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An Integrated Study into the Reservoir Characteristics of Miocene Mangrove Deposits of Mallorca

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Several oil reservoirs around the world are producing from ancient carbonate-related mangrove deposits. Little previous research has been undertaken on fossil mangroves, especially regarding their lateral heterogeneity, structure, permeability and porosity. This has resulted in a relatively poor understanding of reservoir mechanisms and consequent reservoir performance of such reservoirs. This integrated study on outcropping late Miocene, mangrove deposits of eastern Mallorca, Spain, provides insight into the potential reservoir properties of carbonate mangrove reservoirs.

Introduction

A series of Miocene carbonate outcrops along the south eastern coast of Mallorca. These include interpreted fossil mangrove deposits. These often extensively rooted intervals are part of the Santanyi Limestone and form the subject of this integrated study. Three weeks of fieldwork were undertaken during which sedimentological and petrographical data were collected from 12 logged outcrops in order to examine petrophysical properties and lateral heterogeneities. Rock samples were taken and were analysed to elucidate their porosity, permeability and petrophysic characteristics. From these data a sedimentological model was established.

The outcrop data were then used as a framework to build a three-dimensional static reservoir model using the software package Petrel. Rock properties measured from the rock samples were used to populate the facies model with porosity and permeability data. The Petrel model was then imported into Eclipse, a dynamic simulation computer package, in order to build a dynamic model to simulate production from the mangrove deposits. In this software package several well placement scenarios were simulated based on the supposition that the Santanyi Limestone and surrounding facies could act as a reservoir.

The main outcome of the study was that the low horizontal and high vertical permeabilities of the mangrove facies strongly favour field development using horizontal wells.

Geological History

In southern Mallorca the Santanyi Limestone lies directly upon the Reef Unit, and was deposited during the Messinian (7.2-5.3 million years ago) (Pomar et al. 1985). During the Messinian a relative sea level fall occurred in the Mediterranean Sea. The climate was warm and arid. It was in these conditions that the Santanyi Limestone was deposited.

The Santanyi Limestone can be subdivided into four intervals. The lower interval contains mangrove carbonates and associated facies. This part of the Santanyi Limestone is the focus of this study. The second interval contains layers with oriented shells and wavy laminated cryptalgals. This is overlain by the Oolitic Unit. The final interval comprises the Stromatolitic Unit (Fornos & Pomar, 1984) & (Pomar, 1996). All the contacts, with the exception of karst associated with soil development, are considered to be conformable. On a regional scale depositional environments during the Pliocene varied from shallow marine at the base to aeolian at the top. They fill in the Palma Basin and are interbedded with conglomerates and sandstones interpreted as fan-delta deposits (Alonso-Zara et al. 2002).

Mangroves

A mangrove is a tree species which has a tolerance for salt water and can survive in intertidal zones (Plaziat, 1995). Mangals (mangrove swamps and forests) almost always occur in tropical zones. However, the air temperature can be as low as 5°C. More important is the temperature of the water in which the mangroves grow. The water temperature has to be above 20°C in winter (Hogarth, 1999).

Mangrove environments show zonation on different scales. On shores which are tide-dominated, vertical zonation appears. Also on banks or tidal reefs zonation occurs. On a larger scale zonation takes place up river, as the water becomes less saline. Some species only exist in almost fresh water along rivers far away from the coast and its tides. Finally, on a global scale, several zones can be distinguished. Some species can only survive in tropical areas, whereas other species also survive on desert coasts.

The soils of mangrove environments typically consist of fine mud and faecal pellets. Skeletons of dead organisms are also deposited. Small and large mangroves and sea grasses begin to colonise the substrate. The pneumatophores of the mangrove trees and the small roots of the grasses penetrate the soil vertically. Organisms that live in the soil delve themselves into the soil. The vertical penetration by roots and pneumatophores result in a soil which is heavily bioturbated. Due to the presence of the roots in the water, the velocity of the flowing water decreases. The particles that are in suspension in the water will settle out and sedimentation takes place.

Data Acquisition

During fieldwork twelve outcrops were logged. The distance between these outcrops varies between 100 to 2300 metres. All the outcrops are situated along the coast of SE Mallorca. The two most widely separated outcrops are about 8 km from each other.

