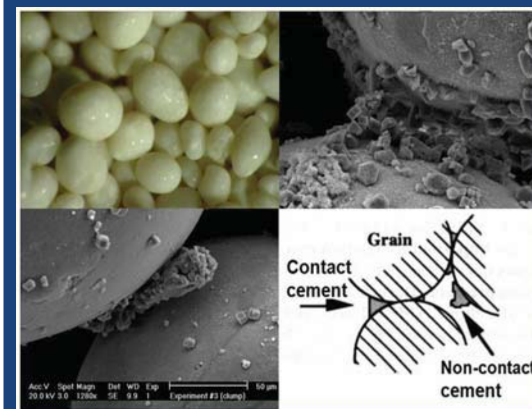
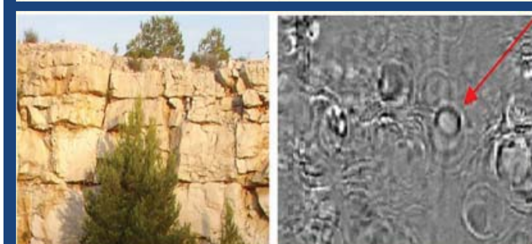
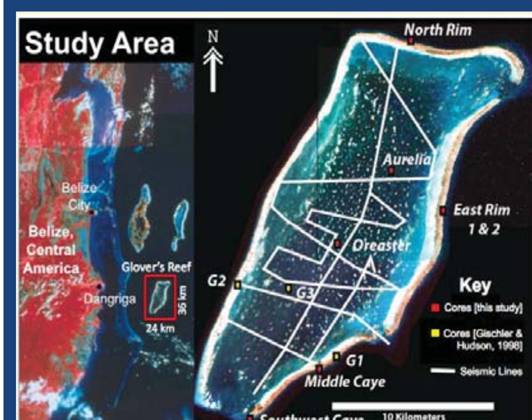
Comparative Sedimentology Laboratory

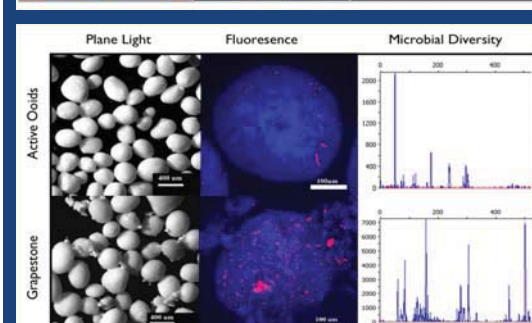
Rosenstiel School of Marine and Atmospheric Science

University of Miami









2011

Research Program Prospectus

Comparative Sedimentology Laboratory

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2011

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CSL

University of Miami

Table of Content

Carbonate Systems and Reservoir Characterization

Mission of the Comparative Sedimentology Laboratory

The mission of the Comparative Sedimentology Laboratory (CSL) is to conduct fundamental science for improved carbonate reservoir prediction and characterization.

To fulfill this mission, we perform multidisciplinary research in geology, geophysics, petrophysics, diagenesis, and geochemistry of carbonates by integrating fieldwork, laboratory experiments, and theoretical studies. New equipment in both the geochemistry and the petrophysics laboratory offer exciting opportunities to address some unresolved questions in diagenesis and petrophysics. In addition, improved geophysical equipment enables us to image the sea floor and the near surface on land. For 2011, the research projects are grouped into the following categories

1. Carbonate Systems and Reservoir Characterization
    - The Platform Top - Processes and Architecture
    - Mixed Shelf Systems
    - Deep-Water and Slope Processes
2. (Bio)geochemistry and Diagenesis of Carbonates
3. Petrophysics and Geophysics of Carbonates

Twenty-four individual projects are designed to address various aspects of these themes. They are described in detail in this prospectus and are retrievable on the website www.cslmiami.info.

Knowledge Transfer

The Comparative Sedimentology Laboratory transfers the research results to our industry partners through annual meetings, our website, and publications. We also offer field seminars and short courses as continuing education for geoscientists in the participating companies.

We present the research results at the **Annual Review Meeting** and provide each company with a CD of our presentations and the publications stemming from CSL sponsored research. On our **website** research results from previous years can be viewed in the archive section, providing a comprehensive data base for many topics and areas. Upon request, we also share original data sets with participating companies.

In 2011, we offer the seminar “Facies Successions on Great Bahama Bank “ (June 20 - 25, 2011) as a field seminar combined with a seismic and core workshop to our Industrial Associates. The field seminar is a platform transect from the leeward to the windward margin of Great Bahama Bank.

Personnel

Gregor P. Eberli*, Ph.D. 1985, Geological Institute ETH Zürich, Switzerland*
Research Interests: Shallo w and deep-water carbonate sy stems; seismic facies analysis and sequence stratigraphy, pe trophysics of carbonates, and mixed carbonate/siliciclastic systems.

Mark P. Grasmueck, Ph.D. 1995, Geophysical Institute ETH Zürich, Switzerland
Research Interests: Applied geophysics , reflection seismic, Ground Penetrating Radar, 3-D and 4-D near surface imaging, reservoir characterization.

James S. Klaus, Ph.D. 2005, University of Illinois
Evolution and extinction of Cenozoic to Recent reef corals, paleoecology of Cenozoic reefs, geo-microbiology of modern coral reef ecosystems.

Donald F. McNeill*, Ph.D. 1989, University of Miami/RSMAS*
Research Interests: Sedimentology and stratigraphic correlation of carbonate and mixed systems, integrated stratigraphy (bio-, Sr-isotope-, magnetostratigraphy).

Peter K. Swart, Ph.D. 1980, King's College, University of London, England
Research Interests: S edimentary geochemistry, stabl e isotope geochemistry, organic geochemistry, global climate change, coral reef sedimentation.

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2011 Research Focus

Shallow and deep-water environments are the focus of this year's research in **Carbonate Systems and Reservoir Characterization.** Three projects investigate the influence of small-scale (5- 15 m) sea-level variations within highstands on the facies arrangement and stratigraphic architecture. In the Exumas, the search for these suborbital sea-level changes is proceeding with facies mapping and drilling of cores through the Holocene and Pleistocene margin strata. A completed drilling transect across reef terraces in the Dominican Republic is the basis for a comprehensive study on facies geometry, diagenesis, and petrophysics of carbonate rocks subjected to repeated cycles of freshwater and marine diagenesis from regional uplift and high-amplitude changes in sea level. In Belize, the diagenetic changes are investigated with petrography and geochemical analysis of the reef succession drilled in several cores. In all three areas, a comprehensive petrophysical characterization of the stratigraphic successions will be conducted.

The prograding Upper Jurassic-Lower Cretaceous mixed carbonate-siliciclastic system mixed system in the major hydrocarbon province of the Neuquén Basin (Argentina) is the focus of seismic outcrop to subsurface correlation. This year's effort will concentrate on constructing a synthetic seismic section based on the outcrop depositional geometries.

A consortium of French scientists invited members of the CSL to participate on a seismic and coring cruise (CARAMBAR) along the slopes of Little and Great Bahama Bank. This cruise, under the leadership of Thierry Mulder, was very successful as it collected multibeam data that produced high-resolution bathymetric maps of the slopes. These maps reveal unexpected morphologies that are generated by gullies, canyons, and spectacular slope failures. The data sets are treasure troves that, when all the research is completed, will advance our understanding of the slope processes, carbonate turbidite distribution, and age and location of the abundant cold-water coral mounds that inhabit this deep-water environment. The CSL will be involved in the investigations of the initiation and causes of the large scale slope failures, the processing of the multichannel seismic data that will be the basis for a refined stratigraphy of the slope strata, and the slope and ages of the cold-water coral mounds. The ongoing project of the slopes and re-deposited carbonates along the Maiella platform margin and the planned description of a core through the time-equivalent strata in the Adriatic will provide a comparison of the young Bahamian slope system with Cretaceous-Tertiary slope-basin strata.

In the **petrophysics laboratory**, the first results using the new Autolab 1000 are emerging and document the wide spectrum of new scientific questions that can be addressed with this new equipment. The Autolab 1000 is capable of measuring not only sonic velocity but also resistivity and permeability under variable confining pressure. The first study of electrical resistivity in carbonate rocks shows that it is controlled by the combined effect of porosity and pore structure, while mineralogy, limestone vs. dolomite, and effective pressure have a limited effect on variations in resistivity. In 2011 these relationships are further tested with experiments in lower porosity rocks and with the incorporation of Mercury Injection Capillary Pressure (MICP) analyses.

Another advantage of the new piece of equipment is that pore fluid can be circulated through the sample. This allows measuring fluid permeability at various pressure. In addition it enables to circulate chemically controlled fluids and extraction of fluids after they pass through the samples for chemical analysis. We plan several experiments of the rock-fluid interaction with chemically controlled fluids and assess both the petrophysical and chemical changes.

The pre-salt reservoir facies offshore Brazil are often compared to stromatolites and/or travertine. We plan to measure the petrophysical properties and quantify the pore structures of samples from both facies.

The **geophysics projects** revolve around near surface investigations using Ground Penetrating Radar (GPR). Understanding fluid flow in the carbonates has been a major topic of CSL research in the lab and more recently at the 1 – 10m scale in the field. One of these projects is an infiltration experiment in fractured Cretaceous carbonates in a quarry in Italy. 4D ground penetrating radar (GPR) surveys allow quantifying of water content changes and tracking flooding/drainage zones through matrix, deformation bands and open fractures.

In the late Barremian strata in the Solvay quarry in Cassis (France), we visualized solution-enhanced fractures with the migration of diffractions caused by open fractures and karst. This year’s project addresses the origin of individual diffractions caused by fractures in order to move from pure delineation of fractures to quantification of fracture properties.

Geochemical Studies are concentrated into four areas in 2011. One project is bio-geochemical in nature. It aims to characterize the microbial community composition of surface sediments collected along an east-west transect of Great Bahama Bank to better understand the role of microbial communities in carbonate precipitation processes, including ooid formation. Inorganic geochemical projects are proposed in three general areas. These three areas are (i) Development of a ‘Clumped’ isotope facility in the Comparative Sedimentology Laboratory, (ii) Refinement of the use of stable C and O isotopes for diagenetic studies, and (iii) Investigation of the use of the carbon isotopes for stratigraphic purposes.

The geochemical capabilities of the CSL have been significantly improved in 2011 with the acquisition of two new stable isotope mass spectrometers. One of these instruments is capable of analyzing C and N isotopic composition of organic material and the $\delta^{13}C$ of gases such as CH_4 and CO_2. The second instrument is capable of measuring the ‘clumped’ isotopes of CO_2. The development of the clumped capability will position the CSL as one of the few facilities capable of making these measurements.

2011 Planned Projects

Carbonate Systems and Reservoir Characterization

- **Stratigraphic Heterogeneity of a Windward Platform Margin, Exumas, Bahamas**
- **Dominican Republic Drilling Project - Year 2: Integrated Analysis of Cores from Reefal Clinothems**
- **Evaluating Porosity Evolution within the Stacked Pleistocene Reef Sequences of Glover's Reef, Belize**
- **Composition and Morphometrics of a Miocene Karst Platform – Los Haitises, Dominican Republic**
- **Synthetic Seismic Modeling of the Mixed Carbonate-Siliciclastic Quintuco Formation, Neuquén Basin, Argentina**
- **CARAMBAR – Deep-water Processes and Coral Mounds along the Slopes of Little and Great Bahama Bank**
- **Core-Seismic Correlation and Physical Properties of Slope Sections; Their Link to Diagenesis**
- **Geometry and Initiation of Large Slope Failure along Little and Great Bahama Bank**
- **Architecture, Distribution, and Sequence Stratigraphy of Cold-water Coral Mounds around Great and Little Bahama Banks**

Laboratory Experiments in Petrophysics

- **Pore Throat Dimensions, "Apparent Cross-sectional Area", and Electrical Resistivity in Low Porosity Carbonates**
- **Rock Fluid Interaction: Velocity Evolution during Controlled Precipitation and/or Dissolution**
- **Petrophysical Properties and Pore Structures of Stromatolites and Travertine**
- **Petrophysical Characterization of Carbonate Turbidites in Outcrop and Subsurface, Maiella Platform, Italy**
- **Petrophysical Characterization of Danian Deep-Water Coral Mounds, Faxe, Denmark**

Near-Surface Geophysics

- **4D GPR for Fluid Flow Quantification in Fractured Carbonates: Cretaceous Orfento Formation, Madonna della Mazza, Italy**
- **Fracture Properties from 3D GPR Diffractions**

(Bio)Geochemical Projects

- **Microbial Characterization of Carbonate Surface Sediments from Great Bahama Bank**
- **Clumped Isotopes: Application to Diagenesis**
- **Decoupled inorganic and organic $\delta^{13}C$ records in periplatform sediments: A global signal unrelated to the global carbon cycle?**
- **Recognition of a Global Diagenetic Isotope Signal**

Costs

The contribution of each Industrial Associate towards the research is **$45,000**. The CSL raises additional research grants from national funding agencies such as the National Science Foundation and the Petroleum Research Fund for many of the proposed projects. For example, most of our deep-water coral work, and most of the funds for new equipment for the geochemical studies, have been made possible by grants from federal funding agencies.

Reporting

The results of the projects will be presented at the **Annual Review meeting in Miami October 10-11, 2011**. In conjunction with the meeting, a fieldtrip to the Belize Barrier Reef and Glover's Reef, an offshore atoll, is tentatively planned for **October 11-15, 2011.**

Carbonate Systems and Reservoir Characterization

Stratigraphic Heterogeneity of a Windward Platform Margin, Exumas, Bahamas

Kelly L. Jackson, Gregor P. Eberli, Donald F. McNeill, and Paul M. Harris[1]
[1] *Chevron Energy Technology Company, San Ramon, CA*

Project Purpose

Windward carbonate platform margins are often assumed to stack vertically during sea level highstands but recent studies document a more complicated architecture of onlapping and overstepping wedges that stack laterally and prograde seaward (McNeill and Hearty, 2009). In addition, there is growing evidence that Pleistocene sea-level highstands contain higher frequency, suborbital sea-level fluctuations (Thompson and Goldstein, 2005). Both factors potentially contribute to significant facies and stratigraphic heterogeneity along windward margins. The objectives of this project are:

1. To address the fundamental question of how high frequency sea-level changes influence the stratigraphic facies heterogeneity.
2. To assess windward margin stratigraphy and heterogeneity through mapping the modern facies and coring the Pleistocene parasequence-scale stratigraphy along the ~200 km windward margin in the Exumas, Bahamas (Figure 1).
3. To deliver a baseline for improved carbonate heterogeneity estimation and reservoir characterization in windward margin settings.

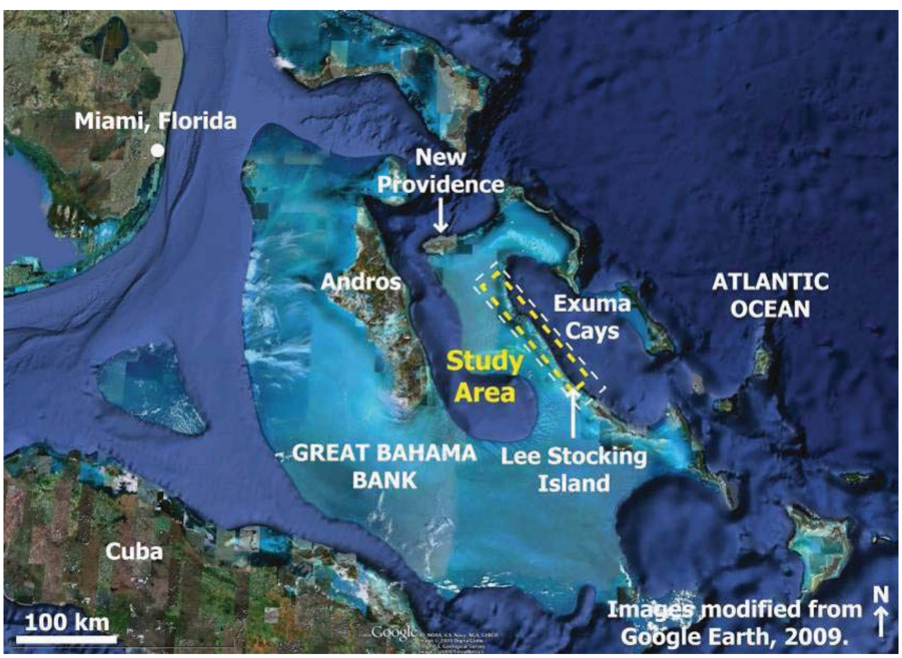

Figure 1: The Exuma Cays are located along the windward margin of Great Bahama Bank forming the western margin of Exuma Sound.

Project Background and Motivation

In the Pleistocene, high amplitude sea-level changes occur quickly due to the waxing and waning of ice sheets. During times of high sea level, carbonate platforms, like the modern Great Bahama Bank, are flooded and a new layer of sediment is deposited. Sea level, however, did not rise to the same level and was not always stable during the highstands. For example, during the last sea-level highstand 125 kyrs ago, marine isotope stage (MIS) 5e, sea level peaked approximately 6 m higher than present and before that fluctuated for several meters (Thompson and Goldstein, 2005). Likewise, older sea-level highstands were also higher (MIS 9 and 11) or lower (MIS 7) than the current sea level. The Quaternary stratigraphy of the Bahamas records the depositional events occurring during highstands in a complicated array of stacked and laterally accreting marine and eolian deposits as seen on Eleuthera Island (Kindler and Hearty, 1996) and New Providence Island (Garret and Gould, 1984; Hearty and Kindler, 1997; Reid, 2010). Along the Exumas platform margin, the highstand variability and impacts of sea-level changes are recorded in stacked successions of shallow water carbonates (McNeill and Hearty, 2009; Petrie, 2010). Furthermore, there is mounting sedimentary evidence that small-scale sea-level fluctuations within the highstands produce an additional layer of complications both for the lateral facies and the vertical stacking.

The Exumas are an ideal location to address some fundamental questions regarding the sedimentary record of carbonates influenced by high frequency sea-level changes and suborbital, small-scale sea-level variations within highstands.

