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Palaeoenvironmental interpretation of a sand-dominated coastal system of the Upper Miocene of eastern Guadalquivir Basin (south Spain): fossil assemblages, ichnology and taphonomy

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Abstract

The palaeontological study of fossil assemblages from the Upper Miocene (Tortonian) marine deposits of the eastern sector of the Guadalquivir Basin allows interpreting palaeoenvironmental and depositional conditions when this basin acted as a connection between the Atlantic Ocean and the Mediterranean Sea. The Arroyo Escobar section represents a sand-dominated coastal system in transition to offshore deposits located on the northern margin of the basin. The materials are constituted by alternations of highly bioturbated fine sands (Skolithos ichnofacies) and bioclast-rich cemented coarse sands. In this context, several fossil remains of vertebrates have been recorded, corresponding to marine mammals, mainly cetaceans and pinniped. The remains are incomplete due to different factors, mainly the action of large scavengers. The palaeoenvironmental interpretation of these deposits has been based on the analysis of lithofacies, as well as the study of trace fossils and benthic macroinvertebrate assemblages. Background dynamic was affected by the input of high energy deposits coming from shallower and more proximal environments which incorporates allochthonous faunas with different preservation. In addition, this work is the first study of fossil marine mammals in the eastern sector of the Guadalquivir Basin.

Keywords: fossil macroinvertebrates, ichnology, marine mammals, taphonomy, palaeoecology

Resumen

El estudio paleontológico de las asociaciones fósiles en depósitos marinos del Mioceno Superior (Tortoniense) del sector oriental de la Cuenca del Guadalquivir permite la interpretación de las condiciones paleoambientales y deposicionales de la cuenca cuando ésta actuaba de conexión entre el Océano Atlántico y el Mar Mediterráneo. La sección del Arroyo Escobar representa un sistema costero dominado por arenas de cuarzo en el margen norte de la cuenca en su transición hacia depósitos más distales. Los materiales están constituidos por una alternacia de arenas cuarcíticas finas intensamente bioturbadas (icnofacies de Skolithos) y arenas gruesas cementadas ricas en bioclastos. En este contexto, se han registrado restos de vertebrados que corresponden a mamíferos marinos, principalmente cetáceos y pinnípedos. Los restos están incompletos por diversos factores, principalmente relacionados con la actividad de grandes carroñeros. La reconstrucción paleoambiental de estos depósitos se basa en el análisis de litofacies, así como en el estudio de trazas fósiles y asociaciones de macroinvertebrados bentónicos. La dinámica de fondo se vio afectada por la entrada de depósitos de alta energía desde ambientes más someros, posiblemente tempestitas, que incorporan faunas alóctonas con una mejor conservación. Este trabajo es, además, el primer estudio de fósiles de mamíferos marinos en el sector oriental de la Cuenca del Guadalquivir.

Palabras clave: macroinvertebrados fósiles, icnología, mamíferos marinos, tafonomía, paleoecología

1. Introduction

Stratigraphic and palaeontological studies of marine Miocene deposits in the eastern Guadalquivir Basin (Fig. 1) are scarce due the absence of good outcrops (Tjalsma, 1971; López-García and Bustillo, 1994; Bustillo and López-García, 1997). This is more accentuated in the case of fossil remains from marine vertebrates (Reolid and Molina, 2015; Reolid and Reolid, 2015). In other Neogene areas of the Guadalquivir Basin fossil marine vertebrates have been reported (Mayoral *et al*., 2001a; Toscano *et al*., 2013; Santos *et al*., 2015) as well as in Pliocene deposits (Sendra *et al*., 1999; Mayoral *et al*., 2001b; Esperante *et al*., 2009). The analysis of Upper Miocene deposits and fossil assemblages from this sector is especially interesting due to this area was a narrow basin connecting the Atlantic Ocean with the Mediterranean Sea through different straits (Reolid *et al*., 2012; García-García *et al*., 2014; Martín *et al*., 2014). This work is focused on the analysis of lithofacies as well as fossil assemblages including trace fossils, invertebrates and vertebrates with special attention to taphonomic features, for interpreting palaeoenvironmental conditions. This is the first study on ichnology in these deposits and the first report of marine vertebrates.

2. Geological setting

The studied outcrop, called Arroyo Escobar section (AE), is located in the northern margin of the eastern Guadalquivir Basin, (Jaén Province, South Spain, Fig. 1). The stratigraphic interval studied in this section is composed of 22 m-thick of sandstones with different degree of cementation (Fig. 2). The outcrop conditions of this area, characterized by soft relief densely exploited for agriculture with olive field, complicate the identification of good sections. The studied section was analysed in a narrow and deep ravine crossing the olive fields for 1 km (38º05’42.94”N, 3º55’46.35”W, 284 m above mean sea level (mls) to 38º05’50.69”N, 3º55’11.08”W, 307 m mls). These deposits belong to an Upper Tortonian-Lower Messinian depositional sequence, the third according to the sequence stratigraphy proposed by González-Delgado *et al*. (2004). These deposits represent a sand-dominated coastal system in transition to offshore deposits related to the northern margin reliefs of the Guadalquivir Basin. In close areas, proximal facies of fan deltas were described by Santisteban-Navarro and Martín-Serrano (1991).

3. Materials and methods

The section was analysed and sampled bed by bed. Ten thin sections were prepared from hard rock samples and five rock samples with low cementation degree were sieved. Specimens of fossil macroinvertebrates were collected and counted from the different beds with preliminary identification. The results on fossil macroinvertebrates are based on taphonomic analysis including shell mean size, position within the bed, disarticulation and breakage, estimated by counting on bedding surfaces of 50 x 50 cm cuadrats when possible. Trace fossils were studied in the field including their morphology, type of hosting and filling sediment, size, orientation, type of wall and spatial interrelations between them.

Respect to the sieved samples of sands with low cementation degree, no special chemical treatment of the samples was required prior to the washing procedure, which involved a column of standard stainless steel sieves with mesh openings of 500, 200, and 100 µm. Foraminifera and ostracods were hand-picked with a hair paint-brush on a standard black picking grid-tray under stereoscopic microscopy (Motic SMZ-168 and Olympus SZ60, Universidad de Jaén). Gold-coated specimens of microfossils from sieved samples were analysed under scanning electron microscopy (SEM); and images were produced with a Merlin Carl Zeiss SEM in the Centro de Instrumentación Científico-Técnica of the Universidad de Jaén.

Both vertebrate remains and invertebrates were cleaned with a pneumatic pen *Ken Mannion Pen SP*. Vertebrates were consolidate with a mix of cellulose nitrate ($C_{24}H_{28}O_{20}(NO_2)_{12}$) and acetone ($C_3H_6O$). The macroinvertebrates were determined at genus level. The surfaces of the fossil bones were analyzed for determining the presence of bioerosion traces.

4. Results

4.1. Lithofacies

The succession is mainly composed of fine sand with common burrows and macroinvertebrate fossil remains. Sedimentary structures indicating currents are absent. Two main types of lithofacies are differentiated in alternance (Figs. 2, 4):

(a) Fine quartz sand (Fig. 3A–C), well-sorted, in 1.5–4 m-thick packages. Trace fossils are common, locally very abundant and diverse. Thin-shelled bivalves are dominant; most of them very fragmented. Charcoal wood fragments are also

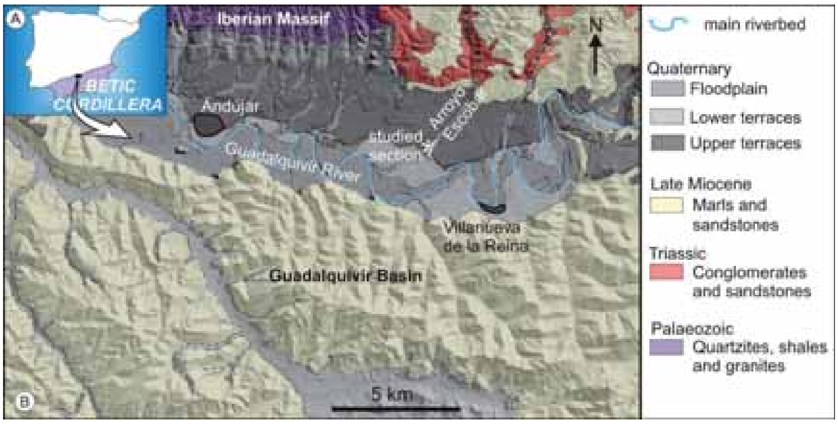

Fig. 1.- Location of the Arroyo Escobar section in the eastern sector of the Guadalquivir Basin.

