personal collection of the main author (LPSP, University of Oran).

The sampling method is based on that proposed by Gitton (1978) which provides for the collection of macrofauna to make a sample of a bag of sediment on the order of 1 m^3, which is hardly conceivable. Depending on the conditions encountered in outcrops, sampling was performed in fact throughout the series, both in unlithified and weakly indurate facies (marl) where macrofauna is very dispersed, and the specimens were taken from the surface or digging about 30 cm in the sediment than in the consistent facies (sandstone) where samples were taken on the surface or on the edge of the bench. Sometimes, marls reach considerable thickness (over 100 m), and thus, the stratigraphic location of the fossil is much less accurate.

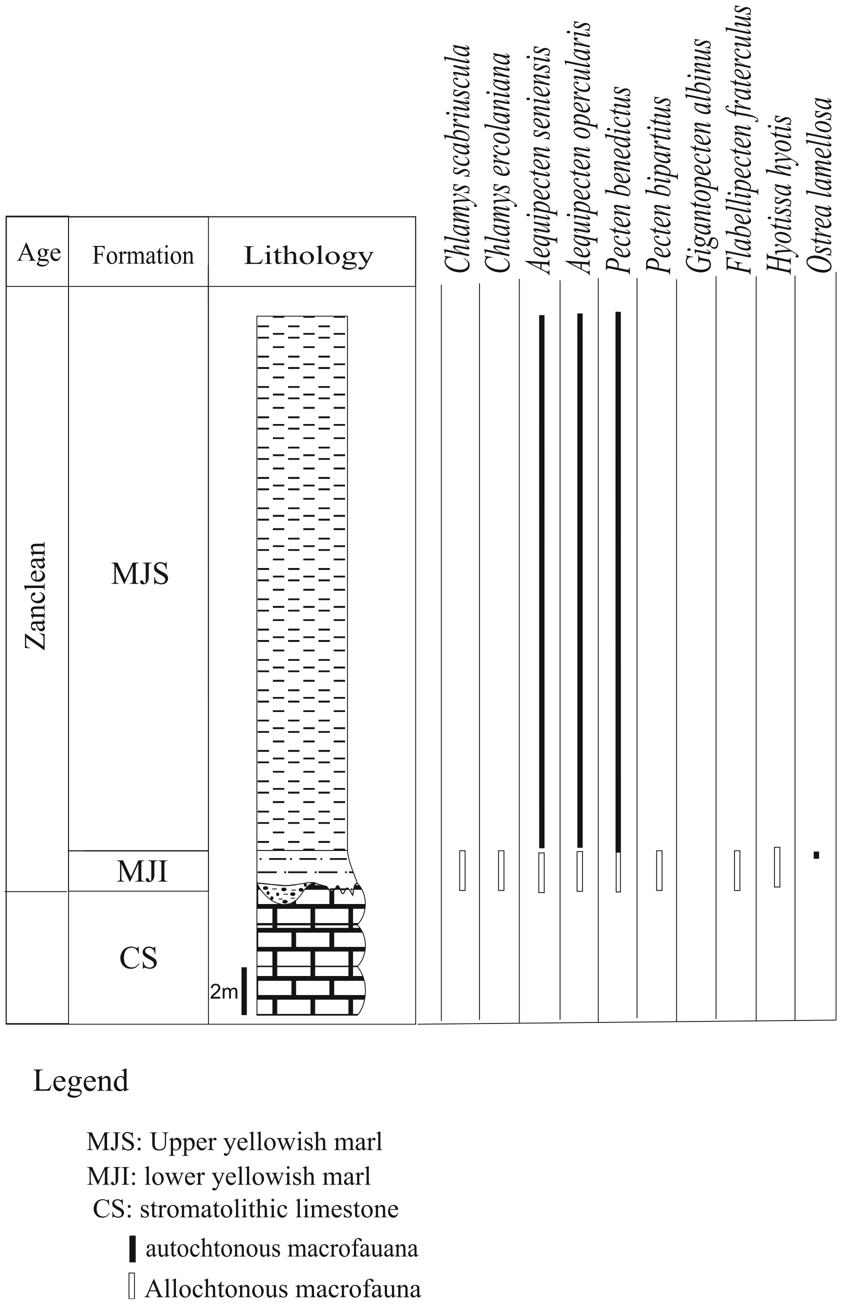
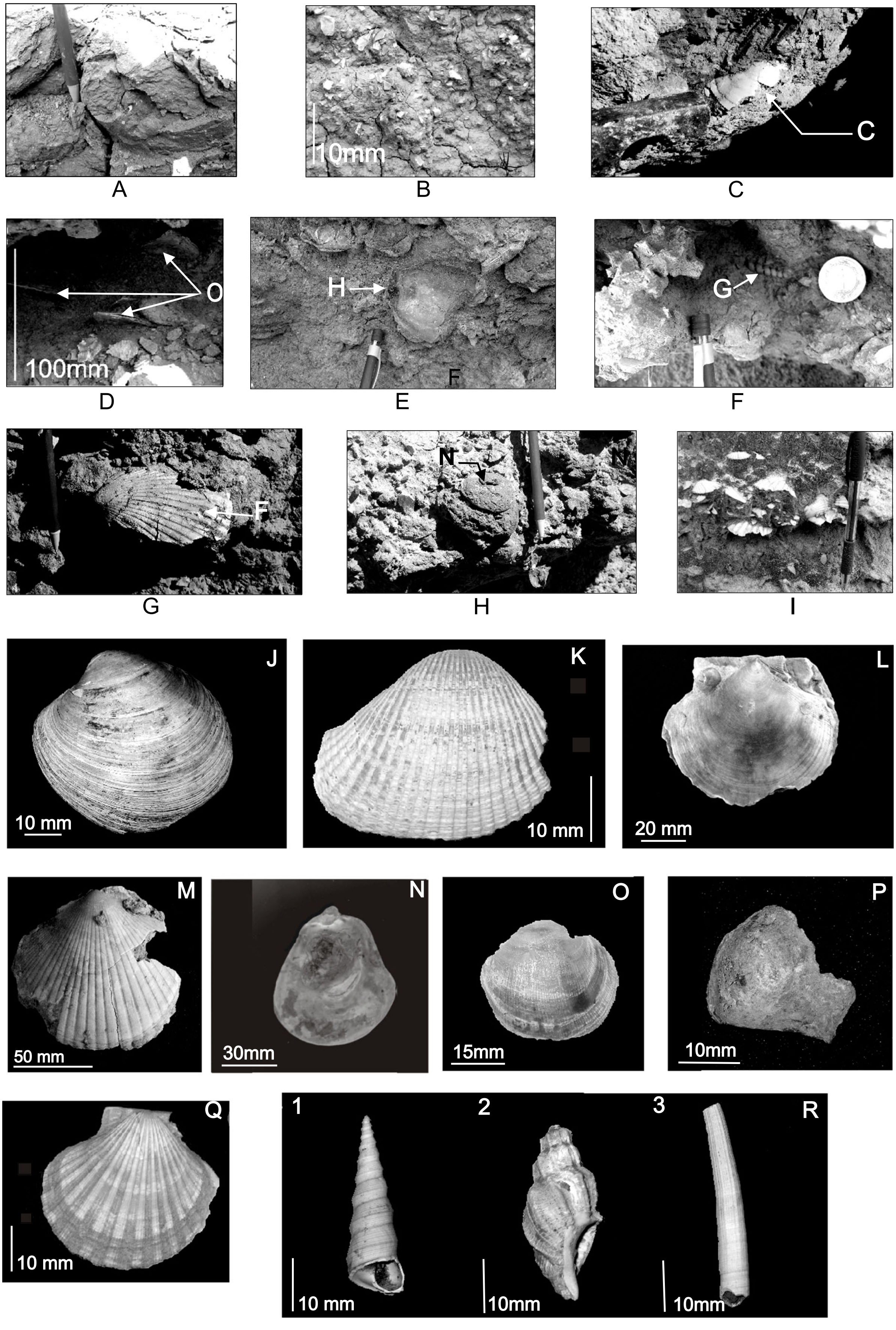


