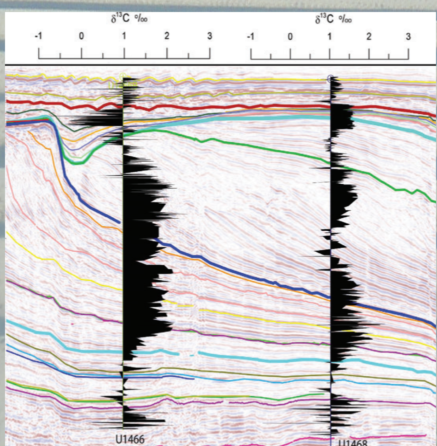
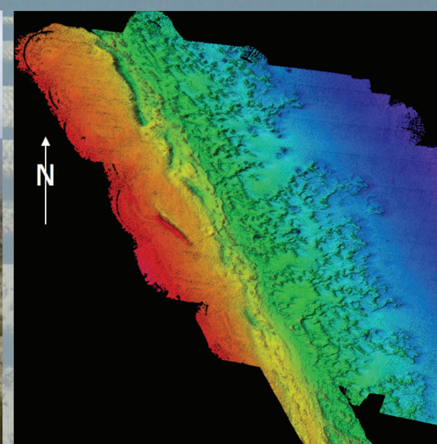
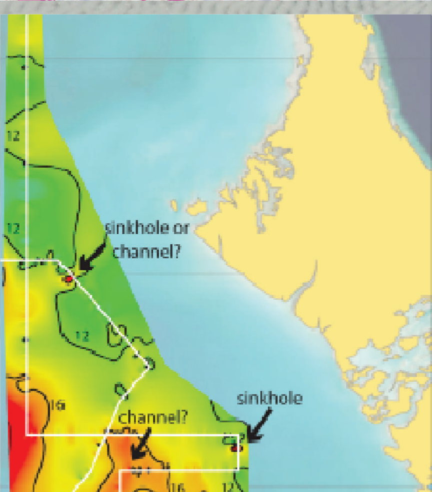
CSL
Center for Carbonate Research
and Education







Prospectus
2019

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

CSL
CENTER FOR CARBONATE RESEARCH

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MISSION OF THE CSL – CENTER FOR CARBONATE RESEARCH

The mission of the CSL – Center for Carbonate Research is to conduct fundamental research in carbonates for improved reservoir prediction and characterization.

The research conducted within the CSL - Center for Carbonate Research (CSL – CCR) is intended to advance studies in a variety of emerging topics in carbonates. In addition to the fundamental knowledge gained from these studies we aim to inform our industrial associates on the newest research techniques that potentially can be incorporated into the workflow of projects or help to solve longstanding problems in exploration and production.

The 2019 projects integrate geology, geophysics, geo-microbiology, and geochemistry and combine observational, laboratory, and theoretical research, covering four areas:

- Carbonate Systems and Reservoir Characterization
- Petrophysics and Near-Surface Geophysics
- Unconventional Reservoirs
- Geochemistry and Geo-Biology of Carbonates

Performing research within these four general research disciplines allows us to address fundamental questions in carbonate research in a comprehensive way. As a consequence, some of the research projects are interdisciplinary while others are designed to advance knowledge in one specific area. The various projects are described in detail in this prospectus and are retrievable on the website www.cslmiami.info.

KNOWLEDGE TRANSFER

The CSL – Center for Carbonate Research transfers the research results to our industry partners through an annual meeting, our website, webinars and publications.

We continue to offer field seminars and short courses.

A Certificate Program in "Applied Carbonate Geology" offers geoscientists the opportunity to become experts in carbonates.

We present the research results described in the prospectus at the **Annual Review Meeting** and provide each company with a digital version of our presentations and publications stemming from CSL sponsored research. On our **website** research results from previous years can be viewed in the archive section, providing a comprehensive database for many topics and geographic areas. Upon request, we also share original data sets with participating companies. Also on request, we offer **webinars** of various aspects of our research to our industrial associates.

PERSONNEL

PRINCIPAL INVESTIGATORS

Gregor P. Eberli	Professor, Seismic Stratigraphy
Mark Grasmueck	Adjunct Professor, Subsurface Imaging
Paul (Mitch) Harris	Adjunct Professor, Applied Sedimentology
James S. Klaus	Associate Professor, Paleontology
Donald F. McNeill	Scientist, Sedimentology, Stratigraphy
Sam Purkis	Professor, Sedimentology
Peter K. Swart	Professor, Geochemistry
Amanda Oehlert	Assistant Professor, Geochemistry

ASSOCIATE SCIENTISTS

Mara R. Diaz
Greta Mackenzie
Ralf J. Weger

SCIENTIFIC COLLABORATORS

G. Michael Grammer	Oklahoma State University
Christian Betzler, Thomas Lüdmann	University of Hamburg, Germany
Dierk Hebbeln and colleagues	University of Bremen, Germany

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2019 Research Focus

New projects within the four research areas that are the focus of the CSL- Center for Carbonate Research aim to further develop the research directions in each area.

Within the Shallow-Water Carbonate System theme these new projects aim to enhance the understanding of hydrodynamics atop a large isolated carbonate platform and their influence on the production and distribution of sediments. Three projects are launched to address several aspects of this fundamental problem. All three studies use remote sensing to assess the response of the sedimentary system in a quantitative way. One project focuses on the grain production on the shallow bank top in order to develop a model of the sediment budget on top of shallow-water platforms. The relationship of mud production in whitings to the hydrodynamic forces and the pattern of mud production uses a deep-learning algorithm to identify whitings in daily MODIS ocean-color imagery over decadal timescales. In two case studies- a carbonate platform in the central Indian Ocean and the tidal-flat carbonates of Andros Island - time-separated remote sensing enables the rates of facies migration to be quantified and also permits the sediment dynamics of autocyclic versus allocyclic processes to be examined. Two studies on karst development in the Miami oolite and the Nullarbor Plain (Australia) employ spatial statistics to quantify the lateral expression of surficial karst.

We continue with a project in Colombia that investigates the changing nature of Oligocene and Miocene reef systems in the southern Caribbean. Together with the completion of a petrophysical study on fringing reefs in the Dominican Republic it will add information on the relatively small platforms that develop on volcanic edifices within the Caribbean. Acoustic measurements from the Dominican Republic data set is intended to provide information for pre-stack depth migration models in these areas.

Several recent studies that will be published this year in a themed issue of Sedimentology outline the importance of currents in deep-water carbonate deposition. The CSL has contributed to this issue with several papers from last year's projects. Follow-up projects in carbonate contourites and drifts are planned for this year. One investigates the onset of the modern ocean circulation and the concomitant influence on Neogene platform architecture. Another addresses the relative importance of bedload and suspension load for transporting coarse carbonate grains in current-controlled environments.

In the Petrophysics theme we continue with the petrophysical analyses of carbonate contourite drifts in cores and from outcrop samples in order to assess reservoir quality and heterogeneity of these current-controlled deposits. These drift samples, and the large data set from the fringing reefs in the Caribbean, will add to the spectrum of our petrophysical data base of various carbonate environments. A project to investigate how microbially-mediated precipitation of micritic meniscus cement alters the elastic properties of carbonate grainstones proves to be an experimental challenge but first results are encouraging.

In the Unconventional theme, we began a multi-year project, with the aim of establishing baseline values and the range of petrophysical characteristics in different (carbonate) mudrocks. In this collaborative research effort with G. Michael Grammer (Oklahoma State University) we also characterize the pore system architecture of these mudrocks using BIM-SEM images. Additional samples from the Vaca Muerta Formation in the Neuquén Basin, Argentina, will expand our extensive dataset and further assess the controlling parameters (mineralogy, TOC, carbonate content, porosity and pore structure) for their acoustic and electrical properties.

We also expand our field area in the Neuquén Basin by measuring new sections towards the north to assess the degree of lateral variability between different sections only separated by a few kilometers. Two projects, on TOC distribution and clinoform development, will be completed this year.

The Geochemistry group concentrates on three topics. The first is to refine and improve the calibration of the clumped isotope temperature proxy. Two projects in dolomites and biogenic carbonates are used for achieving this goal. The second focuses on the application of different isotope systems in assessing the extent of diagenesis in carbonates, in particular using the B, S, and clumped isotope proxy. Finally, we are investigating controls on the global pattern of $\delta^{13}C$ values in the carbonate and organic components of marine sediments using material from the Bahamas, the Nicaraguan Rise, and the Maldives.

In the Geobiology theme, the Hamelin Pool stromatolites are revisited. The environmental and morphometric study done earlier is complemented with an advanced geochemical analysis. Another study, in collaboration with G. Alejandra Santiago from Oklahoma State, examines the role of microbes in early cementation in reefs and slopes.

Below is a list of all planned projects. The detailed objectives and deliverables of each project are outlined further in the 2019 research prospectus.

