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 5: General conclusions and future research

PhD Thesis
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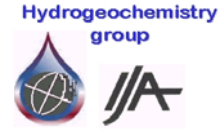


Chapter 5

General conclusions and future research

5.1. General Conclusions

This chapter offers a summary of the main findings of this thesis. The main contributions of this thesis are as follows:

1) An improved understanding of the geological controls and processes that shaped the onshore-offshore sedimentary architecture of the Llobregat delta. These geological controls and processes provide a consistent picture of the late Quaternary evolution in the Mediterranean context. This was undertaken using a multidisciplinary approach. As for the Holocene deposits, this approach consists in a) a stratigraphic correlation using cores from onshore; b) radiocarbon dating; and c) in correlating a) and b) with changes due to human activity and climate. As regards Pleistocene deposits, this method consists in a) a stratigraphic correlation from cores and seismic profiles from onshore and offshore, respectively; b) amino acid racemization dating; and c) in palaeontological analyses.

2) A general hypothesis about the vulnerability of Quaternary coastal aquifers to seawater intrusion is presented. A deeper insight into the aquifer connection to the sea should prove helpful in upgrading the management of water resources. The results obtained in Chapters 2 and 3 for the Llobregat delta were compared with stratal patterns of other Mediterranean deltas and their controls.

As regards the first contribution of this thesis, the integration of a multidisciplinary approach based on sequence stratigraphy in the Llobregat deltaic system reveals a late Quaternary sedimentary record composed of four depositional sequences (DS IV, III, II and I) with smaller high-frequency sequences. These sequences are bounded by prominent, well-defined, and widespread regional erosional surfaces (SB). Depositional sequences reveal contrasting patterns between the northeastern and southwestern shelves, and also show significant variability in dip direction. The geometries observed in the depositional sequences provide information about the type of delta variability generated under different sea-level conditions. They show a well preserved transgressive-regressive cyclic vertical pattern. This general pattern displays peculiarities compared with most Mediterranean Quaternary deltaic shelves given that the transgressive and highstand intervals appear to be significantly preserved both onshore and offshore. The preservation of these deposits is attributed to the existence of high subsidence in the continental margin controlled by Quaternary faults and the structure of the basement, and by sediment inputs.

The chronology available from well preserved Pleistocene delta plain allows us to propose a chronostratigraphic framework for the depositional sequences observed in the whole system. This approach provides guidelines on the correlation of stratigraphic bodies, which enables us to match depositional packages with well established Quaternary sea level curves. The most significant and widespread erosions were interpreted as occurring during gradual sea-level falls in the framework of 100 kyr glacial-interglacial cycles, as reported for other shelves in the Mediterranean. However, most of the regressive deposits show a more complex internal architecture, suggesting the imprint of higher-frequency cycles. The highly reworked and

resedimented foraminifers and reworked ages confirm the high energy in a Highstand environment and the fluvial cannibalization during sea level fall. The later sedimentary processes caused the erosion of the earlier materials and their redeposition. Subsequently, during the following sea level rise, these sediments were eroded and resedimented again.

Particularly emphasis was placed on the geological processes and their influence on the stacking pattern of the Holocene parasequences, mainly during the recent highstand (DS I). The deposition of postglacial deposits, as well as the facies distribution is controlled by palaeoreliefs the sea-level stabilization and sediment supply changes. Three phases with contrasting sedimentation rates were deduced from the radiocarbon results and facies analyses:

1) Low sedimentation rates during 14586-6045yr cal BP were controlled by the high accommodation space created during the sea level rise, which favored a retrogradation stacking pattern.

2) Increased sedimentation rates during 6055-1900yr cal BP and particularly from 4500yr cal BP were induced by the slow sea-level rise and concomitant decrease in the available accommodation space in front of the river mouth together with large inputs of sediment supply that favored deltaic progradation.

3) A marked variation in the sedimentation rate during 1900-215yr cal BP was caused by the avulsion of the river alluvial plain, resulting in the sudden abandonment of major river branches and in a delta lobe switch due to palaeofloods and human activity.

As for the second contribution of this thesis, the general stratal patterns of the deltas help us to identify the nature and extent of aquifer connection to the sea. Sequence stratigraphy correlation enables us to build realistic geological models and to determine the facies distribution and their geometries in order to identify permeable deposits and their 3D extension.