Fig. 3 Lithostratigraphic distribution of bivalves of Sassel Beach cutting (basin of Bas Chelif)

Bivalves associated with other fossil groups (e.g., gastropods) were harvested carefully, taking into account the detailed examination of shells, their conservation status, and their position in the enclosing facies (Fig. 4). The conservation status of almost all specimens is good enough (Satour 2012). The calcite shells (scallops and ostreids) are highly conserved, which made them easy to be identified. However, the aragonite shell tests (venerid) show much less degree of conservation, but overall acceptable in so far as the main characters of determination are relatively discernible. Depending on their situation in the various sediments, shells indicated diverse taphonomic states: shells (whole pieces) with two valves in perfect connection, complete, or fragmentary state. Some individuals are represented by a single valve, or not well preserved, usually without trace of perforation or algal activity; others are present only as fragments. Additionally, few balanid colonies were sometimes observed on the outer surface.

Systematic inventory

The adopted nomenclature for the systematic inventory of bivalves is that of Moore (1969) and Waller (1978, 1993). For the determination of several bivalve taxa, we referred to


A
10mm
B
C
C
O
100mm
D
H
F
E
G
F
F
G
N
H
I
J
10 mm
K
10 mm
L
20 mm
M
50 mm
N
30mm
O
15mm
P
10mm
Q
10 mm
1
2
3
R
10 mm
10mm
10mm

◀ **Fig. 4** **a** 3D census assemblage included in the whitish marl of the Tahria formation (Sidi Brahim section). **b** 3D allochthonous assemblage of the grey marl of the Tahria formation (we note fragments of the left and right valves of the Oyster *O. lamellosa*). **c** *C. cristatum* (*C*) of grey marl (upper member) of the Tahria formation (Sidi Brahim section). **d** Shells and right and left valves of *O. lamellosa* (*O*) compose the "Oyster bed" (sandy marls of the top of Tahria formation). **e** Valves of *H. hyotis* (*H*) at the internal surface of sandstone bench at the beginning of the Slama formation. **f** Internal mold of gastropod (*G*) included in the sandstone at the beginning of the Slama formation. **g** *F. flabelliformis* (*F*) appears at the upper surface of the same previous sandstone bench (Slama formation). **h** 3D multihabitat time-averaged assemblage of the upper sandy marls of Slama formation (we note the big size of the gastropod *Natica* N). **i** 3D multihabitat time-averaged assemblage of the lower sandy marls of Sassel Beach section. **j** Left valve of *P. brochii* (Sidi Brahim section). **k** Fragmented right valve of *A. diluvii* (Sidi Brahim section). **l** Specimen lightly fragmented of *L. excisa* (we noticed balanid colonies settled on the left rib of the left valve). **m** Specimen lightly fragmented of *F. flabelliformis* (Sidi Brahim section). **n** Left valve of *O. lamellosa* (Sidi Brahim section). **o** Fragmented valve of *C. ercolaniana* (Sidi Brahim section). **p** Left valve lightly fragmented of *N. navicularis* (Sidi Brahim section). **q** Right valve of *A. seniensis* (Sassel Beach section). **r** Associated mollusques (*1*, *T. subangulata*; *2*, *Nassa*; *3*, *Dentalium*)

the classical monographs (Depéret and Roman 1902; Sacco 1898), the important work profusely illustrated (Dolfus and Dautzenberg 1902), and numerous articles (Freneix et al. 1974, 1987a, b, 1988; Lacour et al. 2002; Lauriat-Rage et al. 1993; Satour et al. 2011).

However, the Sidi Brahim section (Figs. 4 and 5) has revealed the presence of two subclasses: Pteriomorphia and Heterodonta among bivalve fauna which are quite diverse. In fact, 4 orders (Arcoida, Pterioida, Ostreoida, and Veneroida), 8 families (Arcidae, Pectinidae, Anomiidae, Gryphaeidae, Ostreidae, Cardiidae, Tellinidae, and Veneridae), 13 genera, and 17 species have been identified and inventoried.

Anadara diluvii (Lamarck 1805)
Crassadoma multistriata (Poli 1795)
Chlamys ercolaniana (Cocconi 1873)
Chlamys excisa (Bronn 1832)
Aequipecten seniensis (Lamarck 1819)
Pecten benedictus (Lamarck 1819)
Gigantopecten albinus (VonTeppner 1918)
Flabellipecten fraterculus (Sowerby in Smith 1841)
Flabellipecten flabelliformis (Brocchi 1814)
Cristatopecten cristatum (Bronn 1827)
Anomia ephippium Linne 1758
Hyotissa hyotis (De Serres 1843)
Neopycnodonte navicularis (Brocchi 1814)
Ostrea lamellosa (Brocchi 1814)
Acanthocardia paucicostata (Sowerby 1839)
Tellina donacina Linne 1758
Pelecyora brochii (Deshayes 1836)

Furthermore, the Sassel Beach section (Figs. 4 and 6) was relatively undiversified but quantitatively very rich in Scallops (137 individuals in complete specimens and/or fragments). Actually, it helped to highlight ten species and seven genera belonging to two families: Pectinidae (Rafinesque 1815) and Ostreidae (Rafinesque 1815).

