Sequence Stratigraphy as a tool for water resources management in alluvial coastal aquifers: application to the Llobregat delta (Barcelona, Spain)

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CHAPTER 1: Introduction

PhD Thesis
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Chapter 1

Introduction

1.1. Introduction: thesis outline

The aim of this thesis is twofold: 1) to better understand the deltaic sedimentary response to glacio-eustatic fluctuations and local factors, and 2) to evaluate the effects of the resulting deltaic architecture on hydrogeology, focusing on seawater intrusion.

The Llobregat delta (Barcelona, Spain) was selected as a suitable study area for the following reasons. From a geological point of view, the Llobregat delta provides a large amount of onshore and offshore geological data. From a hydrological point of view, the deep aquifers in the Llobregat delta supply water to the metropolitan area of Barcelona (Spain). High pumping rates hasten seawater intrusion. Thus, it is necessary to gain an insight into the potential pathways for seawater intrusion in order to be able to provide more effective management strategies. This is the main contribution of this thesis.

This thesis consists of five chapters and it is divided into two parts. Chapter 1 is devoted to the motivation and methodology of this thesis. Chapters 2 and 3 are included in Part I and are focused on the onshore-offshore sedimentary architecture of the Llobregat delta. Chapter 4 is included in Part II of this thesis and deals with the application of sequence stratigraphy to seawater intrusion using the results obtained in Part I. Chapter 5 provides the conclusions drawn in Part I and Part II and considers future research lines. There are five appendixes which contain detailed onshore cross sections, offshore seismic profiles, and other studies on the basement of the delta plain. There are also detailed maps showing the cores and seismic profiles location as well as additional nannofossil analyses (not discussed in Chapter 2).

Part I (Chapter 2 and 3) addresses the first objective outlined above. Dating of the Pleistocene onshore deposits is used to better understand the global controls on the delta architecture and to help us correlate the different onshore-offshore sedimentary bodies. Most of the research on geochronology in Quaternary Mediterranean onshore deltas has been focused on postglacial deposits and few studies have been devoted to Pleistocene materials. This may be attributed to the fact that Pleistocene deposits are often poorly preserved. However, the Llobregat Delta displays well-preserved Pleistocene onshore deposits that provide geochronological information. The geological analyses carried out in Chapter 2 are based on foraminifers, dating and sedimentology. Chapter 2 focuses on a) the construction of a Quaternary age model, b) the role of global high-frequency glacio-eustatic cycles, and c) on the identification of the main factors and processes controlling the stacking pattern of modern Highstand Systems Tract delta.

It is unusual for studies on continental margin deltaic sedimentation to simultaneously focus on the marine realm and on the adjacent deltaic plain. In the Llobregat delta, onshore-offshore is correlated by integrating sediment cores from the deltaic plain and high-resolution seismic profiles from offshore (Chapter 3). This enables the reconstruction of the entire deltaic system and the definition of the stratigraphic relationships. The results are compared with diverse stratigraphic architectures in the Mediterranean and Gulf of Mexico. This allows us to assess the role of global and local controlling factors in the Llobregat delta. The conclusions are supported by geochronological data provided in Chapter 2.

Part II (Chapter 4) of this thesis is devoted to the second objective outlined above. Offshore continuity of onshore aquifers controls the hydraulic connection of the freshwater aquifers with the sea and therefore controls the rate of seawater intrusion under pumping conditions. The identification of potential salinization pathways in aquifers is difficult when using simple geological conceptual models or in the absence of offshore data. In Chapter 4 we use the geological model presented in Chapters 2 and 3. The sedimentary distribution observed in the Llobregat delta can be regarded as a paradigm for comparison with other shelves in the Western Mediterranean. Differences in Pleistocene growth stratigraphic patterns were controlled by local factors. These local factors played a key role in the preservation level of permeable aquifers in each delta. Identification of local geological factors assists in predicting the vulnerability of Quaternary coastal aquifers to seawater intrusion. Finally, a general hypothesis about seawater intrusion behavior is applied to other deltas in Catalonia and Italy.

