COCARDE – COld-water CArbonate Reservoir systems in Deep Environments

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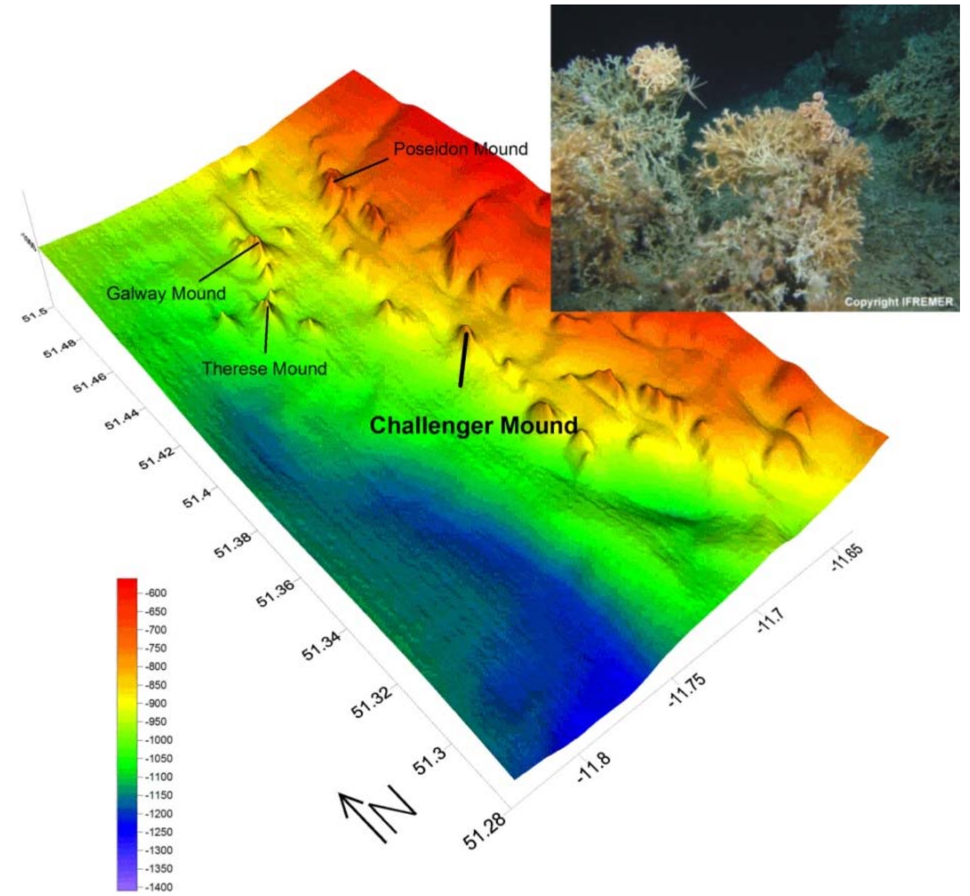

Figure 1. Three-dimensional view of the Belgica Mound Province in Porcupine Seabight, SW of Ireland based on AWI bathymetry (Beyer et al., 2003). Inlet represents surface coverage of mound structures (cold-water corals).

INTRODUCTION

Cold-water carbonate mounds and cool-water carbonates are important, yet often underestimated, carbonate factories in mid- to deeper slope environments. Frontier research during the last decades in such systems has led to a better understanding of carbonate systems thriving in colder and mostly deeper realms. For example, sub-recent cold-water carbonate mounds localized on the European continental margins cannot be any longer neglected in the study of carbonate systems (Fig. 1). They clearly play a major role in the dynamics of mixed siliciclastic-carbonate continental slopes.