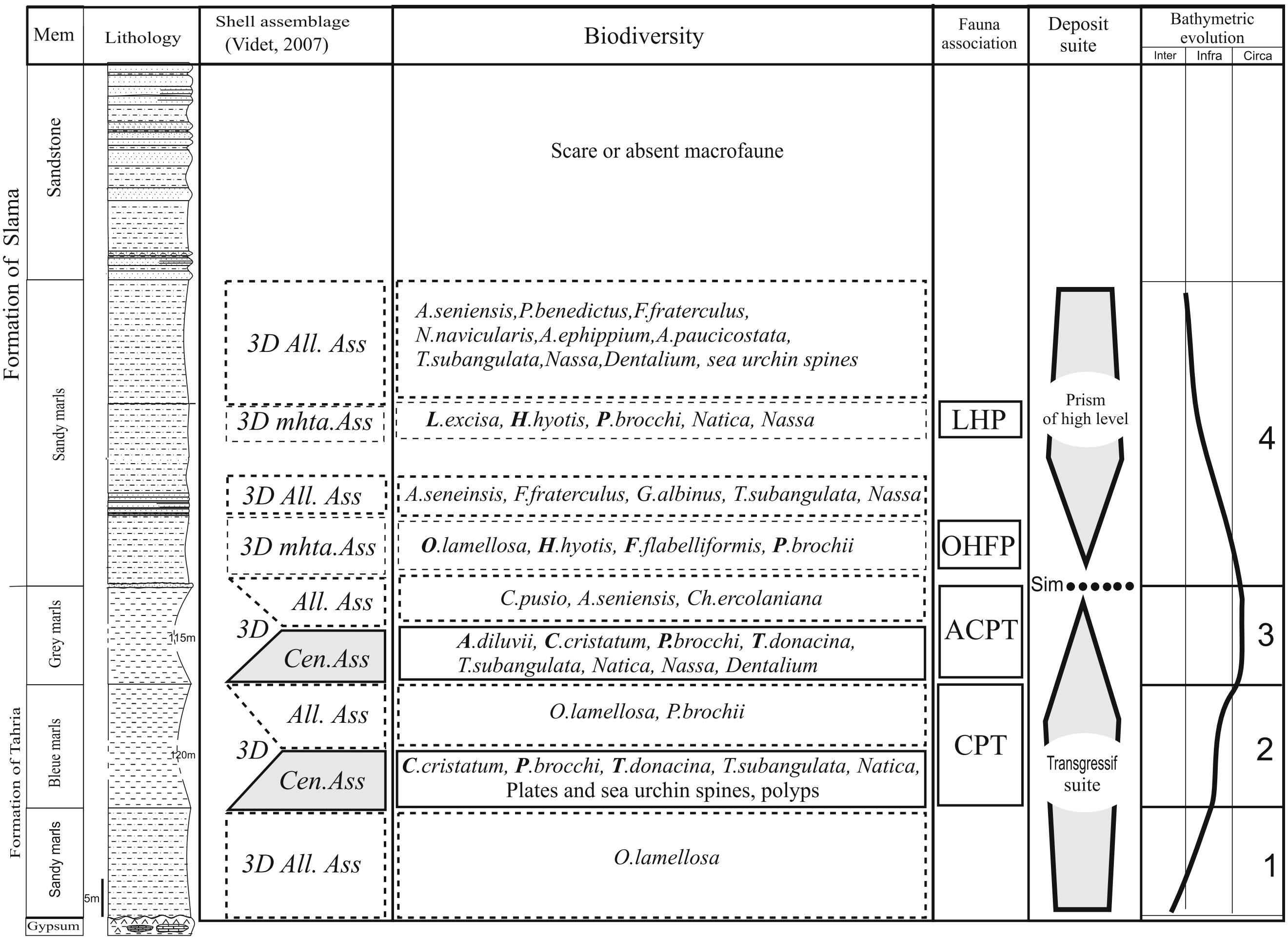
Chlamys scabriuscula (Matheron 1842)
Chlamys ercolaniana (Cocconi 1873)
Aequipecten seniensis (Lamarck 1819)
Aequipecten opercularis (Linné 1758)
Pecten benedictus (Lamarck 1819)
Pecten bipartitus (Foresti 1876)
Gigantopecten albinus (VonTeppner 1918)
Flabellipecten fraterculus (Sowerbyin Smith 1841)
Hyotissa hyotis (De Serres 1843)
Ostrea lamellosa (Brocchi 1814)

Taphonomy

Bivalve shells exhibit various taphonomic states (abrasion rates and predation degree, test dissolution, and encrust shells). These were the source of almost exhaustive summary of Paleobiology, taphonomy, sedimentology, and stratigraphy criteria established and used by Kidwell and Bosence (1991). These criteria were taken and recently have been applied to Upper Cretaceous oysters of the North Aquitaine Basin (southwestern France) and Upper Neogene of Andalucia (SE Spain) by Videt (2007). So we find it interesting to extrapolate and use them to define and classify shell assemblages studied in the current note.

Indeed, the shell assemblages have two different geometries in two dimensions (2D, area) or three dimensions (3D, bench), resulting from the genesis and quite specific evolution of each assemblage. Despite the broad spectrum of environmental distribution of bivalves, these organisms met exclusively in 3D geometric levels, with the exception of oysters (ostreids) that are embedded in matching 3D stratigraphic units and 2D sedimentary discontinuities (Videt 2007).

Valves in good anatomical connection, which are not fragmented, in life position, and well-preserved test, specify the degree of conservation and relationships of organisms with their banking facies and therefore indicate the autochthony of shell assemblage. Other criteria characterizing in situ fauna association (paleo biocenose) were cited by Lacour et al. (2002): the presence of the two valves, fully, unworn and well connected (internal molds included), with multigeneration of populations (juvenile and adult forms) and with the presence of barnacles on the closed shells of bivalves, is an additional autochthony indicator. Associated fauna (gastropod, echinoderm, etc.) must also confirm the autochthonous character of bivalve association. However, in situ assemblages ("2D and 3D census assemblages") reflect fairly the original communities and their interaction with the environment. They are the best to provide as



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Shell assemblages:

3D: in three dimensions

1) All. Ass: *"allochtone assemblage"*

2) cen. Ass: *"census assemblage"*

3) mhta.Ass:*"multi habitat time averaged assemblage"*

Bivalves ssociations:

1). CPT: association of ***C****.cristatum,* ***P****.brochii et* ***T****.donacina,*

2). ACPT: association of ***A****.diluvii,* ***C****.cristatum****,*** ***P****.brochii* et ***T****.donacina*

3). OHFP: association ***of O****.lamellosa,* ***H****.hyotis, F.flabelliformis et P.brocchi*