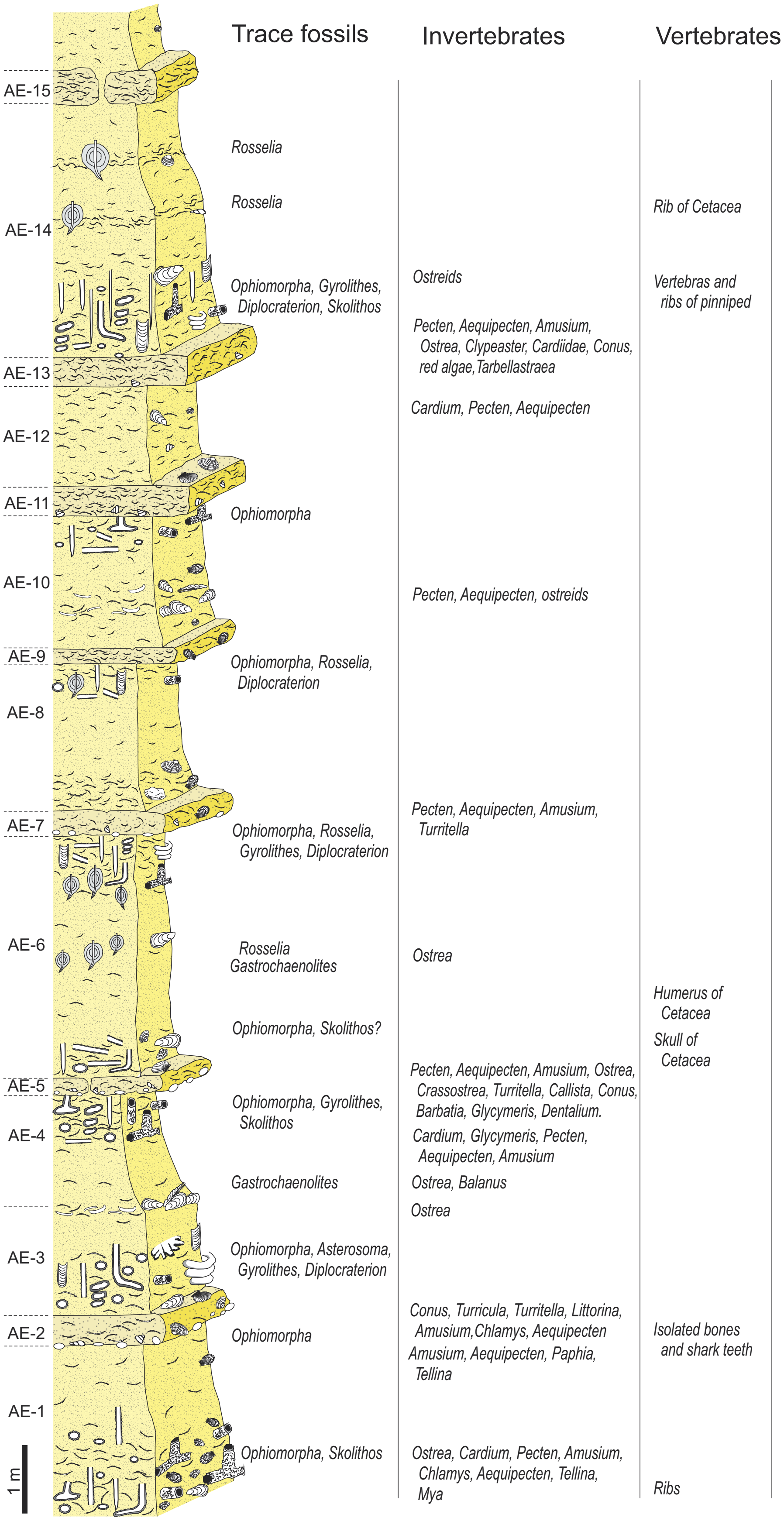

Fig. 2.- The Arroyo Escobar section and the stratigraphic distribution of trace fossils, main fossil macroinvertebrates and fossil remains of vertebrates.

recorded in this lithofacies in the upper part of the section, but they are scarce.

(b) Bioclast-rich cemented coarse sand (Figs. 3D–F), with poorly sorted, rich in bioclasts (mainly bivalves, locally shell-supported fabric, Fig. 3E) with common pebbles and fossil vertebrate fragments and 15–30 cm-thick beds. The beds are arranged in finning-upwards sequences from coarse- to medium sand, commonly with a basal lag containing quartzite pebbles, and large bivalve and gastropod shells. Charcoal fragments are scarce.

The studied stratigraphic interval begins with 2.3 m-thick package of fine quartz sand (AE-1) with common trace fossils *Ophiomorpha* and *Skolithos* (Figs. 2, 3A). The base of the AE-1 is poorly exposed. In this part 16 ribs of indeterminate organisms related to a patch of ostreids have been found (Fig. 4A). The lower part of AE-1 shows high abundance of bivalves, mainly thin-shelled forms, most of them highly fragmented. The best preserved specimens have been ascribed to *Aequipecten*, *Amusium*, *Chlamys*, *Mya*, *Ostrea*, and *Tellina*. In the upper part of AE-1 the bivalves are scarce (*Aequipecten*, *Amusium*, *Chlamys* and *Tellina*).

The next bed, AE-2, is composed of 0.4 m-thick of bioclast-rich coarse sandstone (Fig. 3D) with abundant pebbles at the base. These pebbles are rounded and usually reaching 6 cm long composed by quartzite. Cobbles are less common but also recorded at the base. Mollusks are very abundant and most of them are well-preserved. They include bivalves *Aequipecten*, *Amusium*, *Chlamys* and *Ostrea*, and gastropods *Cerithium*, *Conus*, *Littorina*, *Monodonta*, *Turricula*, and *Turritella*. Some indeterminate small fragments of fossil bones are recorded.

AE-3 consists of 1.5 m-thick fine quartz sand rich in trace fossils *Ophiomorpha*, *Gyrolithes*, *Asterosoma* and *Diplocraterion* (Figs. 5, 6A, B). The fossil invertebrates are scarce (mostly small fragments of bivalves) and recorded mainly in the upper part of this interval where *Ostrea* is locally common.

AE-4 is composed of fine quartz sand (1.46 m-thick) with ostreids. These ostreids are disarticulated and not in living position, showing the boring *Gastrochaenolites*, and remains of *Balanus*. The upper 40 cm are rich in trace fossils *Ophiomorpha*, *Gyrolithes* and *Skolithos*, and bivalves

(*Aequipecten*, *Amusium, Cardium*, *Chlamys*, *Glycymeris* and *Pecten*).

AE-5 is composed of 0.23 m-thick bioclast-rich coarse sandstone (Fig. 4B). The base contains rounded quartzite clasts usually less than 5 cm in diameter. Two types of preservation are recorded in the fossil macroinvertebrates: a) strongly fragmented bioclasts and b) well-preserved mollusks mainly bivalves (*Aequipecten*, *Amusium*, *Barbatia*, *Callista*, *Cardium*, *Chlamys*, *Crassostrea*, *Glycymeris*, *Ostrea*, and *Circumphalus*) and gastropods (mainly *Cerithium*, *Conus* and *Turritella*; Fig. 3F), as well as scarce scaphopods (*Dentalium*). Locally, the top of the AE-5 is colonized by ostreids cemented in living position.

AE-6 is composed of 3.13 m-thick medium to fine quartz sand (Fig. 4C). The lower part is characterised by bioclastic medium sands with high concentration of trace fossils in