Project Hypothesis and Approach

The central hypothesis of this study is that the windward margin stratigraphic architecture records suborbital sea-level fluctuations within Pleistocene sea-level highstands.

Mapping the modern facies and Pleistocene rocks, and dating Pleistocene parasequences of the Exuma Cays, Bahamas will test this hypothesis (Figure 1). Holocene facies mosaics will be evaluated in respect to the underlying Pleistocene topography. Dating of individual parasequences will relate vertical successions to the different Pleistocene sea-level changes.

Project Tasks

Task 1: Produce detailed geol ogic maps of the Exumas wi ndward margin by combining satellite imagery and surface mapping of the Pleistocene/Holocene strata.

Surface mapping of outcropping Holocene and Pleistocene units in the Exuma Cays Land and Sea Park, an area extending 35 km along the windward margin, was completed in 2010 (Figure 2). During 2011, we plan to continue mapping the northern, central, and southern Exumas. This mapping will be integrated with previous studies by Petrie (2010) to produce a detailed surface geologic map of the Exumas margin that will document the lateral heterogeneity of outcropping Pleistocene units and the complex Holocene accretion that resulted.

Task 2: Collect core transects to establish the vertical succession and stacking patterns at key locations.

A twelve-day drilling campaign is scheduled for March 2011 onboard the R/V Coral Reef II to recover 5 long cores (up to ~20 m deep) at various locations along the Exumas windward margin (red dots, Figure 2) including a second west – east transect at Darby Island. Cores will be drilled using a rotary drill with a tripod and wire-line core barrel system. These cores will complement the five cores drilled in 2009 and the more than 30 short cores (< 1 m) drilled in 2009 and 2010. In the successfully cored wells (yellow dots, Figure 2) recovered strata document the interplay between Holocene and Pleistocene deposits from MIS 5, 9, 11, and potentially 13. Cores feature carbonate grainstones deposited in subtidal, beach, and eolian environments, as well as calcrete surfaces that mark exposure horizons that separate the Pleistocene deposits.

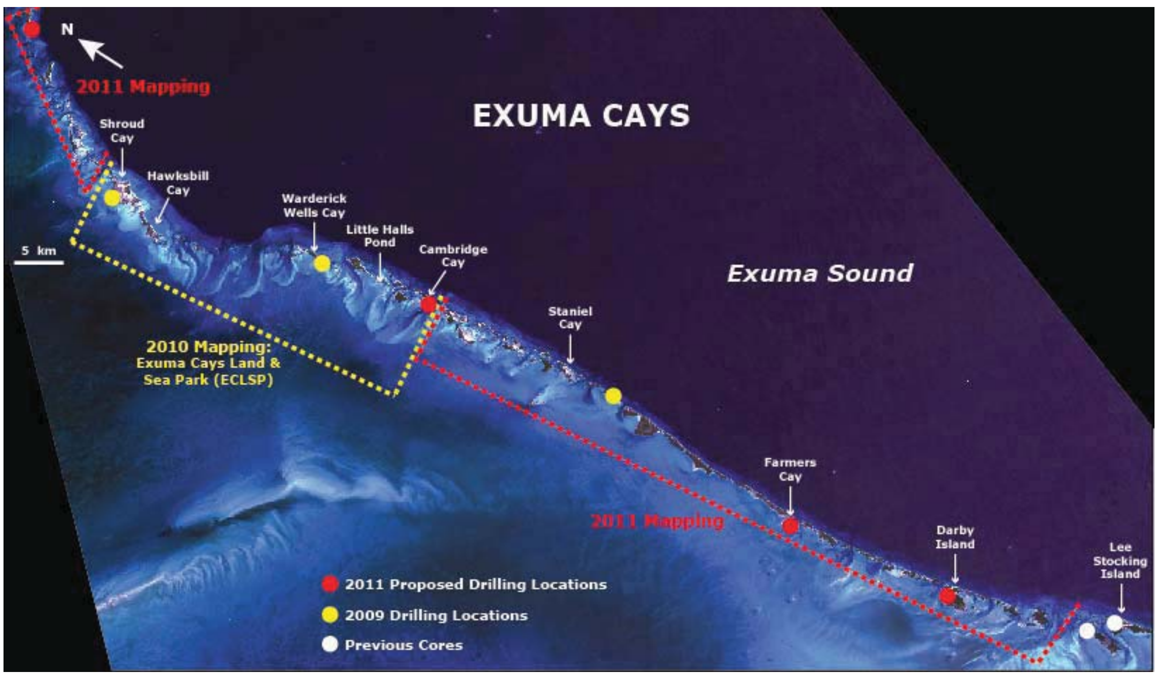

Figure 2: Satellite image of the Exuma Cays indicating region mapped in 2010 (yellow) and proposed 2011 mapping (red). White dots indicate the locations of cores previously drilled that were described and dated by McNeill and Hearty, 2009. Yellow dots indicate locations of the cores (12 – 22 m) drilled in 2009. A transect of three cores was drilled at Warderick Wells. Red dots indicate proposed 2011 drilling locations and will include a transect of two cores at Darby Island.

Task 3: Age dating of Pleistocene and Holocene strata to correlate and decipher the amplitudes of Pleistocene sea-level changes.

The Pleistocene strata will be dated using Amino Acid Racemization (AAR) analyses. In addition to AAR, we also plan to use U-Th dating conducted at RSMAS to try to decipher the ages of Pleistocene units viewed in outcrop and in core.

Task 4: Conduct petrophysical analyses to understand and characterize the reservoir facies of a carbonate windward margin.

Petrophysical analyses will include porosity, permeability, and Vp, under variable confining pressure and pore fluid pressure. The petrophysical analyses will be performed in conjunction with a thorough petrographic analysis to decipher the diagenetic history. Digital image analysis will be used to quantify the pore structures in the various facies and ages.

Expected Results

This study will document the lateral and vertical heterogeneity of the grain-dominated windward margin produced by the sedimentary response to high frequency sea-level changes. The expected outcome is to decipher high frequency variations during the sea-level highstands, and document facies and stratigraphic heterogeneity in relation to the orbital and suborbital sea-level fluctuations during the Pleistocene. Assessing the stratigraphic heterogeneity of a carbonate platform margin will directly impact hydrocarbon reservoir characterization from the rock pore to the platform margin scale in coastal carbonate systems.

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Dominican Republic Drilling Project - Year 2: Integrated Analysis of Cores from Reefal Clinothems

James S. Klaus, Yula Hernawati, Albertus Ditya, Donald F. McNeill, Peter Swart, Gregor P. Eberli, and Ralf J. Weger

Project Ojectives

The principal objective is to determine the facies geometry, diagenesis, and petrophysics of carbonate rocks subjected to repeated cycles of freshwater and marine diagenesis from regional uplift and high-amplitude changes in sea level. The Pleistocene reefs that developed over the past 2.5 million years provide one of the best opportunities to study the complex three-dimensional architecture and controlling factors of fringing reef development during high frequency sea level cycles. A series of laterally stacked reef-skeletal clinothems document successive deposition during uplift and changes in available accommodation space with relative sea-level changes.

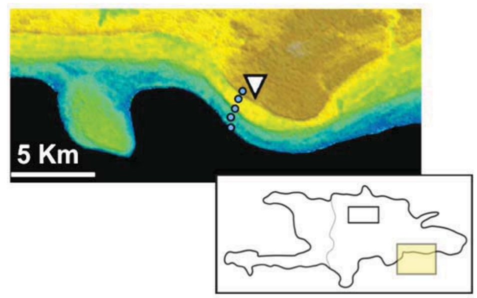

Figure 1: Location of study area and position of the five core transect across the uplifted terraces in the southern Dominican Republic.

Project Overview

In Summer 2010, a five-core transect, sponsored by the Comparative Sedimentology Laboratory, was bored into Pleistocene fringing reef deposits on the southern coast of the Dominican Republic (DR) (Figure 1). These cores are combined with outcrop and quarry mapping performed during several field seasons. This project aims to characterize the composition, morphology, and physical properties of the reefal clinothems and how early diagenesis has impacted these rocks. The work focuses on three main tasks: 1- lithostratigraphy, chronostratigraphy, and facies; 2- geochemical and diagenetic characterization of the clinothem packages; and 3- petrophysical characterization related to depositional facies and diagenesis. Two masters projects are currently underway and during summer 2011 a doctoral student will begin work on a synthesis of outcrop, seismic, and core data.

Key Deliverables

This project will provide an integrated depositional-diagenetic-petrophysical case study of skeletal deposits within a larger siliciclastic-dominated regional framework. The results of this research are expected to provide an understanding of key depositional and diagenetic parameters controlling acoustic properties in reef limestone and the processes that create petrophysical variations. These data will help the geologist improve the interpretation of stratigraphic, seismic, and log data in reefal successions.

Scope of Work

1-Depositional Facies, Chronostratigraphy, and Transect Correlation of Reef Clinothems

(Jim Klaus & Don McNeill, coordinators)

Since reporting on the initial results of the coring at the 2010 Industrial Associates meeting (October), our efforts have been focused on core description and determining the ages of the deposits for core-to-core correlation. We have collected and analyzed a series of strontium isotope samples, mainly molluscs shells, that stable isotope values have shown to be diagenetically unaltered. The initial set of results, returned in December 2010, tentatively date seven depositional packages (Figure 2). These ages are poorly constrained at this point because relatively few samples have been analyzed so far. We will continue to collect appropriate samples for a second phase of Sr-isotopic dating. We will also collect mini-plugs for paleomagnetic analysis to help refine age correlations.

Textural description, depositional facies, and faunal facies of the five cores are underway and will be integrated with outcrop exposures. Seismic data that resolve the upper Pliocene-Pleistocene facies will be evaluated for development of a regional stratigraphic framework. The stratigraphic framework will provide the basis for the diagenetic and petrophysical characterization of the reefal deposits.

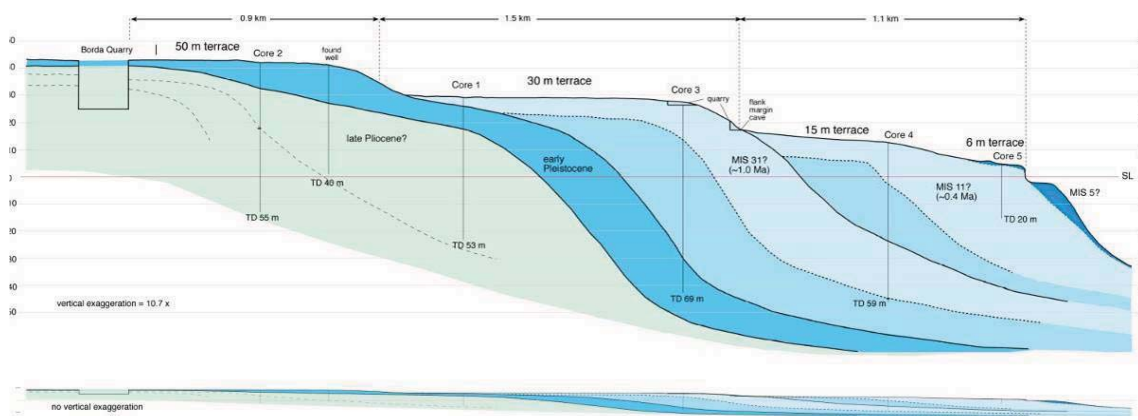

Figure 2. Preliminary stratigraphic correlation of the main depositional units based on initial strontium-isotope age data and the identification of key stratigraphic surfaces within the core borings. Uncertainties still exist in the correlation and additional strontium ages will be determined to refine the stratigraphy.

2 - Diagenesis of Reef Clinothems

(Yula Hernawati & Peter Swart)

The well-developed reef terraces along the southern coast of the DR have undergone several episodes of meteoric diagenesis over the past 1.8 million years as the reefs formed and were subjected to uplift. The uplift produced repeated diagenetic overprints on the older terraces, while the youngest terrace experienced only one episode of exposure. The purpose of this project will be to compare the diagenetic signatures in reefs that have experienced only one episode of exposure with those which have had multiple episodes. In addition, X-ray diffraction has indicated the presence of dolomite in several of the cores. The distribution, volume, and geochemistry of the dolomite will be assessed.

Five long cores (20-69 meters) and several short cores (± 60 cm) were collected from different reef terraces in the southern DR. Samples were collected every 1-2 cm in the short cores and every 10-50 cm intervals in the long cores. Stable C and O isotopes, mineralogy, and trace elements analyses will be performed on all the samples. Diagenetic zones (vadose, freshwater phreatic, and marine) will be identified using sedimentological, petrographical, and geochemical indices. Zones of similar ages will be compared to cores from different terraces.

The classic C and O isotopic signatures accompanying freshwater diagenesis have been described in cores from the Bahamas and Barbados (Allan 1986; Allan and Matthews 1977). The interpretation of such changes have not changed significantly over the past 30 years (Allan and Matthews 1982). In the original work that defined the classic diagenetic zones, no recognition was made of the influence of repeated exposure. This work should help to ascertain whether these signatures change during repeated exposure. The zone of meteoric diagenesis is one of the most promising zone for the development high porosity and permeability, and therefore, the results of this study will be useful for developing a predictive model for the distribution of meteoric and mixing zone induced porosity in carbonate reservoir rocks.

3: Petrophysical Characterization of Reef Clinothems

(Albertus Ditya, Gregor Eberli, and Ralf Weger, coordinators)

This component of the project will characterize the petrophysical properties and the factors that create variations in reefal limestones. We will assess the relationship of pore structure and the petrophysical properties in particular sonic velocity and resistivity. The petrophysical parameters will be integrated with the diagenetic and stratigraphic information to produce a geological and geophysical model of the reef architecture.

Weger et al. (2009) and Verwer et al. (2011) document the strong correlation between quantified pore parameters, such as the perimeter over area (POA) and the dominant pore size (DOMsize) with petrophysical properties such as: velocity, porosity, and permeability and electrical resistivity. Data from outcrop samples corroborate their findings in the reefal limestones investigated from outcrops in the DR (Figure 3).

The recently cored strata have undergone several stages of marine and meteoric diagenesis causing repeated cementation and dissolution that has altered the original pore structures (Anselmetti and Eberli, 1993, 2001). Consistently high acoustic velocities in the hitherto measured samples is attributed to the occurrence of simple pore system created by early meteoric cementation and dissolution, which emphasizes that diagenesis plays a key role in shaping the pore space.

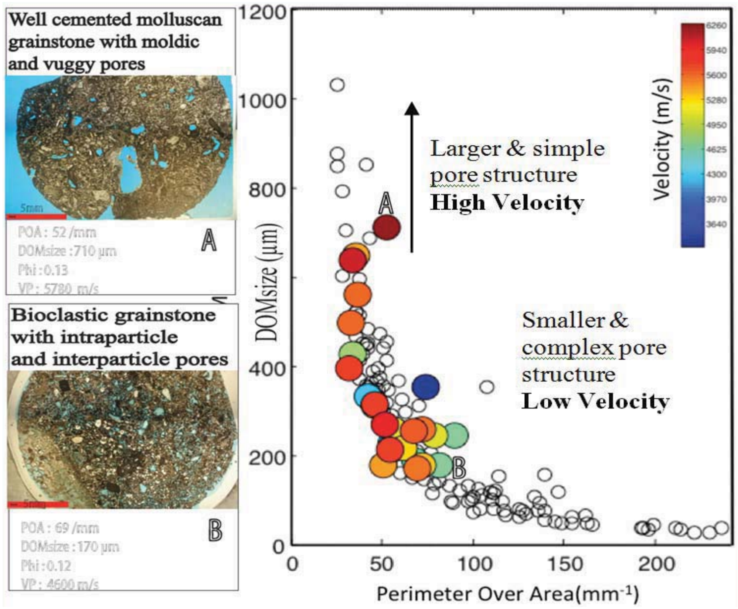

Figure 3. Cross plot POA, DOMsize and Vp in colors superimposed with Weger 2009 et al dataset. Outcrop samples showing simple pore size despite of environments or ages, pore types, or textures. Their high velocity is influenced by pore structure, which is simple. More data needed to prove larger pores are faster.

One hundred and fifty plugs from the different stratigraphic horizons and more than fifty outcrop sample are being measured for permeability, porosity, ultrasonic velocity, and electrical resistivity. The 150 plugs span different lithologies and diagenetic features. Digital image analysis (DIA) will be used to capture pore structure from thin sections of all samples. Porosity, velocity, and permeability will be correlated with DIA parameters. The petrophysical data will be also be placed into the depositional architecture and facies framework. XRD mineralogic and petrographic analysis, as well as geochemical information, will be integrated to assess the diagenetic pathways versus petrophysical properties. The integration of these data is expected to provide a comprehensive petrophysical characterization that can be explained by the sedimentologic and diagenetic processes in the reefal sections, which potentially can be used as an analog for ancient prograding successions.

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Evaluating Porosity Evolution within the Stacked Pleistocene Reef Sequences of Glover's Reef, Belize

Noelle J. Van Ee, Govert J. Buij[1], Anita E. Csoma[1], Gregor P. Eberli, Robert H. Goldstein[2], Darrell Kaufman[3], and Ralf Weger
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Project Purpose

1. To evaluate the effects of multiple sea-level cycles on porosity evolution and to determine the hydrological zones responsible for the diagenetic features observed.
2. To identify trends in reservoir quality in a stacked reef sequence by applying a quantitative approach to the petrography of early diagenetic (pre-burial) features within an age-constrained stratigraphic context.

Approach

Quantitative sedimentological and diagenetic data sets are essential building blocks of forward models and reservoir quality studies. This study focuses on Glover's Reef, a Caribbean atoll that records multiple sea-level highstands within the last 500,000 years (Figure 1), preserving a variety of depositional facies and an early diagenetic overprint. Data sets collected in this study include petrographic data from rotary cores to identify depositional facies and diagenetic features, fluid inclusion Tm ice data to identify the origin of diagenetic features, and petrophysical measurements to evaluate phi/K relationships. These data sets are complemented with point counting of grain, cement, and pore types. In addition, Amino Acid Racemization (AAR) dating is employed to improve age control on the stacked reef sequences.

