COCARDE: An Industry-Academia Partnership for the Study of Cold-Water Carbonate Reservoir Systems in Deep Environments*

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Abstract

Prepared by tens of oceanographic cruises of the flagships of European oceanography, IODP Expedition 307 drilled in 2005 for the first time a giant cold-water carbonate mound off Ireland, exposed at the seabed in water depths of 900 m. The ESF project CARBONATE has the objective to drill in August 2008 several mounds in the Porcupine and Rockall basins with Europe’s most advanced robotic seafloor drilling system – the “MeBo” – capable of drilling to 70m below the seafloor. In the wake of these expeditions, a unique opportunity is shaped to provide an integrated insight to cold-water carbonate reservoir systems on the European and North African margins, as an onset of a trans-Atlantic venture, through a teaming up of the academic mound research community and the hydrocarbon industry.

The exciting research subject of mounds as a fundamental strategy of Life throughout the history of the Earth meets the increasing Industry interest for cold-water carbonate reservoirs. COCARDE Phase 1 (2009-2012) prepares the drilling of two major cold-water carbonate mound provinces off Morocco, one on the Atlantic margin and one on the Mediterranean margin. Both provinces feature to a variable extent active fluid flow (mud volcanoes, etc.), which controls in various ways the early diagenesis of these carbonate reservoirs.

In addition to scientific advances, COCARDE shapes a win-win opportunity of jointly coaching motivated, multi-disciplinary young scientists towards scientific excellence in a field of high industrial interest: Deepwater Carbonate Systems and Reservoirs.

IODP Expedition 307 on Challenger Mound, West of Ireland

In April 2005 the Integrated Ocean Drilling Program's (IODP) research vessel Joides Resolution sets sail from Dublin to drill Challenger Mound, a 155 m high carbonate mound in the middle of the "Belgica Mound Province" discovered in 1997 in water depths of 900 m in Porcupine Seabight, west of Ireland (Henriet et al., 1998). For the first time in history, a giant carbonate mound, fully exposed on the seafloor, is drilled and sampled at very high resolution in an integrated paleo-environmental and biogeochemical/microbiological core flow. Teams from Europe, the US and Japan joined forces to unravel both a 2.5 million year record and the actual signature of pore fluids (Kano et al., 2007). Cold-water corals are found from top to base.

IODP Expedition 307 in Porcupine Seabight came as a first culmination of a sustained effort of 8 years of Europe-driven research on modern carbonate mounds and cold-water coral reefs, in the framework of the EU projects CORSAIRES (FP4), GEOMOUND, ECOMOUND, ACES and the RTN EURODOM (FP5), HERMES (FP6), the ESF EUROCORES projects MoundForce (Euromargins), MiCROSYSTEMS (Eurodiversity) and CARBONATE (EuroMarc), the IOC-UNESCO TTR programme and various national projects. Flagships of European oceanography have surveyed these mounds, some of them year after year, in tens of cruises. About all tools of modern ocean science have been deployed: high-resolution 2D/3D seismic, deeptow seismic, surface and ROV-born multibeam bathymetry, sidescan sonar imaging at a range of frequencies, coring devices from multicorers to the Calypso giant piston corer, remotely operated vehicles, landers, moorings, etc.

In the wake of IODP Exp. 307, the ESF CARBONATE project will drill in 2008 further mound targets both in Porcupine Seabight and Rockall Basin, west of Ireland, in particular to assess mound variability. The drilling and coring tool will be the "Meeresboden Bohrgerät" (MeBo) of MARUM in Bremen, a revolutionary robotic coring system lowered on the seafloor from mission-specific vessels and capable of coring and drilling as much as 75 m of non-consolidated or consolidated sediments below seafloor.

The Morocco Margin Mounds

Waiting for Joides Resolution, RCMG at Ghent University successfully proceeded with the exploration of the European and North-African margins further south, which led to the discovery in 2002 of clusters of carbonate mounds with associated cold-water coral reefs in the middle of a field of giant mud volcanoes on the Moroccan margin (Van Rensbergen et al., 2005). The "Pen Duick Escarpment" mounds (Foubert et al., 2008) form the target of a new IODP proposal (673), which jointly with proposal 689 on the proximal Mercator mud volcano (PI D. Depreiter), got the green light for a full proposal (submission 09/2008).