In total 70 samples were taken, representing all major facies. Thirty-six samples were sent to Panterra Ltd, Leiderdorp, The Netherlands, for rock and core analyses. Permeability and porosity were measured. The permeability values in the Mangrove Facies have a high kv/kh ratio. In all other facies the ratio varied from 0.12 to 78.

Thin sections of the samples were made and stained with alizarin red in order to distinguish calcite from dolomite and other minerals. All thin sections were completely stained and it is

hence concluded that they all consist entirely of calcite. The thin sections were analysed to elucidate several characteristics.

Making use of the porosity measurements and the thin section analyses, the porosity was also corrected for cementation.

Interpreted Facies
Making use of all the data gathered during and after the fieldwork, 18 facies were interpreted. All the data was captured in Petrel and a correlation model was made.

Llombards Unit
The Llombards Zone consists of four facies that are laterally extensive. The basal unit is the Green Shale. This is overlain by the Bivalve Facies, and then in turn by the Cryptalgal Facies. The Llombards Unit is capped by the Oolitic Facies. These facies are modelled as a layer cake in Petrel. The facies in these units were modelled with a Kv/Kh ratio of 1.

Mangrove Unit
This Unit is split into two zones. The Far zone is laterally discontinuous although the layers comprising mangrove units are continuous, and these have high kv/kh ratios. The other facies have varying kv/kh ratios ranging from 0.12 to 1 and occasionally above 1. The Savinar Zone consists of six different facies. The facies grade vertically and laterally into one another. Extreme values for horizontal and vertical permeability are present in this zone.

Reef Unit
The Reef Unit is assumed to be continuous with some small areas of discontinuities, which were modelled as the Brown Facies and the Mangrove in Reef Facies. The kv/kh was modelled as 1 in the reef unit.

Sedimentary Model
Figure 1 shows the interpreted sedimentary model. The Mallorcan coast during the Messinian can be described as a low and mixed energy coast. Tides and waves both influenced deposition. The sediment was formed *in situ* and contained mainly calcareous faecal debris and skeletal material. In the fieldwork area no evidence of rivers or deltas was found.

Dynamic Model
Examining the permeability measurements it was concluded that the mangrove facies have a high kv/kh ratio, while in contrast the surrounded facies may have very low kv/kh ratios. A dynamic model was constructed to evaluate the influence of the vertical root structures and their associated high vertical permeability on reservoir performance. In the dynamic model a reservoir bearing oil and water was simulated.

Key observations from the dynamic simulation are as follows:

- The high kv/kh ratio causes flow in the vertical direction and little flow in the horizontal direction. Since the inflow in vertical wells is mainly horizontal, the production of the vertical wells is very low. Therefore it is recommended to use horizontal wells when developing rooted reservoirs.

- The change in recovery factor is not linear with a changing kv/kh ratio. The recovery factor is only impacted to a minor extent if the high kv/kh ratios are reduced by 5 times.
- The watercut increases with increasing kv/kh ratios.
- Horizontal wells produce more water than the vertical wells due to the high vertical permeabilities.

Recommendations for further work

To make the modelling more robust more data is required on the reservoir edges, particularly to the NW and SE. This would give the model more three dimensional control, as at the moment the linear nature of the coastline exposure means that little is known of the seaward and landward edge of the deposits.

