Cocarde Workshop and Field Seminar

Recent and Ancient Carbonate Mounds in Morocco

Rabat, Morocco, 24-30 October 2011

Organized by

Faculty of Sciences, Mohammed V – Agdal University, Rabat, Morocco

Renard Centre of Marine Geology, Ghent University, Belgium

Ibn Battuta Center, Cadi Ayad University Marrakech, Morocco

International University of Rabat, Morocco

The Office National des Hydrocarbures et des Mines (ONHYM), Rabat, Morocco

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Report

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1. Summary

Some 10 years after the first reporting of Recent carbonate mounds off Morocco, the 2011 Cocarde workshop in Rabat has offered an opportunity to assess achievements of past oceanographic cruises, to build bridges between studies of Recent and Ancient carbonate mound systems and to exchange views about prospective actions in the future.

In coherence with Cocarde's capacity building mission and its vision on a holistic approach of carbonate mounds through geological time as a key to fundamental and applied insights and breakthroughs, the workshop was introduced by a full-day, open-access tutorial event, conceived as a voyage through time, space and Geosphere-Biosphere coupling processes in Recent and Ancient carbonate factories in Morocco and elsewhere.

The second day had been made available for targeted strategic meetings, to discuss possibly innovative approaches in carbonate mound research in Morocco on Recent and Ancient mounds - offshore and onshore - and to review opportunities of international collaboration. In addition, the PhD and postdoctoral researchers could present their research in a concise way.

A task group of 31 Moroccan and European scientists, with a balanced mix of senior scientists and PhD and postdoctoral researchers, has visited a number of field outcrops of carbonate mounds and carbonate factories from Ordovician to Jurassic ages in the Central High Atlas and eastern Anti-Atlas. The field seminar had been carefully prepared by the redaction of a comprehensive guidebook. During the field seminar and in the wake of the workshop and field action, various tracks for further research have been explored and phrased. The potential documentation of a future "Moroccan mound reference route" for capacity building and international outreach is part of the challenge.

2. Scientific content and discussions - COCARDE Workshop and Field Seminar (Rabat, October 24-25)

2.1 Scientific content

The tutorial day of the ***Workshop*** (see Annex 1), hosted by the Faculty of Sciences of Mohamed V University in Rabat was well attended by 45 scientists from Morocco and Europe, among them 12 PhD and postdoctoral grantees of the Cocarde-ERN network (6 European, 6 Moroccan). In addition, 32 students from Mohamed V University in Rabat, 9 students from Hassan II University in Casablanca and 7 students from Kenitra University had registered for the tutorial day and could attend the presentations in variable configuration (Fig. 1) (lists of participating institutions and registered participants in Annex 2).

Figure 1. Participants of the COCARDE Workshop and Field Seminar at the Faculty of Science, Mohamed V University in Rabat, Morocco, on Monday, 24 October 2011.

The workshop was opened by Prof. Said Amzazi, Dean of the Faculty of Sciences, who highlighted the longstanding record of collaboration of Moroccan and European teams in the concerned scientific field. Dr. Alexei Suzyumov welcomed the participants on behalf of IOC-UNESCO and framed the Cocarde initiative on the background of the successful IOC-UNESCO "Training-through-research" endeavour. Prof. J.P. Henriet outlined the structure and objectives of the workshop, evoking Morocco's potential to offer to Science and Industry a reference route of exceptional outcrops and field laboratories for the study of carbonate mound systems, which one day might qualify for a UNESCO world heritage label.

In subsequent presentations, scientists reviewed the state of the art in carbonate mound studies, sweeping through geological time and zooming in on processes and methods. An outlook on technology and industrial research concluded the tutorial day. Short contents of the presentations are collected in the Programme and Abstract book (Annex 1).

The second day was introduced by a Round Table hosted by the Office National des Hydrocarbures et des Mines (ONHYM). Dr. Haddou Jabour reviewed the current plays in hydrocarbon exploration in Morocco, both onshore and offshore. The re-visiting of vast data sets and the emphasis on integrative studies, to confront field data with subsurface information, opens new opportunities for collaboration with academia, not the least in the study of non-conventional resources and frontier systems.

The afternoon sessions were hosted by the International University of Rabat at the Technopolis site, a private venture with international and industrial partners, operating under a Development Contract of the Government. As part of the team building exercise in view of the subsequent Field Seminar, the Cocarde-ERN grantees from Morocco and Europe presented some highlights of their research in "flash" presentations of some 5 minutes. This session was concluded with an exchange of views on opportunities for collaboration in ocean sciences, carbonate systems and reservoir studies, also in preparation of further prospective discussions during the Field Seminar.