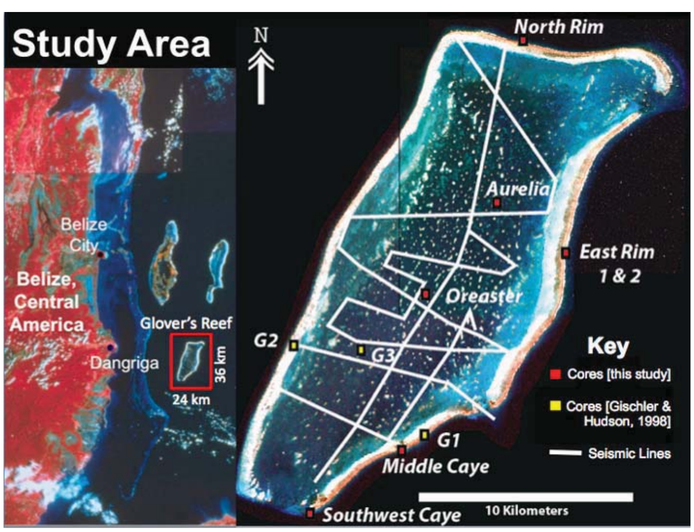

Figure 1. Study area of Glover's Reef, a 260-km2 reef-rimmed platform off the coast of Belize, shown with core locations and seismic data.

Project Description

By using cement stratigraphy and fluid inclusion analyses, we can trace cement phases back to specific sea-level events and hydrological zones, determining which had the most significant effect on the final reservoir quality of the rock. These insights, coupled with sedimentology, can instruct forward modeling exercises that explore porosity evolution through time. Ultimately, we hope to improve the prediction of reservoir quality "sweet spots" by investigating the relationships between facies, stratigraphy, sea-level cycles, and diagenesis.

With respect to age control, we will target samples of *Montastraea annularis* for AAR dating because this Quaternary dating method, based on the deterioration of indigenous amino acids in organic matter, is species specific (Miller & Brigham-Grette, 1989). Results from a pilot test on samples from the Southwest Caye core show good separation of Holocene and Pleistocene samples as well as clustering of the Pleistocene samples from the same exposure horizon, suggesting this method will be successful in providing age control (Van Ee et al, 2010).

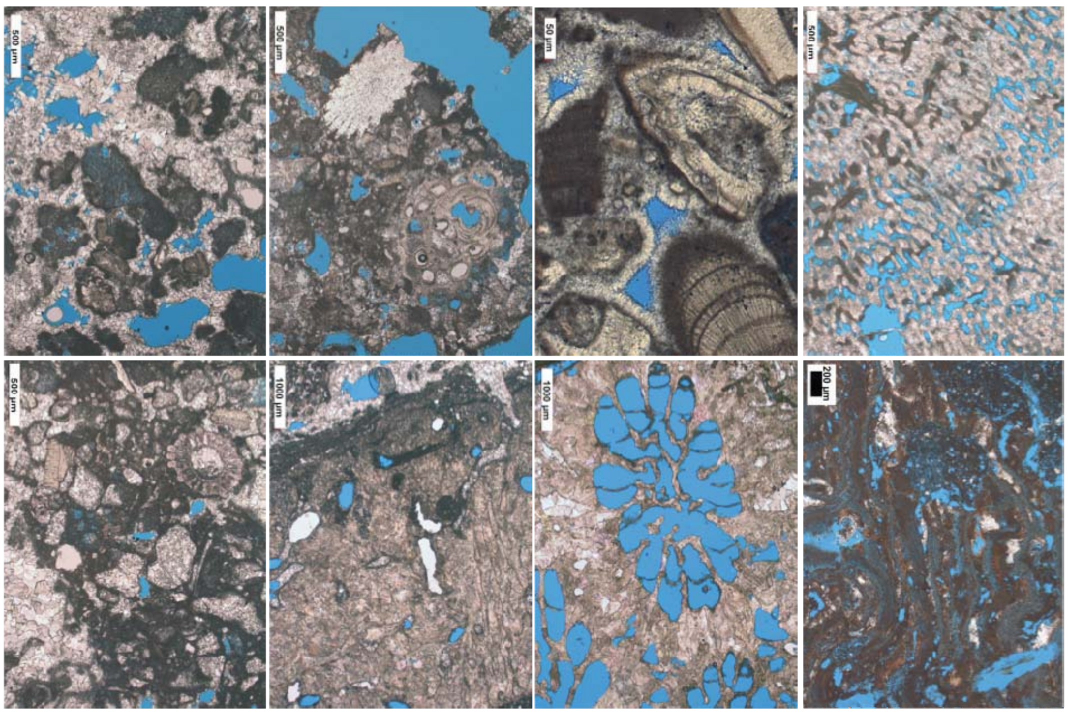

Figure 2. Variations of grain, cement, and pore types in samples from Glover's Reef, Belize.

Key Deliverables

This project provides quantitative measurements of grains, cements, and pore types within a comprehensive stratigraphic framework. Data can be formatted for implementation into CARB3D+ modeling software upon request.

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Composition and Morphometrics of a Miocene Karst Platform – Los Haitises, Dominican Republic

Donald F. McNeill, James Klaus, and Noelle Van Ee

Project Overview

We will initiate a study that combines satellite imagery and field mapping of the Miocene (?) Los Haitises platform in northeastern Dominican Republic. The Los Haitises platform is a ~1000 square kilometer platform composed of shallow water carbonates. The uplifted platform has been exposed to intense meteoric dissolution since exposure in the mid-Pliocene (?). A series of karst pinnacles and ridges with intervening sinkholes and dissolution depressions cap the platform. Our initial reconnaissance of road cut exposures along a new highway indicates that these platform limestones are likely age equivalent with the late Miocene to early Pliocene deposits further east in the Cibao Basin.

Figure 1: Map of the Dominican Republic showing the location of the Los Haitises carbonate platform.

Scope of Work

Two main research tasks are proposed. First, we will characterize the nature of the platform limestones: Their facies, fauna, and age. We will access different areas of the platform to assess regional changes in lithofacies and paleogeography of the reef fauna. Petrographic and diagenetic information will be used to document the development of micro- and macro-scale porosity. The nature of porosity, from mega-porous caves and caverns to bed-scale porosity, will be addressed in the field.

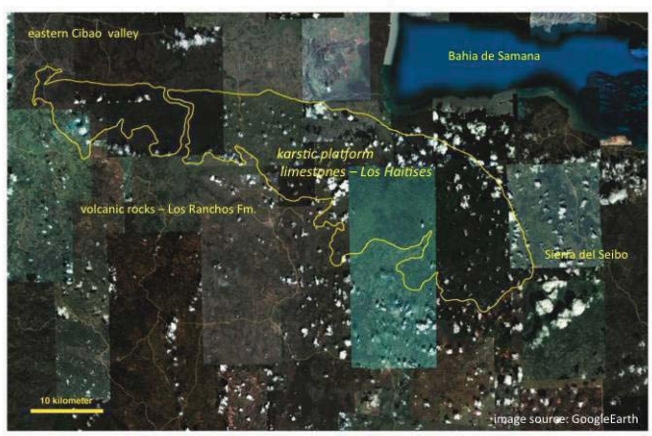

Figure 2: Detailed map of the Los Haitises carbonate platform showing the region of extensive tower karst.

Second, we will use satellite imagery to provide information on regional trends in the karst, characterization of a large fluvial channel that dissects the platform, and to provide basic metrics on the size and spacing of the karst features. These metrics can then be used for comparison to other areas of pinnacle development such as other karst platforms and areas of patch reef development (e.g. Glover's Reef atoll).

Key Deliverables and Expected Results

This study will provide a basic field study of a small, highly karstified carbonate platform. We will generate basic geological sections in road cut exposures to characterize the platform facies and to assess paleogeographic components of the platform. The ground information will be integrated with the satellite images and morphometric data measured from those images. We will generate a morphometric data set on karst feature size, spacing, and directionality of pinnacle/ridge and sink occurrences.

Figure 3: Road cut through Miocene (?) limestone showing the nature of the karst and the formation of pinnacle-like features separated by solution depressions and sinks. Much of the drainage is through subterranean conduits

Figure 4: GoogleEarth satellite image of the eastern part of the Los Haitises platform. The elevated limestone pinnacles and ridges are visible as well as the numerous solution depressions/sinks. Average yearly rainfall is 1.9-2.0 m. Image is 3.6 kilometers across.

Synthetic Seismic Modeling of the Mixed Carbonate-Siliciclastic Quintuco Formation, Neuquén Basin, Argentina

Michael Zeller, Gregor P. Eberli and Jose L. Massaferro[1]
[1] YPF, Buenos Aires, Argentina

Project Purpose

In this ongoing study, a new model for the mixed carbonate-siliciclastic system of the Neuquén Basin has been proposed. This model is based on outcrop and seismic data (year 1) and a detailed assessment of the heterogeneous reservoir properties in subsurface data (year 2). Reservoir heterogeneities are the result of the complex variations of facies and diagenetic history. These variations can only be observed adequately in outcrops but must be considered when making larger scale seismic interpretations. Seismic images can be calibrated to the observed smaller scale variability of depositional geometries in outcrop by using a key tool: Synthetic seismic models. The goal of the proposed research effort is to develop a predictive model that incorporates the outcrop variability of the Upper Jurassic-Lower Cretaceous mixed system in the Neuquén Basin (Figure 1).

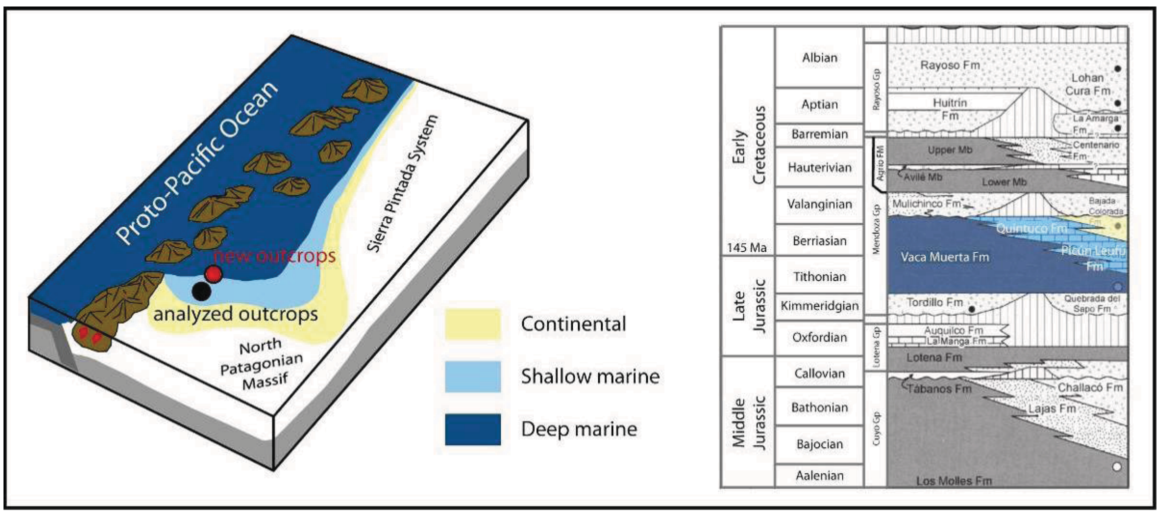

Figure 1: Left: Paleogeographic setting of the Neuquén Basin with locations of analyzed and new outcrop sections. Right: Middle Jurassic to Lower Cretaceous Stratigraphy of the Neuquén Basin, studied interval colored (both modified from Howell et al., 2005)

The Mixed System

The prograding to aggrading mixed carbonate-siliciclastic successions of the Quintuco Formation and the time equivalent basinal shales of the Vaca Muerta Formation comprise the studied interval. These two formations form a mixed system that consists of a lower prograding unit composed of siliciclastics with a coarsening upwards trend (Figure 2). The aggrading middle unit can be subdivided into a lower mixed carbonate-siliciclastic interval capped by a clean carbonate interval, which in turn is overlain by an aggrading upper unit in which siltstones and sandstones alternate with minor carbonates.

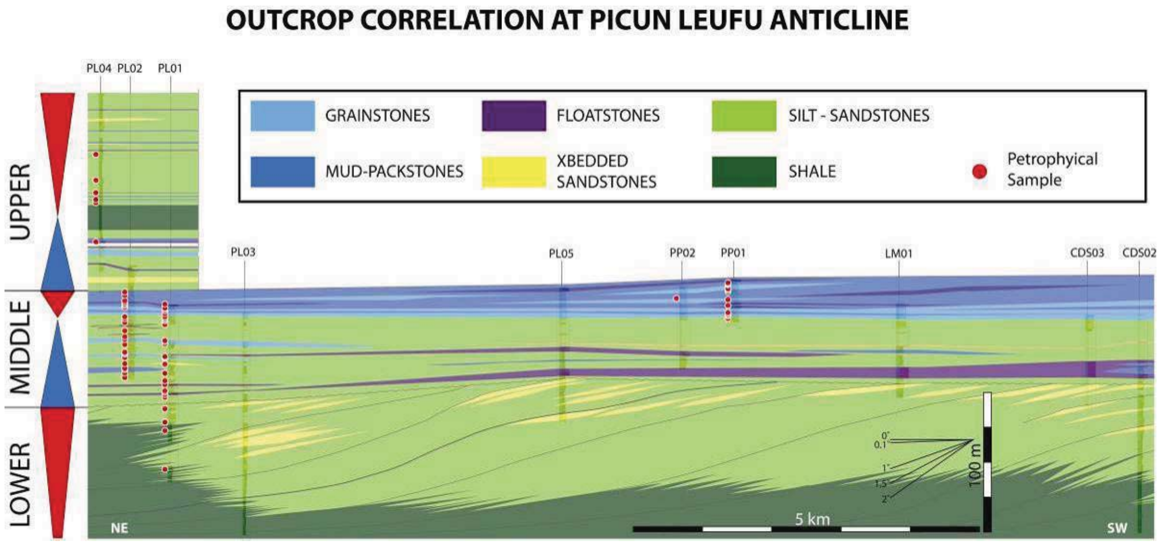

Figure 2: Outcrop correlation based on logged sections along a 15 km long cross section across the prograding-aggrading strata of the Quintuco Formation. The basinal shales are the Vaca Muerta Formation. Red dots display sample locations for the petrophysical analyses.

Scope of Work

In year 1 and 2, we examined the lithologic character and the stratal architecture of the Vaca Muerta – Quintuco Formations in outcrop. In addition, we evaluated several core intervals from a producing field in terms of sedimentological and petrophysical properties. Comparison of the lithofacies character and geometries demonstrated that there are general similarities in the stratal architecture and lithology types of the outcrop and subsurface units. Additionally, initial seismic correlation allowed common unconformities across the basin to be identified.

In year 3, we will analyze the petrophysical properties of 150 outcrop samples and integrate them with the observed outcrop geometries to develop a synthetic seismic model of the Quintuco - Vaca Muerta Formations. This approach has been proven to upscale heterogeneities observed in the outcrop to seismic data (e.g. Janson et al, 2007). The synthetic model will be compared with seismic data from producing fields and, thereby, allow the integration of outcrop-scale variability into the seismic interpretations and reservoir models. In order to assess the lateral evolution and variability of the facies belts, we will also visit, analyze, and sample new outcrop sections, located in a more distal paleogeographic position and in closer vicinity to the producing fields. The goals of this additional fieldwork are 1) to gain more insight into the spatial carbonate-siliciclastic facies distribution along the paleoshelf, and 2) to build a more robust model for an outcrop-subsurface correlation.

Project Tasks

The following tasks will be carried out:

1. Petrophysical analyses that include acoustic velocities, density, and porosity of collected outcrop samples
2. Assessment of the mineralogy, in particular the respective amounts of carbonates and siliciclastics in the various facies
3. Synthetic seismic modeling of the Picún Leufú Anticline using outcrop geometry and facies distribution
4. Comparison to subsurface datasets, in particular seismic sections from the producing fields
5. Extension of the outcrop database to more distal sections to assess longshore facies variability.

Expected Results

In this project we expect:

1. To assess a) the factors controlling the dispersal clastic sediments on the Neuquén shelf and in the basin, and b) the causes for the onset and end of the carbonate deposition. The resulting geological model will help to understand processes generally involved with mixing carbonate and siliciclastics.
2. To assess the seismic record of facies heterogeneity in a mixed shelf system for an improved seismic interpretation of this and similar mixed systems.
3. **3.** To predict reservoir facies distribution within the Upper Jurassic - Lower Cretaceous mixed carbonate siliciclastic system in the Neuquén Basin by integrating lithologic and petrophysical parameters that can be effectively correlated within the established sequence stratigraphic framework. This model/workflow will provide guidelines to enhance reservoir predictability in other fields with mixed carbonate-siliciclastic characteristics.

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CARAMBAR – Deep-water Processes and Coral Mounds along the Slopes of Little and Great Bahama Bank

Gregor P. Eberli, Mark Grasmueck, Rani Sianipar, Thierry Mulder[1], and colleagues from several institutions
[1] University of Bordeaux, France

Project Background

During a multibeam, seismic, and coring cruise called CARAMBAR (October 31 - November 29, 2010), the slope and basin setting along the western side of Great Bahama Bank and the northern slope of Little Bahama Bank were investigated (Figure 1). This cruise on the ship *Le Suroît* was co-organized by the universities of Bordeaux and Marseille, and financed by a grant from the French federal funding agency. The chief scientist on board was Thierry Mulder.

