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Taphonomic analysis of fossil concentrations from La Manga Formation (Oxfordian), Neuquén Basin, Mendoza Province, Argentina

Análisis tafonómico de las concentraciones fósiles de la Formación La Manga (Oxfordiano), Cuenca Neuquina, Provincia de Mendoza, Argentina

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Abstract

Griphaeid-dominated fossil concentrations of La Manga Formation are characterized on the basis of taphonomic, sedimentologic, stratigraphic and palaeoecologic criteria. These concentrations are present in the basal deposits (Unit 1) of three outcrops in the locality of Bardas Blancas. Their attributes allow distinguishing seven different fossil accumulations: A) Channelized fossil concentrations of *Gryphaea* sp.; B) Shell beds of *Gryphaea* sp. highly reworked; C) Shell beds of *Gryphaea* sp. moderately reworked; D) Accumulations of *Gryphaea* sp. with biomicrite to biopelmicrite matrix; E) Shell detritus; F) Accumulations produced by bottom currents; and G) Accumulations found in clumps. Accumulations A-C were deposited by high energy processes (storm waves and currents) in the upper middle ramp. Accumulations D and E were produced by high energy processes (storm waves and currents) but the final depositions were produced out of suspension in low energy environments, in lower middle ramp settings. Accumulations F were generated by weak bottom currents, meanwhile accumulations G correspond to gryphaeids associations reworked by bioturbators or by hydraulic processes after variable periods of permanence in sediment/water interface. Both are interpreted as lower middle or outer ramp. This interpretation suggests that these deposits that in previous works were interpreted as outer ramp settings, characterize middle and outer ramp settings. The vertical distribution of fossil concentrations from upper middle ramp to lower middle and outer ramp settings evidences a continuously growing accommodation space and allows to interpret the Unit 1 as part of a transgressive systems tract.

Keywords: shell beds, gryphaeids, storm deposits, Upper Jurassic.

Resumen

Las concentraciones bioclásticas dominadas por grifeidos de la Formación La Manga (Oxfordiense) de la Cuenca Neuquina fueron caracterizadas sobre la base de criterios tafonómicos, sedimentológicos, estratigráficos y paleoecológicos. Estas concentraciones están presentes en los depósitos basales (Unidad 1) de tres afloramientos en la localidad de Bardas Blancas. Sus atributos permitieron distinguir siete tipos diferentes de concentraciones bioclásticas: A) concentraciones bioclásticas canalizadas de *Gryphaea* sp.; B) Estratos de conchillas de *Gryphaea* sp. fuertemente retrabajadas; C) Estratos de conchillas de *Gryphaea* sp. moderadamente retrabajadas; D) Acumulaciones de *Gryphaea* sp. con matriz biomicrítica y biopelmicrítica; E) Detrito de conchillas; F) Concentraciones generadas por corrientes de fondo; y G) Agrupaciones de conchillas (*clumps*). Las acumulaciones A-C fueron depositadas por procesos de alta energía (olas y corrientes de tormenta) en sectores de rampa media superior. Las acumulaciones D y E fueron generadas por procesos de alta energía (olas y corrientes de tormenta) pero la depositación final ocurrió por decantación en ambientes de baja energía, en la rampa media inferior. Las acumulaciones F fueron generadas por débiles corrientes de fondo, mientras que las acumulaciones G corresponden a asociaciones de grifeidos retrabajadas por organismos bioturbadores o por procesos hidráulicos después de períodos variables de permanencia en la interfase agua/sedimento. Ambas acumulaciones fueron interpretadas como depósitos de rampa media inferior o rampa externa. La distribución vertical de concentraciones bioclásticas desde ambientes de rampa media superior hasta ambientes de rampa media inferior y rampa externa, evidencia un aumento en el espacio de acomodación y permite interpretar a la Unidad 1 como parte de un cortejo transgresivo.

Palabras clave: estratos de conchillas, grifeidos, depósitos de tormentas, Jurásico Superior

1. Introduction

Highly abundant and well preserved gryphaeid shells are exposed in the Oxfordian La Manga Formation in the south of Mendoza province (Argentina). Although they were well known for many years as “Gryphaeid Blue Limestones” (Groeber, 1929), their potential importance for taphonomic and palaeoecologic reconstructions has been neglected in most studies.

In fact, studies of the La Manga Fm have been focused mainly on its lithostratigraphy, biostratigraphy and palaeontology (Leanza, 1981; Riccardi, 1984; Groeber *et al.*, 1953; Riccardi, 1992; Stipanicic, 1965; 1996) and its sedimentological interpretation (Legarreta, 1991; Lo Forte and Palma, 2002; Palma *et al.*, 2003; 2004; 2005; 2007; 2009) as well as diagenetic aspects of the succession (Palma *et al.*, 1997; Palma and Lo Forte, 1998). Some approaches to taphonomic interpretation of griphaeid shell beds has been made by Palma *et al.* (2005); Piethé and Palma (2008), and Palma *et al.* (2007). However, detailed taphonomic works are still necessary in different parts of the basin, in order to improve the interpretation given to these deposits.

Fossil concentrations in La Manga Formation are useful for taphonomic studies due to their abundance in griphaeids, which have a calcitic structure with high preservation potential. In addition, the high quality of the outcrops allows recognizing the taphonomic features of shell concentrations and the very good exposition of the study area through 12 km allows the observation of vertical and lateral variations in the distribution of the beds.

A detailed, layer by layer exam of taphonomic features has been carried out in the outcrops of La Manga Formation in order to discuss the biotic attributes, especially from a taphonomic and palaeoecologic point of view.

The purpose of this paper is: 1) to describe and to interpret the fossil concentrations of La Manga Formation; 2) to use these concentration as a tool to interpret the depositional environment; 3) to analyze the relationship between this interpretation and previous facies analysis. Such taphonomic analysis would lead to a more detailed interpretation of the subenvironments previously determined by Palma *et al.* (2007).

2. Geological Setting

The Neuquén Basin is developed at the west margin of South American platform and is limited by a magmatic arc to the west and a tectonic foreland to the east. The foreland consisted of the Sierra Pintada belt to the northeast and the North Patagonia massif to the south (Fig. 1A).

The Neuquén Basin formation would involve Triassic-Early Jurassic extension followed by a long period of Middle Jurassic-Paleogene intermittent subsidence (Vergani *et al.*, 1995). The basin has been interpreted as a back-arc or retro-arc basin (Digregorio *et al.*, 1984; Legarreta and Uliana, 1991; 1996; Legarreta and Gulisano;

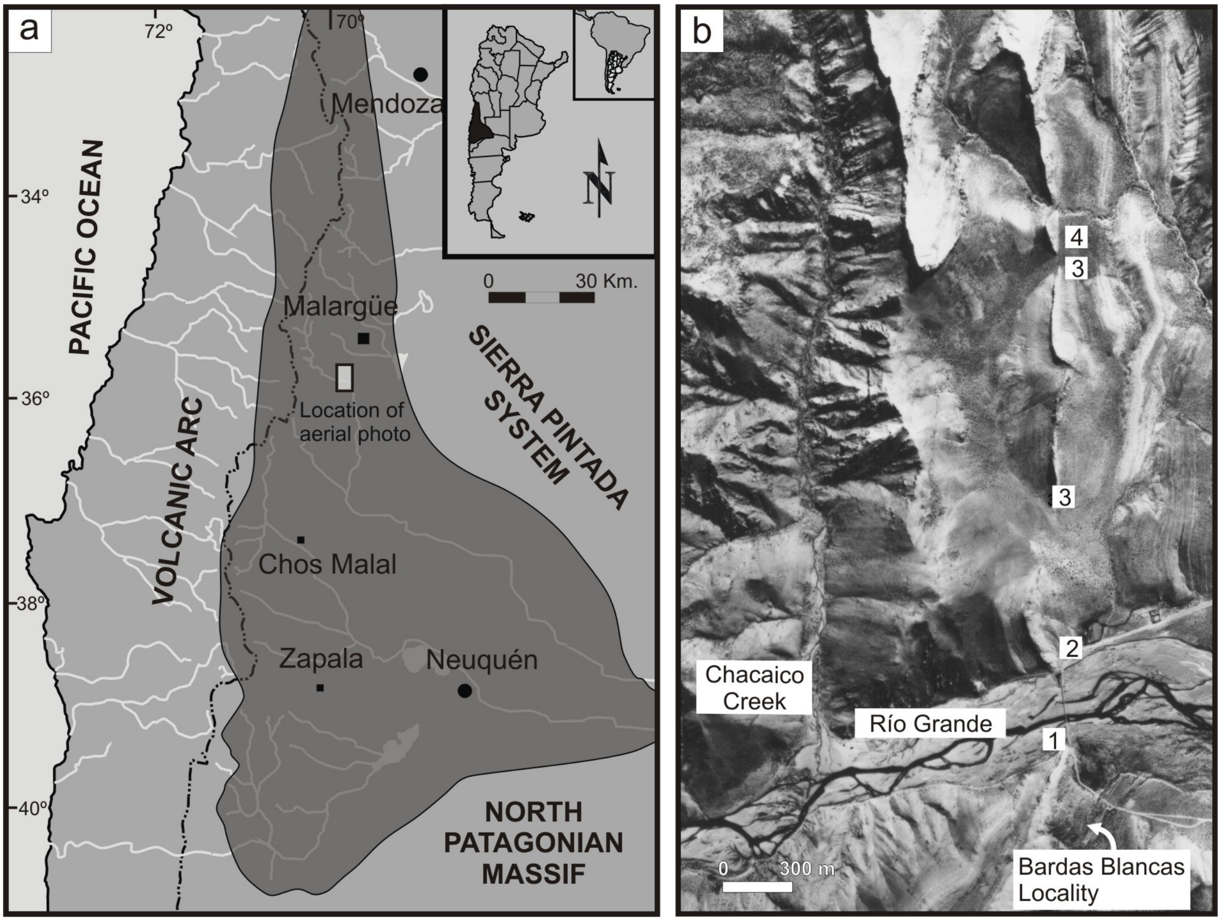

Fig. 1.A- Geographic location of Neuquén Basin; B- Aerial view of the study area, showing the geographic location of the outcrops of La Manga Formation. (Modified from Palma *et al.*, 2007).