1.2 Sequence Stratigraphy Concepts Relevant to Hydrogeology

The methodology used in this thesis is the sequence stratigraphy correlation, which is based on geological controls and processes. The sequence stratigraphy method allows us to build a realistic three-dimensional sedimentary architecture which defines the facies distribution and their geometries. This facilitates the identification of the permeable deposits and the geometries of the aquifers. We apply sequence stratigraphic concepts to characterize the onshore-to-offshore continuity of permeable bodies and to identify the pathways for seawater intrusion in coastal systems.

Sequence stratigraphy is based on the identification of sedimentary packages bounded by erosional regional surfaces. These surfaces were formed by tectonic or eustatic processes which affected stacking patterns throughout the sedimentary basin The sedimentary packages are known as genetic units and contain sedimentary environments in response to variations in sediment supply and space available for sediment to accumulate (Posamentier and Allen, 1999). The contribution of the ages of the sediments improves the stratigraphic correlation (chronostratigraphy) (Haq et al., 1987).

Sequence stratigraphy addresses issues such as (i) the reconstruction of the allogenic controls at the time of sedimentation (fig. 1.1), and (ii) the prediction of facies architecture in hitherto unexplored areas (Catuneanu, 2002). Sequence stratigraphy builds on many existing data sources. It incorporates data obtained from other branches of stratigraphy: biostratigraphy, lithostratigraphy, chemostratigraphy or magnetostratigraphy.

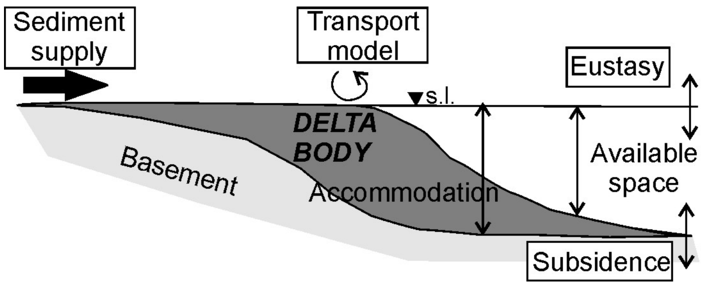

Figure 1.1: Main controlling geological factors in the deposition of the sediments; 1) eustatism, 2) basement movement (subsidence by tectonics or compactation), 3) variations in sediment supply (modified from Rabineau, 2001).

The birth of sequence stratigraphy in the oil industry dates back to developments in high resolution seismics in the late 1970s (Vail et al., 1977; Van Wagoner et al., 1990). This led to significant advances in stratigraphic interpretation and basin analysis, particularly in marine environment. Seismic records were interpreted following standard stratigraphy rules (Mitchum et al., 1977).

Based on the geometry and internal characters in seismic profiles, morpho-sedimentary units can be identified. Analysis of the seismic data following a classical seismic stratigraphic procedure (in terms of reflection endings, erosional truncation, onlap, downlap- and configurations) allows the identification of seismic units and their boundaries. For the sequence stratigraphic analysis we followed a fourfold division of systems tract based on the initial threefold scheme of Posamentier and Vail (1988). The Systems tract is deduced from stratal stacking patterns, the position within the sequence, and the type of bounding surfaces. The timing of systems tracts is inferred as a function of the relative sea-level curve that describes the base level fluctuation on the shoreline. Four systems tracts are currently in use, as defined by the interplay of base level and sedimentation changes (fig. 1.2): Lowstand systems tract, Transgressive systems tract, Highstand systems tract and Falling stage systems tract (Catuneanu, 2002).