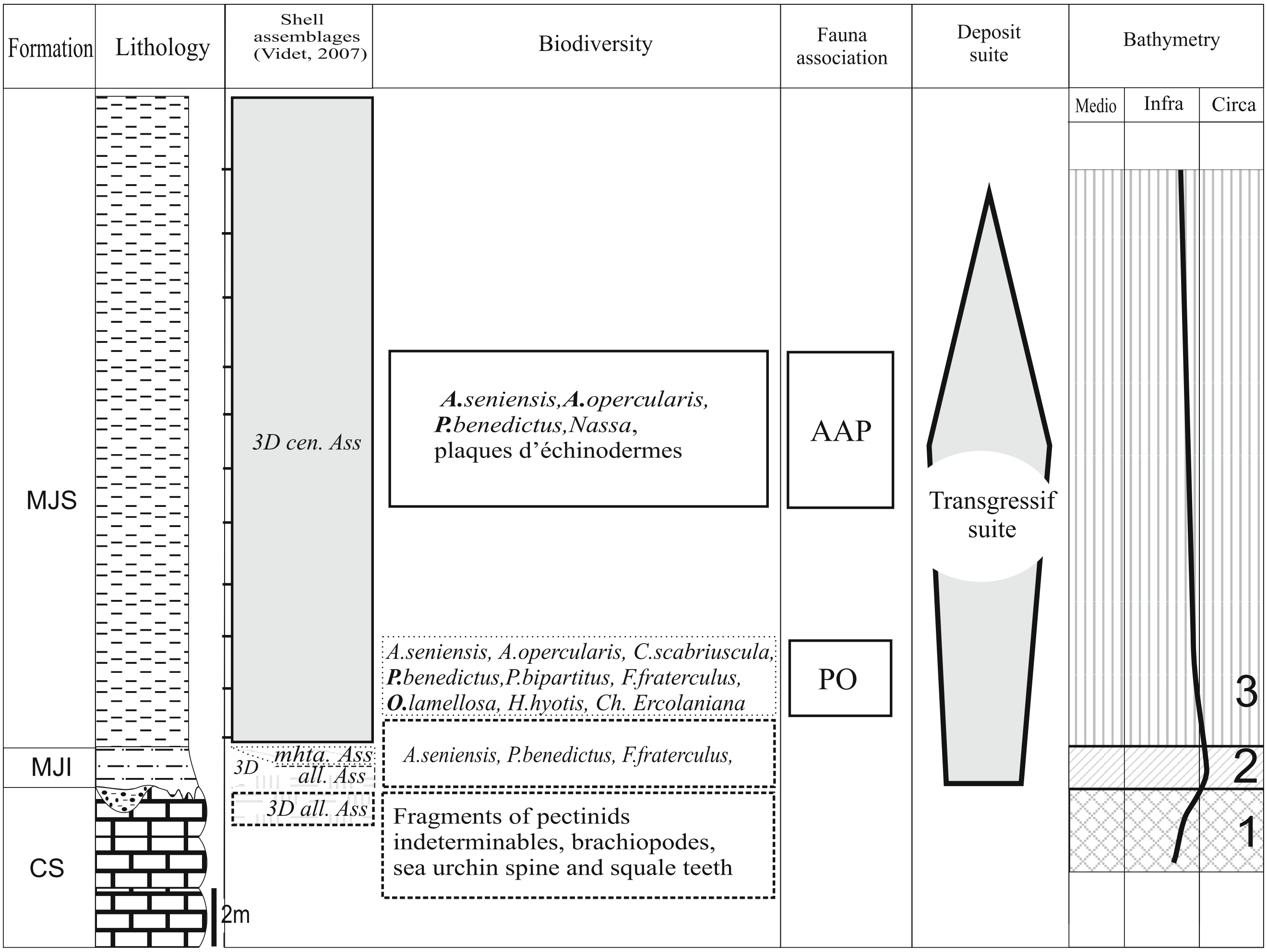
4). LHP: association ***of*** ***L****.excisa*, ***H****.hyotis et* ***P****.brocchi*

Fig. 5 Shell assemblages, fauna associations, and eustatic fluctuation of sea level of Sidi Brahim cutting (basin of Bas Chelif)

much information on the most real paleoenvironmental conditions (amalgam time and taphonomic feedback are minimal or absent), despite their short time of resolution, ranging from days to a few decades. They can be associated with sedimentary discontinuities often at a regional scale.

The time amalgam may affect successive populations from the same habitat ("2D and 3D within-habitat time-averaged assemblage"). Taphonomic and taxonomic characters are more complex, and the temporal resolution is higher (few tens of years to few thousands of years).

If environmental change is faster than the rate of accumulation of shells, then it results to fauna of successive habitats ("2D and 3D multihabitat time-averaged assemblages"), indicating an estimated time resolution of thousands or tens of thousands of years. The postmortem process is multiple, including burial, exhumation, taphonomic feedback, and fairly common recolonization.



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Shell assemblages:

3D:in three dimensions

***1). all. Ass:** "allochtone assemblage"*

***2). cen. Ass:** "census assemblage"*

***3). mhta. Ass:** "multi habitat time averaged assemblage"*

Bivalves associations:

1). **PO**: association of ***P.*** ***Benedictus*** and ***O.*** *lamellosa*

2). **AAP**: association of ***A.****seniensis,* ***A.****opercularis and* ***P.****benedictus*

Fig. 6 Shell assemblages, fauna associations, and eustatic fluctuation of sea level of Sassel Beach cutting (basin of Bas Chelif)

Paleoecology

The Neogene studied fauna can be compared, however, with some reservations, to present fauna, as if almost all species are extinct today; genus (except *Gigantopecten*) are present in our days, in the Atlanto-Mediterranean warm temperate domain or in the subtropical and tropical regions (Satour et al. 2011). Meanwhile, the epibenthic suspensivore forms (mobile or sessile) predominate in the harvested material (85 %), while only three genera are placed in the category of detritivore feeders.

However, the Miocene–Pliocene transition has undergone several extinctions, followed by replacement of fauna, affecting the tropical and subtropical macrofauna (Lauriat-Rage et al. 1992). In fact, about 30 % of new bivalve species appeared during the Pliocene (Georgiades-Dikeoulia 1995) including several genera, and species of this period are still present now in the Mediterranean deep fauna. This can probably be explained by the hypothesis of persistence, during the Messinian salinity crisis (Rouchy 1986; Clauzon et al. 1996; White 2000; Taviani 2002) in the protected areas where some of the deep sea fauna maintain or survive (Ben Moussa et al. 1988; Barrier et al. 1989; Di Geronimo 1990; Laubier and Emig 1993), particularly in peripheral basins.