In early times of hydrocarbon exploration, the potential of carbonate mounds as reservoirs was not always readily identified. However, discoveries of hydrocarbon accumulations in such mound systems (f.e. Lower Permian mounds of Karachaganak, Kazakhstan) soon became an eye-opener and presently spurs new exploration insights and strategies. The comprehension of the importance of carbonate mound systems as hydrocarbon reservoirs passes through the understanding of the fundamental processes of mound initiation, growth and demise, and through the identification of plausible sizes, geometries, basin settings and controls. The diversity of carbonate mound systems in the sub-recent world is a key to the diversity of mound settings, morphologies and characteristics in ancient time. The comparative analysis of mound evolution – with a focus on early to late diagenetic processes, products and patterns – in the recent and ancient world through integrated ventures in oceanic and continental scientific drilling fuels new insights in reservoir plumbing systems and spurs improvements in reservoir prediction. The scientific objective of the international initiative "COCARDE: An Industry-Academia Partnership for the Study of Cold-Water Carbonate Reservoir Systems in Deep Environments" (www.cocarde.eu) is to confront recent and ancient carbonate mound systems (COCARDE-Science). The processes learnt from recent carbonate mound studies play a primordial role to understand ancient carbonate mound systems and their reservoir interests.

INSIGHTS FROM RECENT CARBONATE MOUND SYSTEMS

Recent carbonate mounds and cold-water coral reefs along the European continental margins can form structures up to 300 m high and are located in water depths ranging between 100 and 900 m. They are frequently associated with contourite drifts (Van Rooij et al., 2007) which might be the key for connectivity within a larger system. During IODP (Integrated Ocean Drilling Program) Expedition Leg 307 aboard the R/V Joides Resolution, a recent carbonate mound, Challenger Mound (Porcupine Seabight, SW of Ireland), was drilled from top towards mound base (Fig. 2) (IODP Expedition Scientists, 2005). The Challenger Mound sediments can be described as a facies of cold-water coral fragments and other biogenic fragments embedded in an alternating biogenous (carbonate-rich) to terrigenous (siliciclastic) matrix (Foubert & Henriet, 2009).

Early differential diagenesis overprints the primary environmental signals, with extensive coral dissolution (aragonite dissolution) and the genesis of small-scaled semi-lithified layers in the Ca-rich intervals. The alternation between carbonate-rich and siliciclastic-dominated matrix results in a cyclic record, corresponding with glacial-interglacial variations. Challenger Mound started to grow between ~2.50 and ~2.70 Ma, coinciding with the onset of the northern hemisphere glaciations (Kano et al., 2007). Mound decline started probably around ~1.50 Ma, but a new phase of mound growth started ~0.50 Ma, to end ~0.25 Ma. The switch towards more intense and prolonged glacial states during the Mid-Pleistocene Revolution (MPR) may have been responsible for the decline of mound growth. Extensive off-mound sedimentation started around the same period, reflecting the more intensive glaciations after the MPR in Porcupine Seabight which resulted in an increase in terrigenous input from the shelves. In terms of Deep Biosphere, Expedition 307 demonstrated that carbonate mounds and their substrate might represent a significant prokaryotic subseafloor habitat (Webster et al. 2008). The low activity within the mound interval however suggests that Challenger Mound, partly in the burial stage, is moving into a fossil stage, where present microbial patterns at best reflect a "faded" image of times when the mound was thriving.

TOWARDS THE DIAGENETIC AND PETROPHYSICAL BEHAVIOR OF ANCIENT CARBONATE MOUND SYSTEMS

The processes learnt from recent carbonate mound studies play a primordial role to understand ancient carbonate mound systems and their reservoir interests. What are their structural and basinal settings? Which palaeo-environmental parameters controls mound growth? Are the cyclic records observed in recent carbonate mounds a primary template to understand reservoir compartmentalization? What is the impact of early diagenesis on carbonate dissolution, precipitation, dolomitization, porosity and permeability? Do cementation processes play an important role in mound consolidation? How affect hydrothermal processes mound diagenesis in a later stage? What is the microbial role in triggering diagenetic processes and therefore in creating and/or occluding porosity and permeability?

