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Facies and facies association distribution on the Triassic carbonate platform of the Alpujarride Complex (Betic Internal Zone, SE Spain)

Distribución de facies y asociaciones de facies en la plataforma carbonatada triásica del Complejo Alpujárride (Zona Interna Bética, SE de España)

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ABSTRACT

La Formación Meta-carbonatada de la unidad de Gádor-Turón (Complejo Alpujárride, Zona Interna) está formada por seis miembros, en los que se han reconocido diferentes intervalos, facies y asociaciones de facies. Se han distinguido 15 litofacies, con texturas predominantes mudstone-wackestone y que incluyen una fauna relativamente abundante (moluscos, foraminíferos, crinoides, equinodermos, esponjas, algas y ostrácodos). Estos materiales son interpretados como el resultado del depósito en la zona externa, media e interna de una rampa carbonatada homoclinal. El análisis secuencial de la sucesión parece indicar la existencia de una secuencia deposicional de tercer orden de edad ladiniense, formada por los miembros 1, 2 y 3. Las partes baja y media del miembro 1 constituirían el transgressive system track mientras que la parte superior del miembro 1 junto con los miembros 2 y 3 serían el higstand system track. La interpretación secuencial del resto de los miembros es más compleja. Considerados conjuntamente los miembros 1, 2 y 3 pueden ser fácilmente correlacionables con ciclos análogos descritos en el Trías Germánico y en el Alpino. Sin embargo, esta correlación es difícil de realizar con los miembros 4, 5 y 6, probablemente como consecuencia del incremento de la actividad tectónica registrado a partir del Ladiniense

Key words: *Triásico, plataforma carbonatada, rampa, plataforma, Complejo Alpujárride.*

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Introduction

This paper deals with facies analysis of the Alpujarride Complex Triassic carbonates (Betic Cordillera, SE Spain). The Betic Cordillera is divided in two domains: the External and Internal Zone. The Betic Internal Zone is formed by three tectonic complexes (made up of Palaeozoic? and Meso-Cenozoic rocks), that are, from top to base: the Malaguide, Alpujarride and Nevado-Filabride complexes. The last two complexes are affected by metamorphism. The Alpujarride successions comprise continental clastic and shallow marine carbonate Triassic rocks (Delgado *et al.*, 1981), originally deposited on the area that formed the focus of Pangea break-up. The present study focuses on the Triassic carbonates of the Alpujarride Gador-Turon unit (Sierra de Gador), which comprises one of the thickest and best-preserved Middle-Upper Triassic carbonate successions in southern Spain. Taking into account the scarce literature devoted to these carbonates, this research represents a significant contribution to the knowledge of its Triassic stratigraphy.

Facies analysis

The Gador-Turon unit is formed by a succession, 1500 m thick, composed of a lower Meta-detrital fm (Anisian) and an upper Meta-carbonate fm (Ladinian-Carnian). The Meta-detrital fm is formed by clastic deposits with a carbonate intercalation, while the Meta-carbonate fm is composed of six members. These members have been denoted, from base to top: (1) marly-calcareous-dolomitic member, (2) dolomitic member, (3) fossiliferous calcareous-marly member, (4) cherty calcareous member, (5) mineralized calcareous-dolomitic member and (6) marly-calcareous member (Martin-Rojas *et al.*, 2009). In these members, several lithostratigraphic intervals showing different facies and facies associations have been distinguished. The lithofacies identified in the Meta-carbonate fm are 19 and have been denoted with letters E-W (facies A-D recognized in the Meta-detrital fm are not here described). Table I synthesizes the main facial features, as microfacies textures, skeletal grains, fossil content and sedimentary structures. Taking into account the facial features and relationships between lithosomes, a palaeoenvironmental interpretation is proposed at the scale of facies associations and members.