The ***Field Seminar*** had been thoroughly prepared by a major effort of local research teams from Marrakech and Rabat universities and their international partners (Abdellah Ait Addi, Roberto Barbieri, Joseph Canérot, Barbara Cavalazzi, Driss Chafiki, Fulvio Franchi, Naima Hamoumi, Kamal Taj-Eddine), which resulted in a highly informative Guidebook. The initial programme of Friday 28 October (cfr. Programme and abstract book, Annex 1) was modified in common agreement to carry out an exploratory raid on a unique site of Carboniferous Waulsortian mounds, described by Wendt et al. (2001). The Ibn Batutta Mars missions test site visit planned for Saturday 29 October was skipped to maximize the observation of the Ordovician setting in Alnif. The Jurassic and Bajocian mound sites of the High Atlas, reached at dusk on Wednesday 26 October, were re-visited the morning of Sunday 30 October.

In response to this preparatory effort, a number of participating scientists (Roberto Barbieri, Anneleen Foubert, Philippe Lapointe, Philippe Léonide, John Reijmer, Andres Rüggeberg, Elias Samankassou) have been invited to express views on scientific challenges and opportunities. This brainstorming exercise, compiled during and shortly after the field seminar, adds to the information and views brought by the teams presently active on various visited sites and is summarized below, as a possible nucleation point of ideas and actions.

2.2 Discussions

The ***Workshop*** compared Recent with Ancient mounds. To allow adequate reconstructions of the paleo-environments, the use of similar tools is necessary. Isotope and element ratios determined in carbonate material have the disadvantage that they may be overprinted by diagenetic alteration or recrystallization during burial processes, especially in aragonitic material. However, the continuous progress of new tools in line with new technical and instrumental development helps to overcome the difficulties of comparing different mound settings.

Clumped-isotopes (isotopologues of CO_2) for instance were discussed in more detail as they provide a powerful tool in reconstructing temperatures of carbonate precipitated material far back in geologic time. In comparison with $\delta^{18}O$ – the best-known and established temperature proxy – the advantage of clumped-isotopes is the independency to the oxygen isotope composition of the water in which the carbonate precipitated (Gosh et al. 2006). This is important especially for the study of marine sediment records of critical time periods, when the $\delta^{18}O$ of seawater is not well constrained (Schmid 2011). However, there are limitations like the precision of 10 ppm resulting in quite a large temperature uncertainty of 2 °C, or the existing calibrations only on Recent carbonates in a temperature range between 1 and 70 °C (see Schmid 2011 and references therein).

Nevertheless, clumped-isotope studies so far reconstructed for example Arctic land surface temperatures of early Pliocene (Csank et al. 2011), seawater temperatures from belemnite guards of Early Cretaceous (Schmid 2011), from aragonitic molluscs of the Carboniferous, and from brachiopods of Early Silurian (Came et al. 2007), or formation temperature in dolomites of Triassic Latemar carbonate build-ups (Ferry et al. 2011).

At the ***Round table*** at ONHYM on Tuesday 25th October 2011, Dr. Haddou Jabour introduced the "source-to-sink" approach as an important nucleus for collaborative basin research, not the least in frontier reservoir systems.

During the ***Field Seminar*** (Fig. 2) different paleo-environmental, pure carbonate- sedimentological to diagenetic and petrophysical questions were addressed with a perspective on the nature and significance of the visited carbonate mound systems. In addition to early carbonate systems of Ordovician times, several large-scale carbonate mound settings were visited: (1) Jurassic mounds, (2) bioclastic Carboniferous mounds, (3) Devonian Kess Kess mounds and Hollard mound (mudmounds related to/altered by fluid dynamics), and (4) a seep-related Silurian mound. The mounds are part of a whole sedimentary system. Studying the whole system and the entire sedimentary environment is necessary to understand the processes of mound genesis (generic mound classification), mound build-up (internal structure) and mound alteration (diagenesis).

Figure 2. Intense discussions at Ordovician carbonate outcrops introduced by Prof. Naima Hamoumi.