Furthermore, Peres and Picard (1964) had identified two biocenosis of infralittoral and circalittoral floors: the biota of the *Posidonia* meadow (HP), composed of the superposition of two biotope photophile settlements of shallow infralittoral and sciaphilous deep settlement of circalittoral; and the soft unstable bottom biocenosis (MI), with transitional character that sets up momentarily during phases of sedimentary imbalance of circalittoral seabed before being replaced by other biotic communities of the new state of equilibrium.

Shell assemblages

Sidi Brahim section

Tahria formation

It is characterized by the development of two associations of bivalves (*C. cristatum*, *P. brochii*, and *T. donacina* [CPT] and *Anadara diluvii*, *C. cristatum*, *P. brochii*, and *T. donacina* [ACPT]) included in the marl facies. The analysis of their taphonomic state allowed the identification of two shell assemblages: the autochthonous assemblage in situ ("3D census assemblage") and allochthonous assemblage ("3D allochthonous assemblage").

Indeed, the sandy clays of the base (one member) are very poor even in quality and quantity. Macrofauna is represented only by a few small opercular valves and fragments of *O. lamellosa* (dap=10 mm), exposed on the outer surface of this facies. It does not have any paleoecology signification (reworked fauna) and corresponds to 3D allochthonous assemblage.

The first fauna association (CPT) consists of a paleobiocenose, which appears in the whitish marl (second member) of the Tahria formation (Fig. 5). The richness and diversity of paleontological materials are relatively unimportant (polyspecific level), despite that the autochthonous fauna character is quite pronounced. The aragonite shells of very small size are present in the chalky state for the majority of the observed taxa. We have recognized the following species: *C. cristatum*, represented by small specimens (dap≈30 mm), which tend to most often disappear, leaving only internal molds; *T. donacina*, in a tiny size (not exceeding 10 mm of dap), presents fine chalky test with aragonite shell, showing both valves, without any trace of fragmentation; and *P. brochii*, whose shells are relatively thin and small (dap approximately 30 mm), containing joined valves.

The important involved fauna consists mainly of small gastropods (*Turritella subangulata*, 20 mm), some with complete specimens with chalky shell of *Natica* sp. Additionally, few small (20 mm) solitary polyps were also collected in this level, always in chalky appearance. In contrast, the top surface is dotted by some opercular valves of *O. lamellosa* and small fragments of *P. brochii*. Washing performed in this same facies have distinguished several juvenile forms of *P. brochii* and *T. donacina*, plates of echinoderms, foraminifera, and ostracods.

The simultaneous presence of three bivalves *P. brochii*, *C. cristatum*, and *T. donacina* characterizes a variable depth range between the infralittoral and circalittoral. In addition, the dominance of very small forms in this level argues in favor of an unfavorable living environment for benthic life, may be with euxinic conditions, which begins to open with the introduction of new non-confined environmental parameters to the overlying marl strata. This impoverishment of macrofauna with brittle test suggests that the water of large shallow mudflats and low hydrodynamics is destitute of salt and limestone. Accordingly, it is not conducive to growth and development of the marine benthos (Perrodon 1957). According to Saint Martin (personal communication 2008), this paleoecosystem could possibly be attached to the current *Posidonia* seagrass of the subtidal circalittoral (Peres and Picard 1964).

Meanwhile, shelly assemblage seems to reflect the original community; the taphonomic feedback is minimal or absent, and almost all the shells retained its natural relationship with the substrate (in life position). This implies the presence of a rapid burial process, lasting and significant, which allows to offer the best paleoenvironmental definition possible, characterizing the 3D census assemblage.

The second fauna association (ACPT) characterizes the gray marl. The upper surface of this facies delivered straight valves and numerous fragments of allochthonous small valves (rarely exceeding 10 mm in dap) of *O. lamellosa*, fragments of *C. multistriata*, with very fragile test and some broken specimens with the current lack of umbonal part of valves of *A. seniensis* and *C. ercolaniana*. This set is a composite assemblage (3D allochthonous assemblage), without any important paleoenvironmental signification.

Four autochthonous species characterize this association: *P. brochii*, which often presents complete specimens of quite large species (dap can reach 80 mm) with very well-preserved test. The scallops are represented by *C. cristatum* (complete specimen), which have a tendency to large sizes (dap more than 100 mm). As for *T. donacina*, shells are always small, showing very brittle chalky test. The presence of *A. diluvii* enriched the previous faunal assemblage, and shells are well preserved and have an average size (dap=40 to 50 mm). Many gastropods (*T. subangulata*, *Nassa*, and *Natica*) and scaphopods (*Dentalium*), with an average size (respectively

45 and 70 mm) and very well-preserved shell, complete the fauna association.

The (ACPT) association demonstrates a significant development of autochthonous fauna of the same macrofaunal association cited in the previous level, but it is enriched progressively by the presence of new taxa of deeper fauna (*A. diluvii*), in quiet muddy areas, reflecting a deepening bathymetric trend from the lower infralittoral to circalittoral. The stability of most of the environmental parameters (except the unlithified seabed) favored the installation of the same type as the previous shell (3D census assemblage). Biodiversity and bathymetric position have highlighted a fairly significant affinity between this current association and the transitional unstable soft bottom biota (Peres and Picard 1964), which appears momentarily and will be replaced by a new biotic sedimentary state balance.

Slama formation

The sandy subtidal facies of this formation has marked the transition to shallow environments (intertidal zone). The two members that make up this formation (Fig. 5) have revealed the presence of two different associations to those defined in the previous formation. Their location within the enclosing facies coincides sometimes with significant sedimentological surfaces (hard ground). The application of taphonomic concepts on various collected specimens has highlighted two distinct associations.

The association of *O. lamellosa*, *H. hyotis*, *F. flabelliformis*, and *P. brochii* (OHFP) is very discernible on the ground and has accompanied the establishment of the first sandstone bed, formerly regarded them as “Oyster level” marking the beginning of Plaisancian (Perrodon 1957). In fact, large full shells of *O. lamellosa* (dap=80–90 mm), *H. hyotis* (dap=80 mm), and *F. flabelliformis* (dap=120 mm), as well as internal molds *P. brochii* (juvenile and adult forms with dap max=20 mm) are placed parallel to the stratification planes. All of these criteria led to the conclusion that this assemblage consisted of fauna produced in situ from different successive habitats (epifaunal set or mobile infauna), which reflects the instability of the environmental conditions and, therefore, the presence of an important amalgam of time behind the genesis of this shell accumulation whose assemblage corresponds to environment condensation (3D multihabitat time-averaged assemblage). Several allochthonous taxa of bivalves and other fossil groups (shells disjointed, fragmented, and in jumbled position) are also present on the upper surface of the same fossil bed (*A. seniensis*, *P. benedictus*, *F. fraterculus*, *N. navicularis*, *A. ephippium*, *A. paucicosta*, *Turritella*, *Dentalium*, sea urchin spines, etc.). They correspond to a mixture of different taphonomic states; it can be attributed to the allochthonous assemblage (3D allochthonous assemblage).