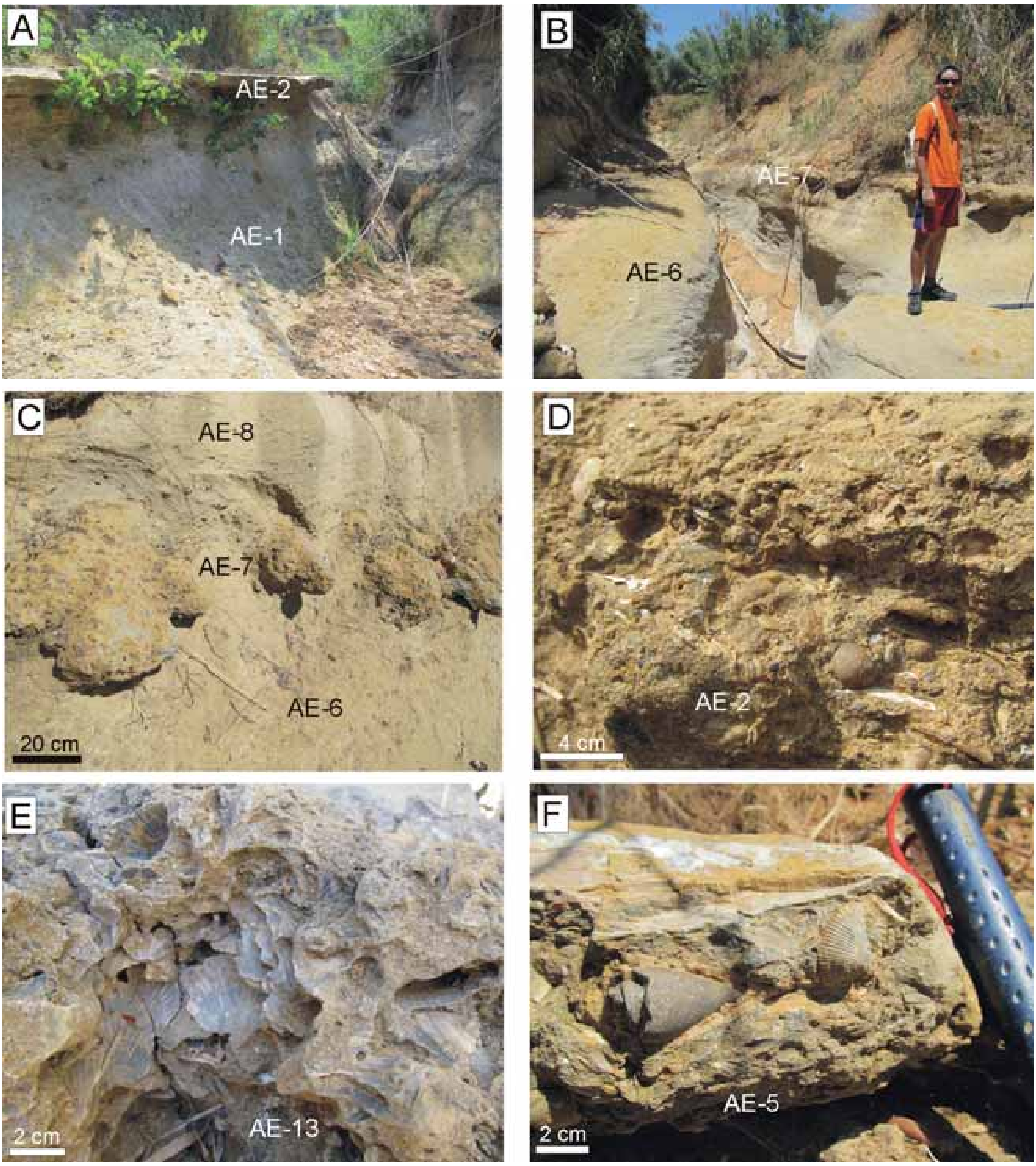

Fig. 3.- Lithofacies. A. Fine quartz sand (AE-1) and bioclast-rich cemented coarse sand (AE-2) in the lower part of the section. B. Fine quartz sand with abundant trace fossils (AE-6) and bioclast-rich cemented coarse sand (AE-7). C. Irregular stratification of the bioclast-rich cemented coarse sand AE-7 between Fine quartz sands (AE-6 and AE-8). D. Detail of the bed AE-2 of bioclast-rich cemented coarse sand. E. Detail of bed AE-13 of bioclast-rich cemented coarse sand with abundant bivalves. F. Detail of the bed AE-5 of bioclast-rich cemented coarse sand with gastropods, bivalves and a large fragment of ostreids (upper part).

the lower part of package AE-6 (*Ophiomorpha*). The middle part is composed of fine sands and dominated by *Rosselia* (Figs. 4C, 6D, E), whereas *Gastrochaenolites* is recorded on large ostreid remains (Fig. 6C). Bioclasts include very small fragments of thin-shelled bivalves and less commonly gastropods (fragments of *Chlamys* and *Tellina*). The last meter of AE-6 presents a diverse assemblage of trace fossils *Ophiomorpha*, *Rosselia*, *Gyrolithes* and *Diplocraterion*, as well as charcoal. Large vertebrate remains are recorded in this stratigraphic interval, an uncomplete humerus (18.5 cm length) and an incomplete skull with a cervical vertebra (41.6 cm length).

AE-7 is 0.33 m-thick bed of bioclast-rich coarse sandstone (Fig. 3B, C), with common bivalves *Aequipecten*, *Amusium* and *Chlamys*, and gastropods, mainly *Turritella*.

AE-8 corresponds to 1.90 m-thick medium to fine quartz sand rich in bioclasts in the lower part, usually small fragments, rarely well-preserved thin-shelled bivalves. The upper part of AE-8 is composed of fine sands rich in trace fossils *Ophiomorpha*, *Diplocraterion* and *Rosselia*.

AE-9 is 0.2 m-thick bed of bioclast-rich cemented coarse sand with abundant poorly preserved bivalves and gastropods. The fossil remains of invertebrates are highly fragmented.

AE-10 is constituted by 1.7 m-thick medium to fine-grain sand with abundant *Ophiomorpha*, as well as thin-shelled, highly fragmented bivalves. Some ostreid valves are recorded as well as carbonate concretions developed on some trace fossils.

AE-11 is composed of 0.4 m-thick bioclast-rich coarse sandstone with common mollusk fragments. Gastropods are more frequent at the base. The macroinvertebrate assemblage is dominated by pectinids, mainly *Chlamys*.

AE-12 is 1.26 m-thick medium to fine sand, poorly exposed in the outcrop with similar features to the other stratigraphic intervals with this facies.

The bed AE-13 is 0.4 m-thick bioclast-rich coarse sandstone with abundant pebbles at the base (usually < 6 cm long). Pebbles are composed by quartzite and carbonates. Bivalves are densely packed and constitute the main component of the rock (Fig. 3E). The genera *Pecten* and *Aequipecten* dominate the assemblage. Fragments of the coral *Tarbellastraea* and red algae are recorded.

The top of the studied section is composed of 3.26 m thick of fine quartz sands (AE-14). In the lower part there are abundant trace fossils *Ophiomorpha*, *Gyrolithes*, *Teredolites*, *Diplocraterion*, and *Skolithos* (Figs. 6F, G). In the upper part of AE-14 only *Rosselia* appears. The most common fossil invertebrates correspond to bivalves of the genera *Aequipecten*, *Amusium*, *Pecten*, *Ostrea*, and numerous unidentified specimens of the Family Cardiidae. Less common are gastropods (*Conus*) and echinoderms (*Clypeaster*; Fig. 4D). In this stratigraphic interval

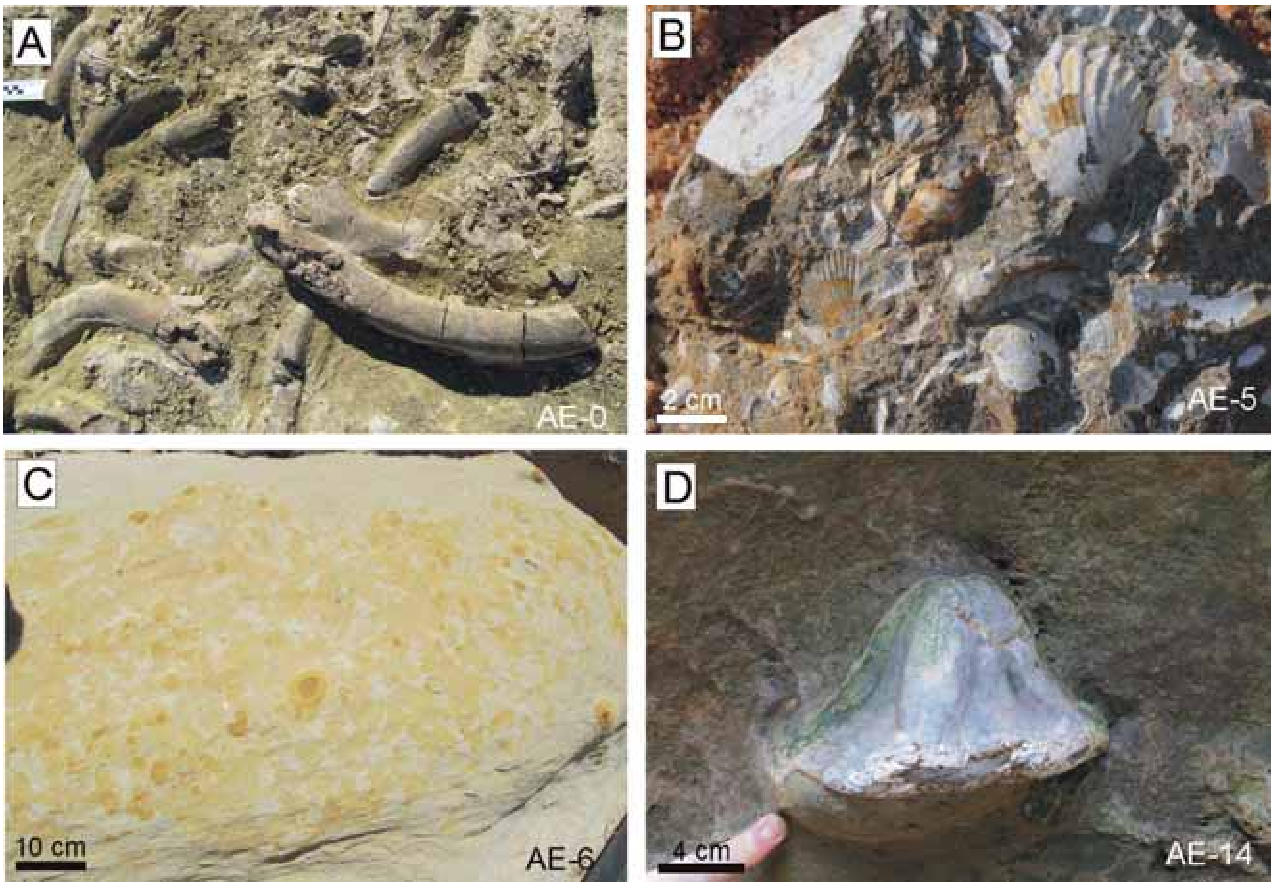

Fig. 4.- Fossil remains in the lithofacies. A. Swollen ribs of sirenians from Fine quartz sands, just in the base of the section (AE-0). B. Dense accumulation of mollusk shells from bioclast-rich cemented coarse sand of AE-5. Note that shells have not a preferential orientation within the bed. C. Trace fossils *Ophiomorpha* and *Rosselia* trace fossils in the upper part of the level AE-6, Fine quartz sands. D. Well-preserved *Clypeaster* from Fine quartz sands (AE-14).

some vertebrate remains, such as a partial thoracic cage (45 cm long) and a rib fragment (41.6 cm long) are recorded.

4.2. Invertebrate fossils and trace fossils

4.2.1. Fine quartz sands

The sieved samples contains scarce exclusively benthic foraminifera *Nonion commune* and *Ammonia beccarii* (Fig. 7A, B) and spines of irregular echinoids (Fig. 7C).