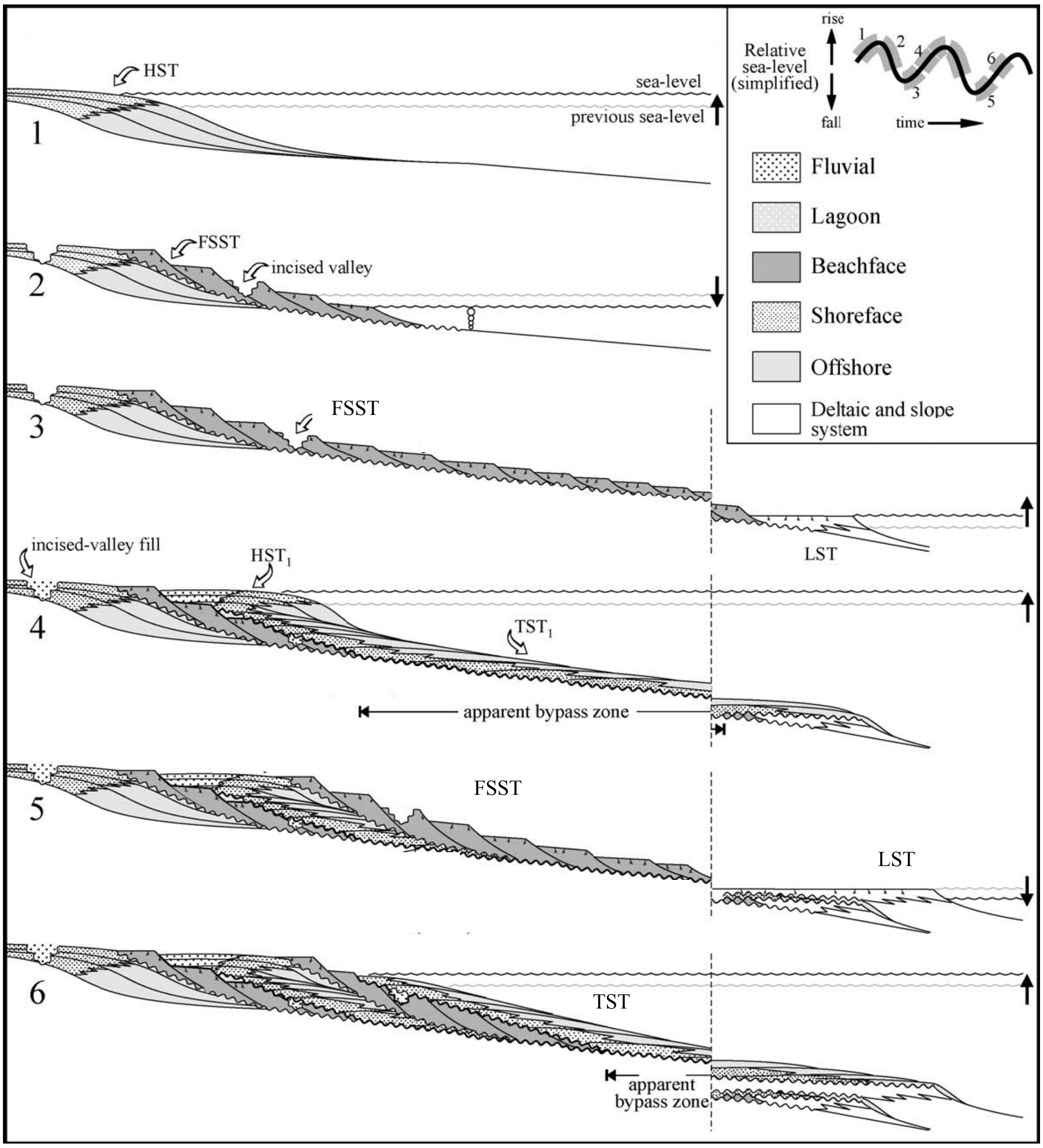

Figure 1.2: Sketch illustrating each high-frequency sequence, composed of late LST, TST, HST and FSST. The stacking pattern in deltaic systems can be very complex as shown by the Plio–Pleistocene conceptual model from the the Periadriatic basin fill in central Italy (modified from Cantalamessa et al., 2004).