Species *L. excisa*, *H. hyotis*, and *P. brochii* composed the second identified fauna association (CHHP). It coincides with the establishment of an iron-hardened surface. The scallop *C. excisa* shows a complete specimen, with thin and well-preserved shell. On the left valve, remarkable colonies of balanids were set. The veneridae *P. brochii* is represented essentially by internal molds, reflecting several stages of life (juvenile and adult forms at the same time). In addition to its in situ feature, the associated fauna (especially gastropods, often in complete internal molds) are represented by individuals rather large (copies of *Natica* measuring approximately 100 mm). Many activities of épizoaires and balanids were recorded on the external parts for shells (*L. excisa*) and on the disarticulated valves. The simultaneous presence of autochthonous fauna, from successive and different habitats, allowed suggesting an environment condensation assemblage (3D multihabitat time-averaged assemblage).

A diverse reworked fauna is represented by numerous valves and fragments of bivalves and gastropods: *G. albinus*, *F. fraterculus*, *A. seniensis*, *Nassa* sp., *T. subangulata*, etc. The common taphonomic feedback suggests an allochthonous assemblage (3D allochthonous assemblage).

Sassel Beach section

Pliocene macrofauna of Sassel Beach seems to have an overall in situ to subautochthonous character. Bivalves are lightly altered for all deposits that make up the series, with the exception of basal conglomerate level where fauna is very recognizable (some fragment scallops, brachiopods, and shark teeth), with its bad state of preservation and the high degree of shell fragmentation (>75 %). This level is ranked in the category of allochthonous composite assemblage (3D allochthonous assemblage).

Taxa encountered in the lower sandy clays have several taphonomic states. In fact, the valves of *A. seniensis, P. benedictus*, and *F. fraterculus* are often disjointed and slightly fragmented. They are scattered randomly on the upper surface (3D allochthonous assemblage) to the end of this set which moved to a centimeter-level shell beds, containing aligned epibenthic specimens (mobile and sessile) that belong to different successive habitats (*A. opercularis*, *A. seniensis*, *P. benedictus*, *P. bipartitus*, *C. scabriuscula*, *C. ercolaniana*, *F. fraterculus*, *H. hyotis*, and *O. lamellosa*). The establishment of this level reflects an environmental change faster than the accumulation rate of assemblages, which correspond to an environmental condensation (3D multihabitat time-averaged assemblage).

However, the above sandy clay formation has revealed the presence of well-stratified macrofauna in the sediment. It is organized into several centimeter levels which suggest an autochthonous character. In fact, it is mainly represented by articulated shells, slightly open and rarely fragmented of the

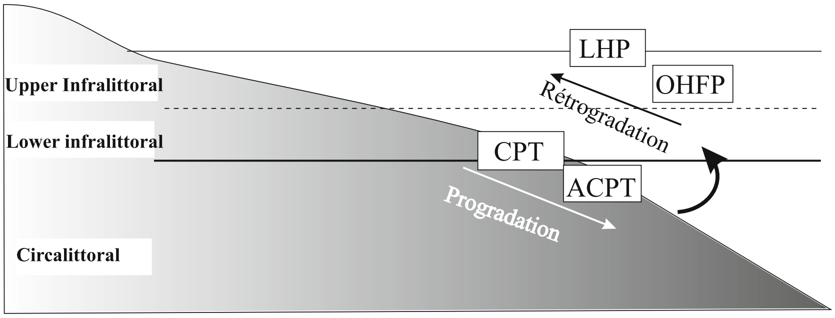

Fig. 7 The dynamic evolution of bivalve associations of Sidi Brahim cutting (basin of Bas Chelif, Algeria)

following taxa: *A. seniensis*, *A. opercularis*, and *P. benedictus*. Many internal molds of small gastropods (*Nassa* sp.), as well as fragments of echinoderms and balanids plate, are also present. It composed of real paleobiocenose of the infralittoral zone, which has retained an almost perfect relationship with the holy bed facies, while reflecting the maximum information on paleoecological and environmental conditions during the set up of this 3D census assemblage.

Discussion

Sidi Brahim section has revealed an evolutionary dynamics from the subtidal marine area and/or upper circalittoral until coastal area. This is evidenced by the relative thickness of marl combs, forming the diverse members of this formation and the presence of coarse detrital discharge, which are more frequent upward of the formation. The sequence of shell assemblages and fauna associations throughout the series have recorded four main transgressive/regressive phases, each of which shows a rather unique environmental setting. The first transgressive phase (sandy clays) at the beginning of the Tahria formation is marked by its turbulence and a quite high hydrodynamics, which help the installation of 3D allochthonous assemblage (Fig. 5, stage 1). Next, the transgressive phase is confirmed by the settling of a transgressive marine suite of whitish and gray marl deposits of the same formation, demonstrating a degree of stability in the environmental parameters (Fig. 5, phase 2) where initial ecological conditions unfavorably have promoted the installation of 3D census assemblages (Fig. 5, phase 2). A relay of the undiversified biocenosis (CPT) of moderate bathymetric muddy environments (subtidal to circalittoral) is established (Fig. 7) by the progressive enrichment of the environment with deep and well-developed forms of the ACPT association belonging to the frankly muddy environments (circalittoral), which advocates the introduction of quite adequate and favorable environmental conditions (normal salinity rate of open environment) to the development of endobenthos (Fig. 5, stage 3) in a circalittoral range of unstable sea floor. The fourth phase (Fig. 5) recorded a swing in the transgressive/regressive regime in the context of shallow sedimentation (subtidal to intertidal zone) corresponding to the formation of Slama that could arrive to the emergence. This allows the setup of two types of shell assemblages: (1) first a 3D multihabitat time-averaged, where the association (*O. lamellosa*, *H. hyotis*, *F. flabelliformis*, and *P. brocchi* [OHFP]) of successive different habitats (epibenthic, *O. lamellosa*; endobenthic, *P. brochii*, and dominance of Ostreidae shells) represent a fairly high rate of detritism in a sedimentary context of high sea-level system tract. The second assemblage 3D multihabitat time-averaged characterizing well-developed infauna within the [CHHP] association with very rich sandy detrital environments of the upper infralittoral–mediolittoral that accompanies the “hard ground” of the Slama formation. At the top, a 3D allochthonous assemblage, with negligible paleoecological significance (composite accumulation), sprinkles the top surface of the first member of the same formation.