Bivalves, mostly thin-shelled forms, dominate the macroinvertebrate assemblage (Fig. 8), mainly Cardiidae (40%) and Pectinidae (25%). They are commonly small fragments of disarticulate shells. Among the genera identified are *Amusium*, *Aequipecten*, *Cardium*, *Chlamys*, *Circumphalus*, *Crassostrea*, *Glycymeris*, *Mya*, *Ostrea*, *Paphia* (*Callistotapes*), *Tagelus*, *Tellina*, and *Venus*. Locally patches of *Ostrea* are recorded. Large specimens of *Clypeaster* are recorded in the upper part of the section (Fig. 4D). Preservation of shells is poor in most of the stratigraphic intervals with fine-grain sands, characterized by high fragmentation degree of thin-

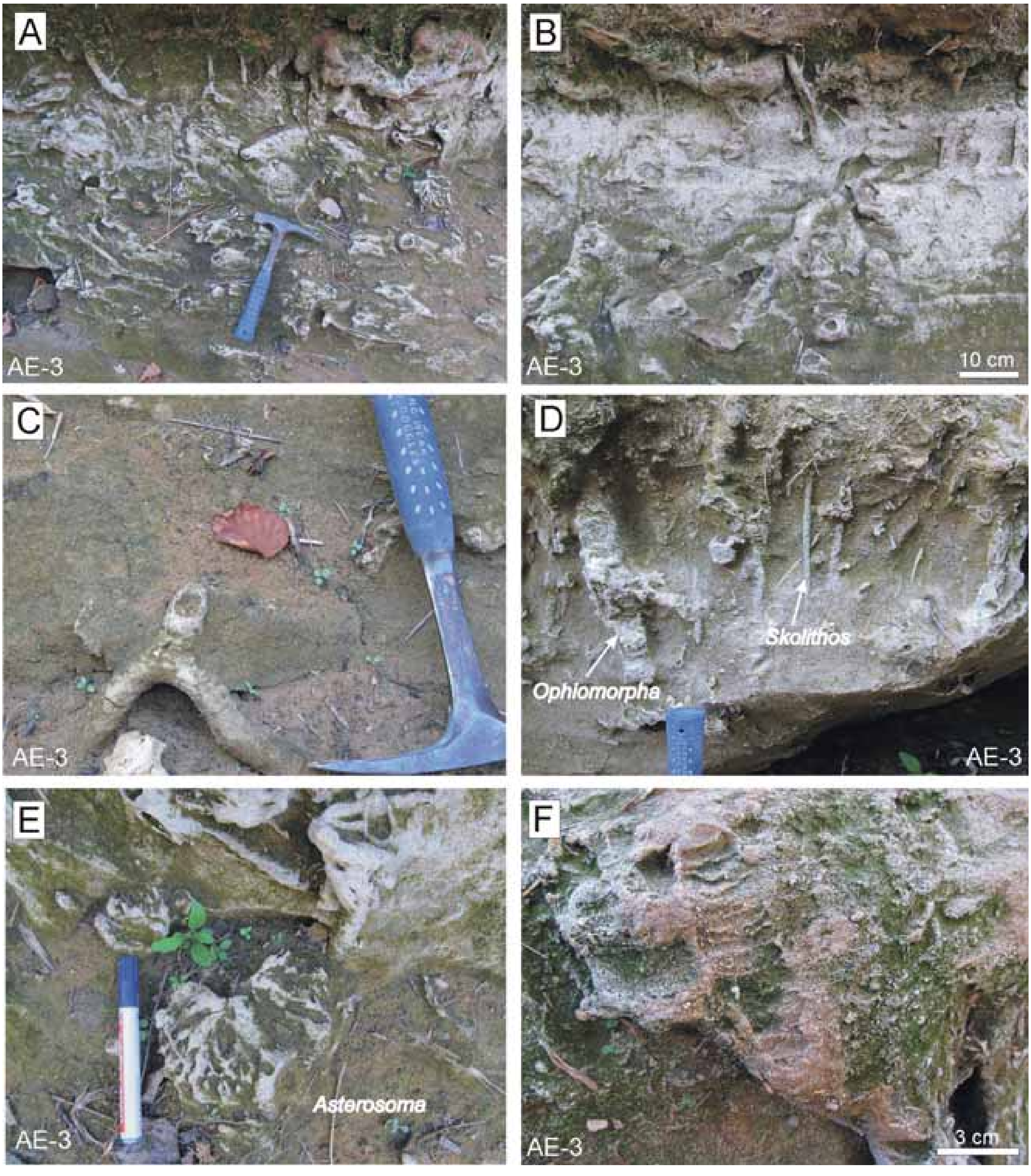

Fig. 5.- Trace fossils recorded in Fine quartz sands. Bed AE-3 show a well-preserved and diverse ichnofossil assemblage.

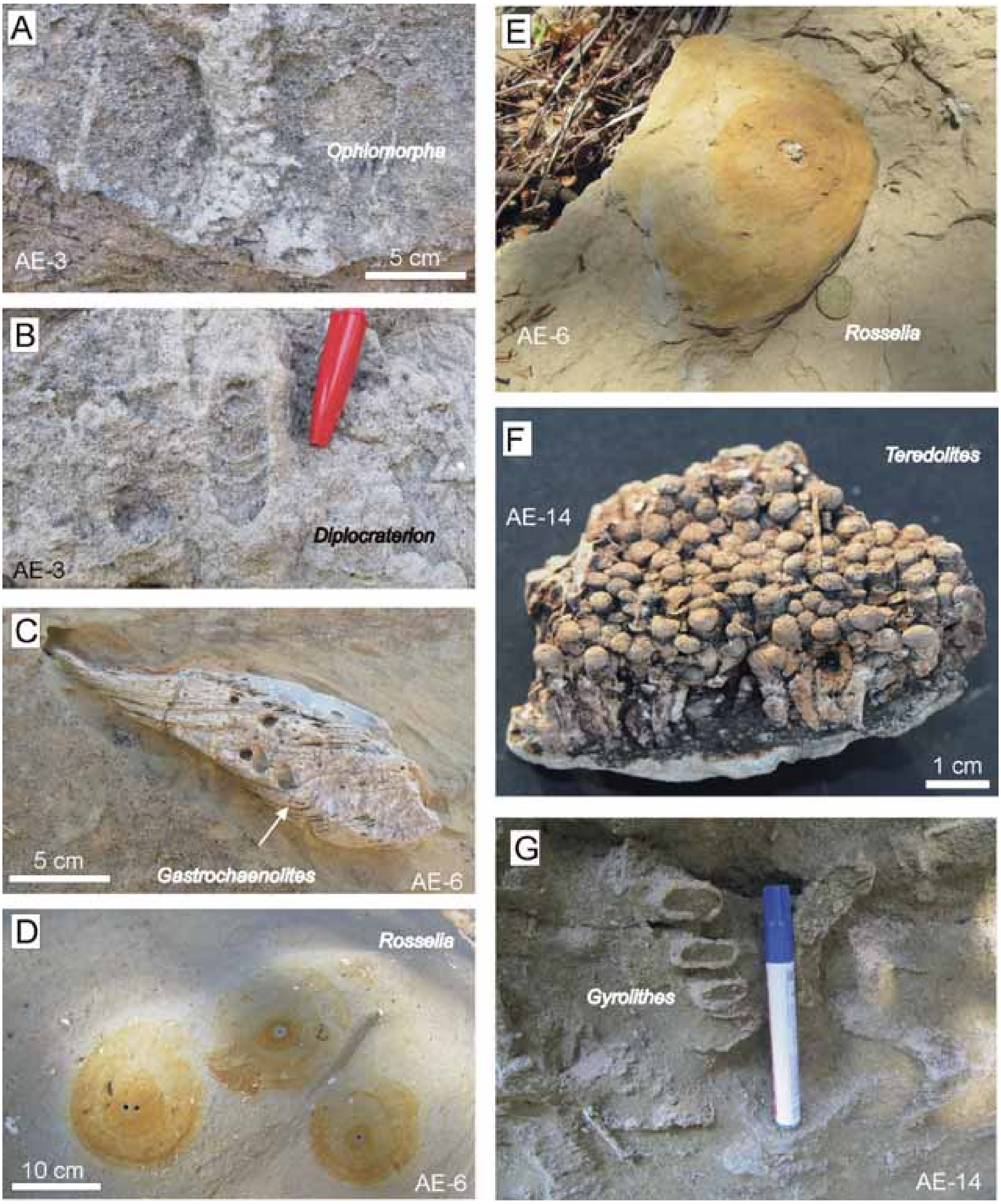

Fig. 6.- Examples of trace fossils from Fine quartz sands.

shelled bivalves. Occasionally some specimens are well-preserved. Usually the shells are not parallel to the bedding and they are variable oriented. Ostreid shells show low degree of fragmentation, but they are disarticulated and frequently not in life position. *Clypeaster* is scarce, but very-well preserved. Colonization of shells is absent, except for some ostreids which show borings and *Balanus*.