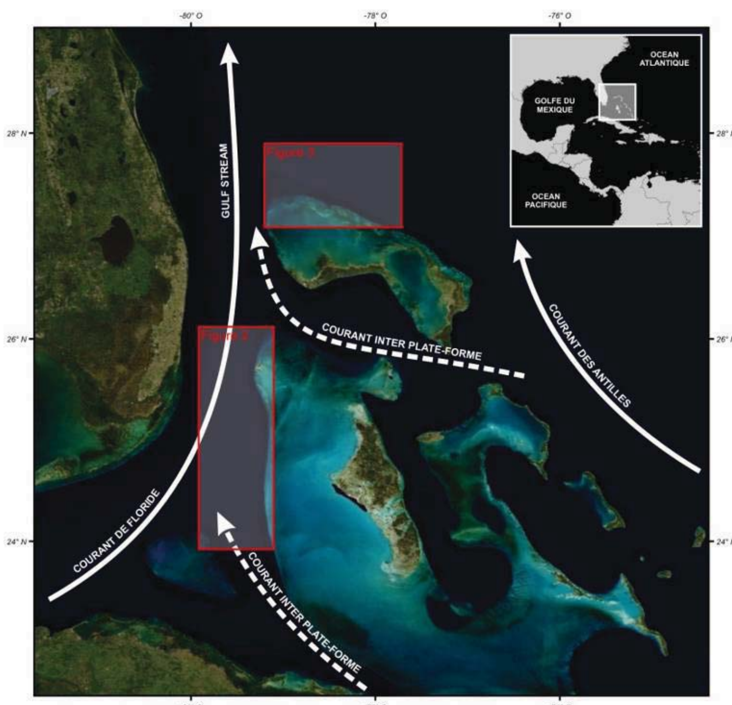

Figure 1: Location map of the two areas surveyed during the CARAMBAR cruise. In both areas, multibeam (EM302) data for seafloor topography, high-resolution multi-channel seismic data, and chirp sonar data were simultaneously acquired. In addition, over 20 piston cores with lengths reaching from 5 – 20 meters using a Küllenberg system were taken of the various sub-environments. (From Mulder et al., in press).

Project Objectives

The primary objective of this international project is the characterization of the morphology and geometry of the carbonate slope system and its relationship to sedimentary processes. Several aspects within this objective can be investigated using the comprehensive data set provided by the CARAMBAR cruise. In addition, the seismic data can be calibrated to the lithology and stratigraphy of the ODP Legs 101 and 166 and Küllenberg cores. Based on the available data, the following sub-projects will be conducted by the participating institutions.

1. Geometry and sedimentary evolution of the recent carbonate turbidite system, including the initiation of the slope gullies.

2. Carbonate slope architecture and geometry of sedimentary bodies using multi-channel seismic data.
3. Sedimentary changes during the Late Pleistocene (including stratigraphy and paleo-environment).
4. Geometry and initiation of large slope failure.
5. Distribution and sequence stratigraphy of cold-water coral mounds.
6. Very high-resolution Holocene stratigraphy to relate sedimentation to known climate events and coastal records.
7. Physical and reservoir properties and their link to diagenesis.
8. Characterization of organic matter in the slope sediments.

The University of Miami will be involved in projects 4, 5 and 7, which we describe in more detail on the following pages.

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Core-Seismic Correlation and Physical Properties of Slope Sections; Their Link to Diagenesis

Bruno Marsset[1], Francois Fournier[2], Gilles Conesa[2], Jean Borgomano[2], Gregor Eberli, Mark Grasmueck, Vincent Hanquiez[3], and Phillipe Leonide[4]
[1]Ifremer, France [2]University of Marseille, France, [3]University of Bordeaux, France, [4]Free University, Amsterdam, The Netherlands

Project Objectives

1. Investigate the relationship between seismic facies, lithology, and physical properties.
2. Assess the reservoir properties in slope sections by correlating the cores from ODP Legs 101 and 166 to the new seismic data set.
3. Examine the reflectivity coefficient of the imaged strata.

Project Rationale

The multichannel seismic survey collected during the CARAMBAR cruise is of higher frequency and resolution than the site surveys conducted in preparation for drilling ODP Legs 101 and 166. The 25 cubic inch air gun images the slope with unprecedented clarity (Figure 1). Because the seismic lines were traced across the ODP dill sites where completely cored wells penetrated strata as far back as the Lower Cretaceous (Site 627), a unique opportunity arises for a refined correlation between the cores and seismic data. This refinement will be best in the sites along the

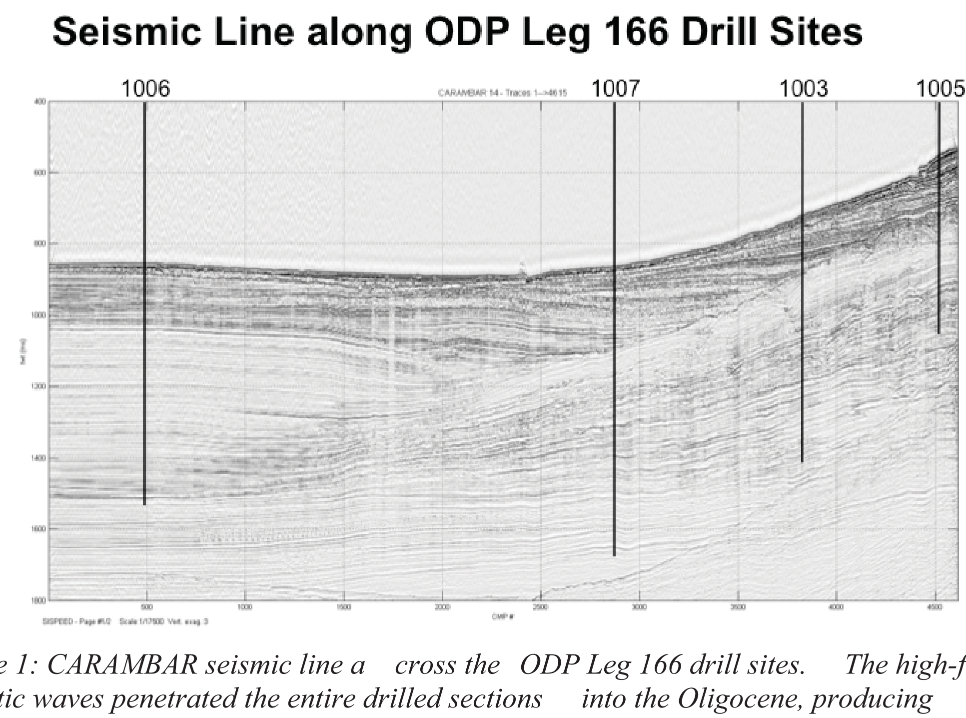

Figure 1: CARAMBAR seismic line a cross the ODP Leg 166 drill sites. The high-frequency acoustic waves penetrated the entire drilled sections into the Oligocene, producing a seismic image of unprecedented clarity along slope of Great Bahama Bank.

Bahamas Transect at the western prograding margin of Great Bahama Bank because, in these sites, a vertical seismic profile was shot after drilling and complete logging suites were run in all of the wells (Eberli et al. 1997). With this refined correlation, we will address some fundamental questions in regards to the control of the reflectivity in these strata and the development of the physical properties.

Scope of Work

The work in this project consists of seismic processing and analysis, and a comprehensive petrophysical analyses. Our colleagues in Marseille and Amsterdam will perform the petrophysical tasks. The CSL will be working with Bruno Marsset from Ifremer on the seismic processing (pre-stack depth migration) and the correlation of the seismic data to the ODP sites of Leg 166.

Key Deliverables

One goal of the project is a refined correlation between the strata of a prograding margin and its seismic signature. This correlation will be the basis for a refined seismic facies and sequence stratigraphic analysis of the slope sections. Although the CSL is not involved in all the follow up projects, we will report on the results of the other tasks performed in France as they become available.

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Geometry and Initiation of Large Slope Failure along Little and Great Bahama Bank

Gregor P. Eberli and Thierry Mulder[1]
[1] *University of Bordeaux, France*

Project Objectives

1. Describe the geometry of a large slope failure and associated mass wasting deposits.
2. Examine the modern sea floor morphology and seismic data along strike and dip of these events to determine the depth of the detachment surface.
3. Revisit core and seismic data of ODP Leg 166 to assess the vertical diagenetic and petrophysical changes in the strata to determine the physical conditions of these slope failures.

Project Rationale

Observations from submersible dives (Grammer et al., 1993) have documented scars in the upper slope of Great Bahama Bank. More recent, high-resolution bathymetry maps revealed a slump scar on the magnitude of 100 meters in relief on the toe-of slope of Great Bahama Bank (Grasmueck et al., 2007). This slump scar at very toe-of-slope is imaged in its entirety with multibeam data collected during the CARAMBAR cruise (Figure 1). Other kilometer long scars are visible along the slope of both Little and Great Bahama Bank. Slope failures of this magnitude and at this low of a position on the slope have not been reported and are hard to explain. This study aims to describe the geometries of these slope failures and to give an explanation for why they occur.

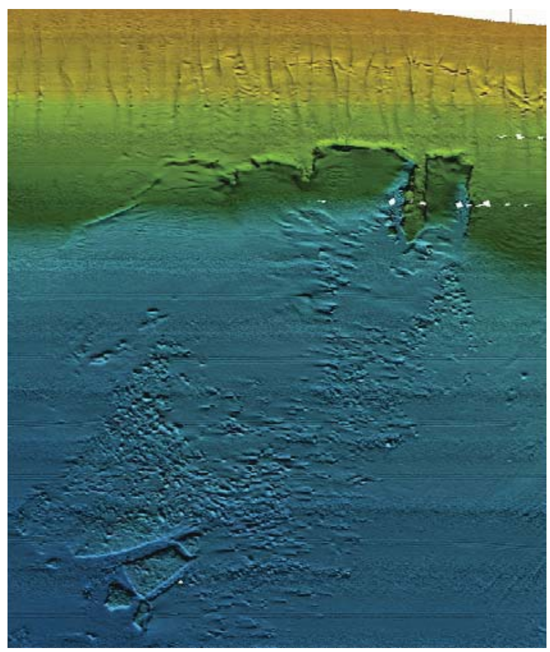
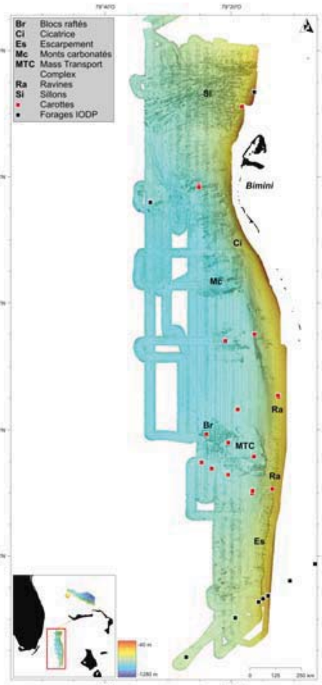


Figure 1: Bathymetry along the western slope of Great Bahama Bank displaying the small gullies in the mid- slope areas and a large, approximately 30km long, slump scar in the ~700 m water depth. Also shown are rafted slope sections kilometers further out into the basin. The slope angle at the location of the scar is less than one degree.

Project description

During Leg 1 of the CARAMBAR cruise, a unique data set was collected that can document, with unprecedented resolution (6m), the geometry of large slope failures on a modern carbonate slope. Multibeam data covering large portions of both Little and Great Bahama Bank display slope failures of various sizes and shapes (Figure 2).



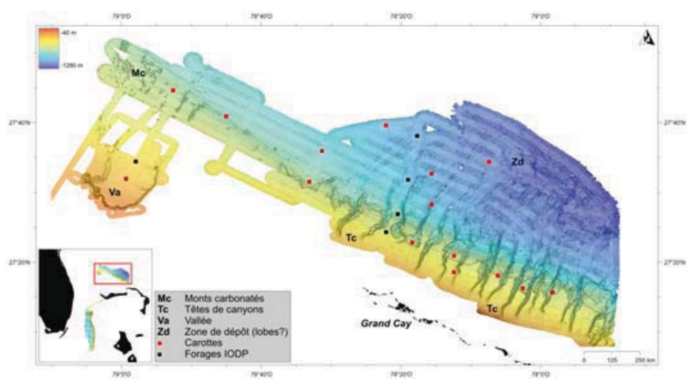


Figure 2: Bathymetry of the slope sections surveyed during the CARAMBAR cruise. Left) The western slope of Great Bahama Bank displaying a major mass wasting complex (MTC, see also Figure 1) and a long incipient scar (Es). Top) Bathymetry of the slope along Little Bahama Bank displaying deep canyons and smaller slump scars between canyons. (from Mulder et al., in press). Red dots are locations of piston cores and black dots are the coring sites of ODP Legs 101 and 166.

The multibeam data will be used to establish the morphometrics of the slope failures. Seismic data across the mass wasting sites will be used to determine the depth of the detachment surface of the slumps and the seismic facies of such mass wasting deposits. A piston core positioned on top of one rafted slab will provide the minimum age of the failure. A large slump mass had been penetrated with a core at ODP Leg 166, Site 1008, providing the opportunity to determine the petrophysical variations across the detachment surface of the slump. This information, together with a petrographic analysis of the diagenetic changes, is expected to provide some clues about the physical conditions that enable slope failure at such low angles.

Key Deliverables

1. Comprehensive description of the dimensions of mass wasting events at the lower slope.
2. Description of the seismic facies of the modern and buried mass wasting deposits.
3. Assessment of petrophysical/diagenetic changes across the detachment surface.

References

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Architecture, Distribution, and Sequence Stratigraphy of Cold-water Coral Mounds around Great and Little Bahama Banks

Rani Sianipar, Gregor P. Eberli, and Thierry Mulder and colleagues[1]
[1] *University of Bordeaux, France*

Project Objectives

1. Determine the number and distribution of deep-water carbonate mounds on the slopes of Great Bahama Bank and Little Bahama Bank based on multibeam data.
2. Determine the ages of the distinct coral mound horizons and the age of the modern coral mounds using high resolution seismic data that are correlated to the stratigraphy in the cores of ODP Legs 101 and 166.
3. Assess role of antecedent topography, in particular slump scars and mass gravity flow deposits, as potential locations for deep-water coral mounds.
4. Examine internal architecture in the top 13 meters of a large mound that was recovered in a piston core.

Project Rationale

Recent studies document that the lower slopes of Great Bahama Bank are sites of extensive cold-water coral growth (Grasmueck et al., 2006, 2007). In some areas, the average density of coral mounds is 18 mounds/km^2. These mounds can be as high as 120 meters and form kilometer long linear ridges. These findings are based on surveys with an autonomous underwater vehicle in five areas in the Straits of Florida, covering approximately 80 km^2. The multibeam data collected during the CARAMBAR cruise reveals an even greater abundance and diversity of mound architecture (Figure 1). Furthermore, the data set allows questions about the punctuated stratigraphic occurrence and the internal growth pattern of such mounds to be addressed.

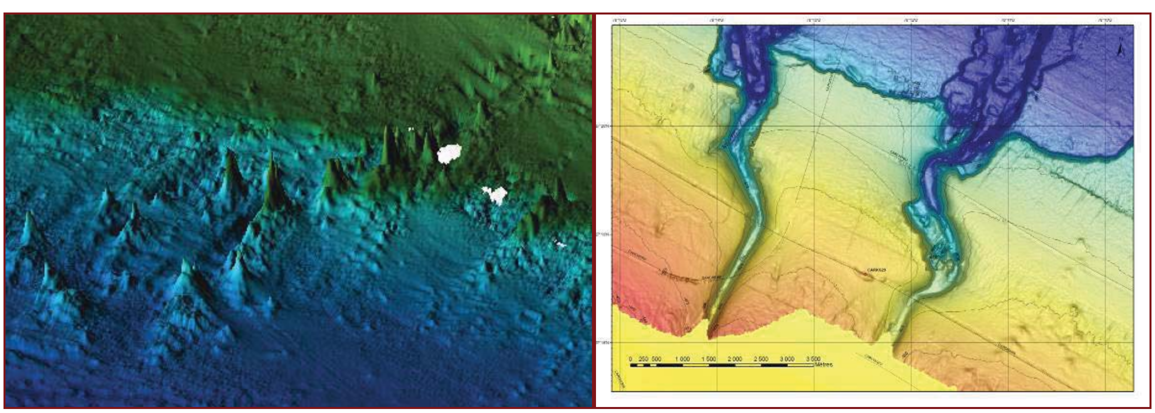

Figure 1. (Left) An approximately 10 x5 km bathymetry map of the lower slope off Bimini in 600-700m water depth images ridges of cold-water coral mounds that cover most of the slope in this area. (Right) A bathymetry map based on multibeam data reveals scattered coral mounds and large meandering canyons on the slope of Little Bahama Bank.

Scope of work

All the modern mounds in the Straits of Florida seem to start growing above a mid-Pleistocene (?) sequence boundary (Eberli et al., 2006). The newly acquired high-resolution seismic and chirp data is capable of separating the individual Pleistocene sequences. Together with the core information, it will be possible to accurately assess the synchronous (?) onset of the modern cold-water coral mound features.

Furthermore, the high-resolution multichannel seismic data images buried mound fields. This will allow addressing one of the unsolved questions about the deep-water coral mounds in the Bahamas: The timing of their first occurrence. A preliminary seismic stratigraphic analysis during the cruise indicates that the deepest buried coral mound north of Little Bahama Bank is as deep as 1700 ms, in middle Eocene strata.

The location for cold-water coral mound initiation remains enigmatic. As in shallow water corals, hard surfaces, such as antecedent topography, are required for colonization by larvae. Based on the multibeam bathymetry data, the edges of gullies and canyons on the lower slope seem like an ideal place for mounds to grow (Figure 1). We will examine the bathymetric maps to assess how big a role these features play in controlling the distribution of deep-water coral mounds.

A piston core with 13 m recovery through the flank of the over 100 meter high Matterhorn mound offers the unique opportunity to examine the inside of these mounds. The large penetration of the core documents that the mound is not cemented, although some early marine diagenetic alteration was observed. A planned CT scan of the core will reveal the distribution of the coral framework and the trapped sediment. U-Th dating of the corals will provide the first information about the growth rate of these cold-water coral mounds.

Key Deliverables

This project will generate a sequence stratigraphic distribution of deep-water carbonate mounds adjacent to Great and Little Bahama Bank. The additional stratigraphic data from the cruise will make more accurate age interpretation of the mounds possible. The number of mounds will be calculated for each bank and their general distribution will be assessed with respect to morphologic features, such as gullies and slump scars.

The piston core through the mound will reveal the growth rate and pattern of cold-water coral mounds and document the early diagenetic processes in the mound.