Fig. 1.A.- Situación geográfica de la Cuenca Neuquina; B- Imagen aérea del área de estudio mostrando la situación geográfica de los afloramientos de la Formación La Manga. (Modificado de Palma *et al.*, 2007)

1989; Ramos, 1999; among others) and is characterized by a quite continuous Mesozoic and Cenozoic sedimentary record, comprising continental and marine clastic, carbonate and evaporitic deposits up to 2,600 m in thickness and cover an area of over 120,000 km^2 (Yrigoyen, 1991). Marine influx took place at different time intervals by connection with the Pacific Ocean (Legarreta and Uliana, 1991). The basement of the basin consists of early Paleozoic to late Triassic metamorphic, plutonic, volcanic and sedimentary rocks.

Groeber (1946) identified three depositional cycles: *Jurásico*, *Ándico* and *Riograndico*. Legarreta and Gulisano (1989) agreed generally with the validity of these cycles, and emphasized the importance of eustatic variations in the development of depositional sequences.

The Jurassic sequences are part of the Lower Supersequence of Legarreta and Gulisano (1989) which includes three mesosequences: *Precuyo, Cuyo* and *Lotena* (Fig. 2). The Lotena Mesosequence consists of five depositional sequences that include marine and continental facies (Lotena Fm), carbonate deposits (La Manga Fm), and evaporites (Auquilco Fm). The Lotena Mesosequence developed from middle Callovian to late Oxfordian-Kimmeridgian times. The ages of the sediments are taken from Legarreta (1991) who based his analysis on data from ammonites described by Stipanicic (1951; 1965; 1969), Westermann (1967), Westermann and Riccardi (1984), Dellapé *et al.* (1979), Riccardi (1984), and from Palma and Kietzmann (2008).

The studied sections belong to three different outcrops which are located in the locality of Bardas Blancas (department of Malargüe) in the Mendoza Province (Argentina), in the proximity of the bridge of National Road 40 over the Rio Grande (Fig. 1B). These outcrops are developed on hills named locally as *bardas*, and will be mentioned here as Barda 1, Barda 2 and Barda 3. Their distribution is shown in figure 1B.

The analyzed shell beds belong to the lower deposits of these outcrops, mentioned here as Unit 1 (Fig. 3A) defined by Palma *et al.* (2007). This unit was originally

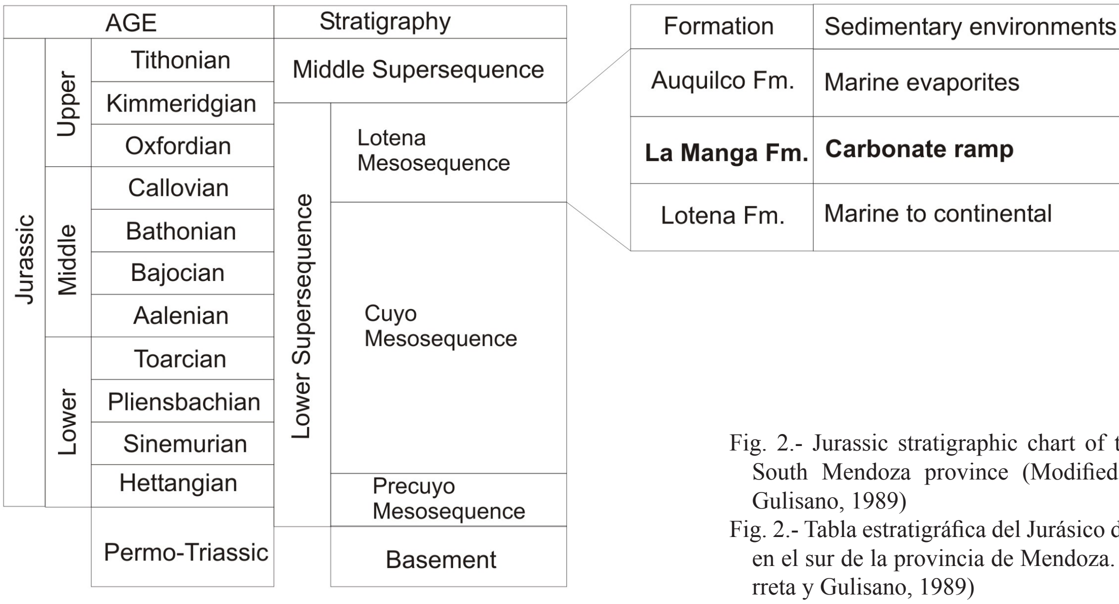

Fig. 2.- Jurassic stratigraphic chart of the Neuquén Basin in South Mendoza province (Modified from Legarreta and Gulisano, 1989)

Fig. 2.- Tabla estratigráfica del Jurásico de la Cuenca Neuquina en el sur de la provincia de Mendoza. (Modificado de Legarreta y Gulisano, 1989)

assigned to the grayish packstone-wackestone facies interpreted as outer ramp facies, and includes an assemblage of lithofacies and microfacies, which are briefly described below:

Packstone lithofacies: occurs in beds ranging in thickness from 30 to 70 cm and showing a thickening upward trend. The packstones are massive but grading is sometimes observed as well as amalgamated beds. They include abundant fossils of gryphaeids and some solitary serpulids. The internal fabric varies from simple to complex. Shells are often disarticulated and randomly oriented. The beds overlie massive or graded wackestone beds and show either sharp or erosional bases.

In thin section, two packstone microfacies have been differentiated: bioclastic packstone (Microfacies 1) and intraclastic-bioclastic packstone (Microfacies 2). The microfacies 1 consists of disarticulated and fragmented gryphaeid shells, some whole pelecypods and small gastropods. Other bioclasts are represented by echinoderms debris, serpulids, and bryozoan. Most grains are highly micritized. Small intraclasts are also common. The microfacies 2 is very similar to microfacies 1, but the particles are more fragmented. Intraclasts of reworked bioclastic or pelloidal wackestone microfacies are very common. Foraminifera, calcispheres, small oncoids and ooids are minor constituents. Bioclasts usually show extensive micritization.

Wackestone lithofacies: this lithofacies is commonly massive, but locally may show parallel lamination or graded beds. Beds range from 8-20 cm in thickness showing a thining upwards trend. Gradational bases are present. Fossils are dominated by gryphaeid shells, and abundant millimetric fragments of undetermined pelecypods. Two main microfacies can be recognized, including pelloidal wackestone (Microfacies 3) and bioclastic wackestone (Microfacies 4).

Microfacies 3 is made up of a clotted micrite groundmass that is locally pelloidal. Peloids appear subrounded and clustered into aggregates. Skeletal particles include pelecypod shell fragments, foraminifera and scattered serpulids; whereas the microfacies 4 consists of pelecypod debris, echinoderms fragments, scattered bryozoans and small intraclasts derived from the pelloidal or bioclastic wackestone.

Mudstone lithofacies: consists of massive to nodular mudstones. Contains sparse fragments of gryphaeid bivalves, echinoids and calcispheres. Beds range from 8-20 cm in thickness forming a thining upwards sequence.

Compositional, textural, and taphonomic features of the facies association of Unit 1 allow recognizing cycles of centimetric to decimetric thickness (Piethé and Palma, 2008). These small cycles consist of bioclastic packstone to wackestone bed sequence showing gryphaeid concentrations at the base (Fig. 3B). A progressive upward thickness diminution of fossil concentration as well as a high disarticulation and fragmentation degrees point out to reworking by action of currents. They are usually topped by laminated wackestone or massive to nodular mudstone beds. Detailed cyclostratigraphic analysis allows grouping these small cycles, where minor thinning and fining of carbonate components was observed, in thicker, coarsening upwards cycles of 1 to 5 metres in thickness.

The Unit 1 belongs to DS-1 (depositional sequence 1) (Palma *et al.*, 2007) that represents part of the highstand systems tract (HST) of the sequence. The rest of this systems tract was either not deposited or eroded. Nevertheless, Piethé and Palma (2008) interpreted this Unit 1 as a transgressive systems tract. The DS-1 shows two important erosive surfaces at both its base and top and crops out only partially in the study area. It reaches its maximum thickness in Barda 1 and thins progressively northwards (Fig. 4), where it is difficult to recognize (Barda 3 north and Barda 4).

Since most previous works were focused on different aspects of the La Manga Formation, an exhaustive taphonomic study was not documented. In particular, detailed bed by bed biofabric and taphonomic features of griphaeid shell beds were sought in order to provide relevant information on environmental setting, energy level, and residence time of the bioclasts on the sea floor.

3. Methods

In the studied outcrops, cross-section views are more abundant than surface views of the sequences. Therefore, the majority of data come from these views, where attributes were measured using quadrants of 20 x 20 cm randomly distributed, placed perpendicular to the bedding. This allows determine qualitative features of the concentrations and to obtain numerical data to establish semi-quantitative scales. On the other hand, there are simple shell beds, which have one specimen in thickness and have been analyzed in smaller sampling quadrants (5 x 20 cm). Some beds were sampled up to four times with quadrants separated on average 2 m from each other in order to obtain further taphonomic data. Also, as far as possible, at least 30 specimens were collected from each storm bed, 750 samples were collected as a whole.