2019 Planned Projects

Carbonate Systems and Reservoir Characterization

- Rates of Intertidal Facies-Belt Migration from Time-Separated Remote Sensing
- Decadal Patterns in Mud Production on Great Bahama Bank via Whitings
- Grain Factories and Sinks - Sediment Budget of the Great Bahama Bank
- Statistical Pattern Analysis of Surficial Karst in the Nullarbor Plain (W. Australia)
- Reef Development during the Oligo-Miocene Transition as Recorded in the Cocinetas Basin, Colombia
- Habitat Map and Geo-Morphometry of East Campeche Bank: A Proxy for Current Directions
- Carbonate Contourites Drift Systems: Expanding the Data Base on Types and Dimensions
- Onset and Nature of Carbonate Drifts in the Bahamas, NE Australia and the Maldives: implications for Carbonate Platform Architecture
- Sedimentary Processes and Products in a Cretaceous Delta Drift, Maiella Mountains, Italy

Petrophysics and Geophysics

- Petrophysical Characteristics of Carbonate Drift Deposits - Maldives and the Cretaceous in the Maiella Mountains, Italy
- Petrophysical Properties of a Fringing Reef Margin: Pleistocene Dominican Republic (year 2)
- The Effect of Microbial Mediated Precipitation on Rock Physics
- Assessing Lithoclast Distribution in Grainstone Drift Deposits Using Pondview Attributes

Unconventional Reservoirs

- Baseline of Petrophysical Characteristics of Unconventional Carbonate Reservoirs (Vaca Muerta, Miss Lime, Bakken, and Eagleford)
- Stratigraphic and Lateral Distribution of TOC in The Vaca Muerta Formation
- Lithologic and Geochemical Calibration of the Basal Clinoforms in the Sierra de la Vaca Muerta, Neuquén Basin, Argentina
- Intra-Formational Flow and Fracture Barriers – Crystal Structure & Porosity of Stratigraphic Concretions, Vaca Muerta Formation
- Lateral Variability of the Vaca Muerta Formation in a Basinal Setting

GEOCHEMISTRY AND GEOBIOLOGY

- Geochemical Facies of the Bahamas Revisited
- New Approaches to Constraining the Temperature vs. Clumped Isotope Calibration for Dolomite
- Clumped Isotopic Variations in Modern Carbonate Sediments: The True Calibration between Temperature and Δ_{47} for Biogenic Organisms
- The Role of Diagenesis in the Control of B, S, and Clumped isotopes: Examples from the Maldives and Bahamas
- Relationship Between the $\delta^{13}C$ values of Inorganic and Organic Material from the Maldives and Other Locations
- Geochemical Signatures of Hamelin Pool Stromatolites
- Examining the Role of Microbial Contribution to Cementation
- Geochemical Facies of the Bahamas Revisited

COSTS

The contribution of each Industrial Associate towards the research budget is **$55,000**. This contribution complements funding the CSL-CCR receives from national funding agencies such as the National Science Foundation (NSF), the International Ocean Discovery Program (IODP) and other funding agencies. Contributions from our Industrial Associates are mainly used to support students working within the CSL, while funding for the data acquisition, such as seismic and coring expeditions and the funds for new equipment have been made possible by grants from federal funding agencies.

2019 Reporting

October 21 - 22, 2019 - Annual Review Meeting

The results of the projects detailed in this prospectus will be presented at the **Annual Review Meeting in Miami, October 21 - 22, 2019**. In conjunction with the meeting we will have a field seminar to Belize on **October 23 - 27, 2019.** We will send out information on the logistics for the meeting and the tentative program in the second quarter of 2019.

October 23 - 27, 2019 - Review Meeting Field Seminar, Belize Lagoon, Barrier and Offshore Atolls


Aerial photograph of Belize Barrier Reef.

Belize carbonates has long been an area of intense study, with the University of Miami at the forefront of research. This trip will take you to a broad spectrum of the classic sites (lagoon patch reefs, barrier reefs, and offshore isolated platforms) where you will examine in details all aspects of their sedimentation and diagenesis. Facies mapping, seismic and core data will be used to reveal the geologic record of these areas. In addition, cores penetrating the Holocene and Pleistocene reefs illustrate the cyclicity produced by sea level fluctuations and small oscillations.

Themes of Seminar:

1) Reefs: Analysis of reef types including barrier, fringing, patch, lagoonal, pinnacle, and rhomboidal (atoll-like). Documentation of pulsed reef growth during sea-level fluctuations, with an emphasis on oscillations within the last highstand that leads to models of the heterogeneous porosity and permeability distributions in reef facies.

2) Facies geometry: Ground-truth the scale and geometry of carbonate build-ups, examine lateral changes in vertical-growth potential of adjacent facies, visualize how these modern stratigraphic features would be represented in both 2D & 3D seismic images.

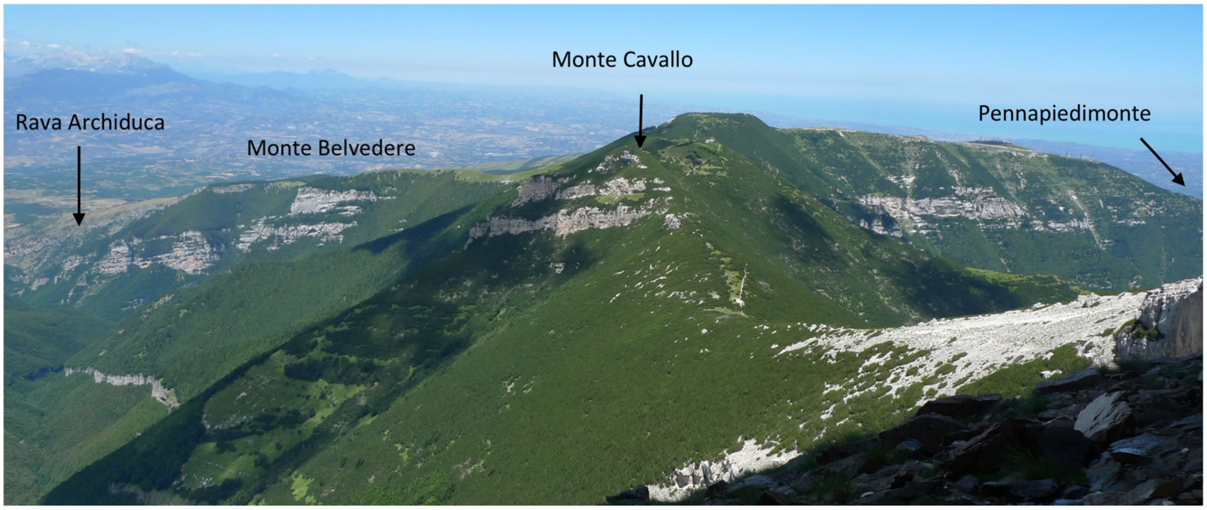
3) Coexistence of carbonate and siliciclastic sediments: Illustrate Holocene transition from nearshore siliciclastics to pure carbonates with reefs.

Cost: Approximately $5,000.-, included are transportation within Belize (mostly by boat) accommodation, meals and course notes.

FIELD SEMINAR MAIELLA MOUNTAINS, ITALY

EXPLORING A CRETACEOUS CARBONATE DELTA DRIFT

JULY 14-19, 2019



Rationale:

The bioclastic wedge of the Upper Cretaceous Orfento Formation in the Maiella Mountains, Italy, is recognized as a Cretaceous carbonate delta drift based on the comparison with the newly discovered delta drift in the Maldives. These delta drifts form where channels open into the adjacent basin and form sedimentary bodies of 350km^2 with a thickness of 360m and 600m, respectively (Fig. 1). Fine-grained contourite drifts are known from both clastic and carbonate environments but the coarse-grained nature of these delta drifts makes them unique current-controlled systems.

Previous studies in the coarse-grained Orfento Formation demonstrate that this delta drift has excellent reservoir potential. In the Madonna Della Mazza quarry, Ground Penetrating Radar (GPR) surveys imaged fractures and faults and an infiltration experiment documented the high permeability of the deposits. Another study focused on the underlying deep-water deposits with breccias and turbidites and compared it to the bioclastic grain- and rudstones of the Orfento Formation.

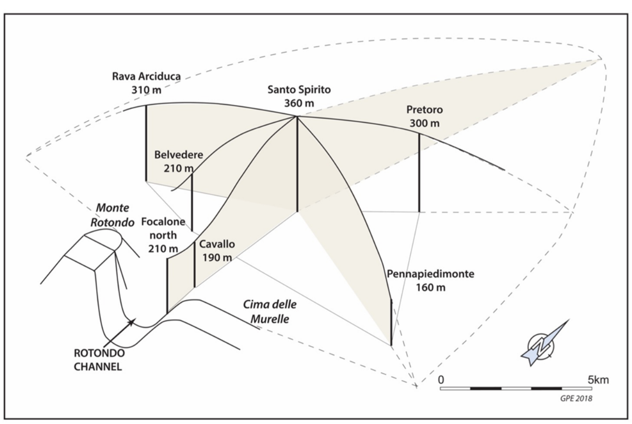
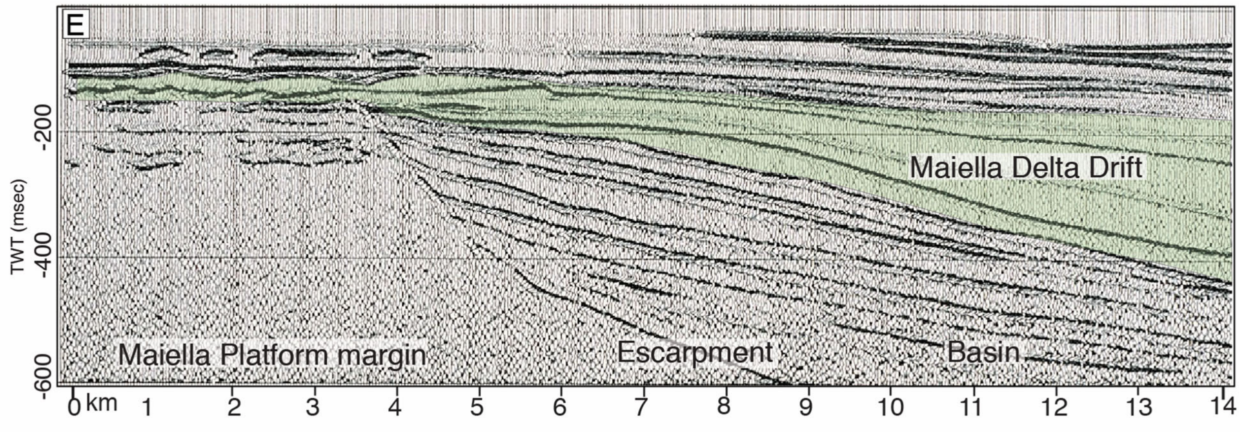


Fig. 1: Schematic display of the Maiella delta drift with the key sections and locations. 150 km^2 of the delta drift are exposed in the Maiella anticline and constitute about a third of the entire sedimentary body. The Rotondo Channel is the feeder channel for the delta drift.