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Laboratory Experiments in Petrophysics

Pore Throat Dimensions, "Apparent Cross-sectional Area", and Electrical Resistivity in Low Porosity Carbonates

Jan H. Norbisrath, Gregor P. Eberli, and Ralf J. Weger

Project Objectives

- Expand the Verwer et al. (2011) resistivity data set into lower porosity rocks to better assess the control by pore throat dimensions on the resistivity of carbonates.
- Evaluate the effect of the "apparent cross-sectional area" on the electrical resistivity

Project Purpose

Previous studies by Verwer et al. (2011) have shown that the electrical resistivity and Archie's cementation factor, *m,* in carbonates are mainly controlled by the fluid filled pore structure. Their most arresting finding is that samples with simple, large pore structures and high permeability tend to have higher resistivity than samples with similar porosity but small, complex pore structures dominated by small pores and lower permeability (Figure 1). Verwer et al. (2011) hypothesize that this trend is related to the "apparent cross-sectional area", which rises with the increasing number of pore throats in microporous, low permeability carbonates. In this study, we test this hypothesis by assessing the complex relationships between the electrical resistivity and the pore structures in both low porosity rocks and highly microporous rocks.

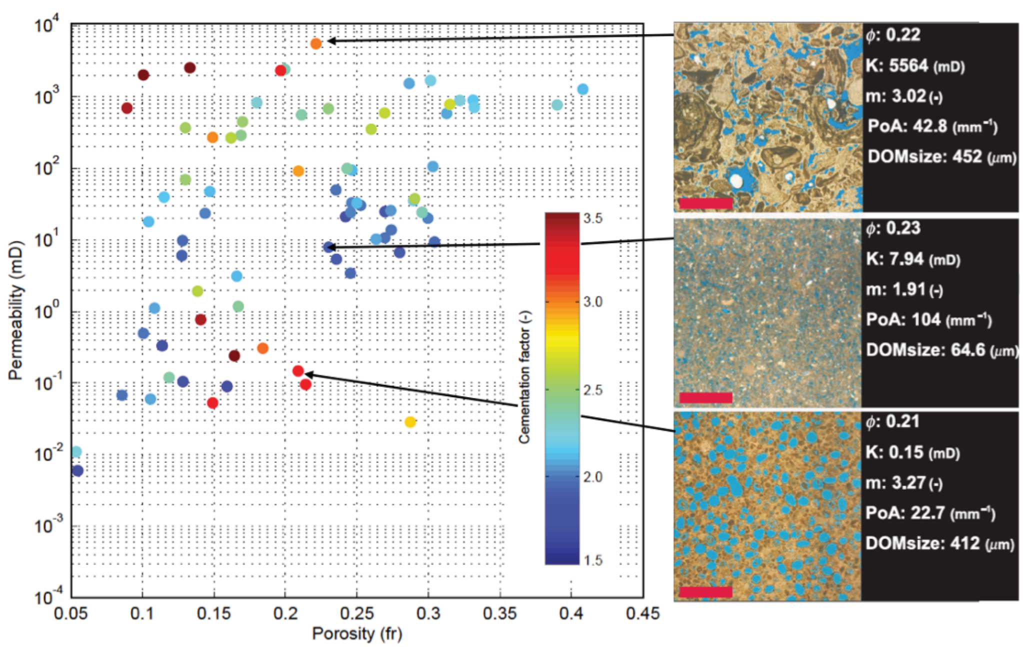

Figure 1: Porosity-permeability cross plot with cementation factor superimposed in color. Samples with high permeabilities have a higher cementation factor for a given porosity, as exemplified by the top two examples on the right. Oomoldic samples are the exception to the general trend (example on the lower right) (modified from Verwer et al. 2011)

Scope of Work

By expanding the data set into the realm of low porosity (< 10%) and dominantly microporous samples, we will try to specifically assess the controls of pore throat diameter and number on the electrical resistivity of carbonates.

Initial laboratory measurements of low porosity core plugs (1-10% porosity) will be compared to quantitative geometric parameters of the rock using the Digital Image Analysis (DIA) method on thin sections. Because in some samples the porosity is mostly microporous, the pore geometries cannot be captured with DIA analysis. To quantify the full spectrum of the pore throat diameters in these samples, Mercury Injection Capillary Pressure (MICP) analyses will be conducted. This information will be used to calculate the "apparent cross-sectional area" of the pore throats, which is assumed to be the most influential factor on electrical conductivity in the rock. The outcome of this project will be a better understanding of the relationship between pore throat dimensions/number and the electrical resistivity of carbonates, particularly those with lower porosities. Moreover, the impact of high microporosities on resistivity will be defined in more detail.

Project Description

1. Perform MICP (Mercury Injection Capillary Pressure) analysis on a broad range of samples from different origins with porosities ranging between 1 and 15%.
2. Measure electrical resistivity, formation factor, and permeability of these samples.
3. Evaluate scatter in resistivity measurements as a function of the apparent cross-sectional area and other physical properties, such as permeability.

Key Deliverables

In combination with the data set described in Verwer et al. (2011), this study will provide a comprehensive data set that correlates resistivity to porosity, permeability, and pore structure, size, and number (using MICP and DIA). The results will help to further improve the inversion of carbonate pore structure from down hole log resistivity data and thereby improve the calculation of water saturation in carbonate reservoirs, eventually leading to improved oil estimates.

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Rock Fluid Interaction: Velocity Evolution during Controlled Precipitation and/or Dissolution

Ralf J. Weger, Peter K. Swart, and Gregor P. Eberli

Project Purpose

Carbonates are prone to diagenetic alterations that result in changes of the petrophysical properties. Small amounts of newly formed contact cement can stiffen the rock. Similarly, dissolution from slightly acidic formation waters or acid treatment during well completion can result in secondary porosity and increased permeability. Although these processes are well known, little data exists to quantify these changes and their influence on petrophysical properties. In this project, experiments that quantify both the chemical changes in the fluids and the diagenetic and petrophysical changes in the rocks are designed to enhance our understanding of the effects of chemical rock-fluid interaction. In particular, the study will capture changes of acoustic velocity and permeability during chemically controlled rock-fluid interaction that causes either precipitation or dissolution of the rock.

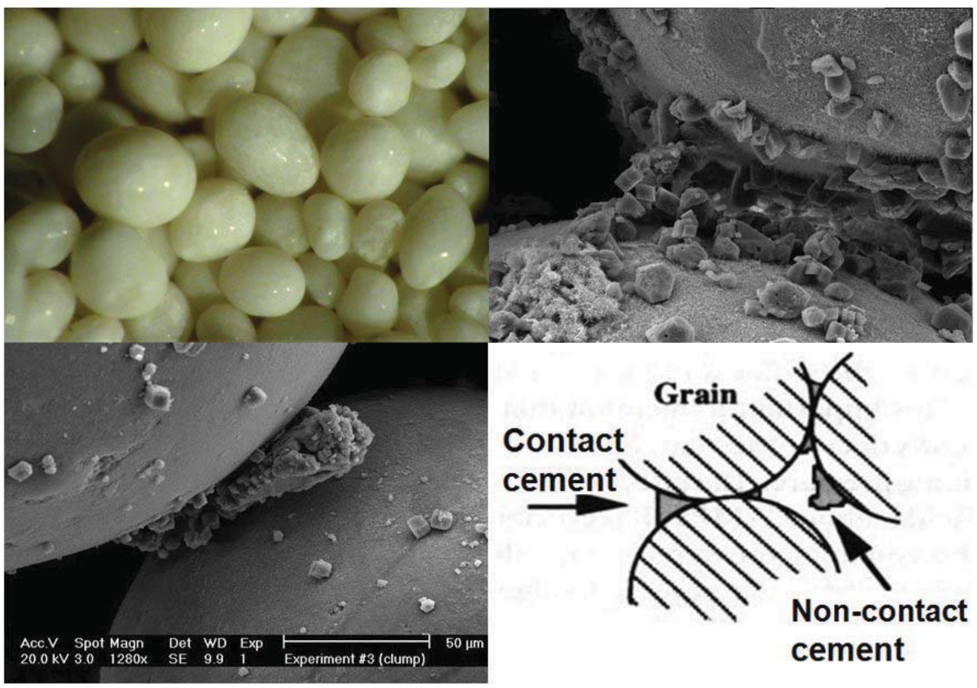

Figure 1: Results of a pilot precipitation study. (Top right) Clean ooids before experiment. (Top right and bottom left) Calcium carbonate crystals precipitated during the experiment. Precipitation occurs preferentially at the ooid-to-ooid grain contacts. These contact cements are responsible for increasing rock stiffness and thus acoustic velocity. (Bottom right) Illustration of contact vs. non-contact cement (from Dvorkin and Nur, 1996).

Scope of Work

Petrophysical properties will be observed before, during, and after altering the rock. Rock evolution and changes will be documented, particularly with respect to acoustic velocity. One aspect will be to evaluate the effects of observed crystallization at grain-to-grain contacts on measured acoustic velocity. Another aspect will concentrate on the effect of dissolution in ooid grainstones on both acoustic velocity and fluid flow permeability.

A first suite of experiments will focus on acoustic velocity alterations during precipitation of $CaCO_2$ (Figure 1). Several long-term experiments (1-4 weeks) are planned. During each experiment, acoustic velocity will be measured in one-hour intervals. Samples will be analyzed under SEM to determine where and how many crystals have formed during the experiment.

In the second phase, the focus will shift toward dissolution. Under-saturated solution will be circulated though the samples for several days. Fluid composition, acoustic velocity, and fluid flow permeability will be measured during the experiment. Changes in the rocks pore structure will be captured by high-resolution CT scans before and after the experiment. Changes in pore geometry will be analyzed in the context of changes in petrophysical parameters.

Precipitation Workflow

1. Measure acoustic velocities of several samples of loose ooid grains in preparation for precipitation experiments.
2. Expose these samples to long-term infiltration with supersaturated solution, whose chemical composition will be constantly monitored and adjusted to the original composition.
3. Measure acoustic velocities in 1-hr intervals during the experiment.
4. Analyze the resulting rock under SEM to determine location and amount of precipitation.

Dissolution Workflow

4. Perform high-resolution CT scan of several samples of variable texture (grainstone, packstone etc.) but similar porosity.
5. Measure acoustic velocities and permeability.
6. Expose these samples to long-term infiltration with an under-saturated solution.
7. Measure velocity and permeability at set intervals during infiltration experiment.
8. Sample and analyze downstream fluid line for chemical changes.
9. Perform high-resolution CT scan and compare pore structure changes.

Key Deliverables

A data set will be generated that captures chemical changes of the pore fluid and the resulting changes in acoustic velocity and fluid flow permeability in the rock. High-resolution images using SEM and high-resolution CT scans will provide estimates of crystallization or dissolution during chemical rock-fluid interaction.

Petrophysical Properties and Pore Structures of Stromatolites and Travertine

Cornelia Rasmussen, Gregor P. Eberli, and Ralf Weger

Project Objectives

- Provide a petrophysical characterization of travertine and stromatolites from both marine and lacustrine environments.
- Describe the pore structures of both stromatolites and travertine.
- Compare the petrophysical properties and pore structures of stromatolites to travertine.

Project Rationale

The pre-salt reservoir facies located offshore Brazil is reported to consist predominantly of microbialites reminiscent of either stromatolites precipitating in a lacustrine setting or travertine. There is a general consensus that no modern environment can serve as an exact analog for these Cretaceous deposits. Furthermore, the pre-salt rocks are not uniform across the entire basin and thus, depending on the location the reservoir facies, might resemble stromatolites or travertine. Both deposits have recently received attention but mostly in regards to the biological interaction involved in their genesis (Figure 1). What is lacking is petrophysical characterization of these deposits and comparisons between them that can serve as a guide for the petro-seismic distinction of similar pre-salt rocks.

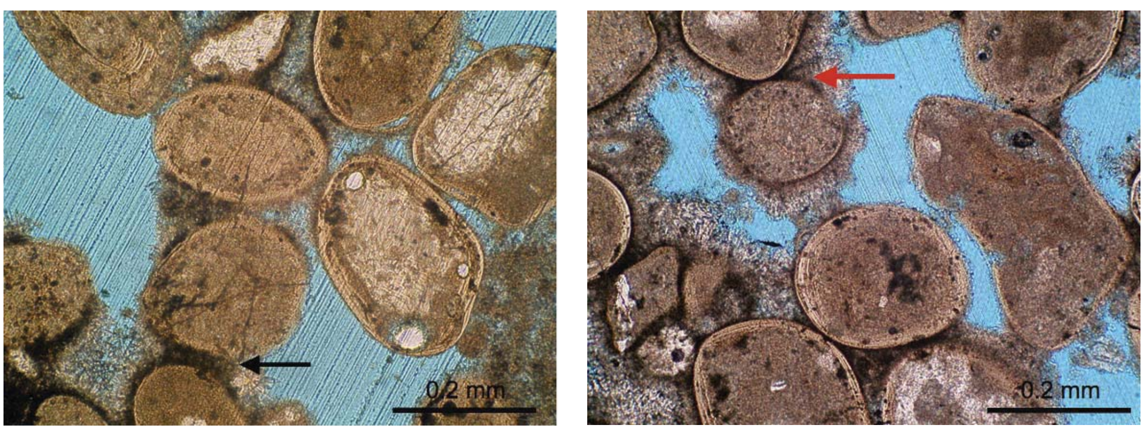

Figure 1: Photomicrographs of modern stromatolites from the Bahamas. Grains are cemented by dark, micritic, contact cements (arrows). Fine aragonite needles overgrow these micritic contact cements. In addition, micritic material is filling part of the pore space. The precipitation of micrite is related to photosynthesis, combined with sulfate reduction and sulfide oxidation, of the microbial community within the stromatolite (Visscher et al., 1998).

Project Description

We plan to collect samples from modern and ancient stromatolites from both marine and lacustrine environments and subject them to suite of petrophysical measurements. Similarly, travertine from various places will be measured. In both data sets, the petrophysical measurements of one-inch plugs will include porosity, permeability, acoustic velocity, and resistivity. In addition, the pore structure will be captured using the quantitative parameters from digital image analysis of thin sections taken from the end pieces of the sample plugs.

Initial results of eight samples from modern stromatolites show porosities between 12 -25%, permeability ranges between 70- 4600 mD (all but one sample have more than 350 mD), and velocities between 4480 – 5420 m/s. These velocities are faster than most limestone samples with similar porosity (Figure 2). These stromatolites are good reservoir rocks with both high permeability and high velocity.

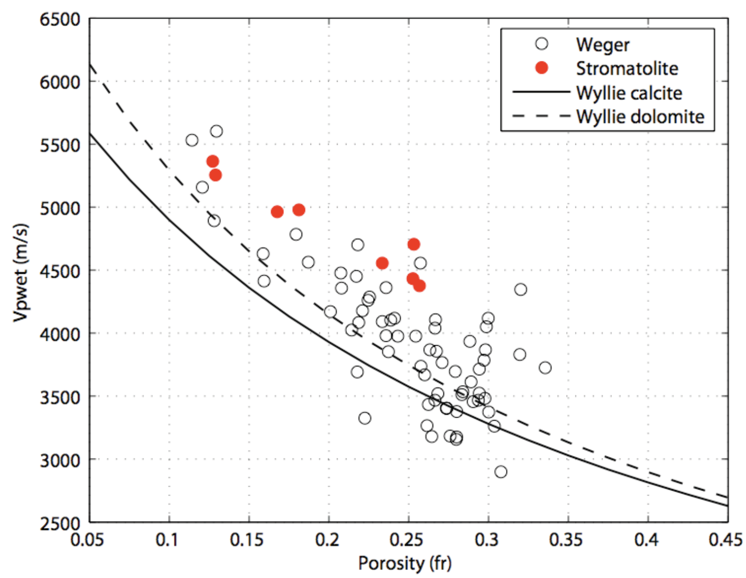

Figure 2: Velocity-porosity cross plot of limestone samples from Wege r et al. (2009)(circles) and mod ern stromatolites (red dots). The stromatolites have mo stly interparticle porosity but their acoustic velocity is approximately 1 km/s faster than what Wyllie's time-average equation predicts at a given porosity.

Deliverables

A data set will be generated that provides pore structures and petrophysical properties of rocks that are reminiscent of the pre-salt reservoir facies. This data set can be used for comparison with various facies in the pre-salt strata.

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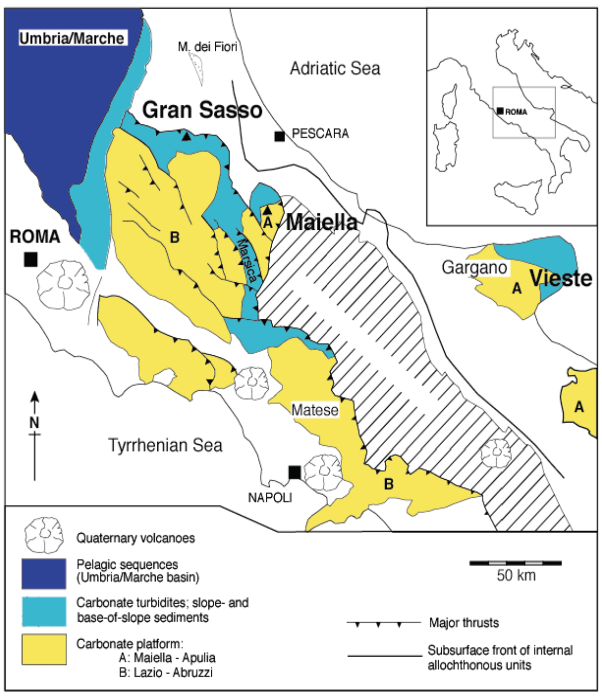
Petrophysical Characterization of Carbonate Turbidites in Outcrop and Subsurface, Maiella Platform, Italy

Irena Andisa Maura, Gregor P. Eberli, and Daniel Bernoulli[1]
[1] *Geological Institute, University Basel, Switzerland*

Project Purpose

In the search for new plays in carbonates, slope sections and calcareous turbidites, breccias, and megabreccias have received renewed attention. To date, only a few reservoirs are producing from carbonate breccias and/or calcareous turbidites. In a previous project, we assessed the reservoir potential of the re-deposited carbonates in the slope sections and the basin adjacent to the Maiella platform exposed in the Abruzzi, Italy (Figure 1) (Eberli et al., 2006). The aim of this follow-up project is to assess the porosity and permeability in a core from the Adriatic offshore through the time equivalent sections in the subsurface portion of the Maiella platform margin. This core is made available for this study by ENI.