Trace fossils are localized in fine quartz sand lithofacies with variable concentration and diversity. The most common trace fossil is *Ophiomorpha*, followed by *Gyrolithes*, *Rosselia*, *Diplocraterion* and *Skolithos*, and scarce *Asterosoma*. *Ophiomorpha* specimens are characterized by a well-developed pelleted mud lining with a maximum size of 5 cm in diameter and < 16 cm long of vertical shaft. They have been classified as *Ophiomorpha nodosa*. *Gyrolithes* recorded are characterized by spiraling helix of uniform diameter of tube (< 14 mm in diameter) and whorls without scratch marks. *Rosselia* are concentric burrow resembling a bulb (usually

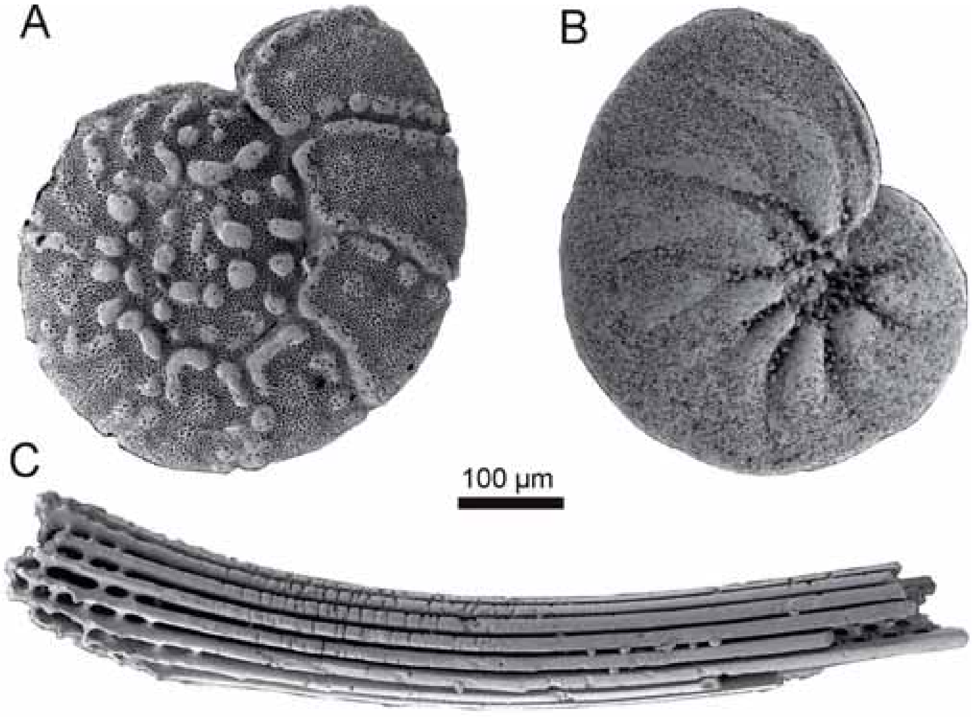

Fig. 7.- Benthic foraminifera (A. *Ammonia beccarii*, B. *Nonion commune*) and (C) Spine of an irregular echinoid from Fine quartz sands.

< 5 cm in diameter, but reaching 18 cm in bed AE-14) with a central cyclindrical pencil-thick tube. *Skolithos linearis* is represented by vertical to slightly inclined cylindrical tube (sometimes J-shaped) with > 10 mm in diameter and < 30 cm long. The recorded *Diplocraterion* are vertical, U-shaped burrow with spreite and parallel arms (< 3.5 cm wide and 12 cm long). They probably correspond to *Diplocraterium parallelum*. *Gastrochaenolites* is also recorded in large shells of ostreids (Figs. 5, 6). The trace fossil *Teredolites* is crowded within the surface of the largest charcoal fragments (Fig. 6F). Intervals dominated by *Rosselia* are usually poor in other ichnotaxa (Fig. 6D). The ichnofossil assemblages throughout the section indicate the *Skolithos* ichnofacies (presence of *Ophiomorpha*, *Skolithos* and *Diplocraterion*, see Buatois and Mangano 2011 for a review) with some ichnogenera of the *Cruziana* ichnofacies (presence of *Rosselia*, and *Asterosoma*). The distal *Skolithos* ichnofacies includes also *Rosselia* (Buatois and Mángano, 2011). *Ophiomorpha* and *Gyrolithes* have been previously described in the range of *Cruziana* and *Skolithos* ichnofacies (Mayoral and Pendón, 1986-1987; Pemberton *et al*., 2001; Buatois and Mangano, 2011). *Gyrolithes* has been also assigned to *Glossifungites* ichnofacies (Netto *et al*., 2007).

4.2.2. Bioclast-rich cemented coarse sand

The composition of macroinvertebrate assemblages changes in the bioclast-rich cemented coarse sands, with increasing proportions of gastropods (reaching 45% of macroinvertebrate assemblage in the bed AE-2 and 24% in the bed AE-5) corresponding mainly to the genera *Cerithium*, *Conus*, *Epitonium*, *Littorina*, *Strombus*, *Turritella* and undifferentiated Neritidae and Bursidae (Fig. 9). Other less common gastropods are *Calyptraea*, *Ficus*, *Harpa*, *Monodonta*, *Nassarius*, *Trochus*, and *Turricula*. The bivalves from this lithofacies are *Aequipecten*, *Amusium*, *Barbatia*, *Callista*, *Chlamys*, *Circumphalus*, *Crassostrea*, *Glycymeris*, *Ostrea, Paphia* (*Callistotapes*), *Tagelus* and *Tellina*. *Dentalium* is only recorded in the bed AE-5. Some reworked fragments of balanids, rhodoliths and the coral *Tarbellastraea* are recorded at the top of the section (bed AE-13, Fig. 10). *Balanus* is also recorded in this bed, but not attached to any substrate.

Mollusk shells show a wide range of fragmentation in the bioclast-rich cemented coarse sand and well-preserved shells are coexisting with small debris. In general, mollusk shells are well-preserved compared with the fine quartz sands. Bivalves are generally disarticulated, except some specimens of infaunal forms such as *Paphia*, *Tellina* and *Tagelus*. Again, colonization by epibionts is absent. Bivalve and gastropod shells in this lithofacies are occasionally affected by dissolution, which occurs irregularly. Shells are usually recorded without preferent orientation except in the bed AE-13 composed of dense accumulation of pectinids in subhorizontal position. The upper part of some beds presents a dominant subdohorizonal orientation of elongated gastropod shells such as *Turritella*.

4.3. Fossil vertebrates

The section is relatively rich in vertebrate fossil remains including sharks, pinnipeds and cetaceans (Figs. 11–13). All these remains come from different beds (Fig. 2) and

Fig. 8.- Well-preserved bivalves recorded from bioclast-rich cemented coarse sand.

then they may be interpreted corresponding to different individuals.

The chondrichthyan fish *Isurus* is represented by two teeth with crown heights of 19 and 26 mm, without serrations, slightly slanted, with well-preserved U-shaped roots (Fig. 12D).

Potential pinniped remains recorded from AE-14 are constituted by a partial thoracic cage (45 cm long), with seven articulated thoracic vertebrae and articulated double-headed ribs and connected with their respective vertebrae via capitula and tubercula (Fig. 11). The thoracic vertebrae, 18 cm wide, are imbricate and present large transverse processes (5–7 cm), a large centrum (8.5–9 cm), and wide neural arch (5–7 cm). The centrum width is larger than the centrum high, and the size of the centrum increases towards the posterior thoracic region. The spinous processes are projected dorsally, which suggest that they are posterior series of the thoracic vertebrae. They are holospondylous vertebrae with the acoelous centrum. The ribs are 3 cm in diameter and wider in close to the articulation head (9 cm). The ribs of the right side, 32 cm long, are fragmented in the outer boundary, but nearly complete. The ribs of the left side are fragmented close to the vertebrae. The head and tubercle are distinct and well separated. In the broken surface, the inner spongy structure of the ribs is visible and corresponding to the cancellous bone. The body of each rib is somewhat square in cross section, and therefore the anterior and posterior surfaces are relatively flat. The relation between the size of the ribs and the vertebrae exclude most of the cetaceans and sirenians such as Trichechidae and some Dugongidae (e.g. Halitherinae and Hydrodamalinae) with swollen ribs (Berta *et al*., 2006a). The presence of ribs with cancellous tissue allows excluding sirenians because this group is characterised by dense bones (Berta *et al*., 2006b). Transverse processes of vertebrae are about as long as they are wide, a typical feature that excludes