The Llobregat delta is a paradigm of deltaic architecture because of its well preserved transgressive and highstand intervals. The well-preserved coarse transgressive deposits are important from a hydrogeological point of view. They act as aquifers with high lateral continuity from onshore to offshore providing paths for seawater intrusion. However, most of the Quaternary Mediterranean shelf is characterized by large-scale regressive wedges with poorly preserved transgressive deposits. This variability of stratal pattern plays a crucial role in controlling seawater intrusion behaviour. The preservation of the transgressive deposits and their exposure to the sea floor owing to the reduced thickness of the prodelta facies, submarine canyons and/or neotectonic faults enhance the possibility of seawater intrusion. Conversely, deltas with poorly-preserved transgressive deposits are less vulnerable to sea water penetration.

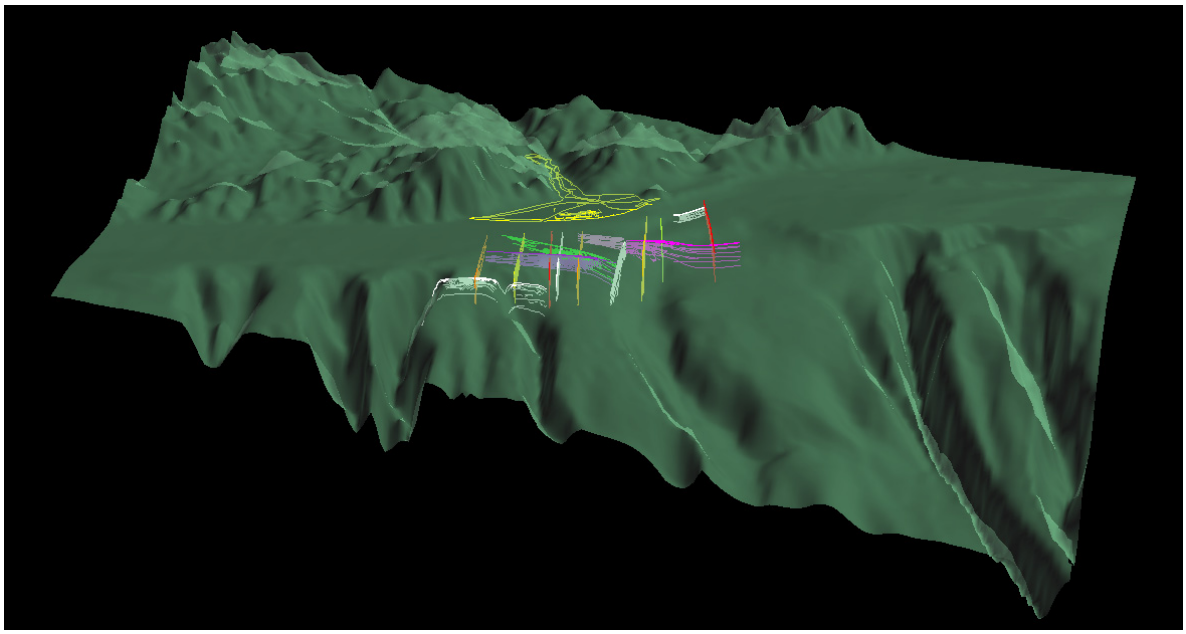