The field seminar will focus on the coarse bioclastic Upper Cretaceous delta drift but the results of the GPR survey in Madonna Della Mazza quarry and the platform margin architecture and mass gravity flow deposits in the basin adjacent to the escarpment-like margin will also be examined.



Synthetic seismic profile across the Maiella platform margin and Maiella delta drift (in green)

ITINERARY

Sunday July 14: Meet in Rome (airport) and drive to the Maiella Mountains
Introduction to the fieldtrip

Monday July 15: Overview of regional geology and platform margin architecture
Blockhaus, Focalone and Pesco Falcone
Examining the strata in feeder channel at Monte Rotondo

Tuesday July 16: Monte Focalone: Mouth of feeder channel and first prograding lobe
Slope Channels at Monte Cavallo

Wednesday July 17: Valley at Pennapiedimonte: Transition from deep water deposits with breccias and turbidites to the delta drift deposits and section through the delta drift into overlying Cenozoic deep water deposits.

Madonna della Mazza: Distal portion of the delta drift and presentation of GPR study of stratigraphy and infiltration experiment.

Thursday July 18: Valley of Santo Spirito: Prograding clinoforms of the delta drift
Drive to Rome and overnight in Rome

Friday July 19: Departure from Rome

COST

Approximately $4,000.-, included are transportation in Italy, accommodation, meals and course notes.

CERTIFICATE PROGRAM

Applied Carbonate Geology

Advanced Education for Geoscientists

GOAL

The goal of the Certificate Program is to provide first-rate continuing education to professionals or geology students who want to become experts in carbonate geology. To reach this goal courses are offered in carbonate sedimentology, seismic stratigraphy, petrophysics, and geochemistry.

MISSION

Certificate graduates will have acquired specialty knowledge in carbonate geology that can be applied to projects in industry and government.

Students will learn how to incorporate acquired knowledge and data into the workflow of applied projects.

OVERVIEW AND COSTS

A Certificate in *Applied Carbonate Geology* requires the successful completion of 16 course credits assembled from 11 courses in the program. The courses combine classroom teaching, laboratory classes and applied projects. No thesis will be written.

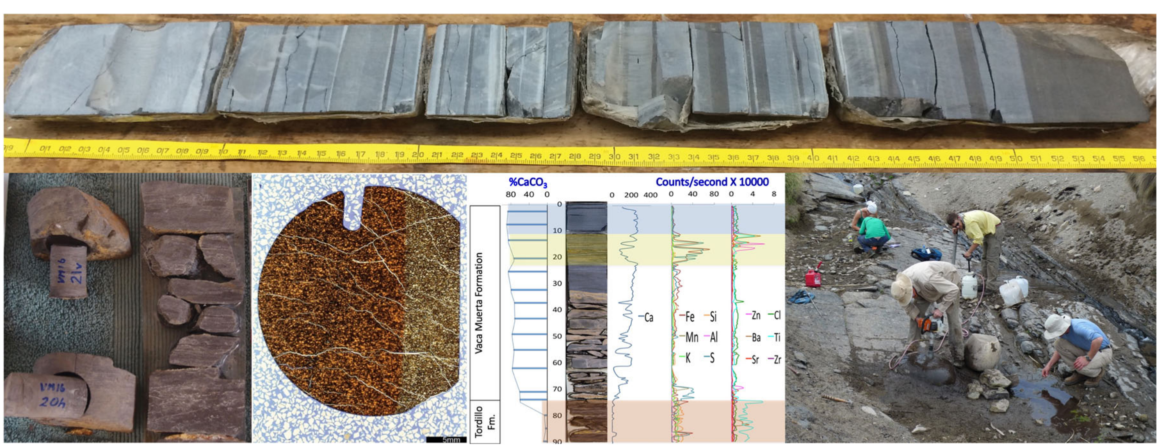
Courses for the Certificate Program will be offered in the Spring Semester and the 1st Summer Session of each year. The student/geoscientist will be in residence for 6 months. The current tuition fee is $2020/credit.

A bachelor degree or equivalent degree is required but can be offset by years of working experience. No GRE or TOEFL are required.

ADMISSION AND REGISTRATION

For more information on courses, lecturers and admission please visit the website

https://marine-geosciences.rsmas.miami.edu/academics/certificate-program/index.html



RATES OF INTERTIDAL FACIES-BELT MIGRATION FROM TIME-SEPARATED REMOTE SENSING

Mingyue Wu and Sam Purkis

PROJECT OBJECTIVES

- To use time-separated remote sensing to quantify rates of facies migration on multi-decadal time-scales for two case studies: an isolated carbonate platform in the central Indian Ocean and the tidal-flat carbonates of Andros Island (Great Bahama Bank - GBB)
- Examine the auto- vs. allogenic drivers of facies dynamics

PROJECT RATIONALE

Facies-belt dynamics are poorly understood at timescales of decades to centuries because of the lack of quantitative data spanning these time periods. A wealth of vintage-military aerial photography acquired in the years surrounding the Second World War exist, however, and can be paired with modern high-resolution satellite imagery to quantify temporal change over sufficiently long periods to allow meaningful extrapolation to geological timescales. This project will focus on quantifying the dynamics of intertidal carbonates at two ends of the energy spectrum. Following Purkis et al. (2016), for Peros Banhos atoll (Chagos Archipelago, Central Indian Ocean), the coastline dynamics of 19 atoll islands situated in the high-energy platform-margin environment will be quantified over a period of 40 years. For the low-energy example, the Andros tidal flats will be examined for a period covering 75 years (Fig. 1).

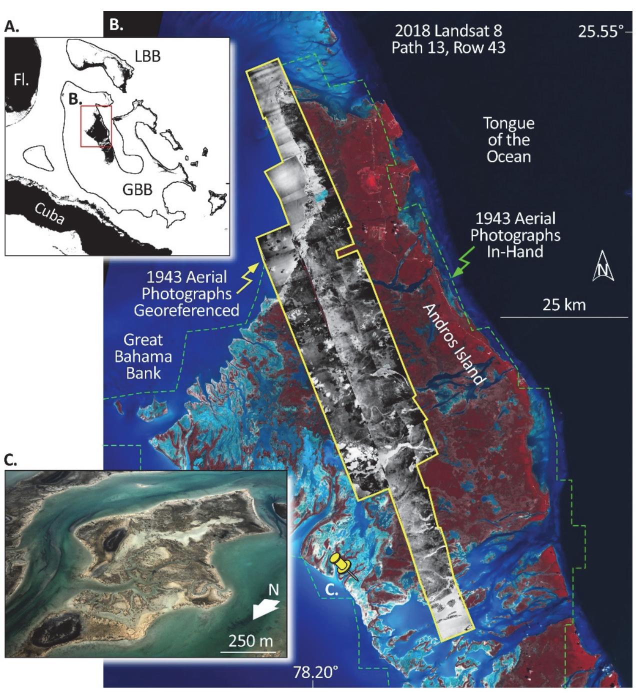


Figure 1. The Andros Island tidal flats. (A) Andros Island is the largest landmass atop the GBB. (B). Red color in this 2018 Landsat image denotes vegetation. The green polygon denotes coverage by 1943 aerial photographs acquired by the Royal Airforce against which landform change can be quantitatively assessed over 75 years. (C) An oblique aerial photograph acquired in 2018 from the southwest of Andros Island (location marked by yellow pin in B.) emphasizes the complex facies mosaic of tidal channels, intertidal muds, and bio-stabilized mangrove islands.

Beyond quantifying rates and motifs of facies migration, this project will examine the role of emergent behavior in structuring intertidal carbonates. Systems displaying emergent behavior manifest significantly different characteristics from those resulting from simply adding up all the constituent parts - an example being how small perturbations can have radical consequences to the system's overall depositional architecture. Whereas numerical modelling by Fagherazzi (2008) demonstrates emergent behavior in intertidal siliciclastic deposits, its presence in equivalent carbonate environments remains controversial. For instance, coring conducted by Shinn et al. (1969) suggests frequent reconfiguration of Andros tidal flats, an observation in conflict with studies conducted by Rankey (2002) and Maloof and Grotzinger (2012) who conclude long-term stability of the tidal-flat architecture. We aim to resolve this contradiction.

APPROACH

Drivers of the change in facies configuration through time will consider allogenic factors, such as gradients in prevailing hydrodynamic energy and creation of accommodation space through relative sea-level rise, as well as autogenic processes, such as organism-environment feedbacks. An example of the latter being sediment stabilization by biota ranging from microbial biofilms to mangrove stands.

SIGNIFICANCE

Migrating facies belts deliver lateral and vertical heterogeneity in carbonate deposits which can be difficult to replicate using forward models. Autogenic dynamics are particularly poorly understood, yet, through emergent behavior, are capable of spontaneously producing coherent spatial facies patterns through internal interactions. Systems configured as such lie close to their point of criticality whereby subtle changes in underlying processes can yield sudden and pronounced shifts in depositional architecture. Understanding these processes and their characteristic length and time-scales has the potential to yield insight into the variability of depositional facies that consistently challenge outcrop and subsurface interpretations.

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Decadal Patterns in Mud Production on Great Bahama Bank via Whitings

Sam Purkis, Amanda Oehlert, Heather Hunter, Peter Swart, [1]Thomas Dobbelaere, [1]Emmanuel Hanert, and Paul (Mitch) Harris
[1] *Université Catholique De Louvain, Belgium*

Project Objectives

- Deploy a deep-learning algorithm to identify whitings in daily MODIS ocean-color imagery over timescales of decades.
- Examine the whiting record for seasonal and multi-year trends and explore their controls.
- Develop an understanding of the variability of non-skeletal mud production through time and its influence on platform-top sedimentology.

Project Rationale

The term "whiting" has been used to describe occurrences of lime mud precipitated directly from both marine and fresh waters. As a result of the potential of whitings to contribute to the Bahamas sedimentary record (e.g. Turpin et al., 2011; Purkis et al., 2017), considerable effort has been applied to understand the triggers and mechanisms of precipitation in this locality – a debate that has continued for more than eighty years.