(1) Jurassic mounds: carbonate mounds rich in siliceous sponge spicules preserved as calcite-cemented molds are widespread in the Phanerozoic rock record. Liassic sponge mudmound sites along the transect Midelt – Errachidia have been visited during the COCARDE Field Seminar 'Ancient Carbonate Mounds in Morocco'. The detailed stratigraphical, sedimentological and geodynamic context has been presented by Prof. Driss Chafiki and Prof. Abdellah Ait Addi (University of Marrakech). The development of those Jurassic sponge mounds seems to be biologically controlled in a specific basinal and paleo-environmental context. However, a better comprehension of the processes that stop the mound growth and preserve such geological objects (early and late diagenesis processes) is needed. Similar Jurassic fossil mudmounds are well known at global scale.

Specifically, the Moroccan mounds are perfect analogues in terms of facies, depositional setting, fauna association and diagenetic features to the Aalenian mudmounds recently described from SE France. Interestingly, these mounds are similarly rich in sponge spicules and stromatactis as their Paleozoic counterparts, but the Jurassic stromatactis mounds are silicified, a feature that makes them unique. Recent detailed diagenetic analyses (cement stratigraphy, systematic isotopic analyses on different cement phases in stromatactis, fluid inclusions in well-defined cements) have shown the importance of early diagenetic processes on the early recycling of silica within these sedimentary bodies and on the control of the mounds stabilization and preservation.

(2) Bioclastic Carboniferous mounds: the absence of vegetation and erosion has exhumed Visean carbonate mounds in the Moroccan Anti-Atlas, making of this area an ideal site for research. These carbonate mounds (Fig. 3), described by Wendt et al. (2001), were visited during the COCARDE Field Seminar. Open questions and potential topics of future research that arose during the field action and subsequent discussions include the overall tectonic and paleogeographic depositional setting, oceanic circulations (e.g. currents and trophic regimes) and the overall ecological and physical conditions that triggered mound growth. These ancient, truly bioclastic mound systems with limited diagenetic alteration, representing bioclastic frameworks intercalating with siliciclastic deposits, may be compared to the recent biogenic carbonate mound build-ups as we encounter them nowadays along the continental margin off Ireland at intermediate water depths.

Figure 3. View from eastern flank of a Visean mound to the next mound further west.

(3) Devonian Kess Kess mounds and Hollard mound: the scenery of this location allows walking on an ancient seafloor (Fig. 4). Together with the Carboniferous mounds described by Wendt et al. (2001), both are scientifically considered to be world heritage carbonate mound outcrops, truly representative to compare ancient mound systems with recent carbonate mound settings. Here we had a demonstration of how methane seepage and hydrothermal fluid circulation influence the mound development and the distribution of the taxa, which allows comparison to the mud mound and coral carbonate mound settings of the Recent Gulf of Cadiz.

(4) Seep-related Silurian mound: the Silurian methane-derived mound of the Middle Atlas represents the oldest known seep carbonate accumulation. Since a number of geological and paleobiological attributes document chemosynthetic processes fueled by fluid seepage, it represent a potential excellent geologic example for in-depth studies on very ancient seep carbonates.

Figure 4. Conical mounds of the Hamar Laghdad (Kess Kess mounds) on a gently dipping seafloor surface (view to NW).

3. Scientific Outlook

3.1 COCARDE OPERATIONS – short-term actions

In the margin of the workshop and field seminar, some task groups could discuss and refine the operational aspects related to the ongoing LIMODRILL ICDP proposal (forthcoming ICDP workshop application, technical specifications of the drilling and logging operations, budgeting, further fund raising, etc.) and the imminent proposal for a German cruise and MeBo drilling on offshore mounds in the Alboran Sea (Melilla mounds) and in the Gulf of Cadiz (Pen Duick escarpment).

3.2 COCARDE SCIENCE – mid- to long-term perspectives

Discussions in the field already identified the need of further investigation and potential carbonate mound drilling initiatives. The ***Jurassic sponge mounds*** from Morocco need detailed diagenetical and geochemical analyses. Opportunities for collaborative projects could develop for instance between the University of Provence, SE France and the University of Marrakech, Morocco, to foster a better understanding of early and late diagenetic processes affecting mound build-up and preservation.