Facies and facies associations

The lower-middle part of member 1 is composed of strongly re-crystallized dolostones (Facies E). The upper part of

F	Facies name	Microfacies texture	Sediment. structures or accessory features	Fossils / main skeletal grains	Guide fossils content	M
			Meta-detrital formation			
A	Claystone and arenite	/	Graded beds, lamination	/	/	/
B	Laminated limestone	Mudstone-wackestone	Yellowish clayey laminae	/	/	/
C	Limestone with cherty nodules and ribbons	Mudstone-wackestone	/	Dasycladaceae algae	/	/
D	Dolostone with cherty nodules	Crystalline dolomite, relic mudstone-wackestone, siliciclastic grains	Fenestrae (?), Red clayey-hematitic seams	Algal mats (?), gastropods, bivalves, echinids, thick-shell ostracods / Peloids	/	/
			Meta-carbonate formation (Carbonate homoclinal ramp)			
E	Grey dolostone	Crystalline dolomite	/	/	/	1
F	Reddish to yellowish marly limestone and marl	/	Bioturbation	/	/	1 3
G	Grey limestone with molluscs	Wackestone-mudstone, packstone	Red clayey-hematitic seams	Abundant pelagic gastropods - bivalves, echinids, sponge spicules, ostracods, foraminifers (abundant nodosariids and rare Involutinacea) / Peloids	*Lamelliconus* gr. *biconvexus-ventroplanus*, *Lamelliconus cordevolicus* Ober., *Triadodiscus eomesozoicus* Oberhauser	1 3 4
H	Brown dolostone	Grainstone-wackestone, mudstone	/	Rare molluscs / Peloids	/	1 2
I	Limestone with foraminifera	Packstone	/	Abundant concentration of great size foraminifers (Involutinacea), nodosariids, pelagic gastropods - bivalves, echinids, sponge spicules / Peloids	*Lamelliconus* gr. *biconvexus-ventroplanus* and *Lamelliconus cordevolicus* Oberhauser	1
J	Bioturbated limestone	Mudstone-wackestone	Planolites	Pelagic gastropods - bivalves, crinoids, foraminifers (nodosariids and small Involutinacea)	/	3 4
K	Marly limestone	Wackestone-packstone	Cross lamination	Gastropods - bivalves, indeterminable bioclasts / Peloids	/	3
L	Lumachella with crinoids	Floatstone-rudstone	Cross lamination	Crinoid ossicles (circular and star forms), bivalves, gastropods, algae, brachiopods (?), foraminifers (rare Involutinacea) / Coated grains, peloids	*Bakevellia* aff. *kiliani* Schmidt, *Lyriomyophoria betica* Hirsch, *Triadodiscus eom.* Oberhauser	3
M	Limestone with algae and cherty nodules	Wackestone-mudstone, packstone, floatstone-rudstone	/	Pelagic bivalves – gastropods, Dasycladaceae algae, spicule sponges, echinids, foraminifers (fine shell nodosariids and rare Involutinacea) / Peloids	Diplorora ?nodosa, Teutloporella ?herculea, *Triadodiscus eomesozoicus* Oberhauser	4
N	Grey strongly nodular limestone	Wackestone-packstones, mudstones	Nodular structure, red clayey-hematitic seams	Pelagic molluscs, sponge spiculas, echinids, radiolarians, rare Dasycladaceae algae, foraminifers (nodosariids and rare Involutinacea) / Fecal pellets	*Triadodiscus eomesozoicus* Oberhauser	4
			Meta-carbonate formation (carbonate shelf)			
O	Dark limestone	Wackestone-mudstone, packstone	Red clayey-hematitic seams	Abundant pelagic gastropods - bivalves, echinids, sponge spicules, ostracods, foraminifers (abundant nodosariids and rare Involutinacea) / Peloids	*Lamelliconus* gr. *biconvexus-ventr.*, *Lamelliconus cord.* Ober. and *Triadodiscus eom.* Ober.	5
P	Dark grey nodular limestone	Mudstones-wackestone, packstones	Nodular structure, red clayey-hematitic seams	Pelagic molluscs, sponge spiculas, echinids, radiolarians, foraminifers (nodosariids and rare Involutinacea) / Fecal pellets	*Triadodiscus eomesozoicus* Oberhauser	5
Q	Limestone with fenestrae and evaporite minerals	Mudstone, wackestone-packstone	Fenestrae, evaporite minerals, fossil soils, red clayey-hematitic seams	Algal mats, echinids, indeterminable bioclasts	/	5
R	Oncoidal limestone	Bindstone, floatstone-rudstone	Massive	Oncoids	/	5
S	Black dolostone (lithofacies)	Mudstone-wackestone, grainstone, boundstone	Cross lamination, fenestrae, evaporite minerals	Algal mats, indeterminable bioclasts, ostracods, rare foraminifers (aulotortidae) / Peloids, coated grains, rare oncoids, ooids	*Baccanella floriformis* Pantic in Member 5	5 6
T	Intraformational breccias	Monomictic and clast-supported, polimictic and matrix-supported. Clasts of Facies Q, S	Slump	/	/	5
U	Limestone with lamination	Mudstone-wackestone, packstone	Evaporite minerals, gutter and pot casts	Algal mats, gastropods, bivalves	/	6
V	Yellowish marl and marly limestone	/	Bioturbation	/	*Bactryllium* sp. Allasinaz	6
W	Lumachella	Floatstone-rudstone	Cross lamination	Bivalves, gastropods, rare crinoid ossicles, algae, brachiopods (?), ostracods / Coated grains, peloids	/	6
Z	Gypsum	Crystalline gypsum	Massive and laminated	/	/	6