The Porcupine and Rockall mound provinces are located on the rims of basins with recognized hydrocarbon potential, and the Belgica mounds are located right above a modelled hydrocarbon migration pathway (Naeth et al., 2005). Still, the possible link with fluid flow remains elusive and debated. On the Challenger Mound site, a zone of anoxic oxidation of methane (AOM) has been identified below the base of the mound. In contrast, the mounds off Morocco fully co-occur with various surface expressions of fluid flow: mud volcanoes, authigenic carbonate crusts, chimney fields, etc. Coral-stuffed cores release a very strong smell of hydrogen sulfide and argue for an AOM at a depth of 3.5 m below the top of the mound. Horizons with strongly corroded corals alternate with horizons of carbonate precipitation (Foubert et al., 2008), which includes authigenic dolomite (S. Templer, ETH-Zürich, in prep.). We clearly have discovered off Morocco a biogeochemical “mound kitchen”, an active “cold-water carbonate factory” where oceanic, biological and geological fluxes of matter and energy meet and interact to build large carbonate build-ups and/or transform them through processes of early diagenesis.

Carbonate Mound Research

Since the 1997 discovery, numerous studies have focused on the living cold–water coral ecosystems along the Atlantic and Mediterranean margins, largely driven by conservation issues. However, in parallel with this significant momentum within the Life Sciences domain, there is a prominent and pioneering concept in the Earth Sciences which moves to the foreground, of both fundamental and applied interest: the functioning of these giant bioreactors, the early shaping of such carbonate build-ups, which are recurrent throughout the geological record, and which in many geological settings have turned into promising but complex reservoirs of hydrocarbons.

What we do read throughout the geological record is the “red thread” of the role of microbial activity in mound build-up and transformation (Henriet et al., 2003). Elucidating the microbial diversity and functionality in cold-water coral ecosystems and mounds is the challenge of the ESF EUROCORES Eurodiversity project MiCROSYSTEMS. A sound understanding of the microbial activity and role in mounds, however, requires a thorough grasp on the fluxes of mass and energy. Studies on both Challenger Mound and the Morocco mounds give a first insight in modern mound porosity development and early diagenesis. They give evidence of an early open system diagenesis, where carbonate dissolution largely exceeds precipitation (Foubert et al., 2008).

Such observation tightly supports a model of mounds as active hydrogeological systems – active as long as they are exposed to strong currents on the seabed. In the framework of a PhD (2008), Davy Depreiter is modelling the current-induced convective flow in mounds, both at a whole-mound scale (residual flow) and in the shallow subsurface (tidal pumping). The latter phenomenon, which is believed to be of fundamental importance in particular inside the thick open dead coral rubble frameworks brought to the foreground by recent ROV surveys off Morocco in 2007 (CADIPOR 3 cruise), is a pioneering idea. It drives new projects around the concept of the “grand coralline GRaveyards’ Inner Life Systems” (GRAILS), which is kicked off by an international cruise of R/V Marion Dufresne in July 2008.

The verification of the concept of mounds as active seafloor hydrogeological systems is within reach, through a totally innovating approach of seafloor experimentation. Turning an accessible mound into an experimental field laboratory is the real challenge for the next decade of research on carbonate mounds.

For assessing the hydrogeological characteristics of mounds, in particular through the study of the propagation of tidal pressure waves, or of pressure waves induced by sudden current surges (observed with landers), we study the feasibility of deploying sensors both in the shallow subsurface (ROV or Lander deployments) and in the core of a mound (‘lost’ MeBo instrumented strings). The probes would comprise pressure sensors, acoustic sensors and various chemical sensors, the latter mainly to be deployed in the uppermost layer of active tidal pumping. All probe components should be fully buried below the mound surface, as a total protection against deep trawling. Data downloading and battery charging would happen through inductive coupling, though innovative concepts of in situ re-fueling of batteries through natural processes in these live bioreactors are well advanced. The periodic data recovery, processing and management can optimally be organized by our Moroccan partner teams with vessels of opportunity. The acoustic sensors allow a high-resolution acoustic tomography of the mound, to unravel the full 3D zonation in physical properties.