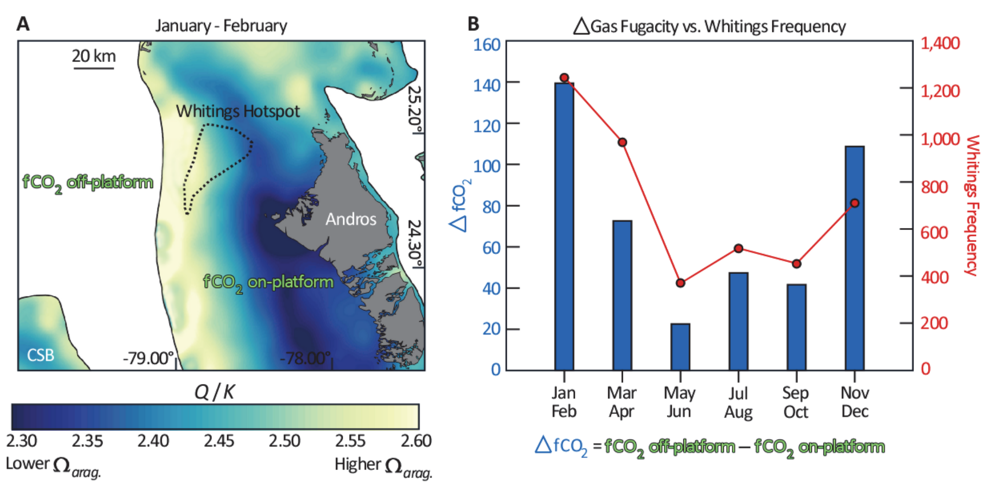

Figure 1: (A) Ωarag. atop GBB is lower in winter than summer, but more spatially heterogeneous because of the mixing of warm off-platform waters with waters chilled by winter storms on the platform top. (B) Cross-plot of bimonthly ΔfCO2 and whitings frequency suggests a possible link between water chemistry and aragonite precipitation.

Recent work by the group has implicated platform-top hydrodynamics as influencing the location and production rate of the whitings mud factory on GBB. Geochemical modeling has suggested platform-top Ωarag. to be higher in summer than winter, as would be predicted from basic thermodynamics, but that this parameter is more spatially heterogeneous in winter. Furthermore, the whitings hotspot is situated in a zone of locally enhanced Ωarag. (Fig. 1A), induced by the inflow of off-platform waters across the western platform margin (likely facilitated by enhanced tidal exchange across the margin associated with the northerly-flowing Santaren Current), as well as inflow across the eastern margin from the Tongue of the Ocean to the north of Andros Island. To capture the seasonal disparity in platform-top water chemistry, the change in CO_2 gas fugacity (ΔfCO_2) between the off- and on-platform water bodies was computed as bi-monthly averages and cross-plotted against the seasonal whitings frequency (Fig. 1B). Correlation between the two parameters supports the hypothesis that the water chemistry induced by mixing in the whitings zone might serve as an important trigger for enhanced winter precipitation. Furthermore, the trigger appears to be sufficient to overcome the kinetic and thermodynamic forcings, which would otherwise be expected to promote summer whitings.

APPROACH

This study will call upon a newly developed deep-learning algorithm to automate the delineation of whitings from satellite imagery. Automating the counts will allow for more accurate examination of seasonality which, hitherto, have been inaccessible because of the laborious process of manual digitization. Seasonality must be determined over a long period because of the disruptive effect of cloudy days. Morphometric routines will be used to quantify the size, shape, and orientation of whitings through time, in order to more fully investigate the possibility that their trigger might vary seasonally.

SIGNIFICANCE

If sea-surface temperature differentials and hydrodynamics exert control on whitings, ocean acidification is expected to suppress their frequency in the coming decades. This observation has particular relevance to the production of carbonate muds in early Earth history – prior to the evolution of the myriad of carbonate-secreting organisms, abiotic precipitation might have been the only means of producing carbonates. Taking the GBB and its present-day water chemistry as an analog, whitings might have been more spatially localized in the rock record than previously assumed. However, integrated over geological time periods, whitings might still produce thick platform-wide sequences of lime mud as the locus of production migrates through time, but these deposits need not be contemporaneous and therefore may not correlatable.

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GRAIN FACTORIES AND SINKS - SEDIMENT BUDGET OF THE GREAT BAHAMA BANK

Ceci Lopez-Gamundi, Gregor Eberli, [1]Thomas Dobbelaere, [1]Emmanuel Hanert, Paul (Mitch) Harris, and Sam Purkis
[1)] *Université Catholique De Louvain, Belgium*

PROJECT OBJECTIVES

- To enhance the understanding of hydrodynamics atop a large isolated carbonate platform and examine their role in directing facies production and accumulation.
- To broadly quantify the GBB sediment budget and link platform-top processes to slope architecture.
- To quantify the importance of uniformitarian versus catastrophic (storm) events on the sedimentary processes of GBB.

PROJECT RATIONALE

Recent studies of Holocene deposits on GBB have focused on mapping sediment distributions, analyzing variable filling of accommodation space, quantifying ooid sand body dimensions, and examining whitings and mud production. Recent work by Purkis et al. (2017) cast these studies in the context of platform-top hydrodynamics using a flow model developed in Mike 3, a simulation now further refined via use of 'SLIM', a numerical ice-ocean model developed at the Université Catholique de Louvain (Belgium).

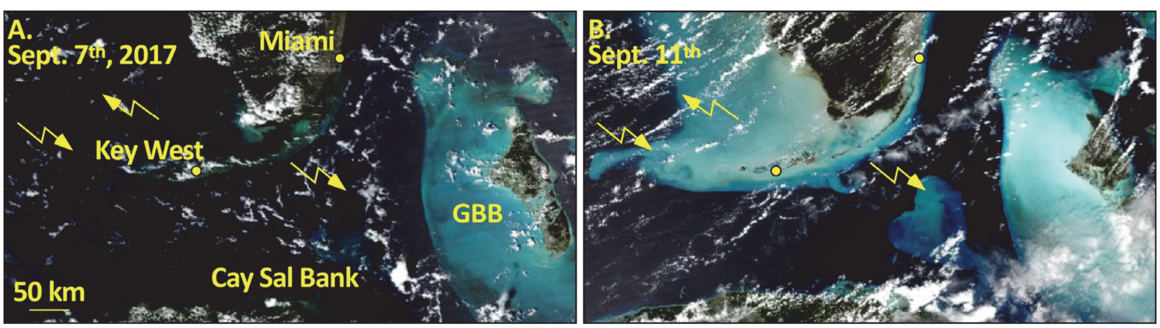

Figure 1. Waters around the southern tip of the Florida Peninsula, Straits of Florida, Great Bahama and Cay Sal Banks before (A. Sept. 7th, 2017) and after (B. Sept. 11th, 2017) the passage of Hurricane Irma (Sept. 9-10th, 2017) as captured by the VIIRS instrument on the NOAA/NASA Suomi NPP satellite. The hurricane is seen to loft vast sediment plumes from the West Florida Shelf, Great Bahama and Cay Sal Banks which become entrained in the Florida Current. It is postulated that during such events, meaningful quantities are lost from the Bahamas platform tops. Hence, hurricanes might exert an important control on the sediment budget of carbonate platforms and shelves alike, when situated in storm belts. Yellow arrows equally positioned in A and B for comparison. North is top.

The rich seam of work conducted on the platform top will be paired with an equally broad portfolio from the CSL and its partners which considers the architecture of the platform's flanks, including its strike-variability (e.g. Anselmetti et al., 2000; Mulder et al., 2012; Schnyder et al., 2018). Links between prevailing sedimentation and current flow patterns on the platform top will be sought with those existing on the slopes. Through this multiple dataset comparison, it will be deciphered whether platform-top facies architecture confers any degree of predictability to the off-platform accumulation of sediments, or whether these two environments, although adjacent, behave largely independent of one another.

APPROACH

Building forward from the GBB-wide facies and bathymetric maps of Purkis and Harris (2016), a map of 'biological depo-centers' (BDCs) will be developed from recently acquired Landsat 8 imagery. Each BDC will be parametrized in terms of potential rates of grain production via a literature meta-analysis. The SLIM hydrodynamic model will then be used to examine the likely fate of grains produced in each BDC, and their possible loss from the platform top during typical daily environmental conditions. This 'uniformitarian' mode of platform-top processes will be compared to those prevailing during short periods of catastrophism, such as during hurricanes, when large quantities of sediment are swept from the platform top onto the slopes, or entirely lost from the system altogether by off-platform current entrainment (e.g. Fig. 1).

SIGNIFICANCE

An understanding of water movement atop the GBB is of paramount importance for understanding sediment production and dispersal. These processes exert physical control over platform-top sedimentation, which, in turn, govern slope architecture variability.

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STATISTICAL PATTERN ANALYSIS OF SURFICIAL KARST IN THE NULLARBOR PLAIN (W. AUSTRALIA)

Lisa Tanh, Gregor Eberli, and Sam Purkis

PROJECT OBJECTIVES

- To employ spatial statistics to quantify the lateral expression of surficial karst across five 500 sq. km focus areas distributed across the Nullarbor Plain.
- To investigate landform morphology and faults, fractures, and joints as controls on the development of the karst template.
- To use the Nullarbor Plain as an analogue to better understand the distribution of karst in an equivalent subsurface setting.