Table I.- Classification and description of the facies.

Tabla I.- Clasificación y descripción de facies.

member 1 is characterized by the facies association F-G-H. This latter is formed by marls (Facies F), limestones (Facies G) and dolostones (Facies H). The uppermost part is formed by the facies association F-I-H, as limestones with foraminifera (Facies I) replace Facies G. A thickening-upwards tendency characterizes these two associations. Great size foraminifers, as *Lamelliconus* gr. *biconvexus–ventroplanus*, *Lamelliconus cordevolicus* (Oberhauser) and *Triadodiscus eomesozoicus* (Oberhauser), indicate a Ladinian age for this member.

The strong re-crystallization affecting dolostones of Facies E hinders an environmental interpretation. However, the arrangement of Facies E above the continental deposits of the Meta-detrital fm, suggests that dolostones presumably represented the first deposits (inner? ramp) related to Triassic transgression. The upper part of member 1 consists of facies association F-G-H. Bioturbation and the lack of high-energy sedimentary structures in Facies F suggest a subtidal depositional in the transition between the middle and the outer ramp. The features of Facies G, such as fauna (Table I) and the lack of high-energy structures and textures, point to a deposit in a pelagic low-energy environment (below the Storm Weather Base-SWB-), probably on the outer ramp. Facies association ends with brown dolostones (Facies H). The interpretation of this facies is difficult because of the strong re-crystallization; however, according to the relic textures, dolostones deposited in a relatively high-medium-energy environment, presumably on the distal part of the inner(-middle?) ramp. In conclusion, facies association F-G-H should indicate an initial deepening-upwards tendency (Facies F-G), followed by a shallowing-upwards evolution (Facies G-H). The uppermost part of member 1 is formed by facies association F-I-H. This facies association differs from the previous one for the presence of limestones with foraminifera (Facies I) instead of limestones with molluscs of Facies G. Facies I and G are very similar, and only differ for the occurrence of tractive parallel lamination and foraminiferal packstone-wackestone textures, both present only in Facies I. These great size foraminifers, after having proliferated in reef environments, were presumably reworked and transported because of storm events, towards more distal areas, comprised between the FWWB (Fair Weather Wave Base) and the SWB, as the distal mid ramp. This facies association ends with the dolostones of Facies H, that, as above-said, probably deposited in a relatively high-medium-energy environment. Acording to that in the facies association F-I-H, the environmental features of facies suggests a shallowing-upwards evolution from the offshore (Facies f) to the offshore transition zone (Facies I) and finally to the inner ramp (Facies H).

At the scale of member 1, facies developed on the entire ramp and an evolution from the inner(?) ramp (lower-middle part) to the distal zone of the inner(-middle?) ramp (upper and uppermost part of the member) could be hypothesized. Consequently, member 1 should probably present an initial deepening-upwards tendency.