A pilot coring exercise with MeBo on the targeted mounds is, however, needed to assess the optimal dimensioning of the MeBo sensor strings, function of the lithology and porosity/permeability structure of the mound. An operational opportunity for MeBo drilling has been provisionally secured in January 2010, which would ideally fit with a possible window of opportunity for a complementary IODP deeper drilling. If we can firmly fix this drilling window by securing as soon as possible the minimal operational costs, we could score on two fronts: (1) the chances of IODP proposal 673 would significantly enhance, the more by the scientific added value of completing the (deeper) IODP exercise by a number of shallow MeBo wells over several adjacent mounds, all properly logged over their whole length (including the IODP site), and (2) all lithological parameters required for the optimal dimensioning of the sensor string (type, number, spacing) in a concept of prototype mound observatory would be made available.

Where Frontier Science and Industry Meet

Palaeozoic cold-water carbonates may form significant reservoirs of hydrocarbons, from natural gas to heavy oil, worldwide. While many of these carbonate formations are associated with outer shelf or upper slope settings, Industry increasingly identifies carbonate systems which argue for a deeper origin, down to 1000 m. This is the depth range of the presently discovered modern mound provinces.

Over the past ten years of modern mound research, our community has accumulated new insights in (i) the structural and basinal setting of mound provinces, (ii) mound province landscapes, (iii) mound size and composition, (iv) key players and oceanic controls, (v) possible primary templates for mound reservoir compartments, (vi) fluid migration pathways and implications for reservoir connectivity, (vii) early diagenesis, carbonate dissolution and precipitation, dolomitization, and hence (viii) controls on reservoir porosity, permeability and compartmentalization. These are topics of outspoken interest for the hydrocarbon Industry.

While consequently obvious potential topics of interest from Industry may be identified in modern mound research, reversely, academic and fundamental scientific research on carbonate mounds may dramatically benefit from the interaction with the hydrocarbon industrial community. Cooperation with Industry indeed may open vast perspectives of an increased access to the vast industrial database on fossil cold-water carbonate reservoir systems, to better confront the observations from the modern ocean with those of the geological record. Only through this approach, we may possibly elucidate a strategy of Life, nearly as old as Life itself – a clear opportunity for a win-win case.

Moreover, at a time when the hydrocarbon industry addresses the more complex reservoirs worldwide – the easy work having been done – it expresses an outspoken interest for the type of recruitment pool which our community is shaping. The present level of recruitment by the research departments of leading oil companies is encouraging, but more young brains are needed in the near future. This is a second opportunity for a win-win case: through an intelligent partnership scheme with Industry, we claim to be able to contribute in a significant way to a sustained flow of top-level Earth scientists for Society and Industry, at least in the next 8-12 years.

These elements form the rationale for an ambitious but sustainable Industry-Academia Partnership which we venture to shape between the academic community investigating modern mounds (the Academic Consortium s.l.) and an Industrial Consortium (s.l.): COCARDE – “COld-water CArbonate Reservoir Systems in Deep Environments”.

COCARDE Concept and Strategy

COCARDE is a proposal for a flexible and modular Industry-Academia Partnership to consolidate and amplify a sustainable mound research and capacity building momentum:

(i) the Spirit: "Open Innovation" in mutual respect of the academic and industrial cultures, which implies opportunities of publication of scientific results and equitable terms on technological IP,

(ii) the Plan: A flexible and modular scheme of science-driven flag actions – 4 years Science Plan and Joint Industry Project or JIP – structured in two-years operation and exploitation phases, on which a continuing flow of PhD's can nucleate,

(iii) the Resources: A backbone of industrial support plus add-on funding and co-funding from ERC, EC, ESF and national funding sources for start-up, further operational support, prototype development and demonstration, networking, exploitation, capacity building, outreach, partnership with SME's, etc., to be addressed at the pace of the calls.

<u>The COCARDE Architecture</u>
COCARDE comprises 4 Task Groups: COCARDE-Forum, COCARDE-Science, COCARDE-Operations and COCARDE-Capacity. These form the 4 pillars of a cost-efficient, distributed management scheme. A Coordination Cell is the central contact point of the project.