Fossil deposits were described considering stratigraphic, sedimentologic, taphonomic and palaeoecologic attributes sensu Kidwell and Holland (1991). Taphonomic features were observed in fossil fragments larger than 5 mm. Particles smaller than 5 mm were considered as shell detritus (bioclasts).

In order to describe the features of fossil assemblages different attributes were taken into account:

1) Stratigraphic features: a) thickness and lateral extension of the deposit; b) geometry (applied to tridimensional concentrations): bed, lens, clumps; c) stratigraphic contacts; d) internal complexity: simple/complex concentrations; items a-d follows Kidwell *et al.* (1986). Complex concentrations are composed by vertical and/or lateral accretion of individual shell beds named here as microstratigraphic units (m.u.) similar to those used by Simões and Kowalewski (1998).

2) Sedimentologic features: a) close-packing of bioclasts: dense/loose/disperse; b) percent-volume bioclasts in deposits; c) size-sorting of bioclasts: well sorted/bimodal/poorly sorted; d) type of matrix. Items a-c described according to Kidwell and Holland (1991). Physical and biogenic sedimentary structures were lacking in the considered concentrations.

3) Taphonomic features: a) orientation in plan view: unimodal/bimodal/random (Kidwell *et al.*, 1986); b) orientation in cross section: concordant/oblique/perpendicular/random (Kidwell *et al.*, loc. cit.); c) degree of articulation of carcasses: low (0-15% articulated specimens)/medium (15-75%)/high (75-100%); d) fragmentation: low (0-30% fragmented shells)/medium (30-70%)/ high (70-100%); e) rounding: rounded/subrounded/ subangular/angular; f) corrasion (sensu Brett and Baird, 1986), based in the recognition of superficial features as radial ribbing and growth lines: low (well defined superficial features)/medium (weak definition of superficial features)/high (unrecognizable superficial features); g) preserved mineralogy. Semi-quantitative scales express percentages obtained from the average values measured in each quadrant. Additional information about some taphonomic features as roundness and corrasion, come from the observation of specimens collected in the field. Encrustation was not observed and bioerosion was recognizable only in thin sections. Fragmentation was characterized by direct observation of bioclast concentrations, and then introducing a bias, taking into account that shells are only partly exposed, making impossible to appreciate fragmentation in the hidden side of the specimens.

4) Palaeoecologic features: a) taxonomic composition; b) relative abundances of species.

According to Kidwell *et al.* (1986), fossil concentrations were classified as sedimentologic or biogenic concentrations, and as autochthonous, parautochthonous or allochthonous concentrations. On the other hand, they were differentiated according with the time involved in its formation (time averaging) (Kidwell and Bosence, 1991).

Palaeoenvironmental model for carbonate ramps of Wright and Burchette (1996) have been followed to interpret the sections studied.

4. Fossil concentrations from La Manga Formation

The most conspicuous fossil concentrations are composed by gryphaeid pelecypods, determined as *Gryphaea* sp. (pers. comm. Rubilar, 2009). Their frequency and good quality of the material led us to focus on the shell concentrations studies to analyze genetic processes suit-

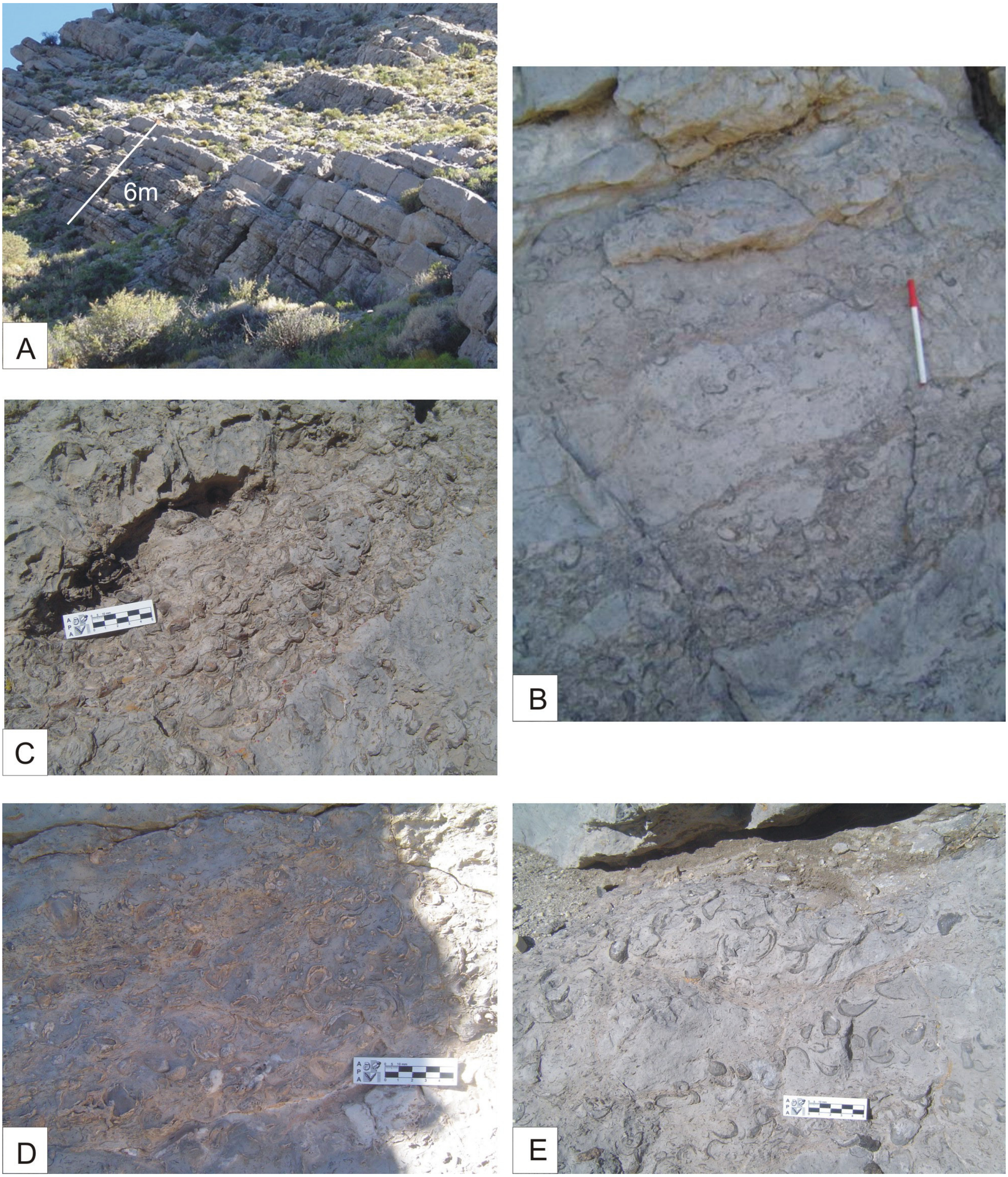

Fig. 3.(This page and the opposite one) A- General aspect of Unit 1 in Barda 2; B- Detail of coarsening upward cycles. Note the packstone-grainstone centimetric intervals (bioclastic concentrations of *type B*) (pen for scale 15 cm); C to K- Fossil concentrations of La Manga Formation: C- *Type A*, channelized fossil concentrations of *Gryphaea* sp.; D- *Type B,* shell beds of *Gryphaea* sp. highly reworked; E- *Type C,* shell beds of *Gryphaea* sp. moderately reworked; F- *Type D*, fossil concentrations of *Gryphaea* sp. with biomicritic to biopelmicritic matrix; G- *Type E*, shell detritus (pen cap for scale is 4 cm); H- *Type* F, accumulations of echinoderm spines produced by bottom currents in a top surface view; I- *Type F,* fossil concentrations produced by bottom currents (in cross section). Note the presence of corals and gryphaeid levels; J- Shell concentrations of *Type G* in clumps; K- Association of bioclastic concentrations *types E* and *F*.