The petrophysical characterization of sub-recent cold-water carbonate mounds is mainly determined by two factors: (1) their primary sedimentary texture and (2) the influence of sub-recent diagenesis. The aragonite dissolution and the genesis of semi-lithified horizons with minor precipitation might form a template for late diagenetic processes (Fig. 3) (Foubert & Henriet, 2009). Understanding (1) the functioning of a carbonate mound as biogeochemical reactor triggering early diagenetic processes and (2) the impact of early diagenesis on the petrophysical behaviour of a carbonate mound in space and through time are necessary (vital) for the reliable prediction of potential late diagenetic processes and for the understanding of the transformation of a recent carbonate mound body in the fossil record. When thinking in terms of reservoir systems (and their petrophysical characteristics), it should be mentioned that late diagenetic processes (burial diagenesis, hydrothermal processes), compaction and fracturation might play an important role. The better understanding of sub-recent diagenetic processes and their impact on the primary fabric and petrophysical

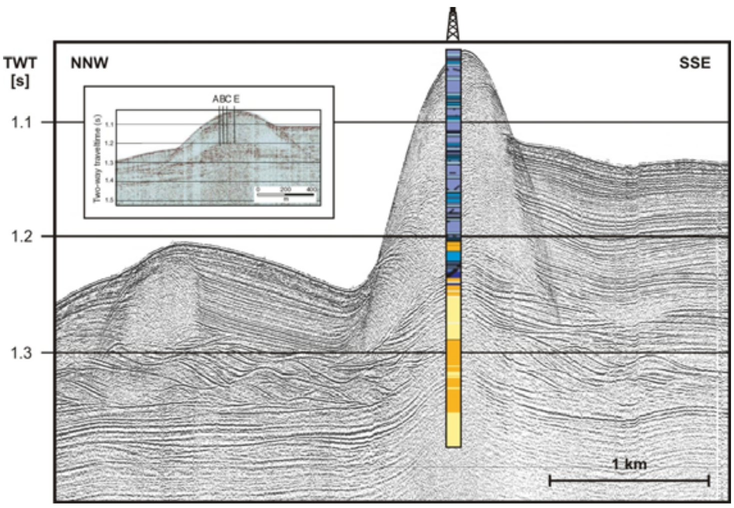

Figure 2. High-resolution seismic profile illustrating Challenger Mound and its environmental setting (modified after Henriet et al., 2002). The drill locations (IODP Expedition 307) are visualized.

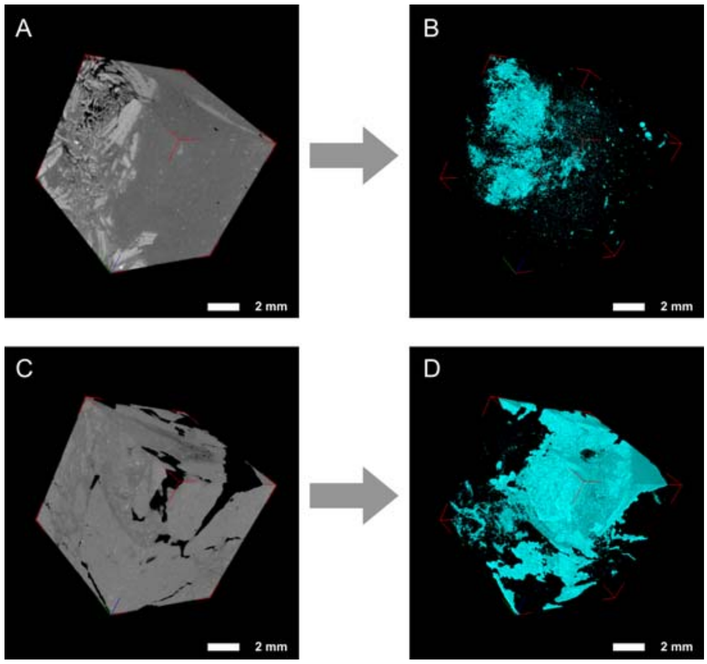

Figure 3. Micro-CT scans representing bioclasts, matrix and porosities (left panels) and porosities (right panel). (A, B) Moldic porosity around cold-water coral fragment. (C, D) Secondary fracture porosity in semi-lithified layers (Foubert & Henriet, 2009).

characteristics of a mound might help to understand and predict the occurrence of later diagenetic processes. The sub-project 4D PETROCARDE aims to understand the 4D diagenetic and PETROphysical behavior of cold-water CARbonate bodies in Deep Environments through time (4D-PETROCARDE). Within this scope, drilling of ancient mound bodies is envisaged through ICDP (International Continental Drilling Program).

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