Contransting shallowing versus deepening upward cycles and their position in a carbonate ramp (Lower Cretaceous, Gorbea, Bizkaia)

Ciclos de somerización, ciclos de profundización y su posición en una rampa carbonatada (Cretácico inferior, Gorbea, Pyrenees)

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Abstract

Contrasting deepening versus shallowing upward cycles formed in different depositional settings of a carbonate ramp: shallowing upward cycles characterize the inner ramp, whereas deepening upward cycles characterize the mid ramp. No cyclicity is preserved in the outer ramp. The cycle type and the ramp constructional dynamics is controlled by the ramp depositional gradient and the rates of relative sea level change.

Resumen

Se ha determinado el desarrollo de ciclos de profundización y ciclos de somerización en dos diferentes dominios de una rampa carbonatada. Los ciclos de somerización caracterizan la zona interna de la rampa, mientras que los ciclos de profundización caracterizan la zona media de la misma. No se reconoce ciclicidad en la rampa externa. El tipo de ciclo y la dinámica de construción de la rampa están controlados por el gradiente deposicional del sistema y por el nivel relativo del mar.

Key words: *Carbonate ramp, shallowing upward cycle, deepening upward cycle, ramp gradient, relative sea level.*

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Introduction

Both shallowing and deepening upward cycles in carbonate environments are well known in the literature. Shallowing upward cycles have been frequently described from shallow marine carbonate platforms (i.e. James, 1984). They form as a result of relative sea level still stand or fall, and generally conclude with subaerial exposure of the platform, which terminates carbonate deposition. Deepening upward cycles are not so well known from carbonate shallow marine environments. They characterize transgressive stages in which carbonate platforms are not able to keep up with rising relative sea level. They are often capped by hard-grounds and condensation horizons representing slowdown of carbonate sedimentation rates.

A symmetric shallowing-deepening upward cycle should form as a result of a complete cycle of relative sea level rise and fall, disregard the sedimentary environment. However, these symmetric cycles are rare, and either the shallowing upward or the deepening upward term dominate, or they are represented exclusively.

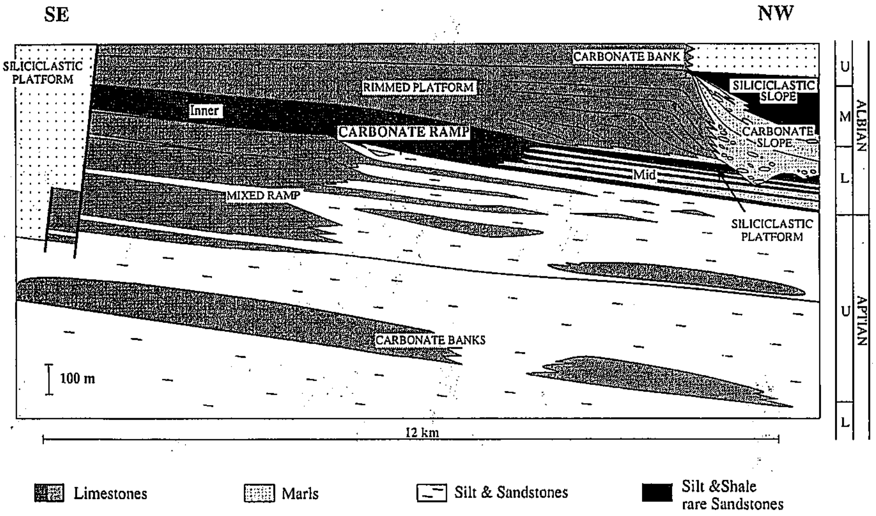
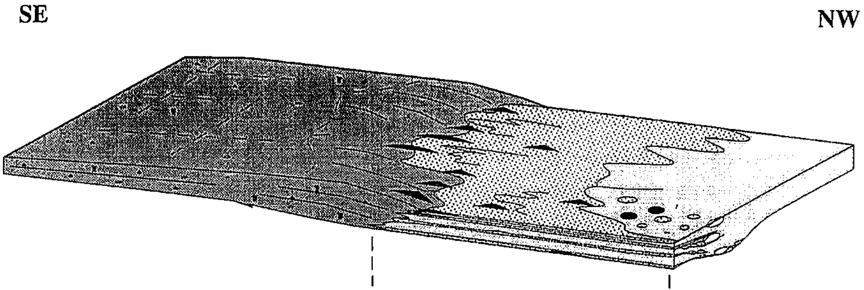