PROJECT RATIONALE

The Nullarbor Plain is part of the arid to semi-arid portion of southern Australia, located on the Great Australian Bight coast with the Great Victoria Desert to its north. It is the world's largest exposed areal karst and occupies an area of about 200,000 sq. km. As summarized by Miller et al. (2012) and Lipar and Ferk (2015), initial karst development most likely occurred during the warm, seasonally wet climatic conditions of the Oligocene, when sea-level fall exposed the recently deposited Eocene Wilson Bluff Limestone for over ~10 m.y. Re-flooding of the plain marked an end to this initial episode before exposure of the Miocene aged Nullarbor Limestone in the Late Miocene and regional uplift. A second episode of karstification then followed in the Pliocene and Quaternary, which was somewhat inhibited by the semi-arid climate, which became increasingly arid ~1 Ma. Exposure of the limestone terrace resulted in the extensive development of surficial dolines that can be identified from high-resolution satellite imagery (Fig. 1).

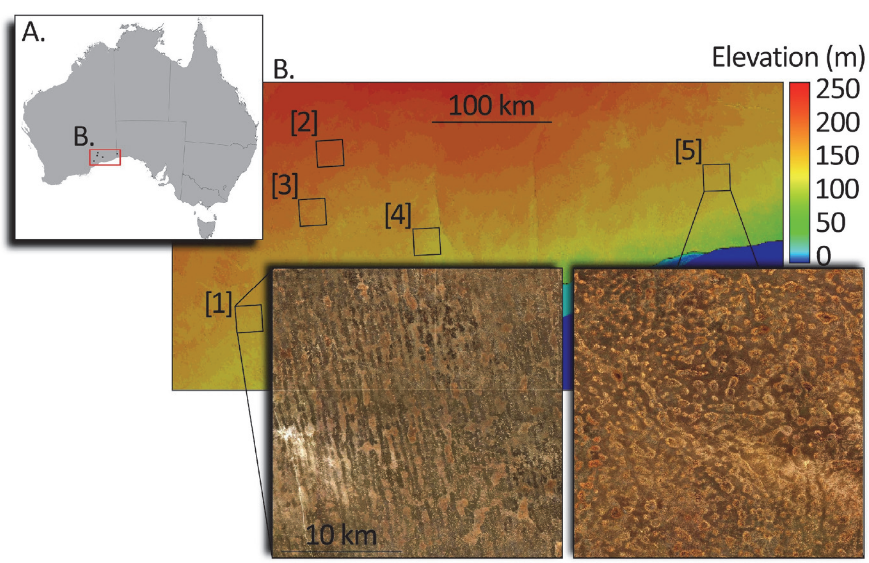

Figure 1. (A) Location of the Nullarbor Plain in S. Australia. (B) Shows the position of the 5 focus areas atop the DTM. True-color satellite imagery for Area [1] and [5] shows the diversity in the expression of surficial karst.

APPROACH

Five focus areas, each covering 500 sq. km, have been selected across the Nullarbor to capture the diversity of surficial karst expression. For each area, m-resolution RGB-IR Pleiades satellite imagery has been purchased along with Digital Terrain Models (DTMs) representing the bare Earth elevation derived from the matching of high-resolution optical stereo imagery. These data will be paired in GIS and the perimeter of each verified doline manually digitized. Following the workflow of Harris et al. (2018), the resulting populations of dolines will be compared within and between focus areas using morphometric indices to quantify, amongst others, size-frequency distribution, separation distance, degree of clustering, etc. If available, the same workflow will be performed on a seismic horizon to facilitate comparison with a subsurface example similarly afflicted with extensive karst. With reference to the available literature (e.g. Webb and James, 2006) and through visual interpretation of the imagery and DTMs, possible controls on the style and patterning of the karst will be explored, as exerted, for instance, by faults and fractures, character of the underlying limestone, and terrain morphology of the selected focus areas.

SIGNIFICANCE

This study is poised to examine the surface topography of a karstified limestone plateau over an area of 2,500 sq. km – a significantly greater extent than has previously been considered. Pairing of high-resolution satellite imagery and a DTM provides the opportunity to investigate the extent and spatial characteristics of surficial karst with a more quantitative, and potentially predictive, approach that will have applicability to other exposed and subsurface karst terrains. Karst-modified hydrocarbon and aqueous carbonate reservoirs are often characterized by extreme heterogeneity, with reservoir compartmentalization commonly attributed to the products of meteoric diagenesis, including dolines, caves, fracture-controlled solution features, vuggy porosity, and collapse breccias. However, the amount of karst overprinting in these systems can vary laterally and its role in influencing reservoir character can range from insignificant to extensive. Our quantitative analysis of the Nullarbor Plain can perhaps aid prediction where karst is, or is not, a dominant factor, and thereby be a potential control on reservoir character in analogous karstified settings.

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Reef Development during the Oligo-Miocene Transition: A new record from the Cocinetas Basin, Colombia

James S. Klaus, Paula A. Zapata-Ramírez

Project Objectives

- To investigate the changing nature of Oligocene and Miocene reef systems in the southern Caribbean.
- To assess the relative importance of oceanographic factors compared to sea level and tectonics in reef development and coral extinctions.
- Compare the new records from the Cocinetas Basin to a compiled database of Olio-Miocene records from the Caribbean region.

Project Rationale

The evolution of Cenozoic shallow marine carbonates has been linked to major perturbations in global climate and environmental conditions (Wilson, 2012). Cenozoic Caribbean reefs appear to be best developed during the Oligocene and Pleistocene, with the record of Cenozoic Caribbean reef diversity punctuated by two intervals of elevated extinction and faunal turnover; the Oligocene-Miocene and Pliocene-Pleistocene transitions. Although the Oliogocene-Miocene faunal transition is broadly recognized, the exact timing and links to climate and oceanographic changes has yet to be firmly established. The Oligocene has been generally perceived as a time of climate stability, despite Antarctic ice sheet and glacioeustatic sea-level oscillations of up to 50-65 m associated with glacial episodes Oi-2 (29.16 Ma), Oi-2a (27.91 Ma), and Oi-2b (26.76 Ma). Oxygen isotope trends suggest a Late Oligocene Warming Event (LOWE) between 26.5 and 24.0 Ma (Zachos et al., 2001) prior to cooling and the Mi-1 glaciation near the Oligocene/Miocene boundary (Mawbey and Lear, 2013). There is currently a lack of stratigraphic resolution in the record of shallow water reef development that inhibits establishing the link between reef collapse and the specific climate and oceanographic factors outlined above.

Figure 1. Fringing reefs from the Siamaná Formation located at the south flank of Arroyo Uitpa.

SCOPE OF WORK

The Goal of this project is to document a new Aquitanian record of Caribbean reef development from the Siamana Formation of the Cocinetas Basin, outcropping within the Guajira Peninsula of Colombia. The Guajira Peninsula, northern Colombia (Fig. 1), provides an extensive and well-exposed Oligocene and Miocene sedimentary and paleontological record for the southern Caribbean. Extensive carbonate deposits within the peninsula offer an exceptional opportunity to study the depositional geometries and the distribution of carbonate facies, and to document the timing and nature of reef development in the Southern Caribbean. A high-resolution biostratigraphic framework of the visited outcrops has been recently conducted (Silva-Tamayo et al., 2017), providing calibrated stratigraphic ranges of the reefal units. Our main objectives are to (1) characterize the faunal composition and nature of reef development in the Cocinetas Basin during the early Miocene, (2) compare the Siamana reef system to other records from the Caribbean region, and (3) by refining the temporal and biogeographic records of Caribbean reef coral development in the southern Caribbean help constrain the response of tropical reef systems to environmental perturbations associated with the Oligocene – Miocene transition.

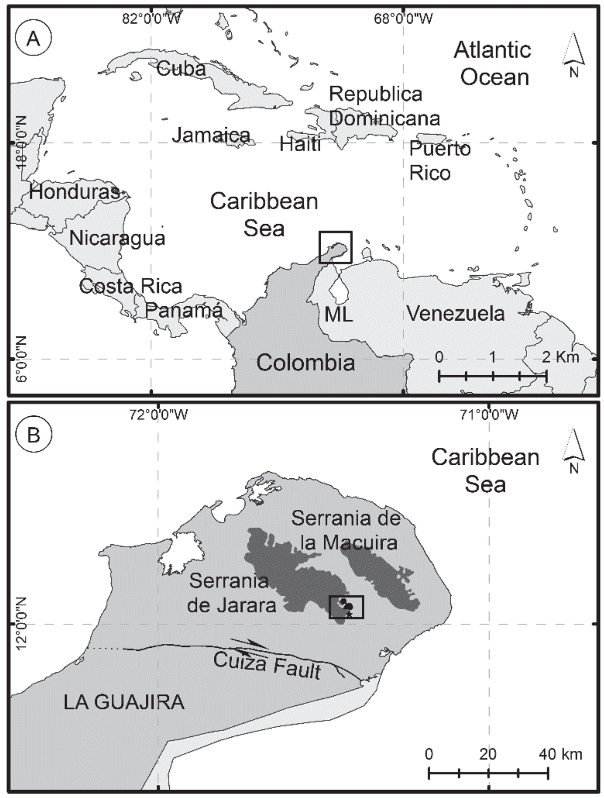

Figure 2. A) Regional Map showing the study area, the Guajira Peninsula of Northern Colombia. ML (Maracaibo Lake). B) Location map of reef sampling localities on the flanks and in the lowlands of Jarara Mountain.

SIGNIFICANCE

Oligo–Miocene platforms and ramps are recognized as good hydrocarbon reservoirs, including the approximately 300 m thick Oligo–Miocene carbonates of the Perla field, offshore Venezuela. These carbonates are predominantly composed of larger benthic Foraminifera and red algae with a minor contribution from shallow water carbonate components (green algae and corals). Comparisons between the Cocinetas and Perla carbonates should provide a broader characterization of facies variability within the carbonate factory of the Oligo-Miocene southern Caribbean.

HABITAT MAP AND GEOMORPHOMETRY OF EAST CAMPECHE BANK: A PROXY FOR CURRENT DIRECTIONS

Kimberly C. Galvez, Gregor P. Eberli, Paul Wintersteller[1], Dierk Hebbeln[1], and Claudia Wienberg[1]

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PROJECT OBJECTIVES

- Geomorphometric analysis and topographic classification of the multibeam data of Campeche Bank.
- Develop a hydrodynamic model in order to obtain a proxy for local/regional currents and relate to coral-habitat distribution.