Lowstand Systems Tract (LST): Package of sediment deposited between the minimum relative sea-level and the marked increase in accommodation space. Parasequences are progradational to aggradational.

Transgressive systems tract (TST): Systems tract overlying a transgressive surface or sometimes a sequence boundary (SB), overlain by a maximum flooding surface (mfs), and characterized by a retrogradational parasequence set and a deepening-upward trend. The bottom of the transgressive deposits is the maximum regression surface. These deposits show backstepping clinoforms and onlap terminations landwards.

Highstand systems tract (HST): Systems tract downlapping onto a MFS and characterized by an aggradational to progradational parasequence set. It forms during the late stage or a stillstand of a sea-level rise, or during the early stage of a sea-level fall.

Falling stages systems tract (FSST): deposited during the relative sea-level fall. There is only a FSST during a forced regression.

Although the sequence stratigraphy methodology offers many advantages, most hydrogeological models still use the lithocorrelation methodology to determine aquifer geometries. The lithocorrelation approach consists in the correlation of units in accordance with their lithology. However, this approach is currently being discarded because it gives rise to unrealistic and oversimplified geometries and facies distributions (fig. 1.3). Outcrops and seismic analogs usually display much more complex geometries and architectures than those derived from lithocorrelation (Gani and Bhattacharya, 2006; Van Wagoner et al., 1990).

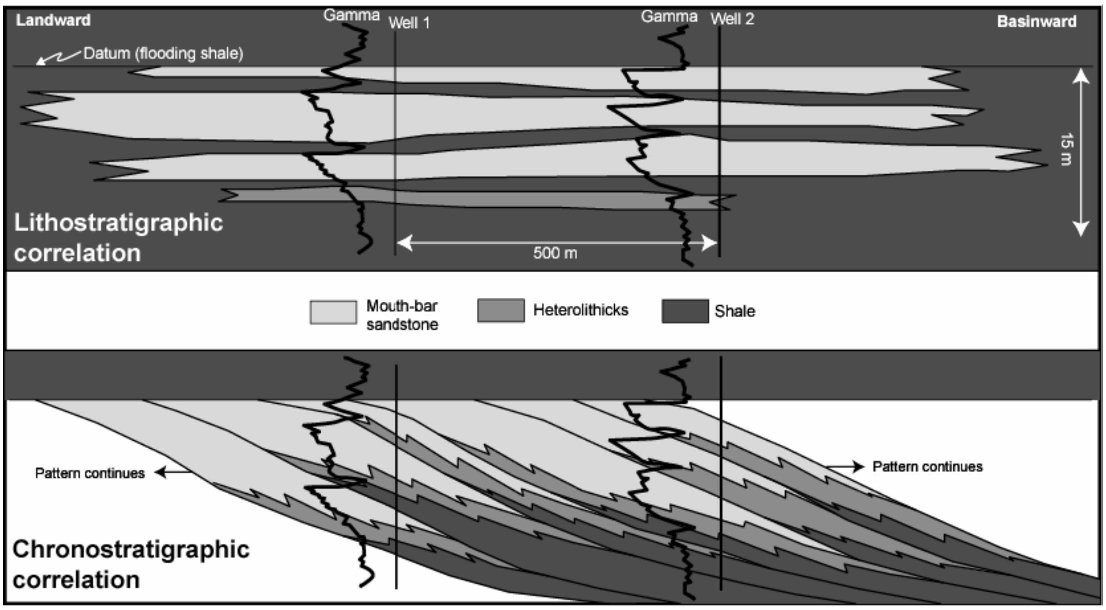

Figure 1.3: Subsurface model of well log correlation along depositional dip. Lithostratigraphic correlation (upper diagram) assumes no dip in sand bodies towards basin, whereas the chronostratigraphic correlation (lower diagram) assumes basinward dipping clinoforms. The chronostratigraphic model using sequence stratigraphy methods predicts the geometries of the aquifer much better (from Gani and Bhattacharya, 2006).