Fig. 1.- Cross-section of the Gorbea carbonate platform. Its evolution occurred in four stages: 1) Mixed siliciclastic-carbonate ramp, 2) Carbonate ramp (highlighted), 3) Rimmed carbonate platform and 4) Carbonate bank.

Fig. 1.- Corte estratigráfico de la plataforma de Gorbea. Su evolución se produjo en 4 etapas: 1) Rampa mixta carbonatado-terrígena. 2) Rampa carbonatada (destacada), 3) Plataforma con resalte, y 4) Banco carbonatado.

The cycle type, -shallowing, deepening, mixed-, is described in relation to the depositional environment -inner versus mid ramp- in an early Cretaceous shallow marine carbonate ramp from the Basque-Cantabrian basin. The identification of the cycle type, along with facies types and other sedimentological characteristics, will help in the interpretation of a ramp depositional setting, specially when working with discontinuous outcrops or subsurface data. This could also be true for other depositional systems and environments in the geological record.



INNER RAMP		MID RAMP		OUTER RAMP
RESTRICTED	OPEN		TROUGH	
-Orbitolinid Ps -Skeletal Ps -Orbitolinid marls -*Chondrodonta* Bs -Coral Bs	-Requieniids & *Chondrodonta* Ws -Orbitolinid Ps-Gs -Coral Bs	Autochthonous: -Marls & Argillaceous Ms Allochthonous: -Skeletal Ps-Gs -Intraclastic Breccias -Coral-rudist Bs (rare)	Autochthonous: -Marls & Argillaceous Ms Allochthonous: -Megabreccias & Olistoliths -Skeletal Ps-Gs	-Marls & Argillaceous Ms + bioturbation & ammonites
Biostromes	Biostromes	Bioherms, gullies, lenses Erosive surfaces	Erosive surfaces	Rhythmic bedding

▨ Ws=wackestone

☐ Ps=packstone/marls
Ms= mudstones

▨ Gs=grainstone

■ Bs=boundstone

Fig. 2.- Depositional environments and facies distribution for the early Albian Egalezaburu carbonate ramp.

Fig. 2.- Ambientes deposicionales y distribución de facies para la rampa carbonatada albiense inferior de Egalezaburu.

Geological setting

The Egalezaburu ramp is a part of the Aptian-Albian Gorbea carbonate platform, formed on a paleohigh in a pericratonic rift basin. The rift formed during Lower Cretaceous tectonic distensive stages related to the opening of the Bay of Biscay and the North Atlantic. The Gorbea platform evolved in four depositional stages from the Upper Aptian to the Upper Albian (Gómez-Pérez, 1994; Fernández-Mendiola *et al.*, 1993) (Fig. 1).

The cycles described in this work are a constituent part of the early Albian Egalezaburu carbonate ramp. According to facies distribution the ramp is subdivided in 3 depositional environments (Fig. 2): 1) Inner ramp, made up of fossiliferous limestones, 2) Mid ramp, made up of marls and skeletal grainstones, and 3) Outer ramp, marl dominated. The transition from mid to outer ramp is locally characterized by breccias and megabreccias accumulated in a sedimentary trough. Based on this characteristics the system is classified as a distally steepened ramp. The reported cyclicity is evident both in the inner and mid ramp settings, but no in the outer ramp. Four stacked ramp cycles are recognized with similar characteristics throughout the section, although they differ from the inner to the mid ramp.