PROJECT RATIONALE

Campeche Bank, the submerged remnant of a larger bank that drowned in the Mid-Cretaceous, and the adjacent Yucatan Strait are under the influence of two current systems; 1) the northbound Loop current and 2) a benthic countercurrent underneath (Hübscher et al., 2010). High-resolution current models (NOAA) display two dominant current directions affecting Campeche Bank seasonally (Fig. 1). On the upper slope of the Campeche Bank a large cold-water coral (CWC) province exists in intermediate water depths of 500 to 600 m where 20–40 m high elongated coral mounds are arranged in a honeycomb fashion (Hebbeln et al., 2012). The CWC province is located where upwelling, a dynamic bottom current regime, and a physicochemical setting provide ideal conditions for coral growth (Hebbeln et al., 2014). This project tests the hypothesis that sediment distribution and the orientation of sea-floor-mound topography are directly related to the current system.

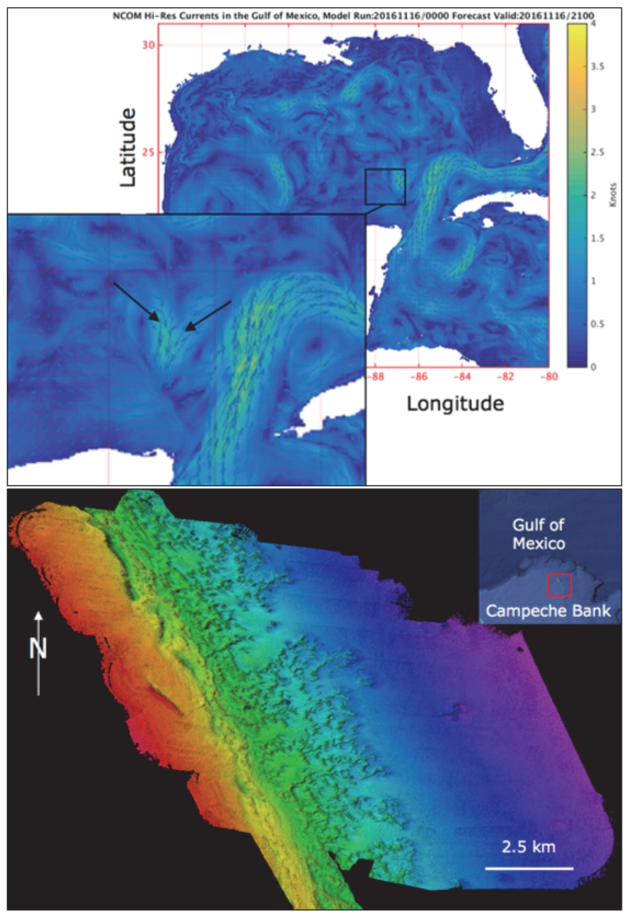

Figure 1. Top: NCOM high-resolution current model in the Gulf of Mexico (from NOAA). Bottom: Multibeam bathymetry of the upper slope of the Campeche Bank with cold-water coral ridges that are onlapped by the muddy sediments of the middle slope. The alignment of the ridges is likely the result of the current directions across this part of the slope.

Cold-water coral ecosystem of Campeche Bank

In the Campeche CWC province coral colonization preferentially occurs from the mid-slope of the elongated mounds towards their peaks (Hebbeln et al., 2012). Coral rubble is deposited on the flanks of the mounds interfingering with a muddy seabed, and small coral thickets grow within the muddy areas where coral rubble is exposed. The pelagic ooze is transported in a NE flow and collects between the coral-covered ridges and in the lower portions of the slope forming a mud-draped seabed (Hebbeln et al., 2014).

Faunal assemblages consist of *Enallopsammia profunda* and *Lophelia pertusa* as the dominant reef-building framework. *E. profunda* thickets form in the mid-slope region while towards the mound peaks, *L. pertusa* dominates (Hebbeln et al., 2012, 2014). The frameworks are mostly built from individual colonies, however, secondary fusion is observed within a number of coral colonies to form a larger structure. Numerous other benthic organisms are reliant on these CWC reefs including crinoids, anemones, echinoderms, sponges, decapods, fish, and crustaceans.

WORK PLAN

High-resolution multibeam bathymetric data and sub-bottom profiles acquired during MSM 20-4 show that the CWC-ridges are aligned in a bidirectional way, resulting in an apparent "honeycomb pattern" (Fig. 1). In this study we plan to perform a classification of the topographic elements and geomorphometric analysis of their orientation as a proxy for current direction. The preferential alignment of CWCs due to feeding purposes will help establish the habitat map for the region. The results will be compared to currently used hydrodynamic models.

SIGNIFICANCE

The goal of the study is to relate morphometric features to physical (current) and biological processes that might be a guide for interpreting current regimes from seismic data.

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Carbonate Contourite Drift Systems – Expanding the Data Base on Types and Dimensions

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[1)] University of Hamburg

Project Objectives

- Assemble examples of erosional features and depositional bodies of bottom currents in carbonates.
- Provide dimensions of the various contourite drift systems.
- Establish a holistic sedimentary model of current controlled deposits in carbonates.

Project Rationale

Carbonate environments inhabit the realm of the surface, intermediate and deep currents that contribute to ocean circulation. Last year the effect of these currents on deposition was evaluated. Carbonate characteristics, such as sediment production, export of sediment into the bottom currents, and their distinct physical properties, were examined to determine how these affect the transport and depositional behavior of carbonate particles in the current. In addition, we demonstrated how the rugged topography of many carbonate provinces causes a heterogonous interaction between bottom currents and carbonate buildups, producing carbonate specific drift bodies (Betzler et al., 2014, Lüdmann et al., 2018, Principaud et al., 2018, Eberli and Betzler, 2019). In recent years, results from several research expeditions to carbonate provinces with a strong current influence have added a wealth of information to comprehensively describe carbonate contourite systems. The goal of this ongoing project is to assemble additional examples of coarse- and fine-grained contourites drift systems, describe their dimensions and relate the architecture and composition to the processes that form these sedimentary bodies.

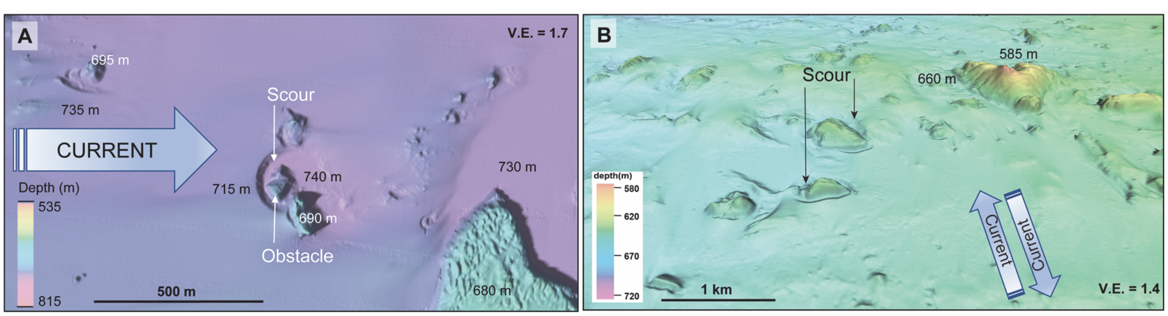

Figure 1: Examples of erosional features from bottom currents around obstacles. (A) A dominant north-flowing current produces a composite scour in fine-grained carbonate drift around three blocks in the Santaren Channel, Bahamas. (B) Scours around blocks covered by corals in a bi-directional current regime in which the depositional trail in the lee of the obstacles is not well-developed. Toe-of-slope western Great Bahama Bank.

Data Sets and Approach

Seismic and multibeam data from several expeditions with colleagues from Germany and France to the Bahamas and the Gulf of Mexico are available for this study. We also received the seismic data set from the Marion Platform that was collected for ODP Leg 194. These data will be studied with regards to the current features. In addition, we plan to screen literature, describing modern and ancient carbonate contourite drift systems, to assemble a comprehensive data base on these systems.

This information will be utilized to develop models of current-controlled erosion and deposition in carbonates that take into account the carbonate-specific characteristics of sediment production, grain density, and topography. These models are then compared to depositional models in siliciclastic environments.

Significance

Historically, depositional models of shallow-water carbonates generally considered ecology, sea level, and hydrodynamics to be the main controlling factors. More recently, internal waves have been recognized as a high-energy source (Pomar et al., 2012). Carbonate slope models until recently mostly considered gravity flows as the main factor controlling architecture. Recent discoveries of the importance of ocean currents in relatively shallow water (<300m water depth), and contour currents along the slopes, prompt a re-examination of these models. In particular, the "carbonate ramp" on seamounts and volcanic islands potentially is more current-controlled than described in existing models. Furthermore, the formation of prograding coarse-grained carbonate deposits in delta drifts add an entirely new aspect to carbonate deep-water deposition. Both the ramp model and delta drifts are potential reservoir facies that have so far been underexplored.

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Timing and Composition of Carbonate Drifts in the Bahamas, NE Australia and the Maldives – Implications for Carbonate Platform Architecture

Sara Bashah, Gregor P. Eberli, and Christian Betzler

Project Objectives

- Investigate the timing of the onset of Neogene ocean circulation based on the contourite drift deposits in the Bahamas, NE Australia and the Maldives.
- Relate composition, shape and dimension of the various drifts to current processes.
- Assess the importance of oceanographic factors relative to sea level and tectonics on the evolution of carbonate platforms.