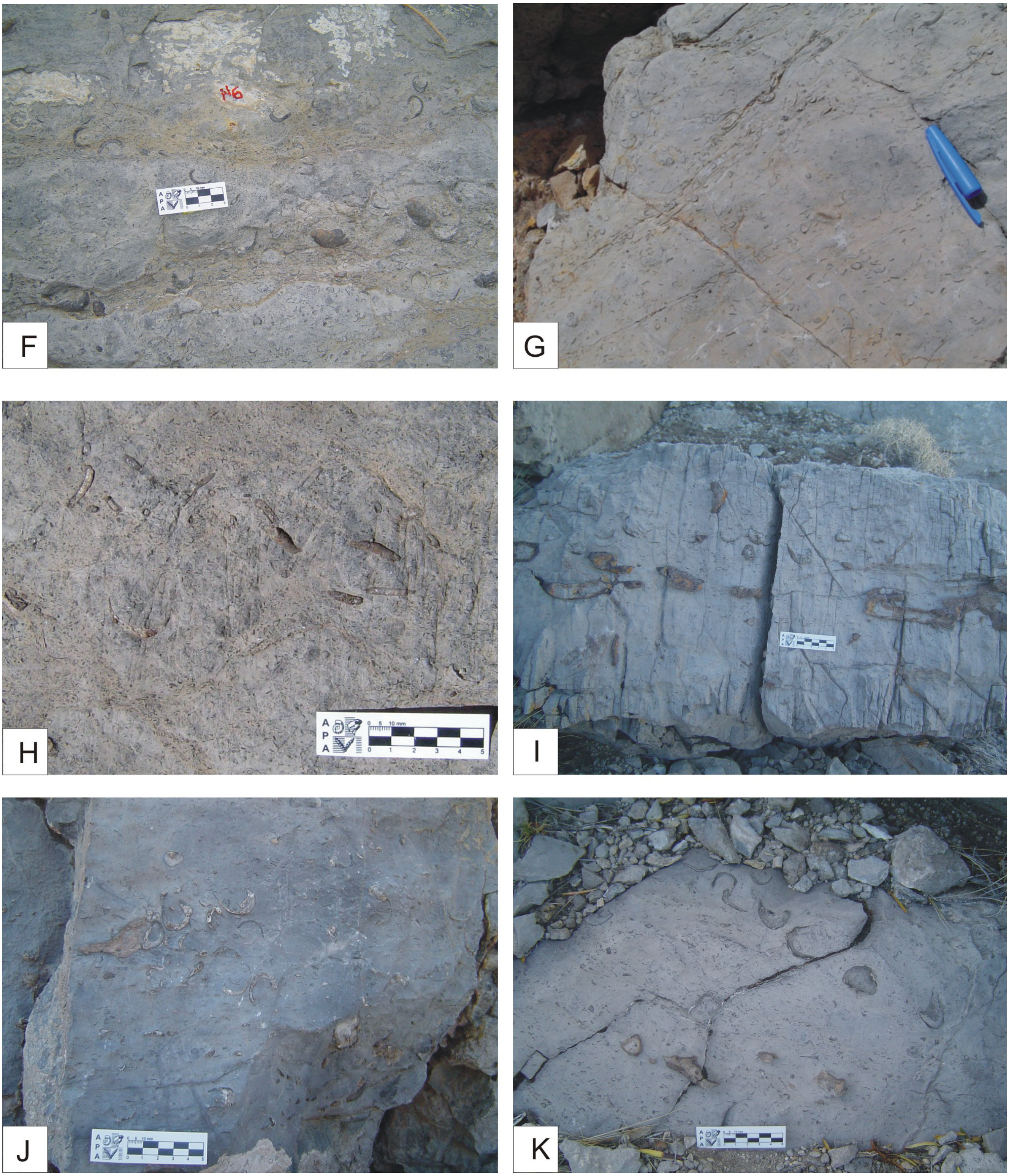

Fig. 3.(Esta página y la previa) A- Aspecto general de la Unidad 1 en la Barda 2; B- Detalle de ciclos de somerización. Observar intervalos centimétricos de packstone a grainstone de las calizas en la base (concentraciones bioclásticas de tipo B) (escala: 15 cm); C a K- Concentraciones fósiles en la Formación La Manga: C- *Tipo A*, concentraciones fósiles canalizadas de *Gryphaea* sp.; D- *Tipo B*, concentraciones de conchillas de *Gryphaea* sp. fuertemente retrabajadas; E- *Tipo C,* concentraciones de conchillas de *Gryphaea* sp. moderadamente retrabajadas; F- *Tipo D*, concentraciones de *Gryphaea* sp. con matriz biomicrítica y biopelmicrítica; G- *Tipo E*, detrito de conchillas (escala: 4 cm); H- *Tipo* F, concentraciones de espinas de equinodermos producidas por corrientes de fondo (vista en planta); I- *Tipo F,* concentraciones producidas por corrientes de fondo (sección perpendicular a la estratificación) donde se observa un nivel de corales y un nivel de grifeidos; J- *Tipo* G, concentraciones de conchillas en agrupaciones; K- Asociaciones de concentraciones de fósiles *tipo E* y *F*.

able for environmental analysis (Fürsich and Oschmann, 1993). This fauna is now in study and all the specimens probably belong to the same species, although different morphotypes can be recognized.

The mode of fossilization of *Gryphaea* sp. ranges from well preserved shells to highly abraded and fragmented material, showing the action of biostratinomic processes (more frequently fragmentation, roundness and corrasion). Usually, the calcitic portion of the valves has remained mineralogically stable with respect to dissolution and replacement, meanwhile superficial silicification is in some cases common. The fossil concentrations are usually composed by disarticulated specimens, particularly left valves, in which umbos can be absent or eroded and ventral margins are broken.

Other taxa are represented by internal molds of undetermined pelecypods, coral fragments, and echinoderm spines that occur scattered throughout these deposits.

4.1 Fossil concentrations type A- Channelized fossil concentrations of Gryphaea sp. (Fig. 3C)

Description

Lenticular shell beds, 5 to 40 cm thick and tens of centimetres to 3 metres of lateral extension. Lower contacts are generally sharp and erosional and upper contacts are gradational with wackestone-mudstones lithofacies. These lenses can exhibit lateral amalgamation, producing extensive beds with variations in thickness. Internally the structure of each shell bed is complex, with vertical and lateral amalgamation of individual microstratigraphic units (m.u.) showing a variation in thickness from 2 to 6 cm and exhibit weak normal gradation.

Fossil assemblages are monotypic, composed exclusively by *Gryphaea* sp. The shell packing shows positive gradation within each m.u., usually consists of dense packing at the base (shell percentages higher than 75%) and loose packing at the top (shell percentages of 15-25%). Fossil remains are poorly sorted and orientation is random (both in surface and cross section). The matrix is biopelmicrite.

Different parts of the same m.u. may exhibit different intensities of reworking. Articulation is low (0-3%) and fragmentation is high. Fragment sizes range from 5 cm to smaller than 0.5 cm. Well rounded fragments of left valves of *Gryphaea* sp. are dominant. These exhibit medium-high degree of corrasion, ventral margin fragmented and umbo is frequently abraded. Some shells exhibit superficial silicifications. These shell beds are present only in Barda 1.

Interpretation

The geometry of the deposits, the erosive basal contact and the normal gradational internal structure suggest that these fossil concentrations are lags at the base of channelized storm deposits. These channels would act as conduits for offshore transport of particles during storms as seen in other storm dominated marine deposits (Siringan and Anderson, 1994; Zuschin *et al.*, 2004; Roetzel and Pervesler, 2004).

The sharp base of most shell concentration points to erosion before deposition of the overlying bed. During storm events, griphaeid shells were concentrated as packstone-grainstone beds. Storm waning led in some cases to deposition of finer-grain or graded shells debris, while after the storms, fine-grain carbonate particles (wackestone-mudstone) settled down from suspension. On the other hand, amalgamated shell beds record several episodes of erosion and deposition characterizing an internal complex concentrations of individual shell beds (m.u.).

Taphonomic features suggest long periods of time in the TAZ (taphonomically active zone). According to Davies *et al.* (1989) storms are short events that are not responsible for destruction of shells. Therefore, taphonomic features observed in gryphaeid shells show the depositional history previous to the storm event responsible for the final deposition. During this time interval, shells would suffer mechanic processes leading to disarticulation, fragmentation, roundness and corrasion (abrasion). These processes are more frequent above the fair-weather wave base. Right valves, thinner and more fragile than left ones, probably made a significant contribution to the fragmented remains. On the basis of beds thickness and composed multiple m.u., these shell beds are interpreted as proximal tempestites (Kidwell, 1991; Fürsich and Oschmann, 1993; Zuschin *et al.*, 2001).

As mentioned before, palaeoecology of *Gryphaea* sp. suggests low energy environments for living (Nori and Lathuilière, 2003), which in these deposits are present in middle and outer ramp environments. Storm processes include erosion of the sea floor above storm wave base, carrying both living specimens (inhabiting between the fair-weather wave base and the storm wave base) and produced elements (reworked remains present above storm wave base). Erosion processes might have been superficial, dragging only epifaunal pelecypods, in this case represented exclusively by *Gryphaea* sp. These remains would be deposited as lags in channelized storm deposits, which usually developed above fair-weather wave base (Siringan and Anderson, 1994). However, analysis of thin sections point out to the presence of calcispheres, foraminifers and