5.2. Future research

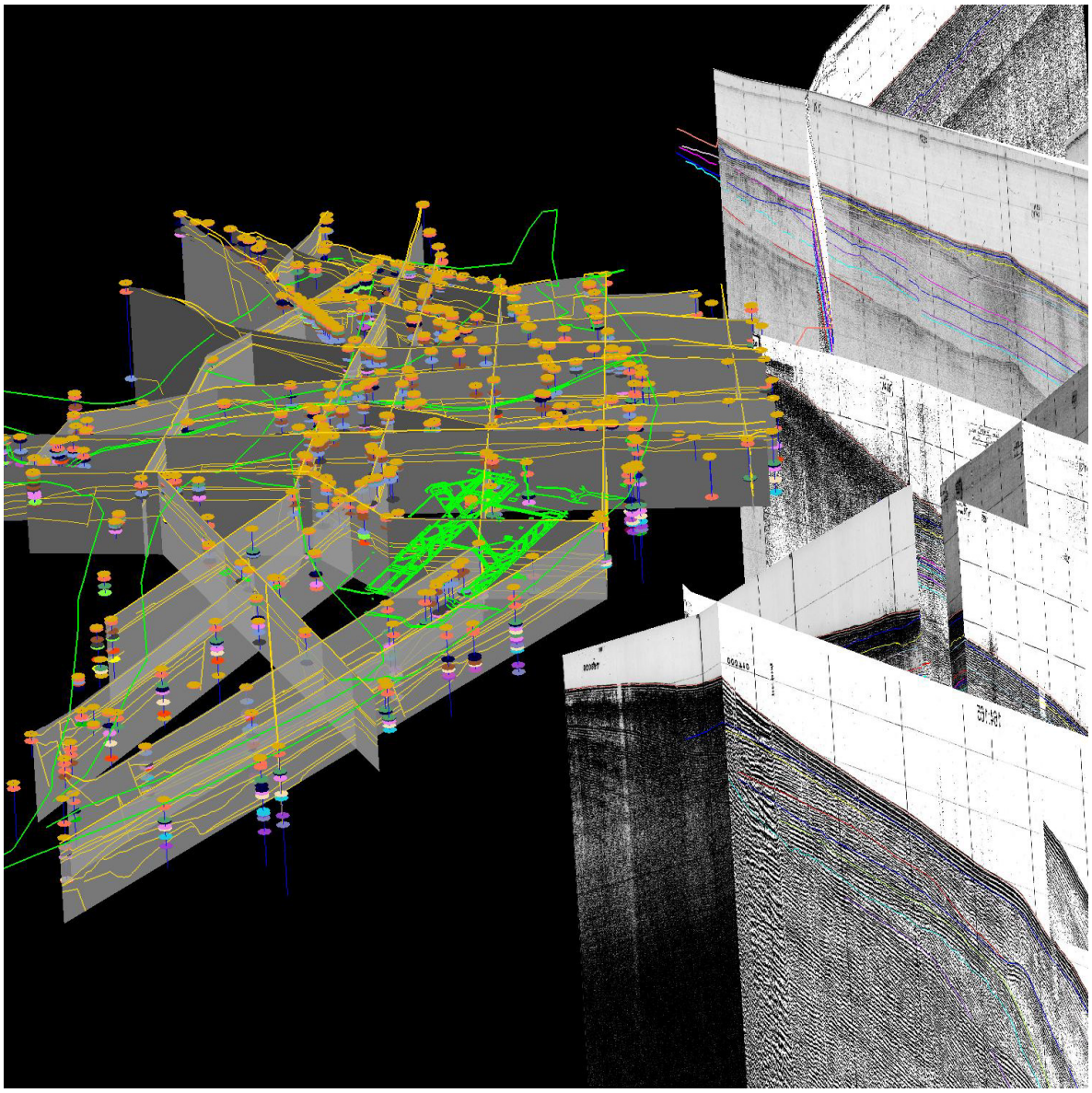
Further work on this subject may be developed along the following lines of research:

5.2.1 Hydrogeological modelling of alluvial aquifer

Alluvial geological models of aquifers used for groundwater modelling are often simplistic approximations of real aquifer geometry and spatial variability. Numerical model restrictions condense or simplify the details contained in the stratigraphic correlation studies. The representation and the analysis of the geological architecture are often made on a 2D basis in hydrogeological numerical models. However, a 3D analysis is necessary to gain a better understanding of complex geological systems.

The geological model of the Llobregat delta presented in this thesis is used to build the 3D geological bodies in order to provide a more effective management of groundwater resources in alluvial coastal aquifers (fig. 5.1).