Project Rationale

In the Middle Miocene, the modern ocean circulation pattern was established with the onset recorded in contourite drifts in the Atlantic, Pacific and Indian oceans. Ages in cores from these drifts indicate a near simultaneous onset of these currents in all three oceans. However, a refined age model is needed to confirm this initial assessment. With the onset of the currents an additional factor shaping platform architecture was introduced. Isolated platforms are large obstacles for bodies of water to navigate and their interaction with the currents produces three types of carbonate-specific contourites around carbonate platforms (Eberli and Betzler, 2019). Although sea-level control is still dominant on the platform top, the effect of current control needs to be taken into account in the adjacent slope and basin to explain the geometries of Neogene platforms (Betzler and Eberli, 2019). This study investigates the current-related platform architecture at three locations (Bahamas, Marion Plateau, Maldives).

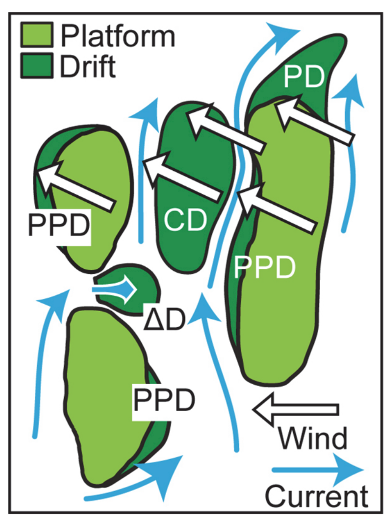


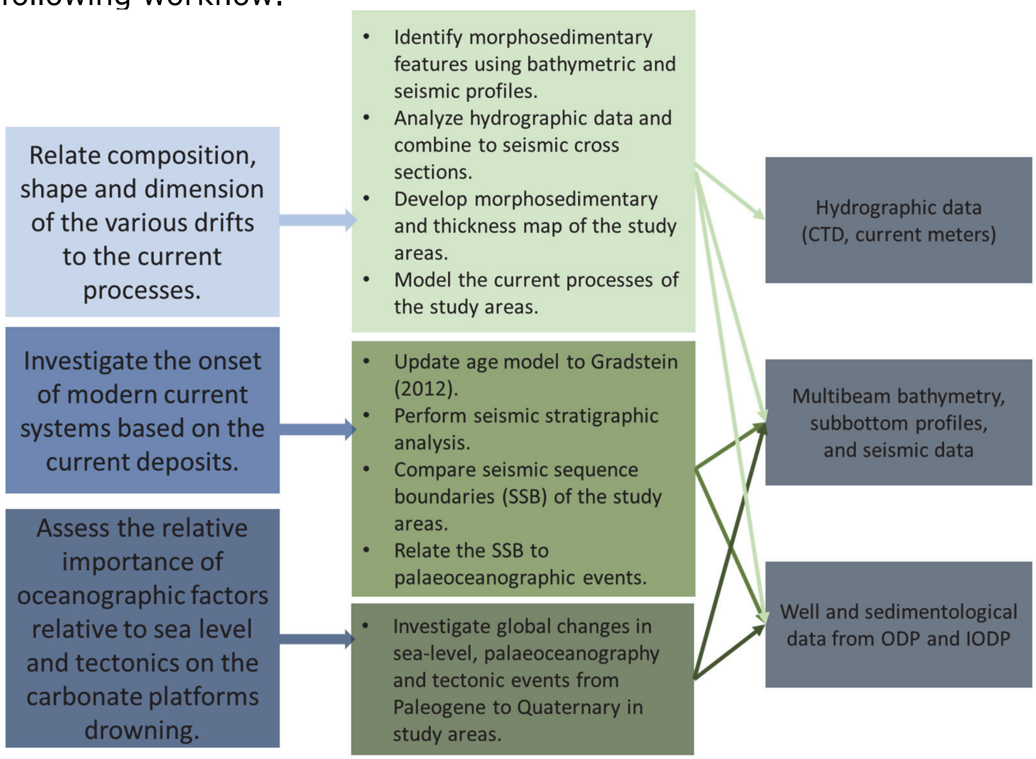
Figure 1: Schematic map view of drift types around isolated carbonate platforms. Periplatform drifts (PPD) form where particles shed from the platform along a line source are reworked and deposited along the slope by contour currents. Patch drifts (PD) occur at the downcurrent edges of carbonate banks and atolls. Delta drifts (ΔD) form on the downcurrent mouth of passages and seaways separating carbonate banks or atolls. Confined drifts (CD) are located along the axis of seaways located between individual carbonate banks (from Eberli and Betzler, 2019).

Data Sets

For this study three data sets, consisting of seismic, core and log data, from two ODP legs and one IODP expedition are analyzed. The first data set is from the Bahamas (ODP Leg 166) where confined and separated drifts, platform edge drifts and confined drifts are found in the seaways. Along the Marion Platforms (NE Australia), separated and platform edge drifts formed. The Maldives are an example of delta drift formation.

Approach and Workflow

Identification of the onset and composition of the contourite deposits, and their influence on the platform architecture, will be accomplished by employing the following workflow.



Significance

The outcome of this study will add information towards a comprehensive understanding of the influence of the currents on platform architecture. This knowledge potentially helps discriminate current-influenced platforms from those evolving during times with less ocean circulation.

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SEDIMENTARY PROCESSES AND PRODUCTS IN A CRETACEOUS DELTA DRIFT, MAIELLA MOUNTAINS, ITALY

Gregor P. Eberli

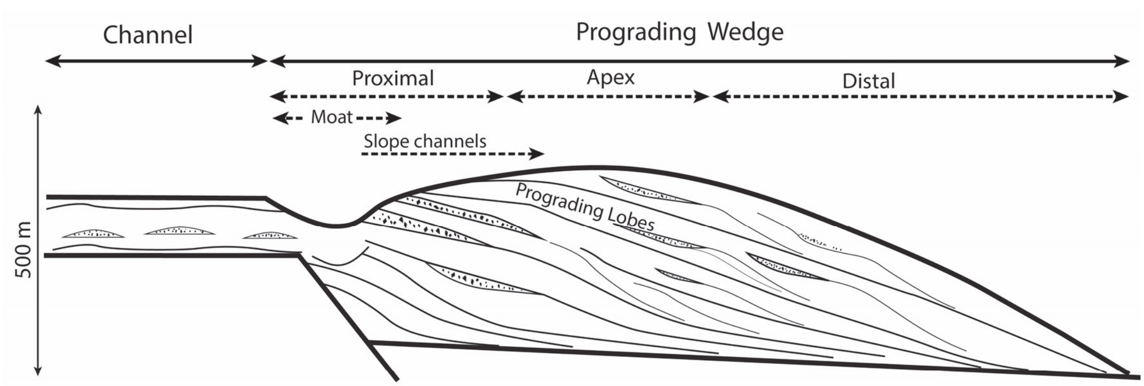
PROJECT OBJECTIVES

- To relate sedimentary structures and geobody architecture to the flow processes in the drift delta.
- Provide detailed facies and dimensions of all elements in the delta drift.
- Identify the sedimentary criteria for recognizing these coarse-grained drift deposits in cores and seismic data.

PROJECT RATIONALE

The bioclastic wedge of the Orfento Formation is a carbonate drift delta that in its geometry, size and composition is very similar to the Miocene delta drift cored in the Maldives during IODP Expedition 359 (Eberli et al., 2019). These similarities include: 1) a feeder channel opening into the basin, 2) an excavation moat at the exit of the channel, 3) an overall mounded geometry with an apex that is at a shallower water depth than the source channel, 4) progradation of stacked lobes 5) channels that pinch out in a basinward direction, 6) smaller channelized intervals arranged in a radial pattern (Fig. 1).

Carbonate drift deltas form when a sediment-laden current flows through a channel that opens to a basin across a knickpoint where current conditions can change from bedload to suspended flow and deposition. The largely mud-free Orfento delta drift contains sedimentary structures that are reminiscent of



Channel	Moat	Slope channels	Prograding lobes	Distal lobes
Facies: Fa 1, 4, 5, 7, 10 Bedforms: - amalgamated channels - lensoid breccia bars - wavy beds - massive grainstones with scours - Foresets - Festoon-like cross-bedding	erosion and non-deposition	Facies: Fa 6, 7, 8, 9 Bedforms: - cut-and fill - erosional surfaces and scours - amalgamated beds	Facies: Fa 2, 3, 4, 7, 8, 9 Bedforms: - sigmoidal clinoforms - channelized topsets - downlapping foresets - thin-bedded bottomset - parallel and wavy beds	Facies: Fa 1, 3, 4, 8, Bedforms: - parallel beds with foresets - massive beds - downlapping foresets - thin mud drapes

Figure 1: Schematic display of the bioclastic wedge of the Upper Cretaceous Orfento Formation with the different environments and their facies and bedforms that is interpreted as a delta drift.

high-density sediment flows. Other beds display structures that are commonly associated with hyperpycnal flow. These hyperpycnal flow characteristics are likely related to the semi-continuous current flowing through the feeder channel. Other common sedimentary features, such as scours filled with pebble- and gravel-sized bio- and lithoclasts, erosive surfaces, and top-cut-out foresets in clinoform beds are found in cyclic steps and supercritical flow (Massari, 2017). A study is needed to decipher the flow conditions in the various elements of the delta drift.