Further investigations on the ***Carboniferous Waulsortian mounds*** should focus on (1) the basal beds, upon which the mounds grew; (2) a critical quantification of mud content, from which microbial precipitation was inferred in the initial study by Wendt et al. (2001), because skeletal components (particularly crinoids) appear very abundant and dominant in the sites visited; (3) the growth dynamics of the entire system (mound core, mound flanks, mound cover beds). Furthermore, (4) comparison to modern mound systems would help to constrain the controlling factors, as pointed out during the field action. Future investigations on the well-exposed Waulsortian mounds in Morocco may significantly improve our knowledge of these enigmatic systems, so common worldwide during the Early Carboniferous. Such investigations appear ideal for collaborative projects involving research groups in Morocco (e.g. Prof. Naima Hamoumi at the University of Rabat, who expressed interest in setting up a research project on Waulsortian mounds). Former scientists from the University of Tübingen (Wendt, Kaufmann, Belka who know well this area and the nearby mounds in Algeria) should be contacted for advice and collaboration.

The exceptional record of Moroccan Paleozoic mounds of the eastern Anti-Atlas, in particular the ***Devonian Kess-Kess mounds***, urge for a good regional geologic mapping and clarification of the chronostratigraphic framework. For future research on this subject the following lines should be developed 1) refined field analyses, in particular comparative investigations of the geometry of the bodies and their facies distribution; 2) the use of the new generations of laboratory techniques; 3) a comparative analysis with modern mounds and their geometries; 4) paleobiological in-depth analyses of invertebrate and microbiological communities. As far as the microbiota is concerned, the tools of investigations should take into account the different types of morphological evidences as well as the molecular evidences (chemo-fossils), possibly preserved in the mounds cement. Some of the above approaches have been undertaken for the conical mounds of the Hamar Laghdad (Kess-Kess mounds) for explaining their (not yet completely explored) genetic processes. They deserve, however, a more systematic approach and the collection of large data sets, with the collaboration of PhD students (from Morocco and abroad). In such ventures, a truly multidisciplinary approach will shape invaluable opportunities. The geologists of the Université Cadi Ayyad, Marrakech (ref. Prof. Kamal Taj-Eddine) and their international partners no doubt have interest for future developments of this research field.

The ***Silurian methane-derived mound*** of the Middle Atlas, presented by Bologna scientists and their partners, represents the oldest known seep carbonate accumulation. Since a number of geological and paleobiological attributes document chemosynthetic processes fueled by fluid seepage, it represent a potentially excellent geologic example for in-depth studies on very ancient seep carbonates. A favorable location (proximity to a main asphalted road) and a reduced aerial extent of this geologic body may also permit to plan drilling operations with a limited budget in order to better investigate key aspects related to the formation and development of the accumulation, which can hardly be settled because of the covering by vegetation and agricultural fields. The drilled material might also provide a complete set of unweathered rocks suitable for standard geochemical investigations (as well as for new geochemical exploration concepts).

3.3 Industry perspectives on mounds

Carbonate mounds are reported throughout the stratigraphic record from the Proterozoic to the Present. They developed on continental margins, in water depths ranging from 1000 to 10's of meters, and represent a target for hydrocarbon exploration. In the past years, there were a number of hydrocarbon discoveries in carbonate mounds, deposited in shallow to deep-water environments, some of significant size. A large part of these objectives were originally misinterpreted as reefs or other carbonates buildups. As per an industry point of view, exploration for carbonate mound targets is a challenging problem.

The main criteria for defining carbonate mounds and particularly deep mounds as valid oil industry objectives imply their identification, location, reservoir potential and petroleum system.

(1) Identification: how to identify and characterize mounds on seismic data, defining simple guidelines to avoid confusion with other carbonate objects, or worse, with volcanoes or mud volcanoes.

(2) Location: what controls their potential location, i.e. where (basin type, continental margin), when (stratigraphic zones prone for their development), and accessory conditions (structural environment, oceanic characteristics).

(3) Questions like "What is the size of the potential tank?" or "What are the general diagenetic trends for these mounds?" help to identify the reservoir potential taking the negative factors of cementing and recrystallization, as well as the positive factors such as fracturing and karst *sensu largo* into account.

(4) For the petroleum system with the potential of oil, the source rock identification (basin type and stratigraphic zones), the burial history, the timing of expulsion/migration, the reservoir creation, and the formation of associated seals need to be identified.

Some of these topics are achieved through bibliographic search or actual mounds studies, on outcrops and cores (marine and continental drilling). They can contribute to a proper basin synthesis. The study of diagenetic processes would require analyses from samples, process evaluation and assessment of the opportunities for development and modeling.

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ANNEXES

Annex 1:

Programme and Abstract Book of COCARDE Workshop, Rabat, Morocco, 24.–30.10.2011

Annex 2:

Participants list of the COCARDE Workshop and Field Seminar, Rabat, Morocco, 24.–30.10.2011

Annex 3:

Financial Report