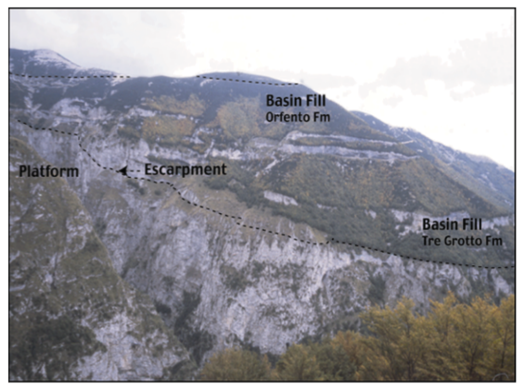


Figure 1: (Left) location map of the Maiella Platform Margin. (Right) Photograph of the lower portion of the escarpment and the onlapping megabreccias (white cliffs in forest), turbidites and hemipelagic sediments (Tre Grotte and Orfento Formations). Horizontal view is approximately 1.8 km and vertical view is approximately 1 km.

Scope of Work

The work will integrate the outcrop and subsurface data sets of the Cretaceous and Tertiary slope and basin strata along the Maiella platform. The offshore well is the focus of this study. It will include core descriptions and a series of petrophysical measurements that are compared to log analysis. In addition, the sequence stratigraphic analysis of the core will be compared to the analysis performed in outcrop by Vecsei et al. (1998). This comparison will address questions surrounding the stratigraphic position (highstand versus lowstand) of carbonate turbidites.

Project Tasks

Core description and sampling of the cores will be performed in the core facilities of ENI in Milano, Italy. The petrophysical measurements will include sonic velocity, porosity, permeability, and some resistivity measurements. A thin section will be cut from the end of each plug for analysis of texture, pore structure, and the diagenetic paragenesis. Digital image analysis of the pore structure will allow relating pore structure to both the acoustic and hydraulic properties. The porosity and permeability measurements of the outcrop samples are completed (Figure 2). They will be complemented with velocity, selected resistivity measurements and the digital image analysis. The outcrop and core data sets will be compared to check if the outcrop samples are similar to the subsurface samples. The petrophysical measurements will also be compared to the log suite from the well for calibration of the slope and basin facies to the log signature. Furthermore, in order to differentiate the age and characterize the facies, a sequence stratigraphic analysis will be performed on the core.

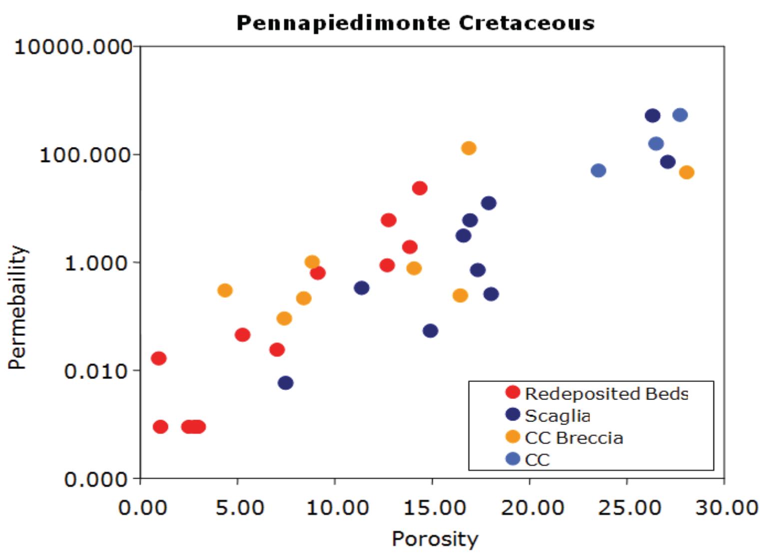


Figure 2: Porosity versus permeability of megabreccias and turbidites (red dots) and the corresponding background sediment (Scaglia, dark blue dots). Breccias rich with rudist debris (Calcare Cristallini CC Breccia, orange dots) have generally less porosity and permeability than the finer-grained sediments (Calcare Cristallini, CC, light blue dots).

Key Deliverables

This project will provide a comprehensive petrophysical and diagenetic characterization of mass gravity flows along the Maiella carbonate platform and an assessment of the reservoir potential of re-deposited carbonates from their seismic and log expression.

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Petrophysical Characterization of Danian Deep-Water Coral Mounds, Faxe, Denmark

Gregor P. Eberli, Cornelia Rasmussen, and Ida Fabricius[1]
[1] Technical University of Denmark, Department of Environmental Engineering

Project Purpose

Deep-water corals form impressive mounds up to 180 m high in the modern oceans. For example, the 155 m high Challenger Mound in the Porcupine Basin is constructed by an alternation of coral floatstone and wackestone units. In the Straits of Florida, mounds can be as high as 120 m and coalesce to form kilometer long ridges. Thus, their size and abundance make them potential but hitherto unexplored reservoirs. Little is known about the petrophysical properties of these mounds. In the early Cenozoic strata (Middle Danian) of Denmark, large reefal mounds, similar in size and shape to modern ones, occur in deep-water carbonate settings. In the Faxe quarry, the reefal limestone and its associated facies are mined and can be sampled for a petrophysical characterization of these mounds (Figure 1).

The Faxe Quarry

The Faxe limestone quarry is dug into a pronounced topographic bank and exposes a complex of inter-bedded coral and bryozoan limestone banks of Middle Danian age. The most extraordinary feature at the Faxe quarry is the great coral bank complex.

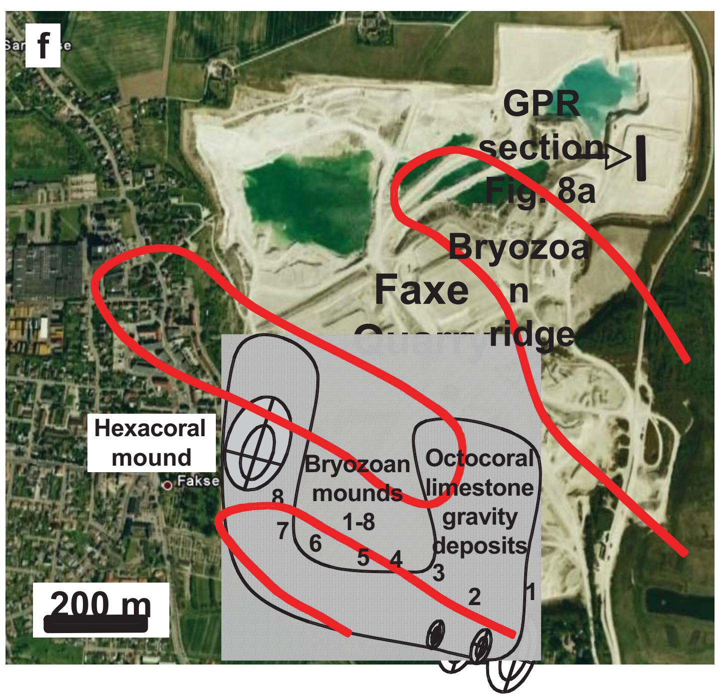


Figure 1: Arial view and geological map of th e Faxe quarry. The red lin es outline the bryozoan ridges while hexacoral mounds and their associated facies dominate the crosshatched area.

The Faxe Mound, which is slightly elongate in the NW-SE direction and covers over 1 km^2, has an immensely rich fauna and has undergone some diagenetic alterations (Figure 2). The individual coral banks are up to approximately 20 m high and stacked mounds are estimated to be up to 100 m high. The coral banks are inter-bedded with bryozoan banks.

The coral mounds are predominantly built by 3 genera of ahermatypic scleractinian corals: *Dendrophyllia, Faksephyllia*, and *Oculina*. Other species of scleractinian coral do, however, also occurr, as do octocorals and stromatoporide sponges. (For more details see http://geosites.dk/themes/danian_selandian/ds_fakse_kalkbrud/index.html).

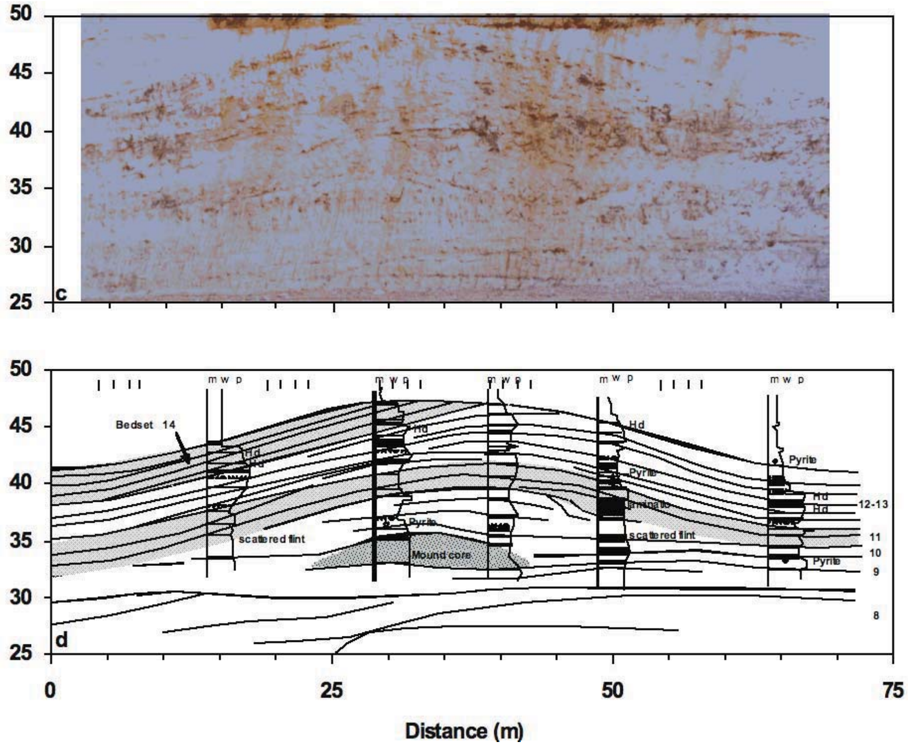


Figure 2: Photograph and line drawing of part of the Faxe Mound displaying the internal architecture of the deep-water coral reef.

Scope of Work

The geometry and texture of the mounds are assessed using photography and surface mapping. The main focus of the project is to the measure porosity, permeability, sonic velocity, and resistivity of the mound strata. In addition, the pore structure will be documented with quantitative digital image analysis parameters. The petrophysical measurements and the digital image analysis will be integrated into a sedimentological and diagenetic characterization of the mounds.

Deliverables and Expected Results

This study will produce the first petrophysical characterization of deep-water coral mounds of Danian age. It is expected to provide a basis for evaluating the reservoir potential of deep-water build-ups of this and other ages.

Near-Surface Geophysics

4D GPR for Fluid Flow Quantification in Fractured Carbonates: Cretaceous Orfento Formation, Madonna della Mazza, Italy

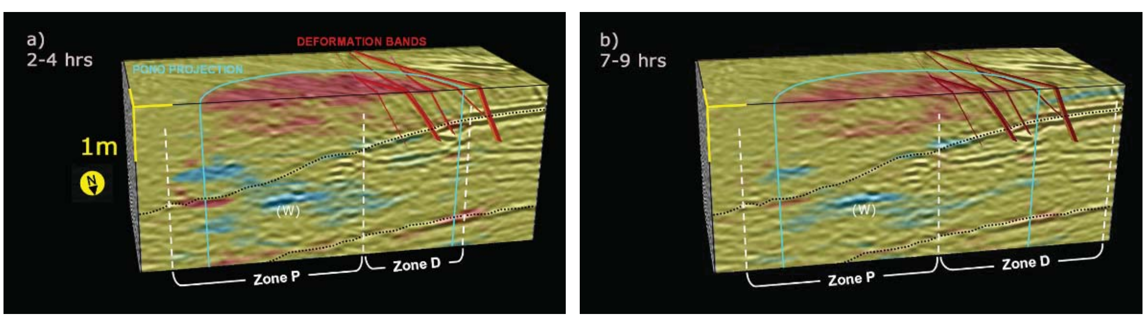
Pierpaolo Marchesini, Mark Grasmueck, and Gregor P. Eberli

Project Objectives

- Calculate volumetric water content changes and visualize wetting/draining zones of a controlled infiltration experiment in fractured carbonates.
- Compute flow rates within porous matrix and quantify the influence of faults and deformation bands on fluid flow.
- Compare the results with the Miami Oolite infiltration experiment and dynamic fluid flow simulation.

Rationale

Characterization of the parameters controlling fluid flow mostly relies on 0.01-0.1 meter scale lab measurements, up scaling, and modeling. To visualize and quantify fluid flow at a more realistic scale of 1-10 meters, we conducted a field experiment injecting and monitoring a moving water mass into a fractured grainstone reservoir analog. 4D GPR is used in this study to quantify local water content changes, delineate wetting and drainage zones, and determine the influence of faults and deformation bands on fluid flow. Characterizing the dynamics of fluid flow in a porous matrix is possible because of variations detected in the GPR response between time-lapse data (Truss et al., 2007). Quantification of fluid flow within a network of faults and deformation bands helps in perfecting flow models and residual fluid recovery.



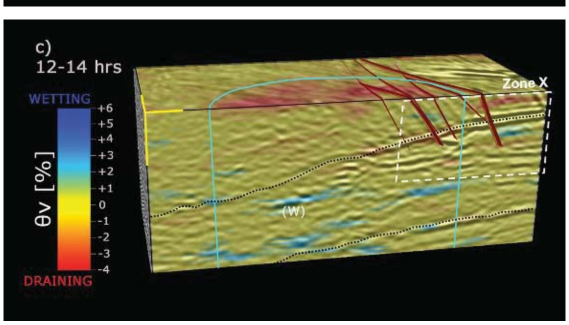


Figure 1: Two hour snapshots of the computed water content changes for pairs of surveys acquired a) 2-4 hrs, b) 7-9 hrs, and c) 12-14 hrs after the pond was removed. Red color indicates areas of draining and blue color indicates areas of wetting.

Project Background and Fieldwork

Data were acquired in summer 2009 at the Madonna della Mazza quarry. This quarry is cut into a sequence of Upper Cretaceous rudist grainstones (Orfento Formation) located in the Majella anticline in southern Italy. We chose the infiltration area where previously acquired 3D GPR surveys revealed the coexistence of dipping layers, faults, and deformation bands in a high porosity matrix. Average porosity and permeability is 30% and 300 millidarcy (mD), respectively. 3000 liters of water were infiltrated over 30 hours from a polyethylene pond with a 4-meter diameter installed on the quarry floor. The time-lapse dataset consists of sixteen repeated 3D GPR surveys (2 before and 14 after the infiltration) monitoring a 20x20x10 meter rock volume over 5 days. A 3D rotary laser positioning and guidance system coupled with a 200 MHz GPR system achieved high-resolution 3D data quality and centimeter precise repeatability between surveys.

Method and 2010 Preliminary Results

Event timeshifts and amplitude differences between repeated surveys are related to subsurface water content changes. GPR reflection travel timeshifts are extracted from survey pairs with a 3D warp algorithm, followed by quantification of volumetric water content changes with the Topp petrophysical transfer function (Topp et al., 1980). For three different infiltration stages, volumetric water content changes have already been computed with an accuracy of 1% (Figure 1). Results show that the momentary wetting and drainage zones are located in the undisturbed strata, compared to strata disturbed with deformation bands. The decrease of permeability, relative to the surrounding rock matrix, slows down the fluid flow across deformation bands (Fossen et al., 2007). We also observe how the gravity driven transport of water, occurring in the first stages of the experiment (with greater hydraulic heads), shifts to a capillary driven transport, indicating that the hydraulic regime changed within 12 hours.

Tasks for 2011

1. Extensive computation of water content changes during the entire experiment over time intervals ranging from 2 hours to 5 days from the start of the infiltration.
    - Preliminary results of water content changes generated for three stages indicate that monitoring the behavior of the infiltrated water mass over time and space is possible with our data. The implementation of a 3D warp code on a GPU processing unit will be completed to process a total of 105 possible pair combinations within the 16 time-lapse GPR volumes. This unique dataset will be used to reach a comprehensive visualization and quantification of fluid flow dynamics with unparalleled accuracy.
2. Comparison of flow behavior in the fractured carbonates of the Madonna della Mazza quarry with the results from the infiltration in the undisturbed Miami Oolite.
    - The first GPR time-lapse experiment was in the oolitic shoal system of the Pleistocene Miami Limestone where 3200 liters of water infiltrated strata with porosities ranging from 20-50% and permeabilities up to 1 Darcy

(Grasmueck et al., 2007). The water preferentially propagated along the dipping stratigraphy, causing an asymmetric wetting bulb. There are indications of local breakthroughs across stratigraphic boundaries (Figure 2). The comparison of the two infiltration experiments allows the role of sedimentary structures, such cross bedding in the Miami Oolite, versus structural deformation, such as deformation bands in the Orfento Formation, to be assessed.

3. Comparison with Eclipse dynamic fluid flow simulation.
   - With guidance from Ray Mitchell (ConocoPhillips), a static model was built of the cube from the infiltration experiment in the Madonna della Mazza quarry. Kirsten Gustafson (ConocoPhillips) then translated the model into Eclipse for dynamic fluid flow simulation (Figure 2). We plan to run several simulations and compare the results to the flow behavior measured with the time-lapse GPR surveys.
4. Integration of 4D GPR results with petrophysical measurements on sample plugs and thin sections analysis.
   - In order to comprehensively capture the flow behavior of the rudist grainstone facies from the plug to the meter scale, plugs from various stratigraphic intervals will be analyzed for their porosity, permeability, velocity, and electrical resistivity.