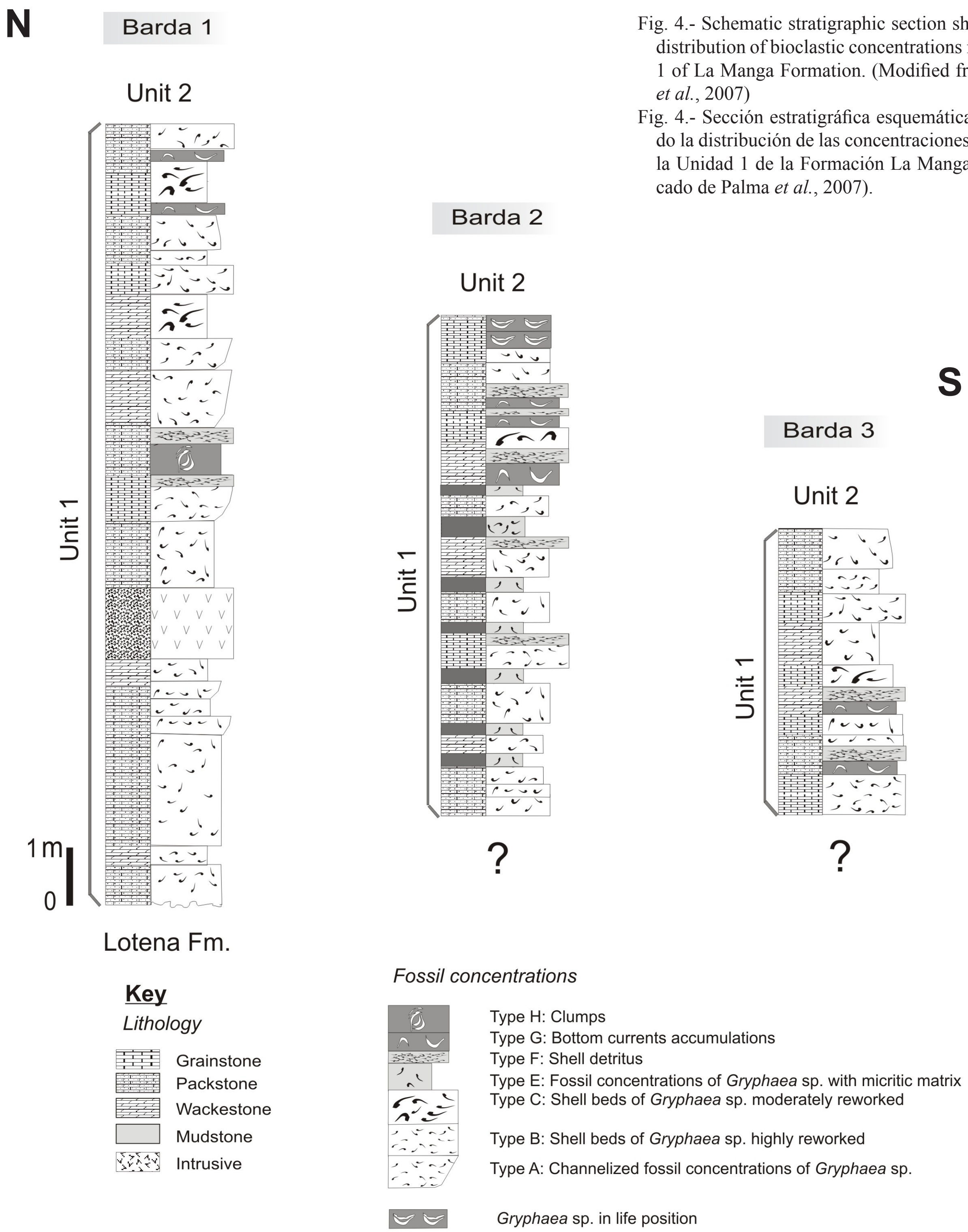

Fig. 4.- Schematic stratigraphic section showing the distribution of bioclastic concentrations in the Unit 1 of La Manga Formation. (Modified from Palma *et al.*, 2007)

Fig. 4.- Sección estratigráfica esquemática mostrando la distribución de las concentraciones fósiles en la Unidad 1 de la Formación La Manga. (Modificado de Palma *et al.*, 2007).

abundant pelloids (microfacies 2 and 3) allowing to interpreting these deposits as middle ramp settings.

Later, these channelized shell beds could be reworked during long periods of time by return flows, winnowing the matrix and increasing the packing as well as the abrasion effect on the shells. Reduction in the size of skeletal remains and a higher proportion of the matrix observed in each microstratigraphic unit could be related to a decrease of energy levels. Random orientation of shells may result from rapid deposition by high-density turbulent flows (Middleton, 1967) or turbulent stirring of seafloor (Greensmith and Tucker, 1969).

4.2 Fossil concentrations type B-Shell beds of Gryphaea sp. highly reworked

Description (Fig. 3D)

Shell beds between 40 and 67 cm in thickness, laterally persistent for tens of metres, showing basal contact irregular, usually erosional, and upper contact sharp or rapidly gradational. Concentrations are internally complex, produced by vertical and lateral amalgamation of m.u. of 3-12 cm in thickness, which individually can exhibit normal gradation.

These concentrations are dominated by *Gryphaea* sp., while isolated undetermined pelecypods (mostly pectinids), echinoderm spines and/or coral fragments may be present. Concentrations exhibit loose to loose-dense packing and shell concentration per volume of rock ranging between 15 to 25%. Sorting is poor, including 4 cm complete left valves to fragments smaller than 0.5 cm. Orientation in both surface and cross section is random. Articulation is low (<5%) and fragmentation is high, fragments smaller than 0,5 cm being abundant.

Disarticulated left valves of *Gryphaea* sp. are the most dominant elements. They appear well rounded, showing medium-high degree of corrosion. Umbos are normally absent and ventral margin is usually fragmented. Their original composition is altered by recrystallization, dissolution and silicification.

The remaining pelecypod taxa are represented by articulated internal moulds, in which taphonomic features as corrosion, roundness, bioerosion and incrustation are impossible to determine. When present, they constitute 2-10% of the concentration and only in one occasion they reach the 36%. These concentrations are the most abundant and have been found in bardas 1-3.

Interpretation

These tabular shell beds are interpreted as storm deposits present in the upper section of the middle ramp. Frequently channelized deposits as those described as fossil concentrations A become nonchannelized as they move offshore producing thinner storm beds (Siringan and Anderson, 1994). Tabular geometry, sharp base and thinner shell beds are features indicating decreasing of hydrodynamic energy conditions.

These concentrations are interpreted as proximal tempestites, meanwhile high thickness corresponds to the amalgamation of individual m.u. producing internally complex concentrations. In addition, taphonomic features suggest long periods of time in the TAZ reflecting a predepositional history similar to those of fossil concentrations A.

The lack of orientation of the shells would be related with rapid deposition by high-density turbulent flows (Kidwell and Bosence, 1991).

Fragments of corals would come from patch reefs that were not found in the field. Corals would be fragmented during storm events and then transported by waves and currents.

4.3. Fossil concentration type C- Shell beds of Gryphaea sp. moderately reworked

Description (Fig. 3E)

Shell beds similar to those describe as fossil concentrations C, but in this case, monotypic (composed exclusively by *Gryphaea* sp.) with valves better preserved. Fragmentation is low-medium, roundness is subangular-subrounded and corrosion is low. Ventral margin of left valve is slightly fragmented and umbos are usually present. These kinds of concentrations are scattered and only present in the outcrops bardas 1 and 3.

Interpretation

These concentrations are also storm event deposits, but unlike fossil concentrations A and B taphonomic features suggest short time intervals in the TAZ. These would be consequence of deposition out of reach of high energy physical processes, close to the storm wave base, in the lower middle ramp or settlement in environments with high rates of deposition, isolating the shell bed from the TAZ.

The absence of other macroinvertebrate remains suggests low spatial mixing. This low mixture and the good state of preservation suggest that these gryphaeids concentrations were probably originated in middle ramp settings.

4.4 Fossil concentration type D- Concentrations of Gryphaea sp. with biomicrite to biopelmicrite matrix

Description (Fig. 3F)

Shell beds between 3-8 cm in thickness and tens of metres of lateral extension, with basal and upper irregular contact, usually showing erosion features produced by overlying wackestone-packstone. These concentrations can be internally simple or complex, in such case, resulting from the amalgamation of two or three individual m.u., generally 2-4 cm thick each.

These fossil concentrations are composed of *Gryphaea* sp., with loose to dense packing, and percentage of bioclasts of 25-55%. Sorting is poor, including left valves of *Gryphaea* sp. that reach 2.5 cm and fragments smaller than 0,5 cm. The matrix between the shells varies from biomicrite to biopelmicrite.

Fossil remains appear randomly oriented. Values of valve articulation are low, while fragmentation, roundness and corrasion are high. Dissolution is low, whereas silicification is common. Shell fragments smaller than 1 cm appear concordant to the stratification. This type of fossil concentration is common in outcrop Barda 2.

Interpretation

These deposits were generated below the fair-weather wave base where could be resuspended and redeposited by multiple storm induced waves. Taphonomic features suggest long periods of permanence in the TAZ. Fine carbonate particles indicate quiet conditions ranging from suspension deposition to low-energy wave regime, probably as distal tempestites. Random shell orientation might be related with the action of burrowers (Kidwell and Bosence, 1991).

4.5 Fossil concentrations type E- Shell detritus

Description (Fig. 3G)

It consists of bioclastic wackestone *beds*, generally 5 to 10 cm in thickness, with both transitional base and upper contact. Internal structure is complex, composed by the alternation of centimetric levels rich in shell detritus with centimetric levels poor in fossil remains.

Bioclasts are represented by shell detritus of calcitic composition, smaller than 0.5 cm, usually well sorted. Packing is loose-disperse with a percentage of bioclasts smaller than 10%, and random orientation. Roundness and corrasion are highly variable. Bioclastic detritus exhibit the same taphonomic signature in all studied outcrops.

Interpretation

These detritus correspond to fragmented pelecypods, mainly gryphaeids, generated under the action of high energy processes like storm waves and currents, probably after long periods above fair-weather wave base. Shell detritus would be transported later to deeper environments until their final deposition. These centimeter-thick shell deposits would require successive events of deposition in low energy environments probably below fair-weather wave base, in lower middle ramp or outer ramp settings.

4.6 Fossil concentrations type F- Concentrations produced by bottom currents

Description (Fig 3H, I)

Thin shell bands, formed by one single shell thick accumulations. These concentrations appear in bioclastic wackestone beds interbedded with fossil concentrations F (shell detritus).

Monotypic, composed of fragments of branching corals, disarticulated valves of *Gryphaea* sp. or echinoderm spines. In the three cases the packing is disperse, with a low percentage of bioclasts per rock volume (< 10%).

Echinoderm spines (Fig. 3H) appear concordant to stratification and floating in a bioclastic matrix. They show a slight surface view orientation. The spines may reach 0,5-2 cm in length. These remains exhibit partial dissolution and silicification.

For coral fragments (Fig. 3I) the sorting is poor, these fragments reach 3 cm in diameter and 10 cm in length and are concordant in cross section. Although it is not possible to observe these fragments in surface view, the cross-section suggest that they are slightly oriented, the preferent orientation being more obvious in smaller fragments. Coral remains are usually silicified.

With regard to the accumulations of *Gryphaea* sp. (Fig. 3I), shells appear disarticulated, chaotic in plan view and cross section. Values of fragmentation, roundness and corrasion are low. These concentrations are present in the outcrops bardas 1-3.