Member 2 consists of re-crystallized dolostones (Facies H). No fossils available for dating have been found.

In member 3, the lower part consists of limestones of Facies J and G, and marls of Facies F. Facies J and G are predominant in this lower part. The middle part also consists of Facies J, G and F, but gradually Facies J is less abundant and the clay content in the limestones increases (Facies F). The upper part is formed by marly limestones (Facies K) and lumachellas (Facies L). Bivalves, as *Bakevellia aff. kiliani* (Schmidt) and *Lyriomyophoria betica* (Hirsch), and foraminifers, as *Triadodiscus eomesozoicus* (Ober.), suggest a Ladinian age for this member.

The lack of high energy structures and fossil content recognized in the lower part of member 3 (Facies J, G, F) should indicate a sedimentation below the SWB, on the outer ramp. The absence of an evident organization in facies associations did not allow us to reconstruct a more detailed environmental evolution. In the middle part of member 3 the decrease in marls content (Facies F) with respect to the lower part of the member could suggest a transition towards relatively shallowest environments. In the upper part, the marly limestones (Facies K) show an undulating appearance and cross lamination (Table I). These features, being interpretable as resulting from the wave action (ripples), suggest a depositional environment over the FWWB, in the inner ramp. Facies K occurs interbedded with lumachella layers (Facies L), which we interpret as storm deposits, extending from the middle to the inner ramp. According to the above mentioned features, the deposits of the upper part could be interpreted as sedimented in a shallow sub-tidal area.

At the scale of member 3, facies developed on the entire ramp (from the outer to the inner ramp). An evolution from the distal part of the outer ramp (lower part of the member) to the inner ramp (upper part) can be hypothesized. Consequently, member 3 shows a shallowing-upwards tendency.

Member 4 is organized in thinning-upwards facies associations. The lowermost part of the member is made up of limestones of facies association M-G-N-J. The middle part is mainly composed of facies association M-G. The upper part consists exclusively of Facies G. The guide fossils of member 4 are represented by Dasycladaceae algae (*Diplopora* cfr *nodosa*) and by *Triadodiscus eomesozoicus* (Ober.). These taxa point to a Ladinian age.

The lower part of member 4 consists of facies association M-G-N-J. The limestones of Facies M are similar to those of Facies G, but they include in addition irregular accumulations of fragmented green algae. Facies M could be interpreted as deposited in the transition between the middle and outer ramp (or on the proximal outer ramp), in areas subject to receive the rests of a patch reef formed on a crest in most proximal zones. Facies G was deposited, as above-said, on the outer ramp (proximal zone). In the nodular limestones (Facies N), no sedimentary high-energy structures appear, indicating a depositional environment below the SWB, probably on the proximal zone of the outer ramp. Finally, bioturbated limestones of Facies J could be deposited on the distal part of the outer ramp. According to that, facies association occurring in the lower part presents a deepening-upwards evolution from the transition between the middle and outer ramp (Facies M) to the distal outer ramp (Facies J). This deepening-upwards evolution is further confirmed by the general thinning-upwards tendency of this part of the member. The middle part of member 4 is formed by facies association M-G, lacking the most distal limestones of Facies N and J. Consequently, taking into account the above discussed for the lower part, this facies association is also characterized by a deepening-upwards evolution, from the middle and outer ramp (Facies M) to a proximal zone of the outer ramp (Facies G). The upper part, being exclusively composed of limestones with molluscs (Facies G), was deposited on the proximal zone of the outer ramp. Despite the absence of a facies association, the thinning-upwards tendency of Facies G points to a deepening-upwards evolution in this upper part.

In conclusion, member 4 evolves from deposits mainly accumulated on the distal area of the outer ramp (lower part of the member) to deposits typical of the proximal zone of the outer ramp (upper part). According to that, member 4 presents a general shallowing-upwards evolution. Facies of this member represent the most distal facies of the ramp.