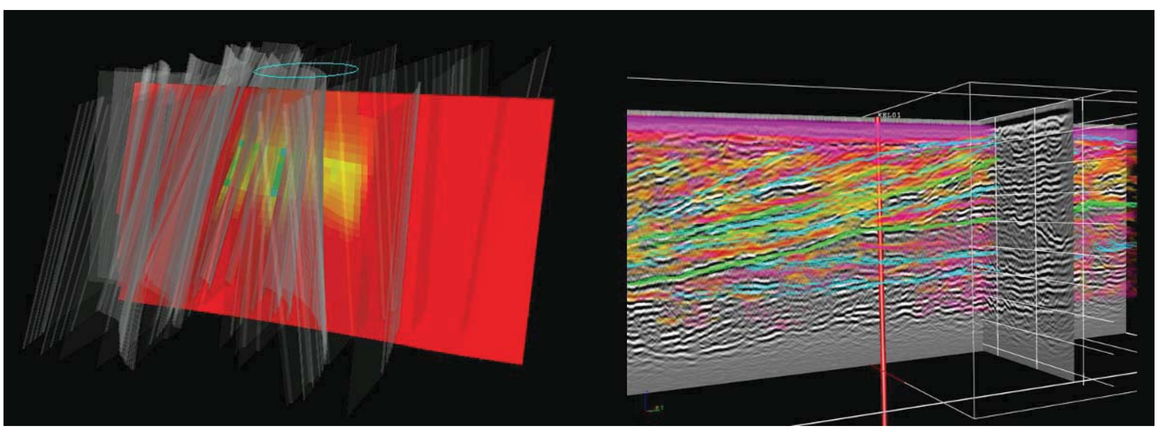


Figure 2: Snapshot of saturation changes from the Eclipse fluid flow simulation. Faults and deformation bands are rendered semitransparent (left). Overlay of regular 3D GPR data and water content changes in the Miami Oolite infiltration experiment (right).

Key Deliverables

This project will deliver fully characterized stratigraphic-structural-hydraulic relationships for the Madonna della Mazza Quarry. This characterization includes the integration of water content change volumes, propagation rates, quantification of fluid mass balance, conventional 3D GPR data, and rock sample measurements. This project also develops the tools and a workflow applicable to other outcrop reservoir analogues where a precise understanding of flow processes is needed.

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Fracture Properties from 3D GPR Diffractions

Mark Grasmueck, Michael A. Pelissier[1] *and Tijmen Jan Moser*[2]
[1]*Marathon Oil company, Houston USA* [2] *Moser Geophysical Services, Den Haag ,NL*

Project Objectives

- Assemble and analyze typical diffraction signatures from 3D GPR surveys in fractured carbonates.
- Propose simple geometrical models for scattering mechanisms causing diffractions related to fractures.
- Verify diffraction signatures with synthetic modeling.
- Investigate sensitivity of diffraction responses to fracture properties.

Rationale

Recent advances in high-resolution 3D GPR imaging show how complex fracture networks, including millimeter thin sub-vertical joints, can be delineated with the help of diffractions previously considered as noise (Grasmueck et al. 2010). For the visualization of the fractures, the 3D GPR data have to be migrated to focus the diffractions. The fracture planes appear as alignments between focused diffractions events.

Figure 1: Intersection of sub-vertical and horizontal fractures, a possible cause of fracture related diffractions.

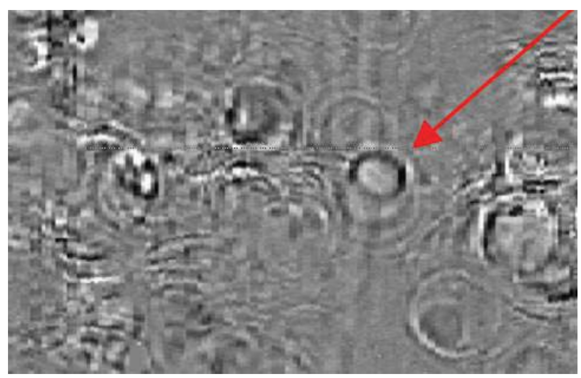

Figure 2: Examples of asymmetric diffractions on a GPR time slice.

This project addresses the origin of individual diffractions caused by fractures. To move from pure delineation of fractures to quantification of fracture properties, a detailed understanding of diffraction mechanisms is necessary. Diffractions originate from sub-wavelength point- and linear-scatterers and, therefore extend the resolution of wave based geophysical methods like GPR and reflection seismic. Such diffraction imaging is also known under the term of super-resolution imaging (Moser and Howard, 2008). Our working hypothesis for the origin of fracture diffractions is the intersection of horizontal and vertical fractures causing sharp edges along fracture planes (Figure 1). This hypothesis needs to be thoroughly tested because inspection of 3D GPR data leaves several open questions, such as: 1) Why is the majority of diffractions circular and not linear as expected from the intersection of 2 planes, and 2) What is the cause of asymmetry in most diffractions (Figure 2)? To date, no model can reproduce these observations of field data. Resolving such questions and advancing the understanding of the nature of diffractions in fractured carbonates is the first step towards quantification of fracture properties, such as dip, azimuth, aperture, and fill from high-resolution geophysical data.

Scope of Work

A detailed analysis of fracture related diffractions has already started in collaboration with Michael Pelissier and Tijmen Jan Moser. High-resolution 3D GPR data examples are used for testing of concepts and techniques. The project involves three main activities:

1. Detailed analysis of diffraction signatures in un-migrated 3D GPR data, with superposition of fracture interpretation obtained from 3D migrated data. The goal is to find the origins and asymmetric patterns related to fracture network and stratigraphy.
5. Develop basic geometric models of scattering points that could cause the observed diffraction patterns. Test if synthetic GPR or seismic data can reproduce the observations.
6. Investigate sensitivity of diffractions to fracture orientation, dip, fill, and aperture by variation of the model parameters.

With the availability of several high-resolution 3D data sets from fractured carbonates in close proximity to outcrops, GPR data are an ideal base to develop a basic understanding of fracture related diffractions. Comparisons with seismic data containing diffraction signatures are used to transfer findings to reservoir depth.

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(Bio) Geochemical Projects

Microbial Characterization of Carbonate Surface Sediments from Great Bahama Bank

Mara R. Diaz, Alan M. Piggot, and James S. Klaus

Project Purpose

Microbial communities can promote carbonate precipitation through a number of processes, including: 1) the lowering of pCO2 through autotrophic metabolism; 2) fungal mediation; 3) heterotrophic bacterial mediation by nutrient cycling processes or ionic exchanges; and 4) extracellular polymeric secretion (EPS). These processes are believed to play a key role in the formation of carbonate mud, stromatolites, submarine cements, dolomite, and potentially ooids (Castanier et al. 1999, Bontognali et al. 2008). Despite the importance of microbial processes in shallow water carbonates, little is known about the spatial variability of microbial communities and their associated microbial metabolisms.

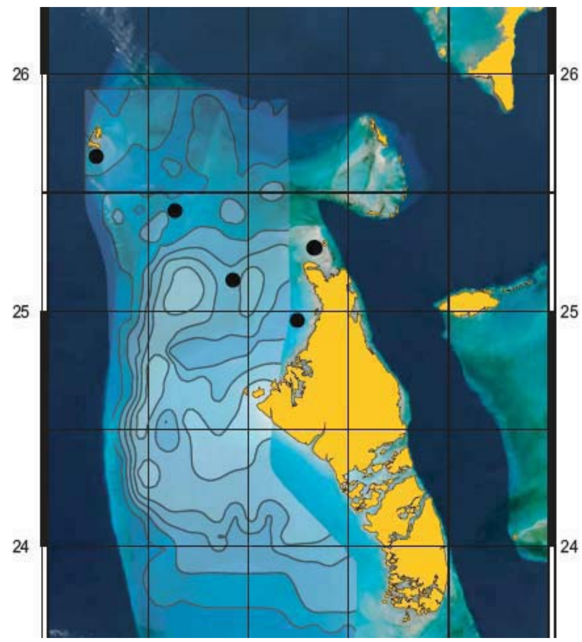

Figure 1: Map of Great Bahama Bank showing bathymetry and the position of key sampling localities to assess the variation in microbial diversity and biofilm development on carbonate sediments

This knowledge gap of microbial processes in carbonates is nowhere more evident than in the formation of oolitic sand bodies. Despite the importance of oolitic grainstones as carbonate reservoirs, the genesis of ooids remains controversial. One school believes that ooid formation results from abiotic processes that induce physicochemical calcium carbonate precipitation (Duguid et al 2010) whereas others have attributed their origin to biogenic factors (Folk and Lynch 2001, Plee et al 2008). Despite these controversial studies, little is known about the microbial composition or metabolisms of the communities associated with ooids and the role that they play in ooid formation.

To fill this knowledge gap and to better understand the role of microbial communities in carbonate precipitation processes, including ooid formation, we propose to characterize the microbial community composition of surface sediments collected along an east-west transect of Great Bahama Bank (Figure 1).

Data Set

During the summer of 2010, surface sediment samples were collected along an east-west transect on Great Bahama Bank (Figure 1) and scattered localities across the Caicos Platform. Samples were collected from a range of depositional environments including: 1) active ooid shoals (Joulters Cay, Cat Cay, Ambergris Cay); 2) stabilized ooid shoals;

3) grapestone facies; 4) peloidal grainstones and packstones of the platform interior; and 5) skeletal grainstones around reefs.

Identification of the Microbial Community

The microbial diversity will be analyzed by the innovative technique called Terminal Restriction Fragment Length Polymorphism (T-RFLP) (Figure 2). T-RFLP is a molecular technique used for profiling microbial communities. Polymerase chain reaction (PCR) is used to amplify the targeted gene with a universal labeled forward bacterial primer. The reverse primer PCR amplicons are then digested with restriction enzymes. Terminal fragments are analyzed on an ABI 3130 sequencer and the terminal restriction fragment (T-RF) peaks are plotted on an electropherogram (Figure 2). A clone library will be constructed in parallel to the T-RFLP analysis to determine the relative abundance and identification of microbial "species" within the community.

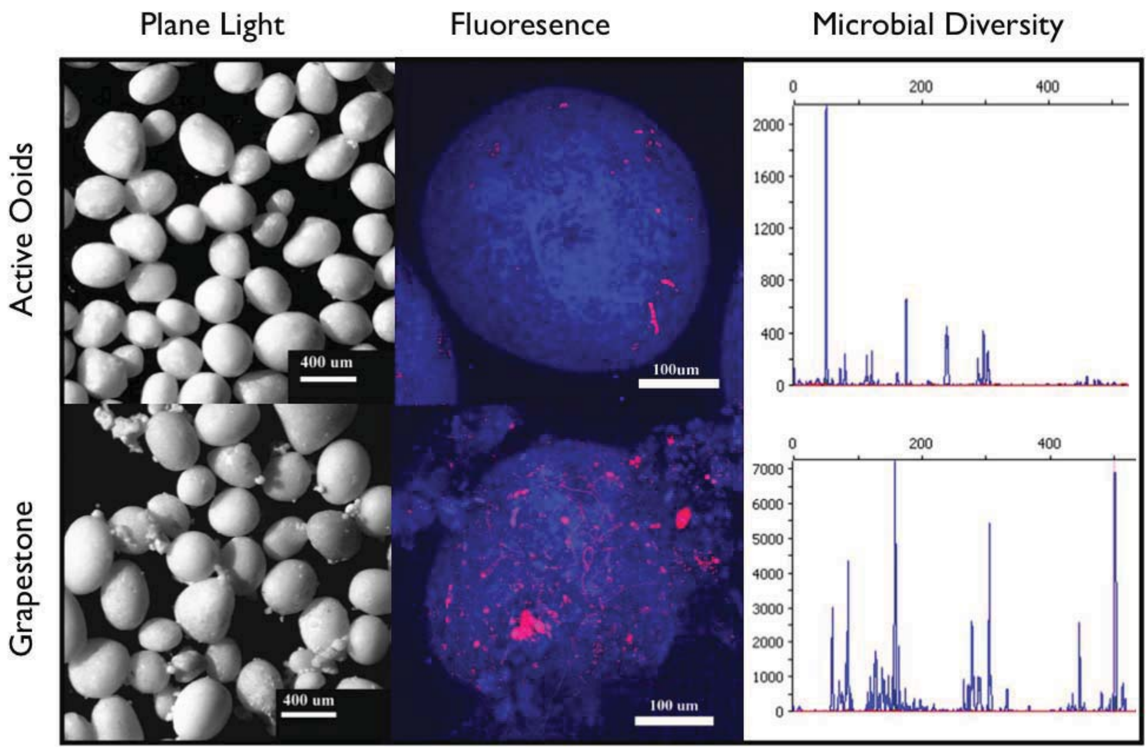

Figure 2: (Left) Plane-light images of sediments collected from an active ooid shoal and grapestone facies. (Middle) Confocal Laser Scanning Microscopy (CLSM) images of ooid and grapestone grains. Blue areas are aragonite and pink areas are stained for extracellular polymeric substances. (Right) Representative T-RFLP microbial community profiles. Peaks represent different bacterial species and their relative abundance in the sample.

Visualization of the Microbial Community

Visual examination will complement the molecular microbial characterizations. Additional sediment samples were preserved in 70% formaldehyde to microscopically analyze the microspatial distribution of attached microbes within biofilms. Confocal Laser Scanning Microscopy (CLSM) provides the ability to acquire in-focus images from selected depths, a process known as optical sectioning or tomography (Figure 2). Images are acquired point-by-point, allowing for three-dimensional surface reconstructions of topologically complex objects like sand grains. Sediments observed with CLSM are stained with the cyanine die-conjugated lectin, wheat germ agglutinin (WGA). The WGA lectin binds to extracellular polysaccharide secretions (EPS) associated with the biofilms (Neu et al 2001). Environmental scanning electron microscopy (ESEM) will be used to obtain high-resolution images of natural sediment biofilms. Together, these studies will allow visualization of the spatial distribution of EPS and microbes on sediment grains and the relationship of these two components in sediment biofilms.

Key Deliverables

- Molecular characterization of surface sediment microbial community and their variation across the primary depositional environments of Great Bahama Bank.
- Preliminary assessment of the variation in sediment microbial metabolisms will be inferred from DNA sequence analysis. The relationship of inferred metabolisms to sediment characteristics and environmental parameters (Temp, pH, salinity, nutrients) will be evaluated across the platform.
- An image archive of the confocal laser scanning micrographs will be produced for the 3-D visualization of sediment biofilms that includes both the extracellular polymeric substances (EPS) and the live microbial cells from the primary depositional facies.
- Assessment of the role of biofilm development in ooid formation using the combined information of the microbial profiles and CLSM micrographs.

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Clumped Isotopes: Application to Diagenesis

Peter K. Swart, Sean Murray, and Monica Arienzo

Project Purpose

Clumped isotopes of CO_2 are solely dependent upon temperature and not on the isotopic composition of the fluid from which they are formed. This opens significant possibilities in unraveling the temperature and water signal, as applied to diagenetic carbonates. Utilizing our newly installed Thermo 253, we will systematically examine the Δ47 in a range of well characterized diagenetic environments.

Scope of Work

Following the successful installation of the Thermo 253, which took place during the first two weeks in January 2011, we will start to investigate the clumped signature in naturally occurring carbonates whose temperature of formation is well constrained. In addition, we will artificially produce carbonates at higher temperature in order to ascertain the temperature dependence of the Δ47 signal in these materials.

Key Deliverables

This work will assess whether the clumped isotope technique can be applied to diagenetic applications.

Project Description

Perhaps the most exciting development in the field of stable isotopes has been the emergence of 'clumped' isotopes. Clumped isotopes refer to the combination of two or more of the rare isotopes in one molecule. In the case of carbon dioxide, the most abundant 'clumped' species occurs at mass 47 and is the combination of ^{13}C and ^{18}O. Ghosh et al. (2006) demonstrated that the abundance of $^{13}C^{18}O^{16}O$ in CO_2 generated from the classical reaction of carbonates with phosphoric acid is proportional to the abundance of $^{13}C^{18}O^{16}O_2^{2-}$ ion species within the minerals. Usually, abundances of mass 47 CO_2 are reported using the variable Δ47 representing the difference in per mil between the measured 47/44 ratio and the expected 47/44 ratio for that sample if its carbon and oxygen isotopes were randomly distributed among all isotopologues. Using this nomenclature, any differences in the $\delta^{13}C$ or $\delta^{18}O$ of the water from which the mineral precipitated is taken care of by the expected 47/44 ratio; therefore, the difference (Δ47) is solely dependent upon temperature. To date, this method has been applied to a number of different carbonate systems (Affek et al. 2008a; Affek et al. 2008b; Ghosh et al. 2006; Huntington et al. 2009), but has not been investigated in the service of diagenesis.

The first requirement for performing a clumped isotope measurement is an instrument capable of simultaneously measuring mass 44-47. The instrument must also have more sensitive amplifiers at mass 47-49 (to measure the species at these masses). This instrument has been installed at the University of Miami and is working satisfactorily (Figure 1). The second step will be to construct an extraction line for carbonates which will purify the CO_2. This process is essential to remove any potential contaminants at mass 47. The third step will be to test the effectiveness of the line and to prepare a series of heated gas standards with which to calibrate our working standard. After satisfactory completion of these three steps, we will be able to start analyzing samples for a series of well-calibrated diagenetic environments. These environments will include:

1. The classic diagenesis associated the vadose, freshwater water phreatic, mixing zone, and marine diagenesis found in the Pleistocene sections in the Bahamas. The temperature of these environments should be close to 20˚C-25˚C; therefore, both the variability of the waters involved and the veracity of the clumped method can be assessed.
2. There are several localities in the Bahamas where dolomite has been found and interpreted as being formed from normal seawater. The temperature of the formation of these dolomites is assumed to be relatively low but can now be tested using the clumped method, which can measure the oxygen isotopic composition of the dolomitization fluids. Assuming knowledge of the fluids and the temperature, the fractionation factor of the process can be determined.