Interpretation

These monotypic, one-shell thick concentrations, showing disperse packing and concordant orientation in the case of prolate remains (corals and echinoderm spines) and chaotic for equidimensional remains (gryphaeids) can be interpreted as the result of redistribution of bioclastic material by the action of weak bottom currents.

Coral fragments suggest transport from shallow water, moderate to high energy environment, and intensive reworking by currents or storms for long periods of time, contributing to fragmentation and corrasion.

Gryphaeids also exhibit evidence of transport, such as disarticulation and chaotic orientation of the remains, although this could be due bioturbation (Kidwell and Bosence, 1991), especially for valves oriented perpendicular to bedding. However, they did not remain for long time in the TAZ, as shown by the good preservation of the shells, especially in high energy environments as those above fair-weather wave base.

Echinoderm spines are related to disarticulation of death specimens, present in low energy environments.

Separation and sorting (Kornicker *et al.*, 1963) and axial alignments (Nagle, 1967; Kelling and Williams, 1967) support current action. This redistribution occurs below fair-weather wave base, in the middle-outer ramp. The environmental interpretation is supported by the interbedding of this concentration with shell detritus (fossil concentrations of type E).

4.7 Fossil concentrations type G- Clumps

Description (Fig. 3J)

These concentrations occur as small centimetre-scale accumulations with margins poorly defined, identifiable as clumps (Kidwell *et al.*, 1986; Fürsich and Oschmann, 1986), and are distributed in wackestone-packstones facies interbedded with fossil concentrations E (shell detritus).

Composed exclusively by *Gryphaea* sp., these accumulations have loose-dense packing, with a percentage of bioclasts of 15-25%. Sorting is poor (1-7 cm). Shells exhibit highly variable orientation, low degree of articulation and medium fragmentation. Left valves are predominant, generally recrystallized or silicified, both preventing the recognition of taphonomic features as abrasion and roundness. These kinds of concentrations are present in the outcrop Barda 1, although very rare in abundance.

Interpretation

These accumulations are interpreted as *in situ* reworked relicts of life assemblages. Is often that gryphaeids form little groups, and if some processes disturb the sediment after the death of the specimens, they will be disarticulated and scattered short distances. This disturbance could be due to the activity of bioturbators (Kidwell *et al.*, 1986) or by hydraulic processes after variable periods of permanence in sediment/water interface. Due to the degree of bioturbation is difficult to establish because of the low preservation potential of trace fossils in these facies, is not possible to discriminate physical from biogenic effects.

Considering that these gryphaeids live in low energy environments (Nori and Lathuilière, 2003), that the remains in these clumps have low dispersion and that they are present in the vicinity of fossil concentrations E, these clumps would be present below fair-weather wave base, in lower middle ramp or outer ramp environments.

5. Additional remarks about fossil concentrations

Analysis of taphonomic, sedimentologic and stratigraphic features supports an interpretation as sedimentologic concentrations (Kidwell *et al.*, 1986) for the fossil concentrations A-F. The features of the remains in the concentrations A, B, D and E indicate long periods in the TAZ. These shell beds would be exposed to numerous processes of erosion, reworking, transport, winnowing and deposition before the final burial. This would lead to accumulations with high degree of spatial and temporal mixture, which can be interpreted as parautochthonous-allochthonous concentrations, within-habitat time-averaged assemblages. Better preservation observed in concentrations C and F indicate less time of permanence in the TAZ, while the monospecific composition could suggest a reduced spatial mixture. Nevertheless, the extensive reworking of storms deposits, with long residence times of shells on the sea-floor or in the upper centimetres of a fossil concentration should be responsible for aragonite dissolution (Brett and Baird, 1986), producing gryphaeid accumulations usually monospecific. It should be noted that other pelecypods are preserved as internal moulds, and fragmented remains of these groups may not preserve. The presence of these moulds and the specific richness observed in thin sheets, as mentioned before, put in evidence the effect of modifying processes about the original composition of the produced association.

On the other hand, gryphaeid clumps (fossil concentrations G) probably represent a mixed concentration type and can be interpreted as biogenic-sedimentologic concentrations, being parautochthonous concentrations, within-habitat time-averaged.

6. Depositional environment

Shell beds studied in La Manga Formation allow recognizing three groups of accumulations (groups 1-3, Table 1), which indicate different depositional environments. The first group corresponds to thick fossil concentrations deposited under high energy conditions (types A-C) by storm waves and currents. As interpreted above, these concentrations would be present in upper middle ramp environments (Fig. 5). These concentrations were generated under high energy conditions and low sedimentation rates, and even when the gryphaeid communities probably developed in middle ramp environments or deeper, erosive storm processes would transport these shells to shallower environments above the fair-weather wave base, where fair-weather waves would be responsible for reworking of the material. These reworking processes would lead to highly fragmented, rounded, abraded shells preventing the colonization of incrusters organisms, and the activity of bioeroders. These shells would be transported to the middle ramp by storm waves and currents leading to multiple cycles of erosion and deposition before the final deposition.

A second group of fossil concentrations was deposited by low energy processes (types D and E), and are present in the middle ramp (Fig. 5). This group includes accumulations that have a history related to high energy processes in inner and middle ramp environments, but the final deposition is produced out of suspension in low energy settings (lower middle ramp and outer ramp environments). These concentrations also involve low sedimentation rates in their formation.

A third group corresponds to fossil concentrations also produced by low energy processes, but with a history developed mostly below the fair-weather wave base (concentrations of type F and G). These accumulations were present in the lower middle ramp and the outer ramp (Fig. 5), where storm wave and currents were weak. These concentrations involve a regime with higher sedimentation rates than the first and the second group of fossil concentrations.

Different sorts of concentrations appear forming associations. This is common with high energy concentrations of first group throughout Unit 1 in the three outcrops studied (Fig. 4). On the other hand, low energy concentrations of the second and third group may occur together, becoming more abundant in the upper half of the Unit 1 (Fig. 3I; K; 4). Thus, fossil concentrations type E and F can appear together in beds less than 0.5 m thick.

This variability of fossil concentrations suggests that deposits of Unit 1, previously interpreted as outer ramp setting, are composed in fact of middle and outer ramp deposits.

Additional material includes small associations of *Gryphaea* sp. interbedded with wackestone bands rich in shell detritus (fossil concentrations type E). These specimens appear articulated, concordant to the stratification, with the plane of commisure horizontal, lying on the left valve. The orientation of the valves can be interpreted as life position for this genus (Hallam, 1968), even though it is not the most stable position for this gryphaeids. The position proposed by Pfannenstiel (1928), i.e. the shell lying on its side, with the plane of commisure approximately vertical, would be more stable but in this case pseudosiphons would have been clogged killing the animal (Hallam, 1968). The semi-infaunal to epifaunal suspension feeding habit requires low sedimentation rates (Machalski, 1998) and the poor stability of the life position requires environments with low energy (Nori and Lathuilière, 2003), which allows interpret this associations as developed in middle-outer ramp environments. The distribution of specimens, showing no evidence of contact with adjacent specimens in the collected material, suggests that these communities probably formed patches where individuals were sparsely distributed. These associations are present in the upper metres of the Unit 1 in Barda 2.

Sections studied are dominated by internally complex fossil concentrations (types A to C), which can be interpreted as composite or multiple-event concentrations (Kidwell, 1991). According to Banarjee and Kidwell (1991), these complex fossil concentrations are interpreted as shell beds developed at the top of parasequences (TOP), and would permit the recognition of flooding surfaces, being particularly useful in the shallower part of the transgressive systems tract where shell beds characterizing the base of parasequences may be lacking.

The small cycles characterized by packstone-wackestone beds rich in gryphaeids (fossil concentrations of type A-C) cup by laminated wackestones or massive to nodular mudstones, can be interpreted as TOP cycles, which are abundant in the lower half of the Unit 1 at Bardas 1 and 2.

On the other hand, the upper half of these sections exhibit also the presence of fossil concentrations characterizing deeper settings (types D to G). The vertical distribution of the fossil concentrations suggests a continuous increase of the accommodation space, which lead to the deposition of metres of complex fossil concentrations in middle ramp settings. The distribution of fossil concentrations evidences a transgressive system tract, supporting the interpretation made by Piethé and Palma (2008).

7. Conclusions

Basal deposits (Unit 1) of three outcrops of La Manga Formation in Bardas Blancas locality are interpreted as middle to outer ramp deposits. This is based in the analysis of the fossil concentrations usually dominated by *Gryphaea* sp. Seven different kinds of fossil concentrations can be recognized, which can be grouped in: 1) accumulations A-C, which were deposited by high energy processes (storm events) usually with long predepositional history (long periods in the TAZ in the vicinity of fair-weather wave base). Present in the upper middle ramp; 2) accumulations D and E, deposited by low energy processes (deposition out of suspension after storm events) with long predepositional history similar to group 1. Present in the lower middle ramp; and 3) accumulations F and G, produced under low energy processes (weak bottom currents and redistribution by bioturbators), which exhibit variable periods of permanence in the TAZ. Present in the lower middle and outer ramp.