Proximal ramp cycles

An innermost ramp ideal cycle is tens of meters thick, dominated by fossiliferous limestones, and made up of the following terms: 1) coral-orbitolinid marls and coral packstones, 2) peloidal rudist-*Chondrodonta* wackestones and 3) *Bacinella irregularis* RADOîCIC (algal) boundstones. The sedimentary environments deduced from this facies succession vary from low energy subtidal areas in the lower part to the photic zone (1), to moderate energy subtidal in the photic zone (2), to low energy-restricted water circulation in the shallow subtidal to intertidal zone (3). The cycles are capped by microdissolution features pointing to subaerial exposure. Facies and depositional environments indicate therefore a gradually shallower and more restricted environment, resulting in the development of **shallowing upward cycles** (Fig. 3a). No deepening upward trend is observed at any point in the innermost ramp cycles. More complete shallowing-deepening upward (mixed) cycles are however recognized in the outermost zones of the inner ramp, near the inner to mid ramp transition zone (Fig. 3b). Chondrodonta and miliolid packstones represent in this area the shallowest and most restricted facies. Microdissolution features are not recognized capping the cycles, and transition from the shallowest terms of the cycles to deeper terms is gradual.

Mid ramp cycles

A mid ramp ideal cycle is also tens of meters thick, dominated by marls, and made up of the following terms (Fig. 4a): 1) skeletal grainstones-packstones resting on an erosive surface, 2) coral-rudist wackestones (local bioherms), and 3) marls/argillaceous

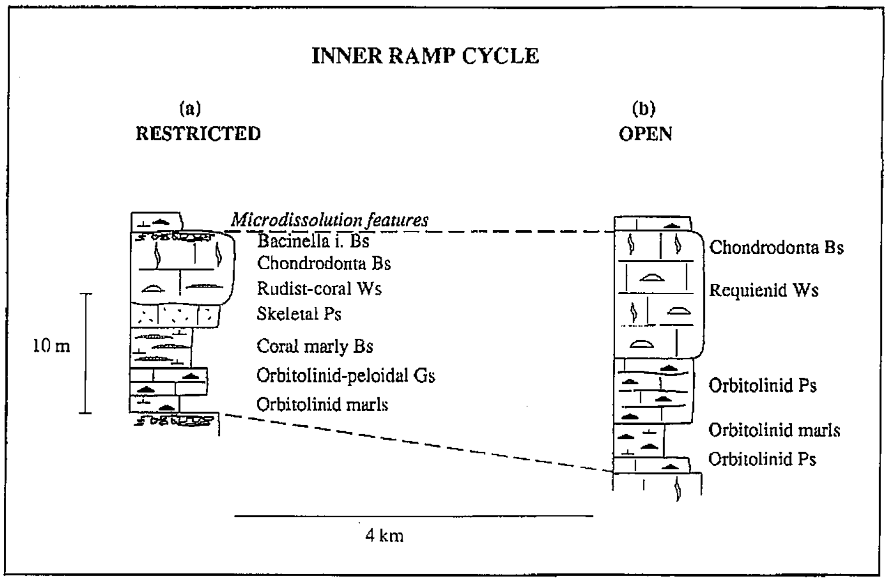


Fig. 3.- Inner carbonate ramp cycles. a) Ideal cycle for the innermost ramp. b) Ideal cycle for the outer settings of the inner ramp.

Fig. 3.- Ciclos de plataforma interna. a) Ciclo ideal en la zona más interna de la rampa. b) Ciclo ideal en la zona más externa de la rampa interna.