The succession of member 5 has been recently interpreted as belonging to a syn-rift sedimentary prism strongly affected by syn-sedimentary extensional tectonics. This latter is testified by capped normal faults, slumps, breccias and unconformities (Martin-Rojas *et al*., 2009). Guide fossils of this member are foraminifers, as *Lamelliconus* gr. *biconvexus-ventroplanus*, *Lamelliconus cordevolicus* (Ober.), *Triadodiscus eomesozoicus* (Ober.), and the micro-problematica *Baccanella floriformis* Pantic. These species suggest a Ladinian-?Carnian age.

This member is composed of four intervals separated by sharp contacts. Each interval consists of a basal calcareous level and an upper dolomitic level. The two lowermost calcareous levels are mainly composed of dark limestones of Facies O, while the two uppermost calcareous ones are formed by Facies O associated with nodular limestones of Facies P (facies association O-P). Limestones with evaporite minerals and algal mats (Facies Q), meter in thickness, are locally present in these four calcareous levels, as well as oncoidal limestones (Facies R). Dolomitic levels consist of black dolostones with evaporite minerals and algal mats (Facies S). These rocks, with exception of dolomitization, are analogous to Facies Q. Occasionally Facies S laterally evolves to slumps and intraformational breccias (Facies T).

Member 5 (as member 6), differently from the underlying succession, is characterized by deposits formed in very contrasting depositional environments. This should suggest sedimentation on a flat depositional environment, probably a carbonate shelf limited by a fault scarp (see below). Carbonates with fenestrae and evaporite minerals (Facies Q, S), as well as oncoidal limestones (Facies R), sedimented in very shallow waters, presumably localized on a carbonate shelf (Table I). Facial features (as pelagic fauna or nodular structure) of dark limestones (Facies O) and nodular limestones (Facies P) are characteristic of more distal environments, presumably developed on a shallow basin. Breccias of Facies T should represent slope deposits and are here interpreted as due to the syn-sedimentary tectonic activity of normal faults. At the scale of the limestone levels, we hypothesize that facies association O-P testifies a deepening-upwards evolution in a basin presumably controlled by normal faults. During short phases of fall of the relative sea level, this basin, localised on the fault hanging wall, evolved to a shelf (Facies Q), that on its turn newly evolved to a basin after a tectonic pulse. The dolomitic levels (Facies S) presumably developed on a shelf and should testify major phases of shallowing.

Member 6 represents the most clayey part of Gador-Turon succession. The lower part consists of facies association S-U-V-W. This facies association is formed by dolostones (Facies S), limestones with lamination (Facies U), yellowish marls (Facies V) and storm-related lumachellas (Facies W). Particularly the clay content present in Facies V should testify the influence in the stratigraphic record of a continental area (Delgado *et al.*, 1981). A distinctive feature of the middle part of this member is the presence of laterally discontinuous gypsum lenses (Facies Z), up to 30 m thick. The upper part of member 6 is composed of facies association U-V-W. In this member, the clay content in the succession increases up-wards. The presence of *Bactryllium* sp. *Allasinaz* suggests a probable Carnian age.

At the scale of member 6, the presence of high energy sedimentary structures (cross lamination in Facies U, storm layers of Facies W) as well as of gypsum lenses (Facies Z) suggests that sedimentation occurred in a very shallow depositional environment, above the FWWB. According to that, member 6 could have been presumably deposited on the proximal area of a carbonate shelf, where arid conditions locally occurred (Facies Z).

Conclusions

Environmental interpretation of facies recognized in the Meta-carbonate fm of the Gador-Turon unit should indicate that the lower part of the succession (members 1-4) deposited on a carbonate homoclinal ramp, while the upper part (members 5-6) on a carbonate shelf.

The transition from the ramp to the shelf environment was recorded by member 5 and happened during the latest Ladinian. We hypothesize that this environmental evolution could be related to syn-sedimentary extensional tectonics, recently documented by Martin-Rojas *et al*. (2009). Particularly, member 5 recorded alternating phases of tectonic activity and inactivity of normal faults presumably responsible for the set up of basin and shelf conditions, respectively.

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