Environments at Sassel Beach recorded a shallow context of the higher infralittoral floor. The transgressive phase, with high hydrodynamic currents (Fig. 6, phase 1), triggered at the conglomerate level (3D allochthonous assemblage) and marks (Fig. 6, phase 2) a slight deepening of the environment (upper

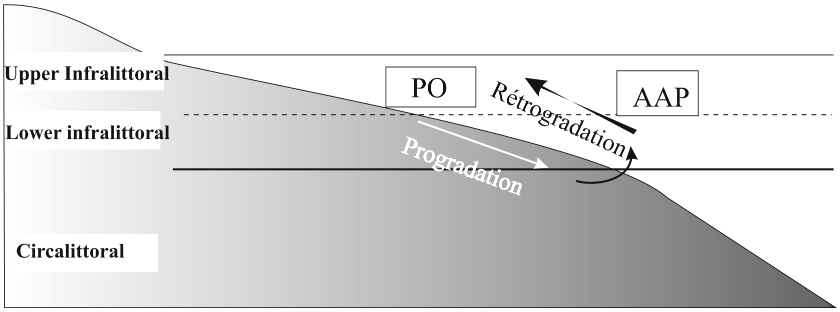

Fig. 8 The dynamic evolution of bivalvia associations of Sassel plage section (basin of Bas Chelif, Algeria)

circalittoral), and then there is the return to a more stable and calm shallow water habitat (infralittoral), which coincides with the installation of the first association (*P. bendictus* and *O. lamellosa* [PO]) of detrital shallow subtidal environment, associated with 3D multihabitat time-averaged shell assemblage at the end of the first marl deposit (Fig. 8). However, the stability of the environment and the rhythmicity of sedimentary contribution/transgression are confirmed by the appearance of many subtidal paleobiocenoses (Fig. 6, stage 3) inserted: *A. seniensis*, *A. opercularis*, and *P. benedictus* [PAA], which indicate infralittoral muddy environments at the upper formation (3D census assemblage).

Conclusions

The present work focused on the taphonomic study on shell assemblages and the paleoecological analysis of bivalve associations included in two Pliocene sections in the center and the northwestern margin of the Neogene basin of Bas Chelif (Sidi Brahim and Sassel Beach). It has highlight for the first time a systematic inventory update of Pliocene bivalves. Likewise, it apprehends knowledge about the settling and the various interactions of shell assemblages and macrofauna associations toward the instability of the environmental conditions, during the eustatic marine fluctuations of the lower and the middle Pliocene of the north of Algeria.

The studied material is mostly characterized by a qualitative and quantitative dominance of scallops. The fauna diversity was low on the western margin of the basin and becomes more significant in its central part.

The four bivalve associations (CPT, ACPT, OHFP, and CHHP) and the three shell assemblages (3D allochthonous assemblage, 3D census assemblage, and 3D multihabitat average time assemblage) accompanying the introduction of transgressive suite in the Sidi Brahim section record the environmental changes in four phases (Fig. 7). First, a deep infralittoral mud dominated the environment of endobenthos with *P. brochii* and *T. donacina*, while the epibenthos is represented by the scallop *C. cristatum*. The deepening of the environment is confirmed by a relatively deeper biota of the unstable circalittoral seafloor. Actually, the previous biotic diversity widens the arrival of new taxa, mostly of the arcidae *A. diluvii*. Bathymetric decreases and the return to a system of coastal sedimentation is established by the installation of the biocenosis [OHFP] including the epibionte (sessile, *O. lamellosa*, *H. hyotis*; and mobile, *F. flabelliformis*) and the endobionte (*P. brochii*) of infralittoral environments rich in detrital. Furthermore, the infralittoral sandy environments that took place in the end of the series are characterized by the biocenosis of *C.* excisa, *H. hyotis*, and *P. brochii*.

In western Oran, such eustatic trend has established in a transgressive marine suite. It is composed of three phases, but in less pronounced degree (Fig. 8). However, in the Sassel Beach section, two paleobiocenoses settle: the *Ostrea lamellose* and *P. benedictus* characterizing detrital infralittoral environments and biological communities of *A. seniensis*, *A. opercularis*, and *P. benedictus* of muddy infralittoral environments. In parallel, three shell assemblages are installed respectively: 3D allochthonous assemblage, 3D multihabitat time-averaged 3D assemblage, and 3D census assemblage.

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References

Anderson RY (1936) Geology in the coastal atlas of western Algeria. Mémoire Geological Society America, New York, p 450

Atif KFT (2001) Modalités du passage Mio-Pliocène dans le Bassin du Bas Chélif. Mémoire de Magister, Université d'Oran, p 133 (Inédit)

Atif KFT, Bessedik M, Belkebir L, Mansour B, Saint Martin JP (2008) Le passage Mio-Pliocène dans le bassin du Bas Chélif (Algérie). Biostratigraphie et paléoenvironnements. Geodiversitas 30(1): 97–116

Barrier P, Di Geronimo I, Montenat C, Roux M, Zibrowius H (1989) Présence de faunes bathyales atlantiques dans le Pliocène et le Pléistocène de Méditerranée (détroit de Messine, Italie). Bull Soc Géol Fr Paris 5(4):787–796 (8)

Belkebir L (1986) Le Néogène de la bordure nord-occidentale du massif du Dahra (Algérie): Biostratigraphie, paléontologie; Paléogéographie. Thèse de Doctorat d'Etat de l'Université d'Aix-Marseille, p 1, 289

Belkebir L, Bessedik M, Mansour B (2002) Le Miocène supérieur du bassin de Chélif: attribution biostratigraphique à partir des foraminifères planctoniques. Mémoire des services géologiques d'Algérie 11:187–194

Belkebir L, Bessedik M, Anglada R (1996) Le Miocène des bassins nord-occidentaux d'Algérie: biostratigraphie et eustatisme. Géologie de l'Afrique et de l'Atlantique sud 553–561

Belkebir L, Labdi A, Mansour B, Bessedik M, Saint-Martin JP (2008) Biostratigraphie et lithologie des séries serravallo-tortoniennes du massif du Dahra et du bassin du Chélif (Algérie). Implications sur la position de la limite serravallo-tortonienne. Geodiversitas 30(1):9–19

Ben Moussa A, Brebion P, Lauriat-Rage A, Demarcq G (1988) Intérêt paléobiologique des mollusques messiniens de Melilla (NE Maroc). Rev Paléobiol Genève 7(2):335–358

Brive A (1897) Les terrains tertiaires du bassin du Chélif et de la Dahra. Thèse de Doctorat d'Etat de l'Université de Lyon, Sciences Naturelles p 135

Clauzon G, Suc JP, Gautier F, Berger A, Loutre MF (1996) Alternate interpretation of the Messinian salinity crisis: controversy resolved? Geology 24(4):363–366

Dalloni M (1915) Recherches sur la période néogène dans l'Algérie occidentale. Bull Soc Geol Fr, Série. 4