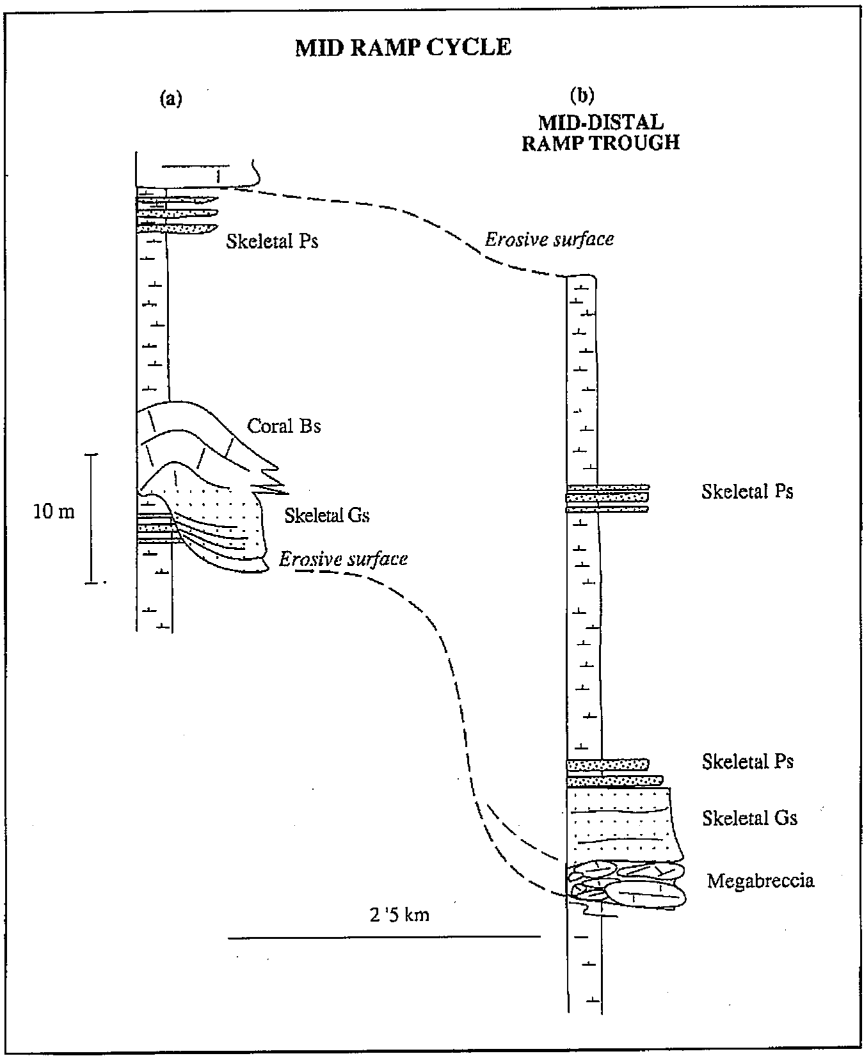


Fig. 4.- Mid ramp carbonate ramp cycles. a) Ideal homoclinal mid ramp cycle b) Trough area cycle (mid to distal ramp transition zone).

Fig. 4.- Ciclos de rampa media. a) Ciclo ideal en la rampa media. b) Ciclo en la zona de surco (transicion de rampa media a distal).

limestones. The uppermost part of the cycle includes occasionally skeletal packstone beds, and is capped by the up to 2 meters deep erosive surface. The represented sedimentary environments range from very shallow high-energy in the photic zone and above wave base (1) to a moderate energy environment in the photic zone and near the wave base level (2), and to a low energy environment bellow the photic zone and the wave base level (3). In the trough area the limestone units are made up of breccias and megabreccias lying on erosive surfaces, and formed gravitationally because of depositional instability. They grade upward to skeletal grainstones and to marls (Fig. 4b). The facies succession reflects a gradually deeper and less energetic environments, resulting in the formation of **deepening upward cycles**. A thin shallowing upward term reflecting increasing energy is locally represented by the uppermost packstone beds, although it is rare, and probably often eliminated by the erosion on top of the cycle. The erosive surface is the base of the overlying cycle, and represents the most energetic and shallowest conditions in the mid ramp. Erosion likely resulted from action of waves and currents in a very shallow marine environment.

Ramp constructional dynamics

The constructional dynamics of the Egalezaburu carbonate ramp is closely controlled by relative sea level changes (Fig. 5), responsible for the development of the described cycles.