Group	Type	Geometry, dimensions and basal contact	Macroscopic composition	Internal complexity	Biofabric	Taphonomic signature	Depositional processes	Environmental interpretation
1	A	Lenticular. 5-40 cm in thickness, ≤ 3 m in lateral extension. Erosive base	Monotypic *Gryphaea* sp.	Complex. Vertical and lateral amalgamation of m.u.	Dense to loose, normal gradation, chaotic orientation, poorly sorted	High fragmentation, low articulation low and medium-high corrasion	Deposition by storm waves and currents	Upper middle ramp settings
	B	Tabular. 40-67 cm in thickness, tens of meters in lateral extensión. Sharp or erosive base.	Politypic *Gryphaea* sp., other pelecypods (pectinids), corals	Complex. Vertical and lateral amalgamation of m.u.	Loose to loose-dense packing, chaotic orientation, poorly sorted	High fragmentation, low articulation and medium-high corrasion	Deposition by storm waves and currents	Upper middle ramp settings
	C	Tabular	Monotypic *Gryphaea* sp.	Complex. Vertical and lateral amalgamation of m.u.	Loose to loose-dense packing, chaotic orientation, poorly sorted	Low to medium fragmentation, subangular to subrounded roundness and low corrasion	Deposition by storm waves and currents	Middle ramp settings
2	D	Tabular. 3-10 cm in thickness, tens of meters in lateral extension. Sharp base	Monotypic *Gryphaea* sp.	Complex. Vertical and lateral amalgamation of m.u.	Loose-dense packing, chaotic orientation, poorly sorted. Argillaceous matrix.	High fragmentation, low articulation and medium-high corrasion	Deposition out of suspension from storm waves	Middle ramp settings
	E	Tabular. 5-10 cm in thickness, tens of meters in lateral extensión. Sharp base	Fragments of *Gryphaea* sp.	Complex. Vertical and lateral amalgamation of m.u.	Loose-disperse packing, chaotic orientation, well-sorted	High fragmentation (detritus), low articulation and medium-high corrasion	Deposition out of suspension from storm waves	Middle ramp and outer ramp settings
3	F	Tabular. One shell in thickness. Centimetric lateral extensión. Sharp base.	Monotypic composed by fragments of corals, *Gryphaea* sp. or echinoderm spines	Simple	Disperse packing. Corals concordant but chaotic in plan view, poorly sorted. Gryphaeids chaotic, well sorted. Echinoderm spines concordant and slightly aligned	Corals fragmented, gryphaeids disarticulated but with low fragmentation and corrasion and silicified echinoderm spines	Distribution by bottom currents	Lower middle ramp and outer ramp settings
	G	Clumps, with irregular limits	Monotypic. *Gryphaea* sp.	Simple	Loose-dense packing, chaotic orientation, poorly sorted	Medium fragmentation and low articulation	Reworked relicts of life assemblages of *Gryphaea* sp.	Middle ramp and outer ramp settings

Table 1.- Typical features of fossil concentrations in La Manga Formation
Tabla 1.- Rasgos característicos de las concentraciones fósiles en la Formación La Manga.

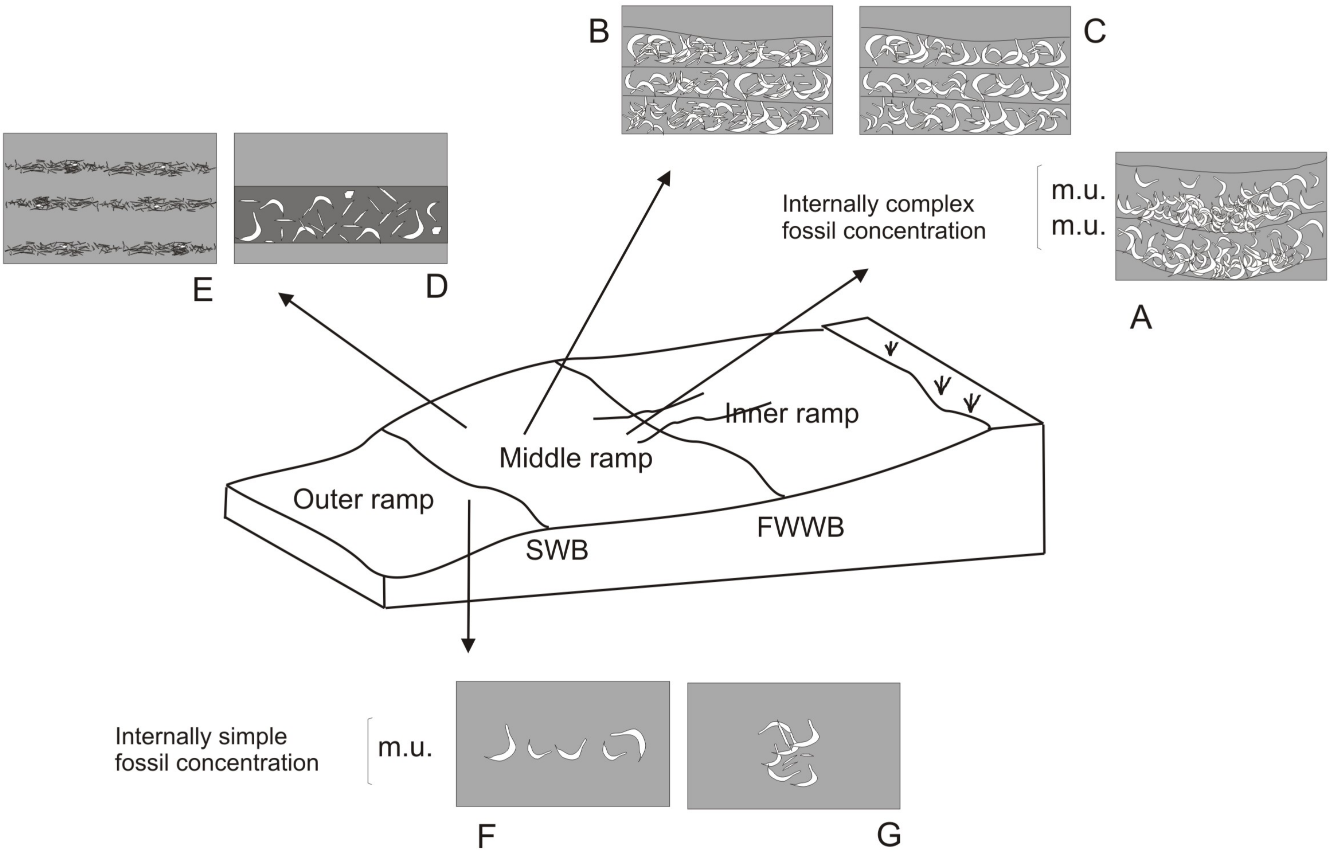

Fig. 5.- Schematic diagram showing the distribution of fossil concentrations in the Unit 1 of La Manga Formation. SWB, storm wave base, FWWB, fair-weather wave base.

Fig.5.- Diagrama esquemático mostrando la distribución de concentraciones fósiles en la Unidad 1 de la Formación La Manga. SWB, nivel de base de olas de tormenta; FWWB, nivel de base de olas de buen tiempo.

The vertical distribution of the different type of fossil concentrations permits to interpret the Unit 1 as a transgressive systems tract and evidences a continuous increase in accommodation space.

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References

Banarjee, I., Kidwell, S.M. (1991). Significance of molluscan shell beds in stratigraphy: an example from the Lower Cretaceous Mannville Group of Canada. *Sedimentology*, 38: 913-934.

Brett, C.E., Baird, G.C. (1986). Comparative taphonomy: a key to paleoenvironmental interpretation based on fossil preservation. *Palaios*, 1: 207-227.

Davies, J.D., Powell, E.N., Stanton Jr., R.J. (1989). Taphonomic signature as a function of environmental process: shells and shell beds in a hurricane-influenced inlet on the Texas coast. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 72: 317-356.

Dellapé, D.A., Mombrú, C., Pando, G.A., Riccardi, A.C., Uliana, M.A., Westermann, C.E.G. (1979). Edad y correlación de la Formación Tábanos en Chacay Melehue y otras localidades de Neuquén y Mendoza. Con consideraciones sobre la distribución y significado de las sedimentitas Lotenianas. *Obra Centenario Museo La Plata*, 5: 81–105.

Digregorio R.E., Gulisano C.A., Gutiérrez Pleimling A.R., Minitti S.A. (1984). Esquema de la evolución geodinámica de la Cuenca Neuquina y sus implicancias paleogeográficas. *IX Congreso Geológico Argentino*, Buenos Aires, Actas 2: 147-162.

Fürsich, F.T., Oschmann, W.M. (1986). Storm shell beds of *Nanogyra virgula* in the Upper Jurassic of France. *Neues Jahrbuch für Geologie und Paläontologische Abhanlugen,* 172: 141–161.

Fürsich, F.T., Oschmann, W.M. (1993). Storm beds as tools in basin analysis: the Jurassic of Kachchh, western India. *Journal of Geological Society of London*, 150: 169-185.

Greensmith, J.T., Tucker, E.V. (1969). The origin of Holocene shell deposits in the chenier plain facies of Essex (Great Britain). Marine Geology, 7: 403-425

Groeber, P.F.C. (1929). Líneas fundamentales de la geología del Neuquén, sur de Mendoza y regiones adyacentes, 58: 1-109.

Groeber, P.F.C. (1946). Observaciones geológicas a lo largo del meridiano 70. Hoja Chos Malal. *Revista Asociación Geológica Argentina*, 1: 177–206.

Groeber, P.F.C., Stipanicic, P.N., Mingramm, R.G. (1953). Mesozoico. In: Sociedad Argentina de Estudios Geográficos (ed.), *Geografía de la República Argentina*. GAEA II, 1: 1–541.

Hallam, A. (1968). Morphology, palaeoecology and evolution of the genus Gryphaea in the British Lias. *Philosophical Transactions of the Royal Society of London (serie B)*; 234: 91-128.

Kelling, G., Williams, P.F. (1967). Flume studies of the reorientation of pebbles and shells. Journal of Geology, 75: 243-267.