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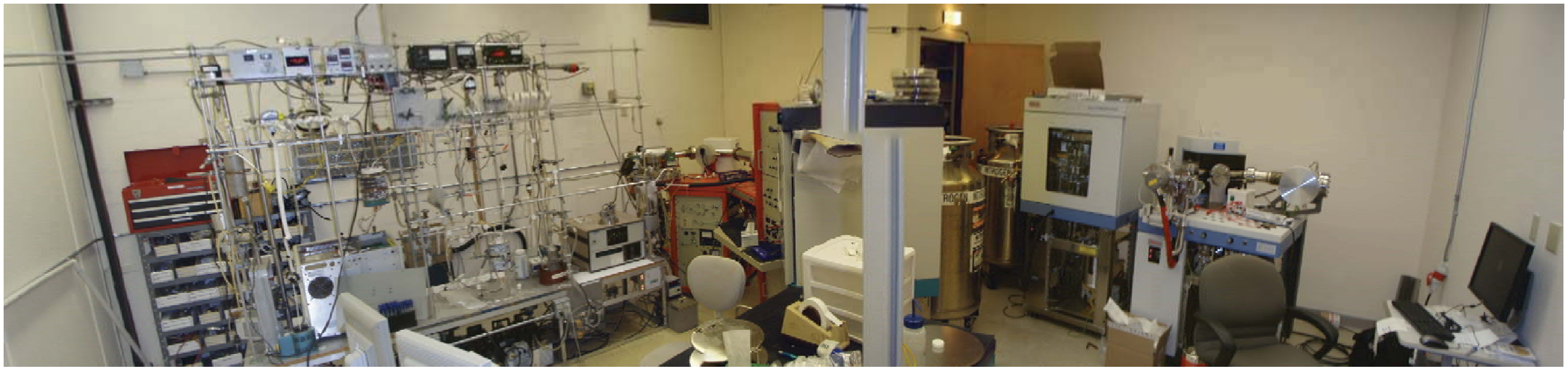
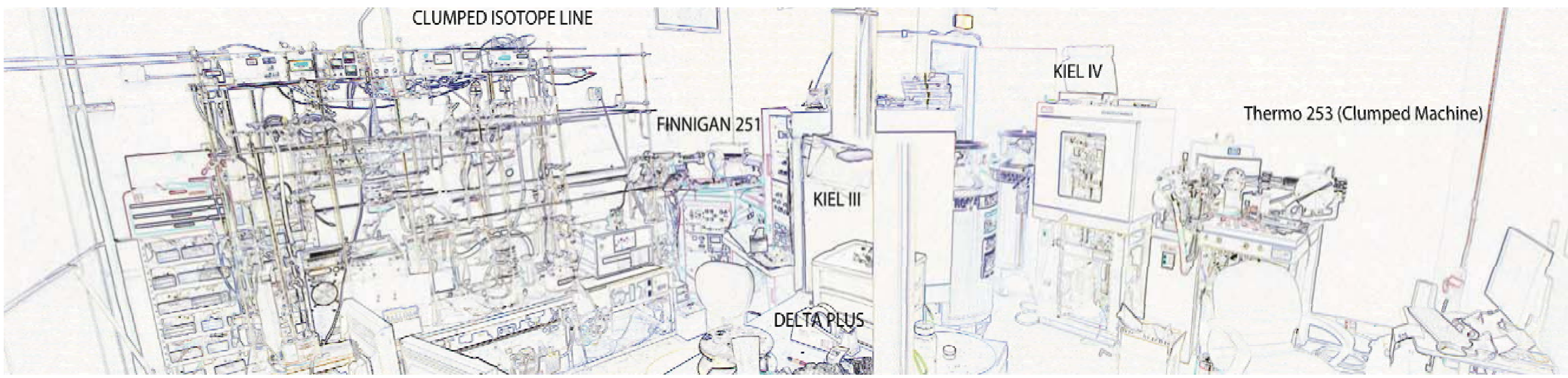
Panoramic view of the stable isotope laboratory with the new clumped isotope machine (Thermo 253)





Decoupled inorganic and organic $\delta^{13}C$ records in periplatform sediments: A global signal unrelated to the global carbon cycle?

Amanda Oehlert and Peter K. Swart

Project Purpose

The degree to which the inorganic and organic $\delta^{13}C$ values covary has been used to assess the primary nature of the inorganic $\delta^{13}C$ record. A direct correlation between inorganic ($\delta^{13}C_{inorganic}$) and organic ($\delta^{13}C_{organic}$) records is used to confirm that the deposit is relatively unaffected by diagenetic alteration, and that the $\delta^{13}C_{inorganic}$ record provides valid information about global carbon cycling. This assumption has been very important in interpreting global carbon cycling throughout geological time (Jarvis et al., 2006, Swanson-Hysell et al., 2010). However, a recent study found that the correlation between relatively modern $\delta^{13}C_{inorganic}$ and $\delta^{13}C_{organic}$ records varied in a series of cores drilled along the western slope of Great Bahama Bank (Oehlert et al., 2012). The decoupling of these records in Pleistocene-Recent periplatform sediments suggests that using $\delta^{13}C_{organic}$ records to support the global nature of $\delta^{13}C_{inorganic}$ records may not be applicable in shallow marine carbonate platform environments. This project will ascertain whether the decoupling of the $\delta^{13}C$ records observed at Great Bahama Bank is a local phenomenon or identifiable in carbonate margins and platforms in a variety of environmental conditions around the world.

Rationale for the Study

Previous studies have shown that trends in $\delta^{13}C_{inorganic}$ over the past 10 myrs are similar in carbonate margins and platforms such as the Great Bahama Bank, the Great Barrier Reef, the Great Australian Bight and the Maldives and that the similarity in the $\delta^{13}C_{inorganic}$ trends are a function of eustatic sea-level changes, and thus reflect a global signal (Swart and Eberli, 2005; Swart, 2008). Although this signal is globally recognizable, it does not track the $\delta^{13}C_{inorganic}$ signal of the global carbon cycle (Swart and Eberli, 2005; Swart, 2008). The global similarity of periplatform $\delta^{13}C_{inorganic}$ records over the past 10 myrs suggests that the phenomenon of decoupled $\delta^{13}C$ records at Great Bahama Bank may be identifiable in other carbonate platforms and margins around the world. Based upon these findings, it is anticipated that the range of $\delta^{13}C_{inorganic}$ and $\delta^{13}C_{organic}$ correlations identified at Great Bahama Bank will be found in the slope transects drilled by the Ocean Drilling Program at the Great Barrier Reef and the Great Australian Bight. The sediments on Great Bahama Bank are predominantly peloids, ooids, and mud-rich wackestones, which potentially make Great Bahama Bank unique in the geological record. Thus, it is very important to generate records of $\delta^{13}C_{inorganic}$ and $\delta^{13}C_{organic}$ in different depositional environments.

Project Description

Cores recovered during ODP Leg 133, drilled at the Great Barrier Reef, provide an opportunity to study the relationship between $\delta^{13}C_{inorganic}$ and $\delta^{13}C_{organic}$ records at mixed siliciclastic-carbonate margin, where the grain sizes produced are much larger than those of Great Bahama Bank. Additionally, the Great Australian Bight (ODP Leg 182) cores will provide insights into the production of carbonates and organic carbon in a non-tropical environment. If the $\delta^{13}C_{inorganic}$ and $\delta^{13}C_{organic}$ records are indeed decoupled at these locations, the results will strongly suggest that using $\delta^{13}C_{organic}$ values to corroborate the primary nature of $\delta^{13}C_{inorganic}$ records in marginal settings is not a valid application in interpreting global carbon cycling.

Analyses of organic $\delta^{13}C$ values will be conducted on samples from two carbonate margins: the Great Barrier Reef, a mixed siliciclastic-carbonate margin (Leg 133), and the Great Australian Bight, a cool water carbonate setting (Leg 182). Approximately 500 samples from the top 150m of Leg 133, Sites 819-823 and approximately 400 samples from the top 150m of Leg 182, Sites 1126, 1128, 1132, and 1134 will be analyzed for bulk $\delta^{13}C_{organic}$ values. These results will be compared to published $\delta^{13}C_{inorganic}$ records from the same locations (Swart, 2008). An analysis of the relationship between $\delta^{13}C_{organic}$ and $\delta^{13}C_{inorganic}$ records will also be conducted in order to compare the records to those of Great Bahama Bank and to validate the hypothesis that the decoupled $\delta^{13}C$ records are a global signal.

Key Deliverables

The results of this project have the potential to confirm that the decoupled $\delta^{13}C_{inorganic}$ and $\delta^{13}C_{organic}$ records identified along Great Bahama Bank are a global signal unrelated to global carbon cycling. Also, records of $\delta^{13}C_{organic}$ values from a grainier margin at the Great Barrier Reef, and the Great Australian Bight will provide insights into the production of carbonate and organic carbon on a mixed carbonate-siliciclastic margin, as well as a non-tropical depositional environment.

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Recognition of a Global Diagenetic Isotope Signal

Peter K. Swart, Amanda Oehlert, and Martin Kennedy

Project Purpose

A fundamental argument that large changes in the C isotopic record during specific periods of time are related to changes in the global carbon cycle is that similar changes in the C isotopic signal are seen on a global basis. The purpose of this project is to compare stable C and O isotopic signals from Plio-Pleistocene shallow-water carbonates in the Atlantic and the Pacific and assess whether their diagenetic isotopic signals mimic global changes in the carbon cycle.

Scope of Work

Stable C and O isotopic composition of shallow-water carbonates from several cores in the Bahamas show a characteristic change in stable C and O isotopic composition from isotopically negative values associated with meteoric diagenesis to heavy values

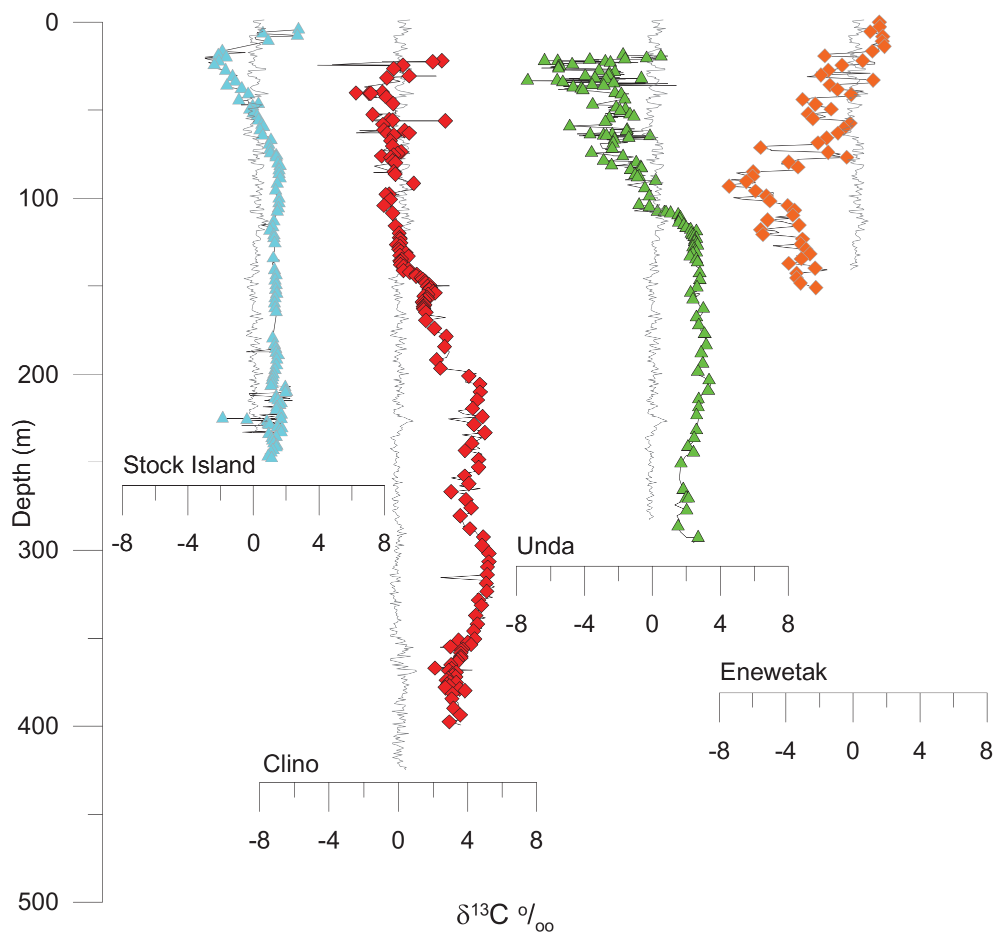

Figure 1: Comparison of carbon isotopic signals fr om three cores in the Atlantic (Melim et al. 2004; Melim et al. 20 01) with the dat a from the En ewetak core (Quinn 19 91). The pattern s of change are similar but the Pacific record is hampered by the absence of data below 150 m.

associated with marine diagenetic processes. Cores through similar aged strata have been taken in the Pacific but have not been analyzed for their stable C and O isotopic composition. We have been given permission to resample a core taken on Enewetak Atoll, which will provide a direct comparison with the Bahamian records.

Project Background

Large carbon isotope excursions occur stratigraphically beneath erosion/exposure surfaces throughout the geological record. In the Neoproterozoic these changes are widely believed to record changes in the global carbon cycle even though they are commonly associated with evidence of diagenetic alteration including, karst, carbonate neomorphism, dolomitization, and covariation between $\delta^{13}C$ and $\delta^{18}O$ within some data sets. In spite of such evidence, a marine origin for C isotope values remains the consensus view based on: 1) the recurrence of excursions in lithologically similar successions in multiple basins, 2) replication of the C isotopic values in some sections within basins, 3) the distinctive magnitude (both positive and negative) of the values perceived to be limited to this period of Earth history, 4) step-wise development of values to define peaks, and 5) a perception that $\delta^{13}C$ values are robust to diagenetic change because pore fluids and interbedded organic carbon do not contain sufficient carbon to affect a mass balance dominated by marine material.

The pattern of the change in the $\delta^{13}C$ and $\delta^{18}O$ data from the Neoproterozoic is very similar to that seen in cores in the Bahamas and Florida. The pattern of $\delta^{13}C$ and $\delta^{18}O$ changes in these cores can be succinctly described by the model proposed by Allan and Matthews (1982) and is completely unrelated to changes in the global carbon cycle over the same time period. Such a signal should be global in nature, but comparison to other localities is difficult as there is a paucity of cores. Several cores have been drilled into carbonate accumulations in the Pacific, but only a partial isotopic record exist. For example the stable isotope record from the Enewetak core was only analyzed over the upper 150 meters (Quinn 1991; Wardlaw and Quinn 1991). Comparison of this portion of the record from Enewetak with the Bahamas reveals a very similar looking record (Fig. 1). In this proposed study we will measure the remaining lower section to assess the correlation across a longer time span.

Key Deliverables

A comparison of the stable C and O isotopic records from the Pacific and Atlantic will assess whether global stable isotopic signals can be produced which are primary diagenetic in nature rather than related to the global carbon cycle.

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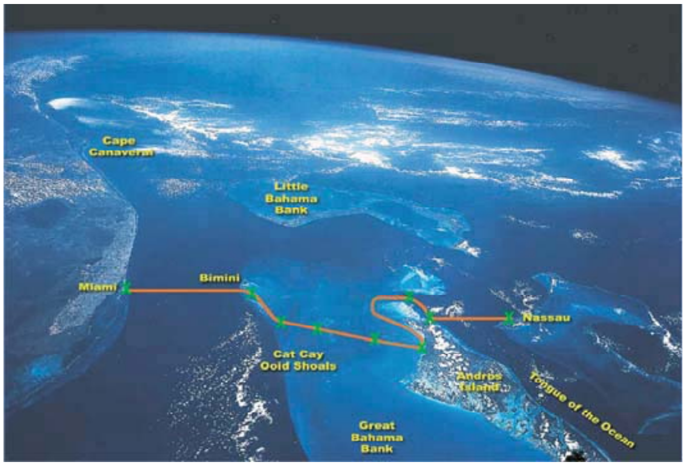

CSL
University of Miami

Field Seminar

Offered by the
Comparative
Sedimentology Laboratory

FACIES SUCCESSIONS ON GREAT BAHAMA BANK
Implications for Exploration and Reservoir Characterization

June 20 – 25, 2011

Leaders: Gregor P. Eberli, Paul M. (Mitch) Harris and G. Michael Grammer

Location: Begins and ends in Miami, Florida. The first day is a seismic and core workshop in Miami, followed by five days on a chartered boat that will cross Great Bahama Bank with stops at all important facies belts.

Objectives:

1. **Illustrate the depositional processes and dimensions of facies belts** on an isolated platform.
2. **Improve the interpretation of subsurface data** of carbonate systems
3. Relate filling of **accommodation space and facies heterogeneities** to reservoir models.

Who Should Attend: Petroleum geologists, geophysicists and reservoir engineers who are working in carbonates and need to understand facies heterogeneities and porosity distribution at exploration and production scales.

Content: This seminar explores the vertical and lateral facies successions and heterogeneities of Great Bahama Bank. The seismic and core workshop on day 1 illustrates the architecture of the prograding western margin of Great Bahama Bank. Cores across the platform margin provide a unique opportunity to examine the sequence stratigraphic distribution of facies and diagenetic modification in platform carbonate reservoirs. Log and laboratory data from these cores provide insights into porosity/velocity relationships and permeability distribution in platform carbonates.

As modern analogs, the facies belts on Great Bahama Bank display the depositional heterogeneities that may occur in ancient hydrocarbon reservoirs. We explore the spatial heterogeneity within a carbonate platform, a facies belt or individual facies bodies, while simultaneously exploring the fundamental controlling processes. In particular, sedimentary structures, dimensions and lateral variability of classic reservoir facies are examined during the seminar. Field stops include the leeward platform margin (Cat Cay Ooid Shoal), the platform interior, the tidal flats of Andros, the ooid shoals of Joulters Cay, patch reefs, and the Andros Island barrier reef. Pleistocene outcrops on Bahamian islands show how these facies are preserved in the ancient rock record.

For the complete program visit: http://www.cslmiami.info/learning/fieldSeminars

On the Cat Cay Ooid Shoal

In an Andros Island tidal channel

Cost: $4,100 - Flights to and from the Bahamas, all ground transportation, on-board boat accommodation in the Bahamas, meals, and course notes are included.

Contacts: **Gregor P. Eberli** (305) 421-4678 geberli@rsmas.miami.edu
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Registration: A soon as possible but no later than May 1, 2011 by contacting:

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