The shallow water calcarenites of the mid ramp are considered lowstand deposits, and have no equivalent on the inner ramp (Fig. 5-1). They made up shoals and gullies and changed gradually to marls and argillaceous limestones of the outer ramp. They lie on the erosive surfaces, related to breccias and olistoliths in the mid-outer ramp sedimentary trough. This facies arrangement resembles closely the classic ramp models (i.e. Ahr, 1973, Read, 1985), controlled by water depth and energy levels.

The transgressive deposits are represented by bioherms of the mid ramp and orbitolinid marls at the base of the inner ramp cycles (Fig. 5-2). The shallow water fossiliferous limestones of the inner ramp are considered highstand deposits, and are equivalent to marls with rare storm deposits on the mid ramp (Fig. 5-2). These depositional facies arrangement was controlled by the photic zone base level and it is considered a protected ramp (*sensu* Burchette and Wright, 1992), presenting similarities with the biohermal complexes (Burchette, 1981).

We observe, therefore, that during relative highstands shallow water deposition occurred on the inner ramp, and during relative lowstands on the mid ramp. Consequently shifts in the shallow water carbonate factory between these settings occurred. The shift is sharp and rapid basinward (inner to mid ramp) and involves subaerial exposure of the inner ramp and erosion on the mid ramp with fast falling sea level. The shift platformward (mid to inner ramp) is rapid but gradual, and it implies a period of relented sedimentation on the inner ramp.

Discussion

Theoretically the transgressive and regressive terms of a cycle should be represented in both inner and mid ramp environments. However the cycles are commonly incomplete, dominating shallowing upward cycles on the inner ramp, and deepening upward cycles on the outer ramp. This fact is related to the relative sea level trend, depositional site, and ramp depositional gradient.

During early regressive stages carbonate factory is active in the inner ramp setting, and with stable or falling sea level accommodation space decreases and the inner ramp facies belt could prograde over mid ramp facies belt. This was not however observed for the Egalezaburu ramp, and it is interpreted as the result of a low ramp sedimentary gradient and a fast relative sea level fall, which resulted in a basinward shift of the coast line and a rapid exposure of wide areas of the inner ramp, preventing progradation of inner ramp facies belts. Some carbonate grains are however transported to the mid ramp with falling sea level, just before erosion occurs, conforming local, thin, shallowing upward sequences. Therefore, for the time when a shallowing sequence could have developed on the mid