Deperet C, Roman F (1902) Morphologie des Pectinidés néogène de l'Europe et des régions voisines (1902–1928). Mémoires de la Société Géologique de France Paléontologie 26:1–168

di Geronimo I (1990) Biogeografiadellozoobenthos del Mediterraneo: origine e problematiche. Oebalia International Journal of Marine Biology and Oceanography, Taranto 16:31–49

Dolfus GF, Dautzenberg P (1902) Conchyliologie du Miocène moyen du bassin de la Loire, I-Pélécypodes (1902–1920). Mémoires de la

Société Géologique de France, (Paléontologie 14) 1(27):163–240

Ficheur E (1890) Les terrains éocènes de la Kabylie du Djurdjura. Thèse Sciences. Paris no. 688, Alger, p 474

Freneix S, Carbonnel G, Courme-Rault MD, Magne J, Obert D (1974) Contribution à l'étude stratigraphique, structurale et faunique (microfaune et bivalves) du bassin de Lalla Kouba (Algérie). Ann Paléontol Invertébr 60(1):43–95

Freneix S, Saint Martin J P & Moissette P (1987a) Bivalves Ptériomorphes du Messinien d'Oranie (Algérie occidentale). Bulletin du Muséum National d'Histoire Naturelle, 4ème série., 9, Section C (1): 3–61

Freneix S, Saint Martin J P & Moissette P (1987b) Bivalve Hétérodontes du Messinien d'Oranie (Algérie occidentale). Bulletin du Muséum National d'Histoire Naturelle, 4ème série., 9, Section C (4): 415–453

Freneix S, Saint Martin J P & Moissette P (1988) Huîtres du Messinien d'Oranie (Algérie occidentale) et Paléo biologique de l'ensemble de la faune de bivalves). Bulletin du Muséum National d'Histoire Naturelle, 4ème série, 10, Section C (1): 1–21

Georgiades-Dikeoulia E (1995) The Messinien of the island of Crete. International conference on the biotic and climatic effects of the Messinian event on the circum Mediterranean. Benghazi, Abstracts, p. 38

Gitton J L (1978) Apport de la paléoécologie à la reconstitution et à l'évolution d'un bassin sédimentaire : l'analyse de la microfaune des marnes bleues nummulitiques des environs de Castellane (Alpes de haute Provence). Thèse de Doctorat 3ème cycle. Université de Paris sud centre d'Orsay. p 420

Kidwell SM, Bosence D (1991) Taphonomy and time-averaging of marine shelly faunas. In: Allison, Briggs (eds) Taphonomy: releasing the data locked in the fossil record, vol 9. Plenum, New York, pp 115–209

Lacour D et al (2002) Les association de bivalves (Mollusca, Bivalvia) du Messinien du bassin de Sorbas (SE Espagne). Geodiversitas 24(3): 641–657

Laubier L & Emig C C (1993) La faune benthique profonde de Méditerranée. In: Della Croce F.R. (ed.) Symposium Mediterranean Seas 2000. Instituto de Scienze ambientale marina, S. Margherita Ligure 397–428

Lauriat-Rage A et al. (1992) Données paléontologiques sur l'évolution du climat, du Chattien à l'actuel, sur la façade Nord-Est atlantique. First congress R.C.A.N.S. Lisboa, Abstracts: 103–105

Lauriat-Rage A et al. (1993) Paleontological data about the climatic trends from Chattian to present along the Northeastern Atlantic frontage. Ciencias da Terra (UNL). Lisboa, no. 12 : 167–179

Mazzola C (1971) Les Foraminifères planctoniques du Mio-Pliocène de l'Algérie nord-occidentale. Proc II Plankt, Roma 2:787–818

Moore R C (1969) Treatise on Invertebrate Paleontology, part N, Mollusca 6 (Bivalvia), vol. 1–2, XXXVIII, p 952, Geology Society America, Inc. and the University of Kansas

Peres JM, Picard J (1964) Nouveau manuel de bionomie benthique. Recueil des Travaux de la Station Marine d'Endoume, Marseille 31(47):5–137

Perrodon A (1957) Etude géologique des bassins néogènes sublittoraux de l'Algérie occidentale. Bull Serv Carte Géol Algérie 12:328

Pomel A (1892) Sur la classification des terrains Miocènes de l'Algérie et réponse aux critiques de M. PERON. Bulletin de la Société Géologique de France, Paris.3e s.,t. XX : 166–174

S.N. Repal (1952) le bassin néogène du Bas Chélif. Publication. XIXe congrès international d'Alger, monographie régionale, 1e série., 16, p 56

Rouchy JM (1982) La genèse des évaporites messiniennes de la Méditerranée. Mém Mus Nat Hist Nat Paris Sér C 50:1–267

Rouchy JM (1986) Les évaporites miocènes de la Méditerranée et de la mer Rouge et leurs enseignements pour l'interprétation des grandes accumulations évaporitiques d'origine marine. Bulletin de la Société géologique de France, Paris (8)2(3):511–520

Rouchy JM, Freneix S (1979) Quelques gisements messiniens de bivalves (formations des tripolis d'Algérie et du Maroc), signification paléoécologique. Annales Géologique des Pays Helléniques, T H S 3:1061–1070

Sacco P (1898) I Mollischi dei terziarii del piemonte e della Liguria. Clausened. Parte 26 (Arcidea): p 92

Saint Martin JP, Cornee JJ, Müller J (1995) Nouvelles données sur le système de plate-forme carbonatée du Messinien des environs d'Oran (Algérie). Conséquences Comptes Rendus Académie Science, Paris 320:837–843

Satour (2012) Les bivalves néogènes de l’Algérie nord- occidental : systématique & paléoécologie. Thèse de Doctorat. Université d’Oran, 311 p., 118 fig., 4 pl., 1 tabl.

Satour L, Lauriat Rage A, Belkebir L, Mansour B, Saint Martin JP, Bessedik M (2011) Les bivalves ptériomorphes du Tortonien supérieur du Dahra: systématique et paléoécologie. Bulletin du service géologique national, Algérie 22:119–139

Taviani M (2002) The Mediterranean benthos from late Miocene up to present: ten million years of dramatic climatic and geologic vicissitudes. Biol Mar Mediterr Genova 9:445–463

Videt B (2007) Typologie des assemblages d'ostréidés (Bivalvia) et interprétations paléoenvironnementales. C R Palevol 6:47–58

Waller TR (1978) Morphology, morphoclines and a new classification of the Pteriomorphia (Mollusca: Bivalvia). Phil Trans R Soc London B 284:345–365

Waller TR (1993) The evolution of “*Chlamys*” (Mollusca: Bivalvia: Pectinidae) in the tropical western and eastern Pacific. Am Malacol Bull 10(2):195–249