The task of COCARDE – Forum (coordination Fribourg University, Switzerland) is mining for ideas and opportunities of cooperation between the academic mound research community and Industry. COCARDE – Science (coordinated by IFM-GEOMAR Kiel) translates the ideas collected into workable 4-years Science Plans and JIP, scouting for the required capacity in the academic world and designing attractive project architecture. Ideally, any JIP should comprise two operational flag actions, one in the first term of two years, the other one in the second term, to generate a quasi continuous flow of PhD's. PhD applicants would thus be offered the perspective of at least one major data acquisition within a 3- to 4-years fellowship term, on which their research could nucleate. With such perspective, they can build a convincing case into their grant application.

COCARDE – Operations (MARUM, Bremen) takes the lead of the operations and logistics of the COCARDE JIP and plans the 2-years operational terms. It is based at MARUM in Bremen, which designed and operates the MeBo drilling system. Bremen moreover features one of the best equipped IODP core repositories and it provides spacious facilities for core curation, description and sampling, geophysical and XRF core scanning, data management (Pangaea), etc. Bremen would – where relevant – manage the subcontracts of potential services such as vessel chartering, etc., also in case of non-MeBo operations.

COCARDE-Capacity (Ghent University, Belgium) is an important background task of COCARDE, essential to stimulate and optimally prepare the input flow of PhD candidates into COCARDE Science. Networking dynamic master programmes throughout Europe and beyond, stimulating professional apprenticeships and temporary staff secondments between Industry and Academia to strengthen graduate/doctoral schools and make them better meet the needs of Society and Industry, gathering industrial support for onshore/offshore field courses and training: these are challenges of COCARDE-Capacity.

Draft Science Plan

The draft of a first Science Plan is in principle the task of COCARDE-Science; still it steadily takes shape from the ongoing dialogue with Industry. The AAPG meeting in Cape Town in October 2008 and the COCARDE Kick-off Workshop scheduled January 2009 in Fribourg will be significant further forums. As "kick-off" draft is proposed: "The Mound Factory at an Ocean Basin scale: Integrated North Atlantic Mound System Study" (2009-2012).

Phase 1a (2009-2010): In the wake of IODP Exp. 307 (2005) and the ESF CARBONATE MeBo drilling (2008) West of Ireland, we venture to drill the Morocco margin mounds in the January 2010 MeBo time slot. Resources permitting, we might consider a two-leg cruise to drill the Pen-Duick mounds on the Atlantic Moroccan margin in a first leg, and the Mellila mounds in the Alboran Sea in the second one. This would allow a most stimulating comparative deciphering of the environmental records in both mounds, no doubt documenting the history of the Mediterranean-Atlantic interchanges during Quaternary times. At the conclusion of COCARDE Phase 1a, all major mound provinces on the European and North-African margins – both Atlantic and Mediterranean facades – would hence be thoroughly documented. Resources permitting, a 3D high-resolution seismic coverage of mounds could be considered in parallel, while pilot studies towards developing a mound observatory could be launched.

COCARDE Phase 1b (2011-2012): Depending on the development of further contacts with our US and Brasilian partners, COCARDE could contribute to initiatives to drill the Florida Strait mounds and/or mounds discovered on the Brasil margin, which would allow the assessment of a possible trans-Atlantic connectivity between mound provinces.

A second Science Plan taken into consideration is "New Views on Old Mounds: Recent versus Ancient, Offshore-Onshore Comparative Study". This could be scheduled for the second JIP (2013-2016), or alternatively – resources permitting – start in parallel with actions in the first JIP. The idea is to visit or re-visit whole-mound surface outcrops and drill and analyze them as far as possible with similar analytical protocols, as nowadays applied in oceanic core studies, to refine interpretational keys.