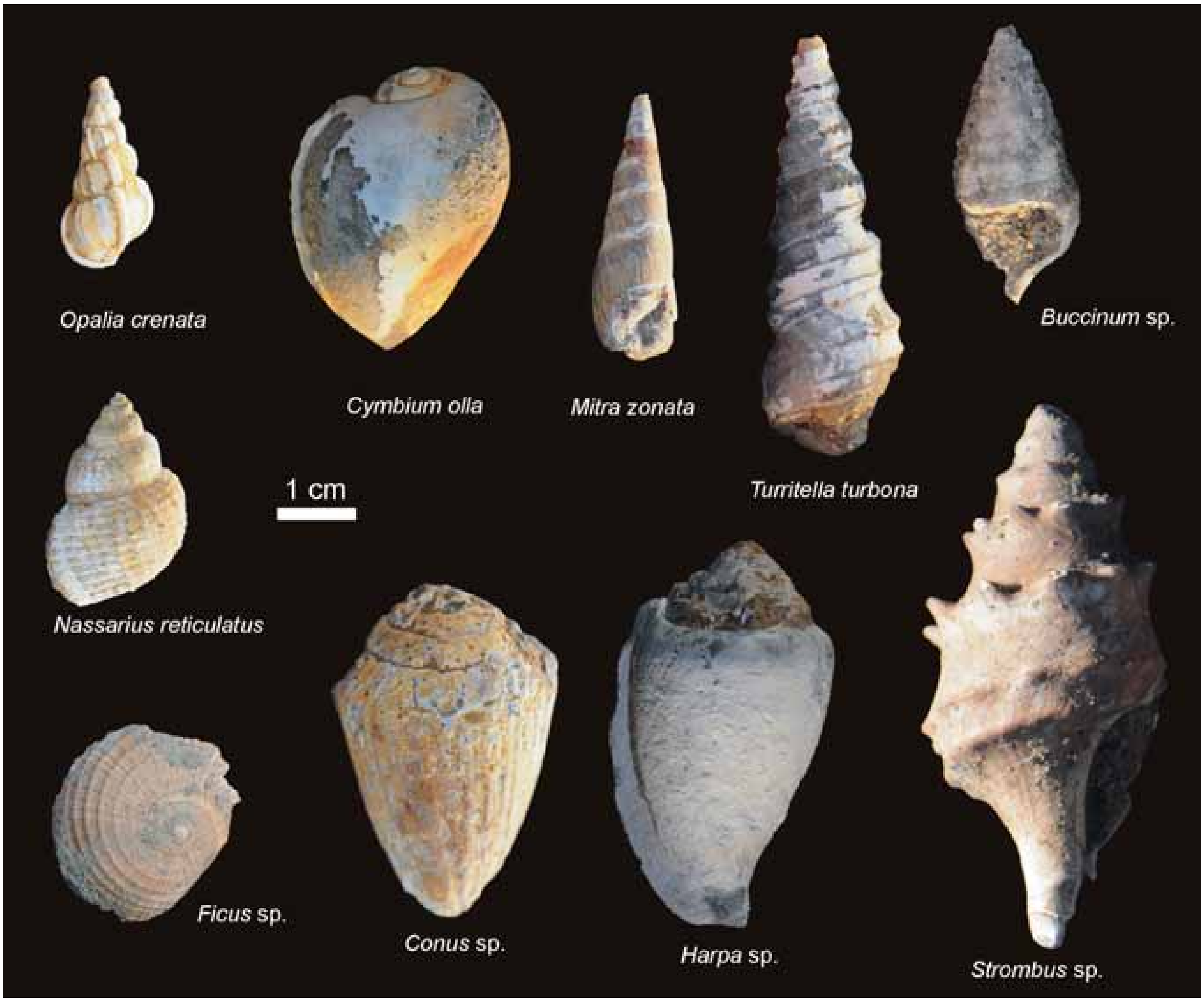

Fig. 9.- Gastropods recorded from bioclast-rich cemented coarse sand.

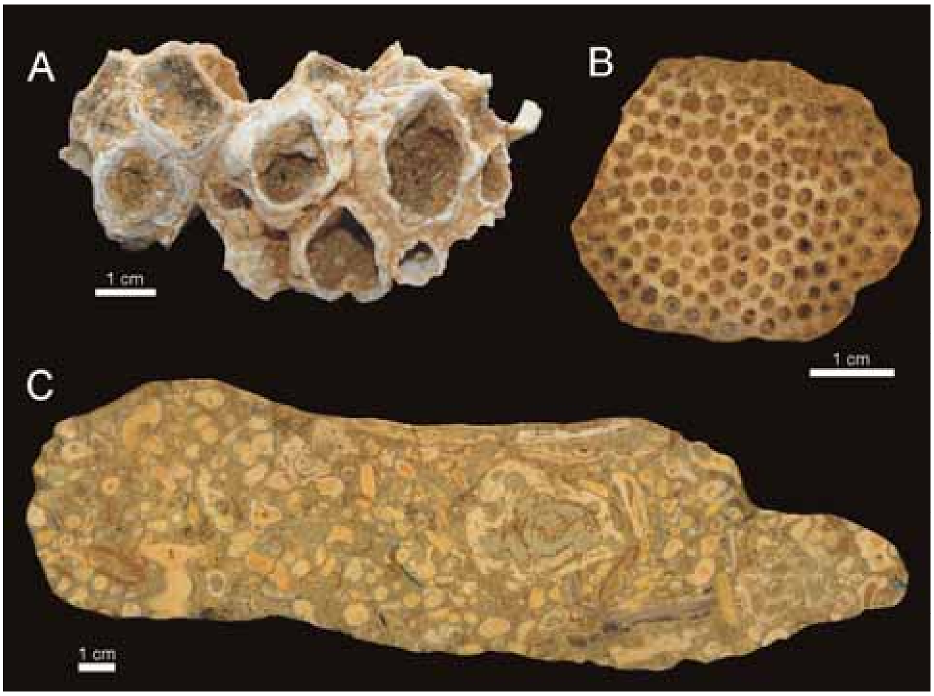

Fig. 10.- Reworked fossils. A. *Balanus* sp. (AE-3/AE-4 boundary, Fine quartz sands). B. Polish slab of the coral *Tarbellastraea* sp. (AE-13, bioclast-rich cemented coarse sand). C. Polish slab of a conglomeratic clast with red algae included in the AE-13 (bioclast-rich cemented coarse sand).

A group of 16 ribs (base of the AE-1) consists of disarticulated elements, all of them with the same appearance and size (average length of 30 cm and average diameter 4.5 cm; Figs. 4A, 12A). These are dense and swollen ribs resembling those of sirenians. The body of each rib is oval in cross section. Most of the ribs are incomplete with fragmentation both in the proximal and distal boundary. Some of these ribs show small areas with traces of bioerosion which are relatively elongated (3–7 mm length) with less than 2 mm depth and 1.5 mm width (Fig. 12A). Sirenians are characterized by heavy dense and swollen ribs (e.g., Berta *et al*., 2006b), however these ribs are not as flattened as in the Family Trichechidae and some subfamilies of Dugongidae (Halitherinae and Hydrodamalinae).

Cetaceans are represented by an incomplete humerus (AE-6, Fig. 12B), an uncomplete skull with a cervical vertebra (AE-6, Fig. 13), and a rib fragment (AE-14, Fig. 12C).

The humerus (AE-6) is a fragment with 18.5 cm long and 5 cm in diameter (Fig. 12B). It is incomplete in the proximal and distal boundaries. It presents a flattened section typical of the limbs of cetaceans. In addition, this bone presents a circular boring 1 cm in diameter and 0.6 cm deep.

The cranial remains (55.5 cm long, 47.4 cm wide and 21.2 cm high) are fragmented in the distal part of the premaxilar and maxilar (Fig. 13). Moreover, a fragment of the right mandible (42 cm long) is preserved and teeth are not observed in the fragment. The skull is bilaterally symmetrical and the rostrum is flat in side view. Excluded the rostrum, the skull has a quadrangular shape in the dorsal view. The rostrum has suboval temporal fenestra and a wide subtriangular supraoccipital. The sagital crest is well developed. The tympanic bulla has a large posterior lobe with a well-developed sigmoid process and fissure, a short conical process, and a short anterior lobe. The first cervical vertebra (17.4 cm in diameter) is preserved. The skull shows an osseous imbrication due the growth of the occipital and supraoccipital, which are elongated and progress to postorbital processes level of the frontals. These cetacean remains can be attributed to Mysticeti based on the shape and size of the skull bones, the high bilateral symmetry, as well as the presumable absence of teeth in the mandible. These remains are quite similar to those described by Cope (1896) from Tortonian of Maryland corresponding to the Family Cetotheriidae, genus *Cephalotropis* and to the specimen in the National Museum of Natural History of Lisbon from the Tortonian of Sesimbra (Portugal, Mocho and Póvoas, 2010). Cope (1896) established some typical features for *Cephalotropis* such as elongated nasal, frontals with divergent angles, presence of prominent temporal crest with a sagital crest, separation between frontals and supraoccipital, and rostrum overlapping the frontals. Some of these features may be identified in the studied remains, however, identification of the genus is tentative.

A fragment of a large rib (41.6 cm long, 6.5 cm in the maximum diameter) recorded from fine quartz sands of AE-14 (Fig. 12C), is characterised by a circular section (5–6 cm in diameter) and the presence of elongated bioerosion traces.

In addition three indeterminated fragments of vertebrae have been recorded in the river. They are two acoelous centra with more or less rounded shape (4.5 cm long, 3.1 in diameter; and 7.5 cm long, 6.6 cm wide in diameter). The larger vertebrae has an ellipsoidal centrum (9.4 cm wide and 5.5 cm high) very thin (2.3 cm long) and preserve part of the neural arch (2.5 cm high), fragmented transverse processes and neural spine.