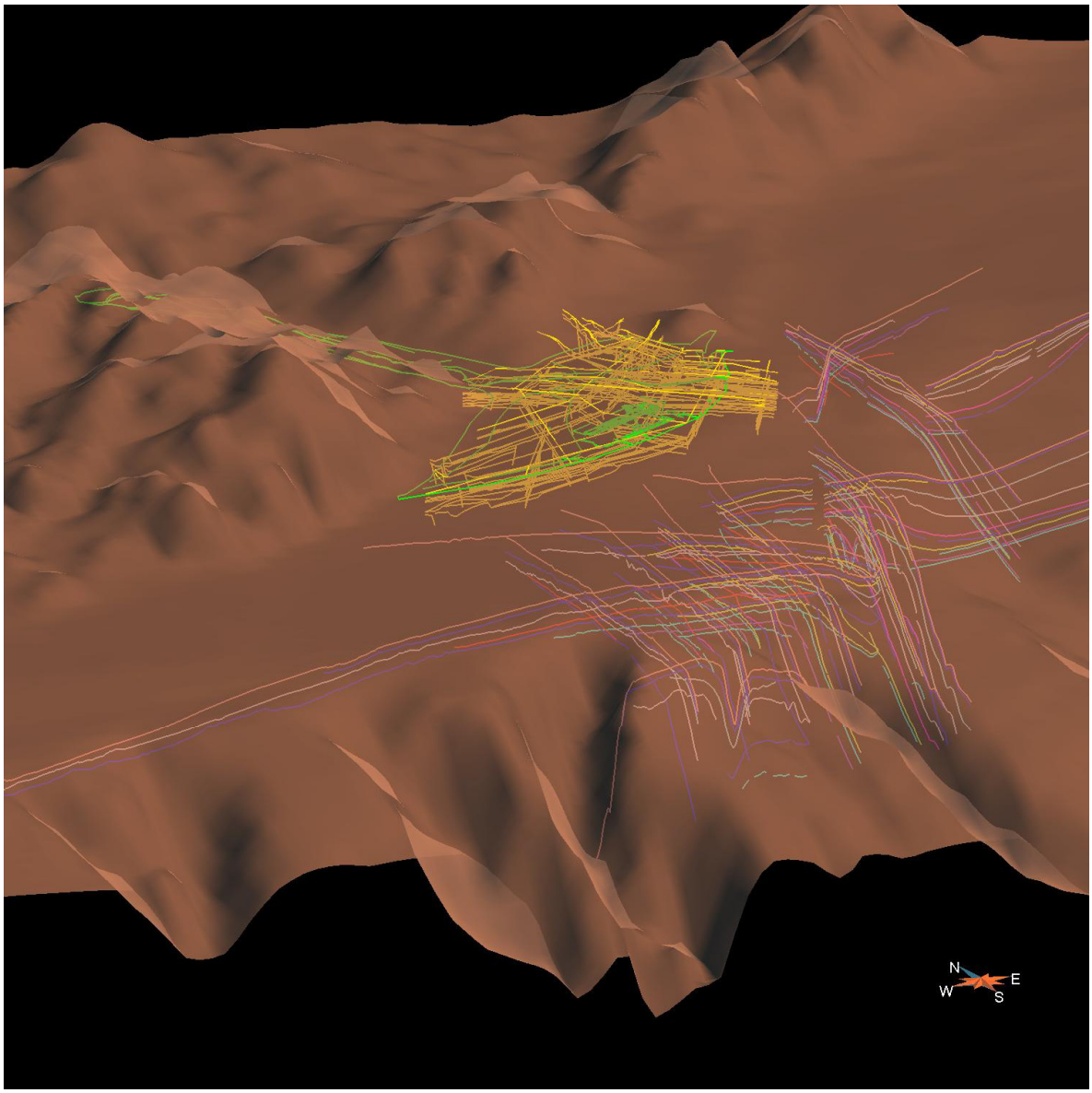


Figure 5.1: Preliminary results of the geological models made with GoCad software. The model shows the wells marked (orange and pink circles) and seismic profiles.

5.2.2 Role of geology in seawater intrusion

A number of questions have been raised in the work described in Chapter 4.

The absence of consistent and detailed geological models of onshore to offshore examples in the Mediterranean and the lack of correlation with hydrogeological data make it difficult to generalise and validate the results of Chapter 4. Thus, in order to make headway in this regard it would be interesting to:

a) test the hypothesis articulated in Chapter 4 in geological contexts with poorly-preserved transgressive deposits.

b) study in greater depth the connection between transgressive palaeochannel infills and submarine canyons.

c) corroborate the role of faulting as a mechanism to expose transgressive aquifers.

d) verify the role of seismic facies distribution and its response from a hydrogeological point of view, e.g. high seismic facies variability in the postglacial transgressive Llobregat delta. These facies consist of at least three seismic subunits (I-PAS). These subunits are described as chaotic, progradational and parallel seismic facies, representing different sedimentary environments. Facies interpretation may help us to enlarge our understanding of the permeability distribution in the transgressive aquifer.