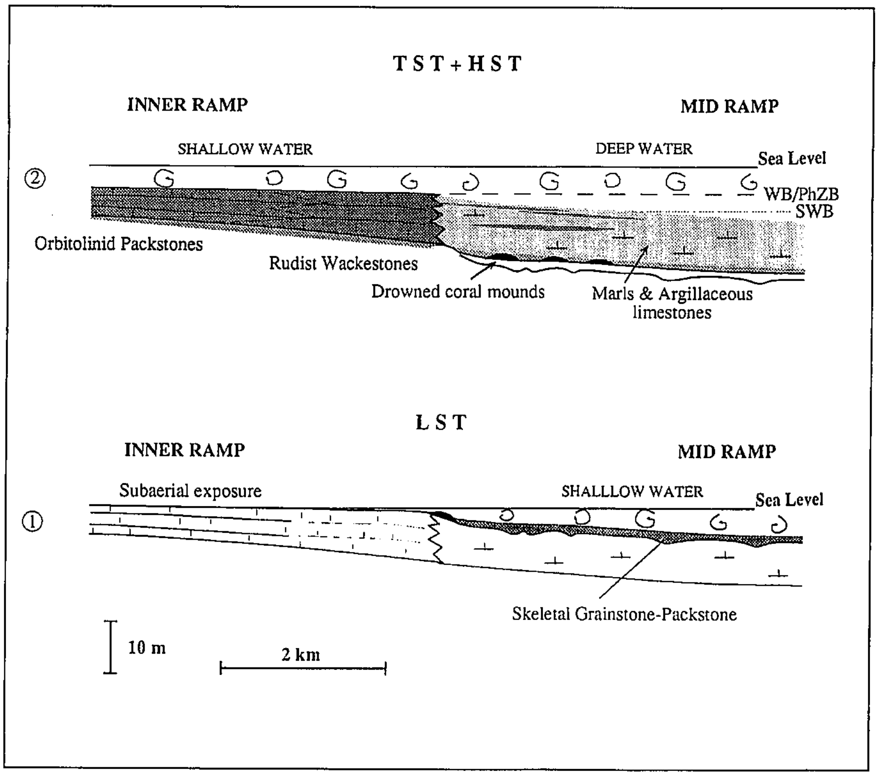


Fig. 5.- Ramp constructional dynamics and relative sea level. Note different sea level trends when shallow marine deposition occurs on the inner ramp (sea level tends to fall) and on the mid ramp (sea level tends to rise). Note also contrasting shallow marine sediments for inner and mid ramp settings.

Fig. 5.- Dinámica de construcción de la rampa y su relación con variaciones del nivel marino. Obsérvese las diferentes posiciones del nivel marino cuando se produce sedimentación carbonatada de aguas someras en la plataforma interna y en la plataforma media. Observese también la diferencia entre los sedimentos marino someros de rampa interna y media.

ramp, deep-water conditions changed too rapidly to very shallow-water to allow the formation of a well developed shallowing upward sequence, and erosion occurred instead.

On the mid-ramp erosive surface the carbonate factory stars in very shallow high energy conditions, now with a slowly rising relative sea level trend. At this point the carbonate factory is then active on the mid ramp, ant it is inactive on the inner ramp (subaerially exposed). A deepening upward cycle forms on the mid ramp as relative sea level rises. Simultaneously the inner ramp is gradually flooded, and it remains initially under relatively deep-water conditions. A period of time is necessary for the factory to recover (start-up phase, *sensu* Kendall and Schlager, 1981), and for the time the factory is again active the relative sea level rise slows down, and the development of a shallowing upward sequence on the inner ramp starts again, as the mid ramp remains now in deep-water conditions.

Regarding to the different types of carbonate sediment produced on the inner ramp during highstands and on the mid ramp during lowstands, the difference could be related to factors as depth, wave and photic zone base levels, controlled by paleogeographic and oceanographic changes. Climatic changes from high to lowstand conditions could also be responsible for the sedimentary style variations, as in the examples provided by James (1996), where grainy sediments characterize cold water ramps, while benthic communities flourish in warm water conditions.

A younger example in wich a very similar arrangement of facies and cycle types was recongnized, and this model could be aplied, has been recently presented by Payros (1997) for a Eocene carbonate platform of the western Pyrenees.

Conclusions

Different cycles formed on a carbonate ramp: shallowing-upward cycles formed on the inner ramp, and asymmetric deepening-upward dominated cycles formed on the mid ramp. More complete mixed, but still shallowing dominated cycles formed in intermediate positions, on the outermost inner ramp. The more complete cycles are those of the outermost inner ramp ramp, where deposition was ininterrupted: no subaerial exposure or erosion is reported with low sea level. These are followed by the mid ramp cycles, for which variable rates of erosion occurred on top. The most proximal inner ramp is the site where the cycles would be more incomplete, as the periods of subaerial exposure imply hiatuses. The cycle type is controlled by the relative sea level trend, the ramp depositional gradient, and the depositional setting.

Shallow water sedimentary style also varied from the inner to the mid ramp: fossiliferous wackestones formed on the inner ramp, as skeletal grainstones and packstones formed on the mid ramp. Controls on sediment type could be an interaction of climatic, paleogeographic and paleoceanographic factors. Depending on the cycle type and composition we can interpret its position on this particular carbonate ramp. This could be also valid for ramp systems of different ages and settings, and likely for other types of carbonate depositional systems as well.

Acknowledgments

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