3D Stratigraphic Forward Modelling of the Facies Distribution and Evolution of Llucmajor Platform, Mallorca Island

Introduction

Stratigraphic Forward Modelling (SFM) uses mathematical equations, algorithms and empirical assumptions to numerically reproduce the processes and factors that acted over geologic time in generating the present-day observable stratigraphic heterogeneities in depositional systems. Internal and external architecture of sedimentary units can be modelled at both reservoir and basin scales. Controls affecting accommodation variation (subsidence/uplift, eustasy compaction, etc.), sediment supply (weathering, erosion, carbonate production and precipitation of evaporites) and transport (fluvial, waves and gravity flows) are the main required input parameters in SFM (Granjeon et al., 2017).

A good candidate for stratigraphic studies is the Llucmajor Platform of the Mallorca Island, Western Mediterranean. There is ample understanding of the geological evolution, stratigraphic and facies architecture of the platform (Figure 1) as well as some of the factors that controlled the evolution of the platform (Pomar, 1993; Pomar et al., 1996, 2012; Pomar & Hallock, 2008; Sàbat et al., 2011). Two models of the facies architecture of the platform have been created (Bosence et al., 1994; Hüssner et al., 2001). However, the science and technology of Stratigraphic Forward Modelling have improved over the years, thus providing an enhanced understanding of the controls on the evolution of platform facies distribution and geometry. Hence, this work presents a reevaluation of the facies distribution and geometry of the Llucmajor platform, with an analysis of the controls that influenced the three-dimensional evolution of the platform over geologic time.

Methods and Input Parameters

For this study, DIONISOS was used to achieve an improved understanding of the platform development with the Llucmajor platform as a reference. The modelling required input parameters such as the initial bathymetry, eustatic variations, carbonate production rates with time and depth and sediments transport parameters. For this study, these parameters were derived from documented detailed stratigraphic and sedimentological studies of the Llucmajor platform (Figure 2). In order to create a simple model devoid of oversimplification of the facies architecture and sediment distribution of the Llucmajor platform, five sediment classes were used for the study. These classes (rhodalgal, dish corals, massive corals, carbonate grains and carbonate muds) are based on the dominant carbonate factories of the platform (Pomar et al., 1996, 2012). The abundance of scleractinian reef builders, green algae, mud-rich lagoons and fast-growing coral reefs at the margin of the Llucmajor platform indicate that the dominant carbonate factory is the T-factory (Schlager, 2005). The input parameters used for the simulation are given in Figure 2 (A-E).

Transport: The mobility of the produced sediment is a function of the transport processes. The efficiency of down-slope sediment transport is quantified by the diffusion coefficient (Seard et al., 2013). In the simulation, factories which are known to be relatively more resistant (e.g. massive corals and dish corals) are assigned relatively lower diffusion coefficients, while relatively less resistant factories are constrained by higher diffusion coefficients. The erosion rates of the sediments were also significant in the generation and distribution of carbonate grains and muds (Figure 2A).

Carbonate Production: the carbonate productions for the different sediment classes were profiled with depth and geologic time. The production rates and depth windows of the five sediment classes presented here were based on the empirical Holocene T-factory profile of Bosence et al. (1994) and modified for this study through the individual characteristic depth windows of the different sediment factories (Figure 2B). The proportion of the sediments produced from the proximal to distal areas were used to constrain the facies definition.

Initial bathymetry: the paleoarchitectural framework of the platform is defined by a basal Heterostegina unit (Figure 1) which unconformably overlies basement rocks (Pomar et al., 1996). The initial bathymetry for the modelling was reconstructed from the stratigraphic and sedimentological interpretation of water wells (Figure 2C). Studies have shown that that during the evolution of the carbonate platform, subsidence was almost insignificant (Pomar, 1991) and so a relatively low constant
subidence rate was adopted for the model.

![Figure 1: the Llucmajor platform with respect to the underlying layer and adjoining sedimentary units (from Pomar, 1991)](image)

**Eustasy:** the sea level curve used in the model is the superposed multi-sinuous curves of Hüssner et al, 2001 (Figures 2D and 2E) which is based on the description of the sea level variation from earlier studies of the platform (Pomar & Ward, 1995). The sea level curve extends through the simulation time, from 8.5 to 6.5 Ma.

**Wave impact:** in order to constrain the production of massive corals and the development of a backreef region of the platform, it was necessary to consider the influence of waves. A wave base of 20 metres was defined and the wave azimuth was pegged at 45°, giving a maximum wave energy flux of 225 kW/m.

**Results and Discussion**

In order to generate a model that is reflects the observed geometries and facies distribution of the Llucmajor platform, sediment distribution, sedimentation rates, wave energy propagation, slope dips and wave exposure time were each considered and their impacts on the resulting platform were analyzed. This analysis is based on the division of the platform geometry into a backreef region, a reef front and slope and an open shelf region (Pomar, 1991; Pomar et al., 1996).

The model (Figure 3) shows aggradation in the reef crest to reef slope region, a development of a back-reef lagoon under favourable wave regimes, during episodes of sea level rise from simulation time 8.5 Ma to 6.5 Ma. From high still stands to sea level falls, there is an aggradation of the slope facies which then resolves into the progradation of the reef facies. As sea level falls, lagoon development ceases with an overall basinward shift of the production locus. The facies model shows the dominant progradation and aggradation patterns of the Llucmajor Platform. Each sigmoid shows the facies shift in response to accommodation changes.

**Conclusion**

The model shows that the facies architecture of the Llucmajor Platform is largely controlled by sea level variation. Carbonate accumulation rates, sediment diffusion rates, wave energy, transformation potentials of carbonate sediments are also important in the generation and modification of the platform morphology, suggesting that the Llucmajor platform stratigraphic heterogeneity indicates a complex interaction of the different environmental factors.
Figure 2: the input parameters used for constraining the simulation. (A) Sediment classes and their characteristics. (B) The carbonate growth profile with depth, profile for massive corals from Bosence et al., 1994 (C) the initial bathymetry map (D) the characteristics of the sinuous sea level curves from Hüssner et al., 2001 (E) the sea level curve.

Figure 3: the facies architecture modelled for the Llucmajor showing the different facies and their distribution. The red dashed lines represent the morphology of possible sequence boundaries. The inset map represents the aerial distribution of the facies at the youngest age of the simulation – 6.5 Ma.

The simulation over a period of 2 Ma shows that at constant sea level variation, the carbonate growth is largely affected by the response of the rhodagal units to small variations in the initial bathymetric configuration. A slight increase or decrease of the carbonate initiation depth results varied rates of Rhodagal production which in turn affects the production and accumulation of the reef builders.
Periods of sea level rise were characterised by a build-up of the reef crest, aggradation on the slope and development of backreef lagoons. The lagoons developed under favourable wave conditions and just enough shedding of reef sediments.

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References