5. Interpretation

The palaeoenvironmental conditions of the eastern Guadalquivir Basin in this area are interpreted from the analysis of lithofacies, the composition of fossil assemblages, the trace fossils and the taphonomic features. The sedimentary facies assemblage is characteristic of a sand-dominated coastal system in transition to offshore deposits with high terrigenous input. The composition of sand and pebbles indicates that

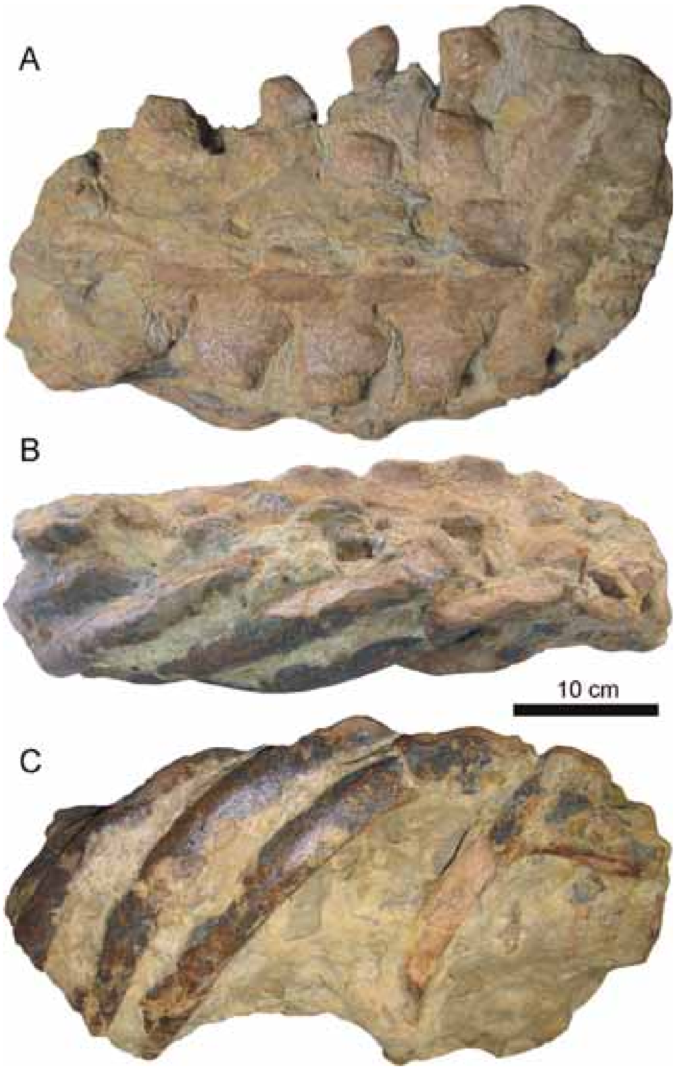

Fig. 11.- Partial thoracic cage of a pinniped (AE-14, Fine quartz sands). A. Dorsal view of articulated thoracic vertebrae. B. Lateral view of the vertebrae and the ribs of the right side. C. Ventral view where ribs of the right side are covering the vertebrae.

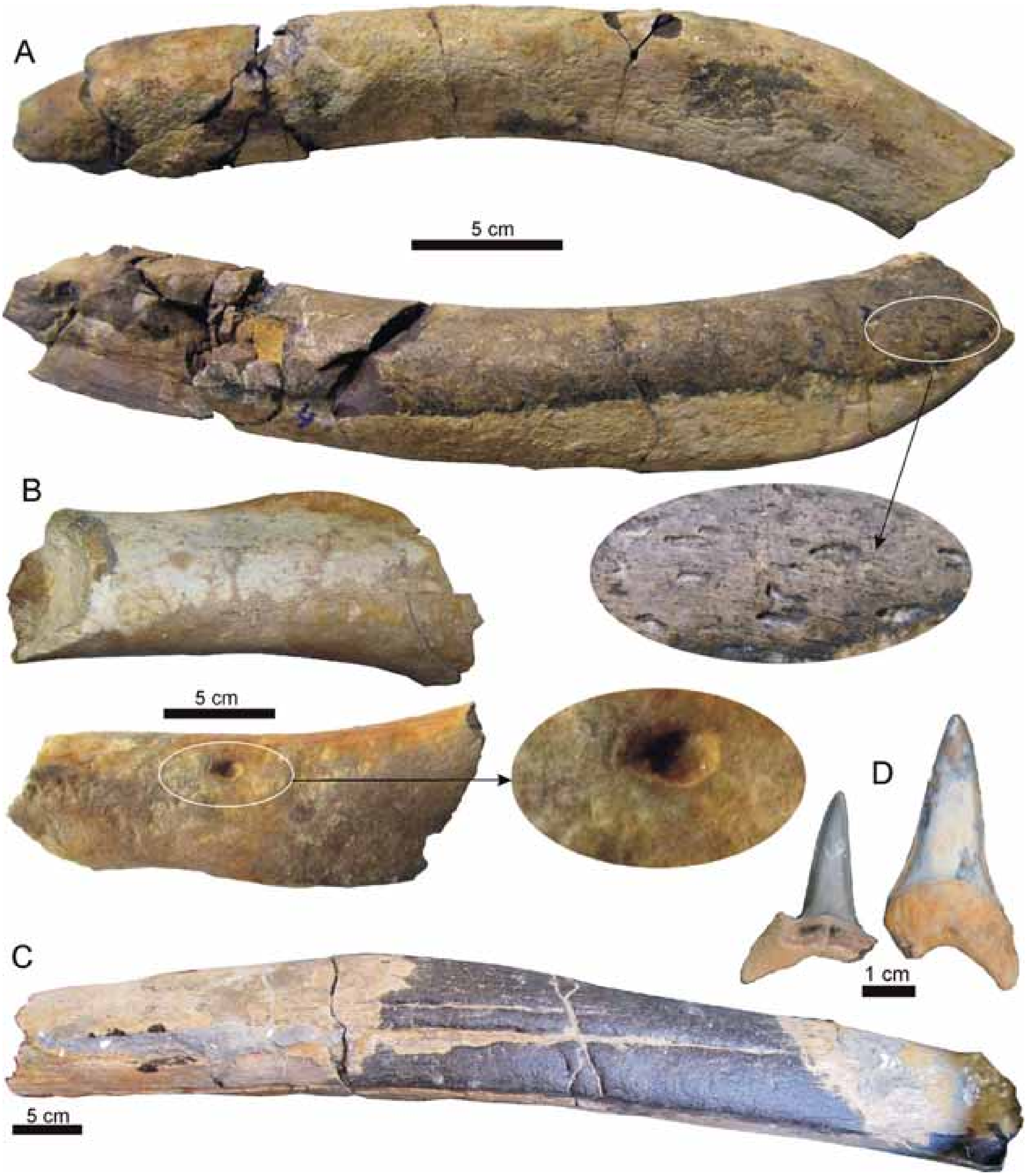

Fig. 12.- Diverse vertebrate fossil remains. A. Ventral and dorsal view of a swollen rib of a sirenian from the base of the section AE-0. Note the detail of scratch traces probably related to predation. B. Fragment of humerus of a cetacean and magnification of a circular boring (AE-6). C. Large fragment of cetacean rib with small boring pits (AE-14). D. *Isurus* teeth from Arroyo Escobar section, but not recorded *in situ*.

they come from erosion of Triassic deposits of the Tabular Cover and the Ordovician Armorican Quartzites of the Iberian Massif.

The granulometry, well-sorting, and the absence of sedimentary structures in the fine quartz sand indicate a distal position within a clastic depositional system, surely below the storm wave base. However, deep-waters conditions are not interpreted due to the absence of planktic foraminifera and the record of the *Skolithos* ichnofacies. The fine quartz sands represent the background conditions with low water energy due to the absence of sedimentary structures indicating high energy. Colonization of shells in the fine quartz sands is mainly related to endobionts represented by borings in large ostreids shells. But probably unstable substrate was not favorable for some epibenthic sessile organisms, including epibionts such as serpulids. Only some patches of ostreids