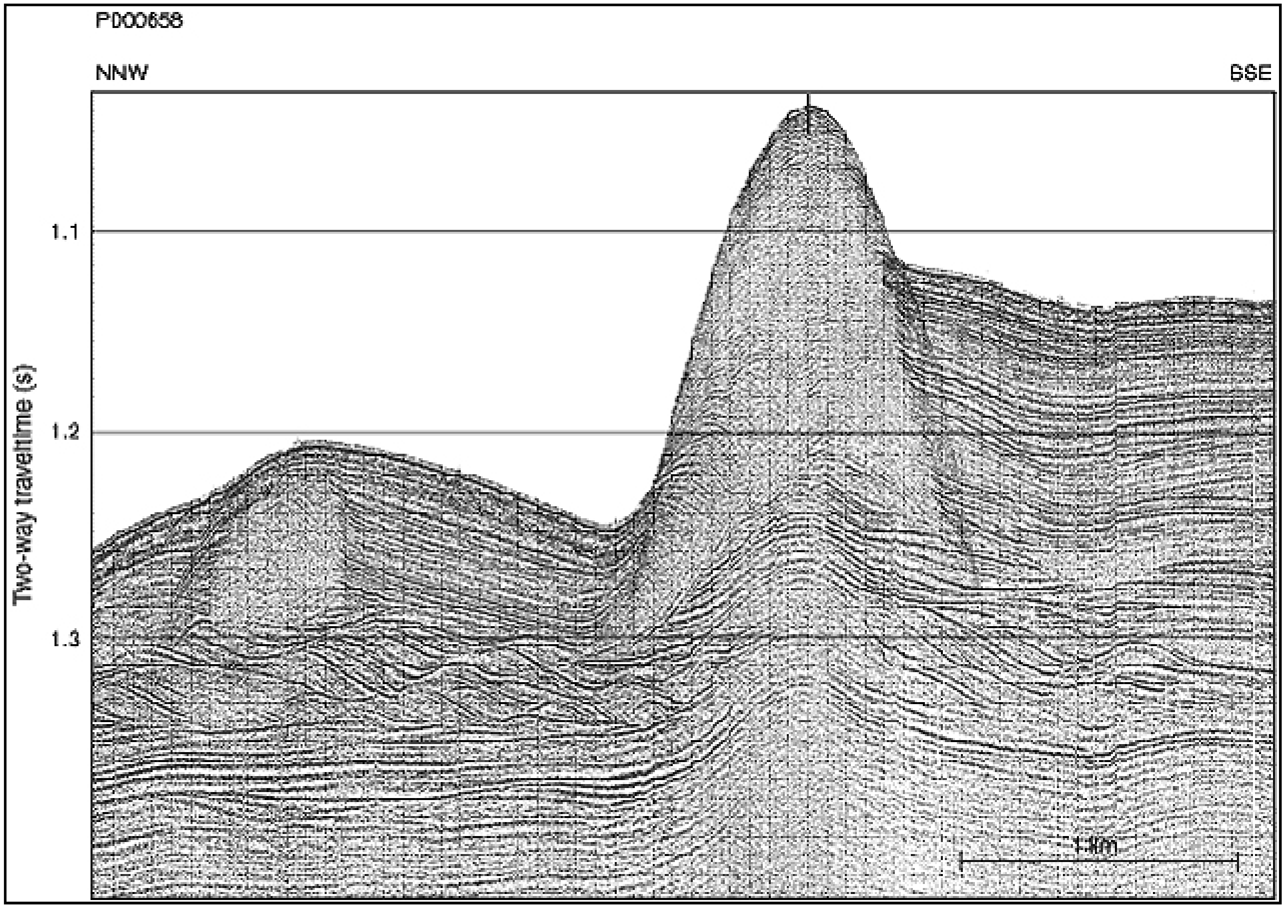

Figure 1. Seismic profile of the Challenger carbonate mound west of Ireland.

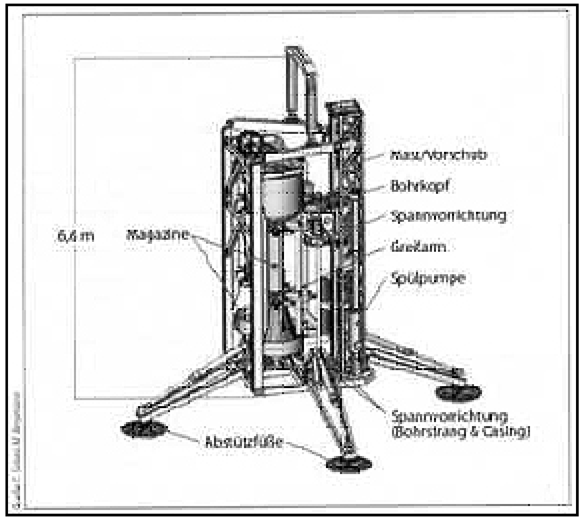

Figure 2. The drilling and coring tool “Meeresboden Bohrgerät” (MeBo) is a revolutionary robotic coring system lowered to the seafloor from mission-specific vessels and capable of coring and drilling 75 m of non-consolidated or consolidated sediments below the seafloor

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