Kidwell, S. M. (1991). The stratigraphy of shell concentration. In: P.A. Allison., D.E.G. Briggs (eds.), *Taphonomy: Releasing the data locked in the Fossil record.* Topics in Geobiology, 9, Plenun Press, New York: 211–290.

Kidwell, S.M., Bosence, D.W. (1991). Taphonomy and time-averaging of marine faunas. In: P.A. Allison, D.E.G. Briggs (eds.), *Taphonomy: releasing the data locked in the fossil record*. Topics in Geobiology, 9: 115-209.

Kidwell, S.M., Fürsich, F.T., Aigner, T. (1986). Conceptual framework for the analysis and classification of shell concentrations. *Palaios,* 1: 228–238.

Kidwell, S.M., Holland, S.M. (1991). Field description of coarse bioclastic fabrics. *Palaios,* 6: 426–434.

Kornicker L.S., Wise C.D., Wise J.M. (1963). Factors affecting the distribution of opposing mollusk valves. Journal of Sedimentary Petrology, 33: 703-712.

Leanza, H.A. (1981). The Jurassic-Cretaceous boundary beds in west-central Argentina and their ammonite zones. *Neues Jahrbuch für Geologie und Paläontologische Abhanlugen*, 161: 62–92.

Legarreta, L. (1991). Evolution of a Callovian-Oxfordian carbonate margin in the Neuquén Basin of the west-central Argentina: facies, architecture, depositional sequences and global sea-level changes. *Sedimentary Geology*, 70: 209–240.

Legarreta, L., Gulisano. C.A. (1989). Análisis estratigráfico secuencial de la Cuenca Neuquina (Triásico Superior-Terciario Inferior), Argentina. In: Chebli, G.A., Spalletti, L.A. (eds.), *Cuencas sedimentarias de la Argentina*. Serie Correlación Geológica 6, S.M. de Tucumán: 221–243.

Legarreta, L., Uliana, M.A. (1991). Jurassic-Cretaceous marine oscillations and geometry of back-arc basin fill, central Argentine Andes. *International Association Sedimentology*, Special Publication 12: 429-450

Legarreta, L., Uliana, M.A. (1996). The Jurassic succession in west central Argentina: Stratal patterns, sequences, and paleogeographic evolution. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 120: 303–330.

Lo Forte, G., Palma., R.M. (2002). Facies, microfacies and diagenesis of late Callovian–early Oxfordian carbonates (La Manga Formation) in the west-central Argentinian High Andes. *Carbonate and Evaporites*, 17 (1): 1–16.

Machalski, M. (1998). Oyster life position and shell beds from the Upper Jurassic of Poland. *Acta Paleontologica Polonica*, 43: 609-634

Middleton, G.V. (1967). The orientation of concave-convex particles deposited from experimental turbidity currents. *Journal of Sedimentary Petrology*, 37: 229-232.

Nagle, J.S. (1967). Wave and current orientation of shells. *Journal of. Sedimentary Petrology*, 37: 1124–1138.

Nori, L., Lathuilière, B. (2003). Form and environment of Gryphaea arcuata. *Lethaia*, 36: 83-96

Palma, R.M., Kietzmann, D.A. (2008). Ciclos de somerización en facies peritidales de la Formación La Manga: tipos, origen y controles. *XII Reunión Argentina de Sedimentología*: 133, Buenos Aires.

Palma R.M., Kietzmann, D.A., Adamonis, S., López Gómez, J. (2009). Oxfordian reef architecture of the La Manga Formation, Neuquén Basin, Mendoza Province, Argentina. *Sedimentary Geology*, 221 (1-4): 127-140.

Palma, R.M., Lazo, D.G., Piethé, R.D. (2005). Facies de tormenta y trazas fósiles en la rampa media de la Formación La Manga, Bardas Blancas, Mendoza. *Actas XVI Congreso Geológico Argentino*, La Plata, 3: 155-156.

Palma, R.M., Lo Forte, G. (1998). Evidencias diagenéticas en la sección inferior de la Formación La Manga (Caloviano), Alta Cordillera-Mendoza-Argentina. *VII Reunión Argentina de Sedimentología*, Salta: 93-95.

Palma, R.M., Lo Forte, G., Piethé, R.D., Crousse, L., González Pellegri, E., Bressan, G.S. (2004). Biohermas de esponjas y tipos de microbialitas en la Formación La Manga (Oxfordiano), Cuenca Neuquina, Mendoza. *X Reunión Argentina de Sedimentología*, San Luis, Argentina, 1: 126.

Palma, R.M., Lo Forte, G., Lanes, S. (1997). Diagenesis of the Lower Callovian Member of La Manga Formation, Aconcagua Basin, Mendoza, Argentina. *XVIII Regional European Meeting of Sedimentology*, Heidelberg, Germany: Heidelbergensis, 1: 260–263.

Palma, R.M., López Gómez, J., Piethe, R.D. (2007). Oxfordian ramp system (La Manga Formation) in the Bardas Blancas area (Mendoza Province), Neuquén Basin, Argentina: Facies and depositional sequences. *Sedimentary Geology*, 195: 113-134.

Palma, R.M., Rodríguez, M., Lanes S.G., Lo Forte, G., Piethe, R.D. (2003). Las facies de esponjas y microbiolitas en la Formación La Manga (Oxfordiano), Cuenca Neuquina. *Simposio Argentino sobre el Jurásico*, La Plata, Argentina:12.

Pfannenstiel, M. (1928). Organisation und Entwicklung der Gryphaën. *Palaeobiologica* I, 381-418

Piethé, R.D., Palma, R.M. (2008). Sedimentología, cicloestratigrafía y análisis secuencial de la Formación La Manga (Oxfordiano), Bardas Blanca, Mendoza. *Revista de la Asociación Geológica Argentina* 63(4): 682-695.

Ramos, V.A. (1999). Rasgos estructurales del territorio argentino. In: R. Caminos (ed.), *Geología Argentina*. Anales 29, Instituto de Geología y Recursos Minerales, Buenos Aires: 715-784.

Riccardi, A.C. (1984). Las asociaciones de amonitas del Jurásico y Cretácico de Argentina. *IX Congreso Geológico Argentino*, Actas 4: 559–595.

Riccardi, A.C. (1992). Biostratigraphy of west-central Argentina. In: G.E.G. Westermann (ed.), *The Jurassic of the Circum-Pacific*. Cambridge University Press: 139–141.

Roetzel, R., Pervesler, P. (2004). Storm-induced event deposits in the type area of the Grund Formation (Middle Miocene, Lower Badenian) in the Molasse Zone of Lower Austria. *Geologica Carpathica*, 55: 87-102

Simões M.G., Kowalewski M. (1998). Shell beds as paleoecological puzzles: a case study from the Upper Permian on the Paraná Basin, Brazil. *Facies,* 38:175-196.

Siringan, F. P., Anderson, J.B. (1994). Modern shoreface and inner-shelf storm deposits off the east Texas Coast, Gulf of Mexico. *Journal of Sedimentary Research*, B 64(2): 99–110.

Stipanicic, P.N. (1951). Sobre la presencia del Oxfordense superior en el arroyo de La Manga, provincia de Mendoza. Revista Asociación Geológica Argentina, 6 (4): 213–242.

Stipanicic, P.N. (1965). El Jurásico de la Vega de la Veranada (Neuquén), el Oxfordense y el diastrofismo divesano (Agassiz-Yailña) en Argentina. *Revista Asociación Geológica Argentina*, 20 (4): 403–478.

Stipanicic, P.N. (1969). El avance de los conocimientos del Jurásico argentino a partir del esquema de Groeber. *Revista Asociación Geológica Argentina*, 24 (4): 367–388.

Stipanicic, P.N. (1996). Milestones in the study of the Jurassic of Argentina. In: A.C. Riccardi (ed.), *Advances in Jurassic Research*. Geo. Research Forum, 1-2: 23-42.

Vergani, G.D., Tankard, A.J., Belotti, H.J., Welsink, H.J. (1995). Tectonic evolution and paleogeography of the Neuquén Basin, Argentina. In: A.J. Tankard, R. Suárez S. and H.J. Welsink, (eds.), *Petroleum basins of South America*. AAPG Memoir 62: 383-402

Westermann, G.E.G. (1967). Sucesión de ammonites del Jurásico Medio en Antofagasta, Atacama, Mendoza y Neuquén. *Revista Asociación Geológica Argentina*, 22 (1): 65–73.

Westermann, G.E.G., Riccardi, A.C. (1984). Middle Jurassic Ammonite evolution in the Andean Province and emigration to Tethys. In: G.M. Friedman, (ed.), *Sedimentary and evolutionary cycles*. Lec. Notes Earth Sci. Springer. Berlin. 1: 6–34.

Wright,V.P., Burchette, T.P. (1996). Shallow-water carbonate environments. In: H.G. Reading (ed.), *Sedimentary Environments: Processes, Facies and Stratigraphy*. In: H.G. Reading (ed.), Blackwell Sciences, Oxford: 325-394.

Yrigoyen, M.R. (1991). Hydrocarbon resources of Argentina. *Petrotecnia*, Special Issue: 38-54.

Zuschin, M.; Harzhauser, M. y Mandic, O. (2004). Taphonomy and paleoecology of the Lower Badenian (Middle Miocene) molluscan assemblages at Grund (Lower Austria). *Geologica Carpathica*, 55 (2): 117-128

Zuschin, M., Mandic, O., Harzhauser, M., Pervesler, P. (2001). Fossil evidence for chemoautotrophic bacterial symbiosis in the thyasirid bivalve *Thyasira michelottii* from the Middle Miocene (Badenium) of Austria. *Historical Biology*, 15: 223-234.