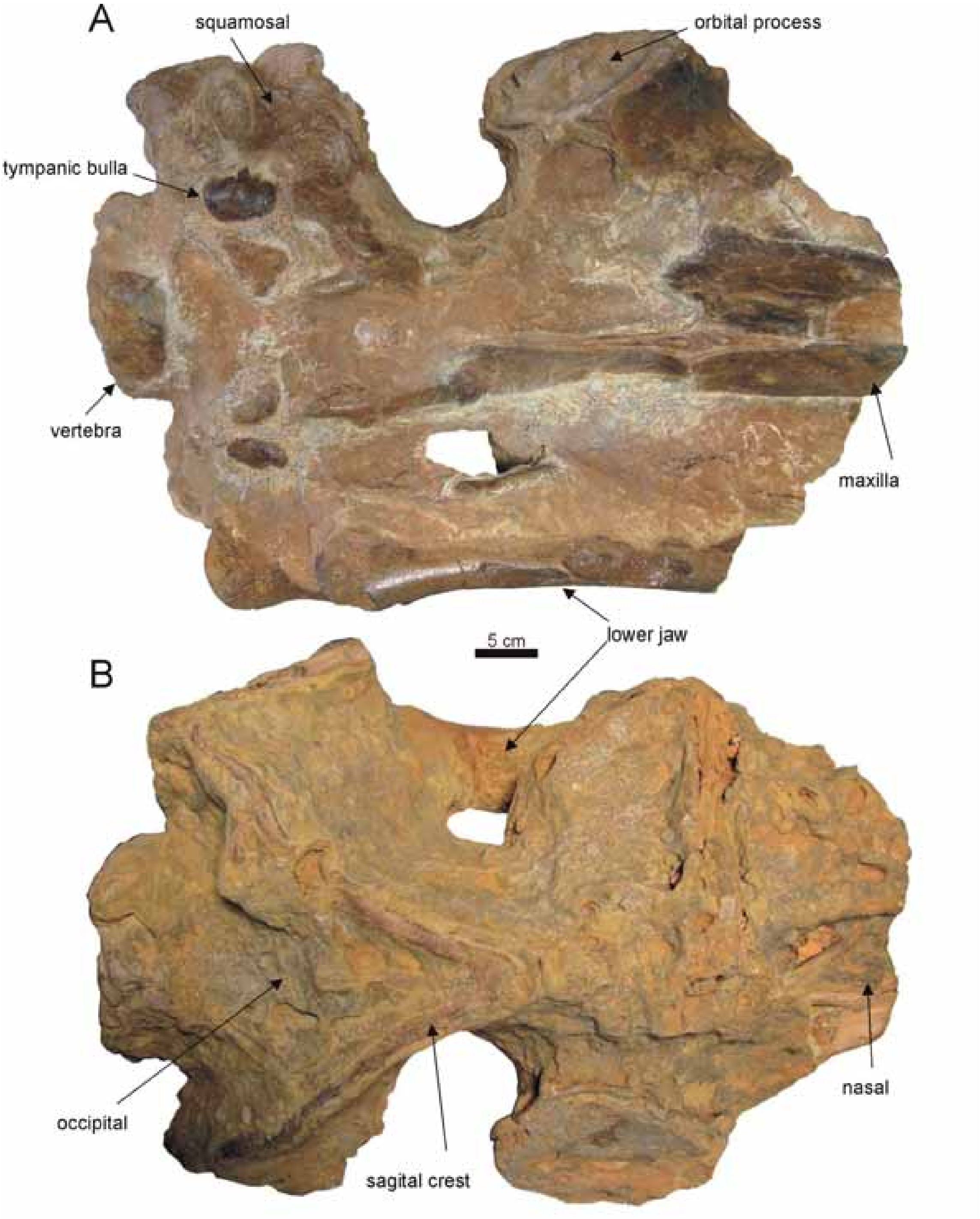

Fig. 13.- Cranial remains of a Mysticeti (fragment of skull, fragment of right mandible and first cervical vertebra). A. Ventral view. B. Dorsal view.

are recorded in the fine quartz sands. Thin-shelled bivalves such as Pectinidae from fine quartz sands are generally represented by small fragments, this means resedimentation process in situ or an incipient reworking. The fragmentation of thin-shelled bivalves may be also favored by the dense burrowing of the bottom, dominated by *Ophiomorpha*.

The studied trace fossil assemblage of the fine quartz sands is characterized by a few horizontal structures with predominance of suspension-feeders or passive tubicolous carnivores among the trace makers and corresponds to the *Skolithos* to *Cruziana* ichnofacies. This ichnofacies indicates softground to looseground with short-term, energy conditions associated with sudden deposition of massive sandy beds. This ichnofacies has been widely reported both in proximal and distal settings, where it reflects local environmental conditions such as high energy, sandy substrate, high levels of oxygen, and an abundance of suspended organic particles (e.g., Crimes, 1977; Crimes *et al*., 1981; Buatois and Lopez-Angriman, 1992; Uchman, 1995; Encinas *et al*., 2008; Buatois and Mángano, 2011). Typical shallow water forms of the *Skolithos* ichnofacies, such as *Ophiomorpha* and *Skolithos*, are not restricted to most proximal zones, but also occur in distal zones if these are affected by turbidity currents (Uchman, 1991; Buatois and Mángano, 2011). Vertical, cylindrical or U-shaped dwelling burrows (with retrusive spreiten) developed mainly in response to substrate aggradation. The dominant *Ophiomorpha*, consisting predominantly of vertical shafts, indicates moderate to relatively high-energy environment. *Ophiomorpha* is a substrate-controlled ichnogenus, registered in fine- to medium-grained sand deposits (Ekdale, 1992). Gibert and Martinell (1999) interpret *Ophiomorpha* as related to erosional surfaces and high energy environments, however, in the fine sands studied in the Arroyo Escobar section, sedimentary structures produced by currents are not present. *Ophiomorpha* also suggests a changing and unstable bottom for fine quartz sands. The record of *Diplocraterion* and *Ophiomorpha* is commonly related to opportunistic colonization of bottom after storm events (Pervesler and Uchman, 2004; Reolid *et al*., 2015; Nagy *et al*., 2016). Other ichnogenera such as *Asterosoma*, *Rosselia* and *Diplocraterion* confirm softground conditions. By the way, *Rosselia*, which is dominant in some stratigraphic intervals, has been also related to tempestites in inner shelf and deltas settings with high sedimentation rate (Miller and Aalto, 2008). Uchman and Krenmayr (1995, 2004) indicated that *Rosselia* is largely independent from the environmental energy level. The record of *Gyrolithes* is apparently not compatible with the inferred context because this is a deep-dwelling burrow, commonly described from marginal brackish shallow-water settings (Beynon and Pemberton, 1992; Buatois *et al*., 2005; Netto *et al*., 2007; Uchman and Hanken, 2013).

The bioclast-rich cemented coarse sand has a coarsening upwards trend in most of the beds where the base is constituted by quartz pebbles and quartz boulders in some beds (AE-2 and AE-5). This is a significant feature of relatively high energy deposits. Trace fossils are not recorded probably due the abundance of mollusk shells, which include shells of gastropods *Conus*, *Littorina*, and *Turritella* typical from proximal and shallower environments (e.g. Bernasconi and Robba, 1993; Waite and Strasser, 2011). Clearly allochthonous fauna is also represented by *Balanus*, red algae and *Tarbellastraea*. This lithofacies is related to storm deposits that produce the transport of shells of very shallow faunas to distal parts of a sand-dominated coastal system (or the distal parts of a fan delta interpreted by Santisteban-Navarro and Martín-Serrano, 1991). The high sedimentation rate explains the presence of well-preserved shells which were rapidly buried and protected from biostratinomic processes. Poorly-preserved shells were also transported by storm deposits and preserved in the bioclast-rich cemented coarse sands. The degree of fragmentation of the shells (mainly bivalves) in the fine quartz sands (representing background conditions) is higher than in bioclastic-rich cemented coarse sands, probably related to comparatively longer exposure.

Therefore, fine quartz sands represent distal facies of a sand dominated coastal system related to the northern margin of the Guadalquivir Basin, where storm deposits represented by the bioclastic-rich cemented coarse-grain sands were recurrently disturbing the normal sedimentation. Proximal fan-delta facies have been described in this sector by Santisteban-Navarro and Martín-Serrano (1991).

The fragmentation and dispersion of vertebrate remains recorded in the fine-grain sands is not related to currents because the absence of the sedimentary structures necessary for breaking and transporting the large remains of cetaceans. The presence of bioerosion pits on cetacean ribs from AE-0 and AE-14 points to the role of large predators and scavengers in this fragmentation and dispersion of remains. Two *Isurus* teeth have been recorded in this section and confirm the presence of high level predators in the trophic chain. Moreover, Reolid and Molina (2015) report the presence of *Carcharocles megalodon* in the Eastern Guadalquivir Basin during the Late Miocene. This large shark was a predator of marine mammals, similarity to the recent *Carcharodon carcharias*. The record of bits by *C. megalodon* on fossil remains of whales and dolphins indicate that they were common prey (see Demèrè and Cerutti, 1982; Cigala-Fulgosi, 1990; Purdy, 1996; Ehret *et al*., 2009; Muñiz *et al*., 2009).

6. Conclusions

The Arroyo Escobar section represents a sand-dominated coastal system in transition to offshore deposits developed during the Late Tortonian and located on the northern margin of the Guadalquivir Basin when this basin acted as a connection between the Atlantic and the Mediterranean. After the palaeontological study of fossil assemblages with special emphasis on the study of trace fossils and macroinvertebrate assemblages as well as the taphonomy of vertebrate remains, we present the following main conclusions:

1. The Arroyo Escobar outcrop consists of marine sediments made up of fine quartz sands and cemented coarse-grained sands. The fine sands are dominant in the succession and arranged in banks of several meters thick. They are characterized by a high abundance and diversity of trace fossils with the dominance of *Ophiomorpha*. The *Skolithos* ichnofacies and the abundance of *Ophiomorpha* indicate an unstable softground a relatively sudden deposition of massive sandy beds. The scarce sessil epibenthic organisms are congruent with softground conditions. The absence of sedimentary structures indicating currents points out to background low energy conditions.

2. The cemented coarse sands arrange in decimetric banks with finning-upward trends and locally some basal lags. This lithofacies is characterized by the high concentration of fos-

sils including abundant bivalves and gastropods and even fragments of assemblages from shallower environments with corals, red algae and barnacles. The fragmentation degree is generally very low and may be related to the rapid burial of the remains compared with fine quartz sands where fragments of thin-shelled bivalves are abundant. This lithofacies, with the finning-upward trend and the high concentration of fossils including allochthonus bioclasts, represents tempestite-like deposits of the most distal parts of a sand-dominated coastal system (probably the bottomset of a fan delta).

3. The fossil remains of vertebrates mostly occur in the fine sands as isolated remains, never as complete skeletons, with significant fragmentation in their outer ends. Long exposure of the remains on the sea-bottom was not probably due the absence of colonization by borers or encrusters on fossil bones. According to the absence of sedimentary structures indicating currents for transporting, disarticulating and fragmenting the large marine mammals remains, the occurrence of such processes was necessarily related to the activity of predators and scavengers, most likely large individuals. The occurrence of bioerosion in some vertebrate remains is congruent with the activity of scavengers.

4. The studied vertebrate fossil remains mostly belong to cetaceous and correspond to different specimens as the remains come from different beds. A total of 16 disarticulated ribs, a humerus, part of a skull with a cervical vertebra, and a fragment of a large rib were found. The detailed study of the skull remains suggests that the skull belongs to the Suborder Mysticeti, the Family Cetotheriidae and probably to the genus *Cephalotropis*. Together with the cetaceous remains there was a partially articulated rib cage of a large pinniped, probably an Otariidae.

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