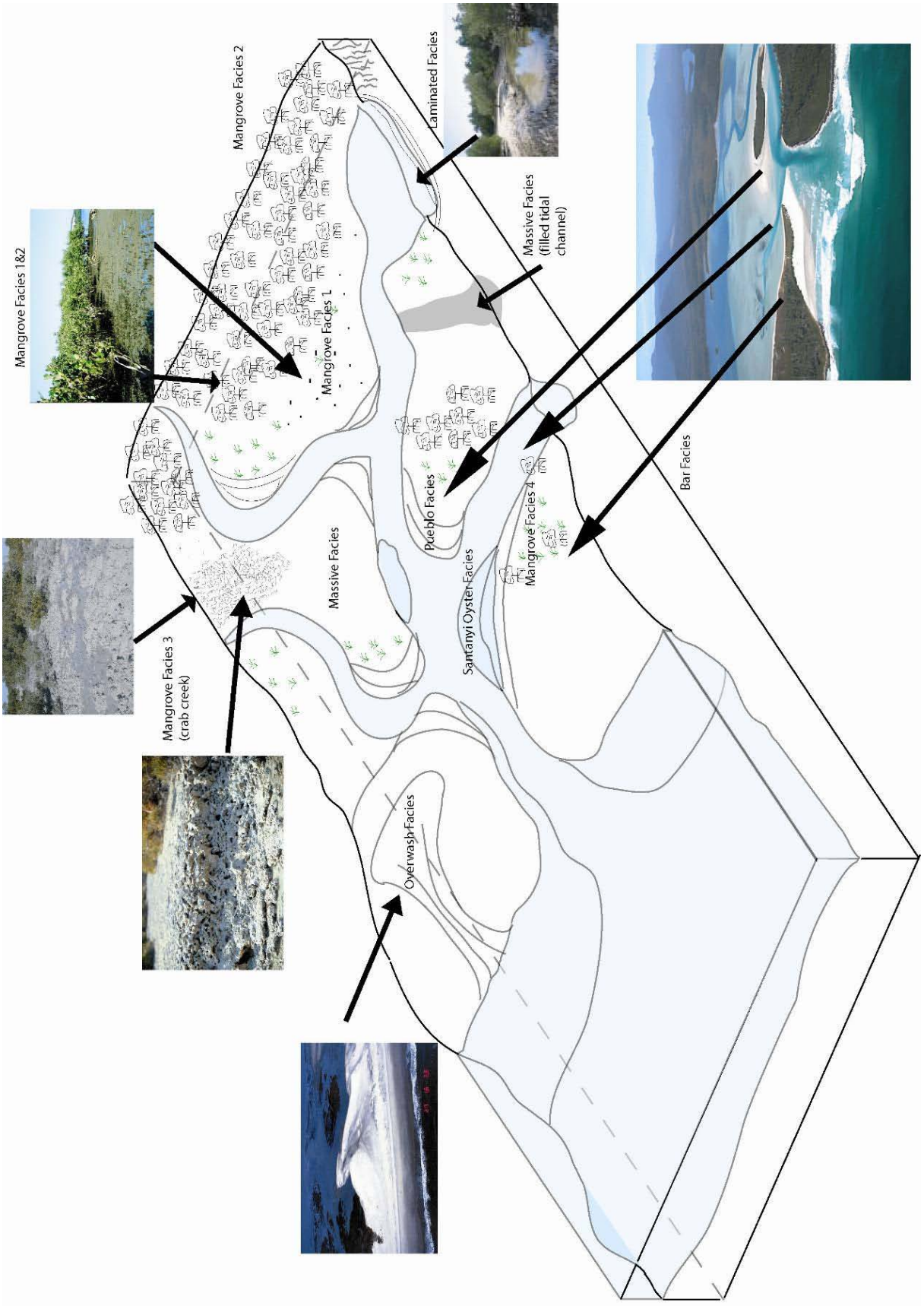
Samples were taken from the weathered zone of the outcrop. Taking samples of the unweathered zone could give more information about the properties of the filled root system as well as the matrix. More work could also be undertaken on the impact of root density on permeability. A more detailed study on how to produce from reservoirs with a high vertical and low horizontal permeability should also be undertaken

Studies on analogues would be very interesting, particularly ancient analogues: both in outcrop and in the subsurface, especially those that are hydrocarbon reservoirs. Their properties could be compared in order to define some corresponding reservoir characteristics for all fossil carbonate mangrove reservoirs.

Conclusions

Detailed logging of Miocene carbonate outcrops of the Santanyi Formation has allowed a robust correlation scheme to be erected for a series of deposits along the SE Mallorca coastline. A total of 18 facies were delineated, and interpreted as representing a mangrove dominated, tropical, low energy coastline.

A three dimensional static reservoir model was constructed and populated with properties, before being exported to a dynamic simulation package. Simulating production on a 25 year scale demonstrated that such reservoirs, where the kv/kh ratio is anomalously high due to extensive vertical rooting, should be exploited using horizontal wells. This behaviour was found not to be linear in character, so even lightly rooted intervals should receive the same treatment. This is believed to be the first time that such a study has been published.


Mangrove Facies 1&2
Mangrove Facies 2
Laminated Facies
Massive Facies (filled tidal channel)
Mangrove Facies 1
Pueblo Facies
Bar Facies
Mangrove Facies 4
Massive Facies
Santanyi Oyster Facies
Mangrove Facies 3 (crab creek)
Overwash Facies