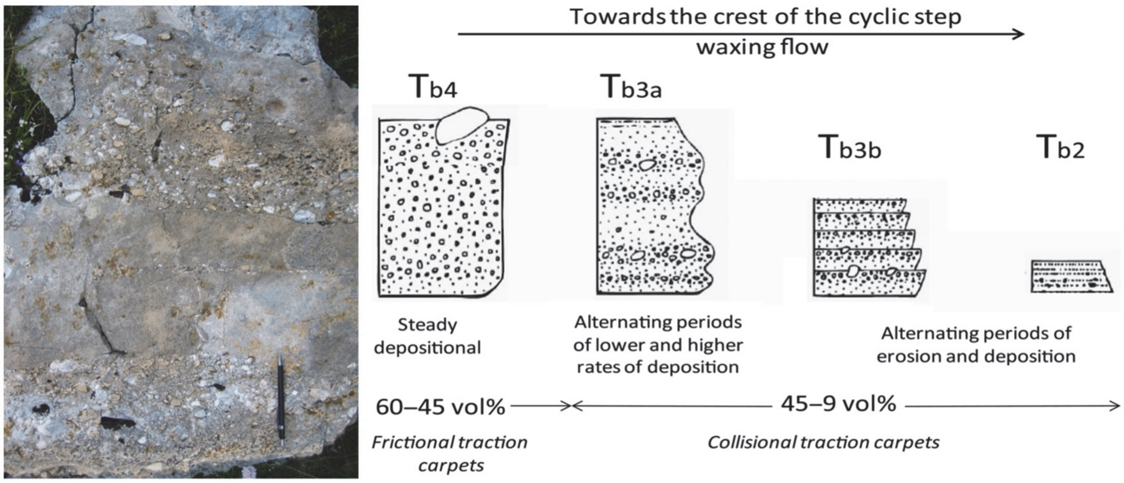


Figure 2: Left: Amalgamated coarsely graded bed with traction carpets. The components of the traction carpets are almost exclusively rounded lithoclasts of the Orfento Formation. This bed and others are similar to those described by Postma et al. (2014) in cyclic steps of gravelly turbidite sequences (to the right).

APPROACH AND DELIVERABLES

Outcrop work in the different facies belts of the delta drift, focusing on sedimentary structures in individual beds, the arrangements of bedsets and the large-scale geometry, will be used to reconstruct the flow conditions in each element. A particular interest will be to capture the transition from bedload to suspended flow and transitions from supercritical to subcritical flow.

The goal of this study is to produce a series of criteria of sedimentary structures and geometry that help identify such delta drift deposits in other outcrops and in subsurface data.

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Petrophsyical Characteristics of Carbonate Drift Deposits – Maldives and in the Cretaceous Maiella Mountains, Italy

Emma L. Giddens, Gregor P. Eberli, Luuk Kleipool[1], and Ralf J. Weger
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Project Objectives

- Delineate distribution and controls on petrophysical properties (porosity, velocity, resistivity and permeability) in coarse-grained carbonate delta drifts.
- Compare petrophysical properties of the Maldives with those in the Maiella mountains, Italy.
- Compare the petrophysical properties of delta drift deposits vs periplatform deposits.

Project Rationale

During the last year, we measured the petrophysical properties of the Miocene delta drift in the Maldives that was cored during IODP Expedition 359. The porosity of these delta drift deposits is very high; in plugs porosity varies from 15 – 62%. Velocity also displays large variations from 1.55 – 5.5 km/s. Velocity decreases with increasing amounts of micro-porosity (Fig. 1). Coarse-grained high-porosity intervals exist at the apex of the delta drift. Logs in these uncemented intervals display porosity above 50%. These coarse-grained facies are comparable to the facies in the Cretaceous delta drift in the Maiella Mountains (Eberli et al., 2019). Limited data indicate a porosity range from 5

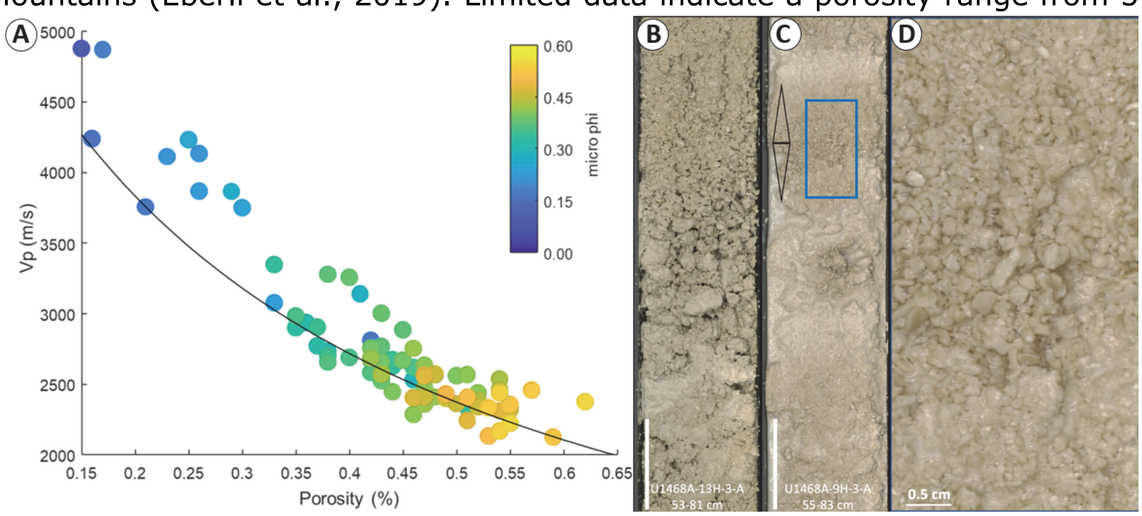

Figure 1: A) Velocity versus porosity plot of the Maldives delta drift sediments with color-coding of micro-porosity, illustrating the influence of micro-porosity on velocity. Right: Core photographs at IODP Site U-1468 located at the apex of the drift delta. B) Graded rudstone with rounded lithoclasts at the base transitioning into skeletal debris. C) Foraminiferal rudstone with thin white intercalations of packstone and a coarsening-fining upward trend. D) Close-up of the rudstone (blue box in C) consisting predominantly of large benthic foraminifera.

– 30% (Fig. 2). Additional samples covering all the facies are needed for a comprehensive petrophysical description of this Cretaceous delta drift. The entire, largely mud-free, bioclastic wedge is a potential reservoir facies. Both delta drifts are deposited on top of (hemi)pelagic strata consisting of periplatform ooze with some turbidites that are expected to be distinctly different from the delta drift facies.

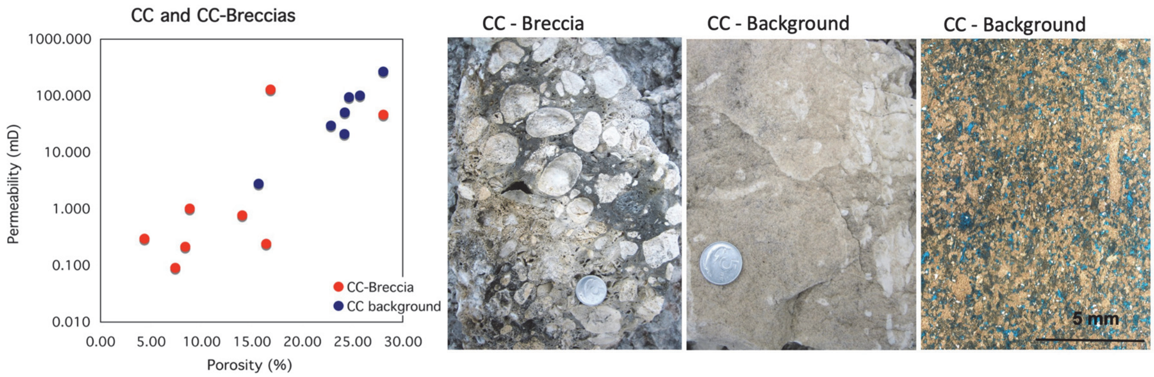

Figure 2: From left: Permeability-Porosity plot of the coarse bioclastic facies (CC) in the mud-free Maiella delta drift. Outcrop Photograph of lithoclasts breccia (coin diameter is 2 cm). Bioturbated rudist grainstone that is the main (background) facies. Photomicrograph of the rudist grainstone facies.

WORKPLAN

The goal of this study is to assemble a comprehensive petrophysical data base of the newly discovered carbonate delta drift in the Maldives that is a potentially underexplored type of carbonate reservoir.

Samples will be collected during the outcrop work planned for the sedimentologic analysis of the different facies belts of the Maiella delta drift. In the laboratory, the same suite of petrophysical properties will be run as were conducted for the petrophysical analysis of the Maldives delta drift. These include porosity, permeability, wet and dry velocity, and resistivity. In addition, texture and mineralogy of each sample will be determined and the pore type of each sample will be analyzed with digital image analysis, following the methodology of Weger et al. (2009).

The underlying strata will also be sampled and measured in order to evaluate the differences in petrophysical properties of the two deep-water carbonate successions, for a potential discrimination of these facies.

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PETROPHYSICAL PROPERTIES OF A FRINGING REEF MARGIN: PLEISTOCENE DOMINICAN REPUBLIC

Robert Goodin, James S. Klaus, Donald F. McNeill, Ralf J. Weger, Albertus Ditya, and Gregor P. Eberli

PROJECT OBJECTIVES

- Determine the petrophysical properties (electrical resistivity, ultrasonic velocity, porosity, permeability, and density) of Pleistocene reefal carbonates within DRDP drilling phase II (cores 1, 6, 4, and 5) to expand the petrophysical survey by Ditya (2012) into previously unsampled slope and lowstand reef facies.
- Assess the relative influence of primary depositional facies and subsequent diagenetic alteration as determined by Diaz (2017) on the measured mechanical and petrophysical properties.

PROJECT RATIONALE

Understanding controls on the petrophysical properties of carbonates is often key to proper interpretation of reservoir properties (porosity, permeability) from either seismic or well-log data (Anselmetti and Eberli, 1993). Petrophysical properties of carbonate sediments exhibit considerable spatial heterogeneity based on grain size, texture, and packing. Furthermore, diagenesis alters the original fabric and rock properties shortly after deposition due to changes in mineralogy and inversion of pore distribution.

The objective of this project is to complete a comprehensive characterization of the mechanical and petrophysical properties of the Pleistocene reefal carbonates of the southern Dominican Republic. Following the initial drilling phase of the Dominican Republic Drilling Project in 2010, a total of 170 plug samples were analyzed for mechanical and petrophysical properties (Ditya 2012). These samples were collected at a maximum depth of ~60 m, and represented primarily by shallow water depositional facies heavily impacted by meteoric diagenesis. In 2012 a second phase of drilling added new deep wells in both younger and older strata, and extended existing wells to recover the deeper water forereef facies.

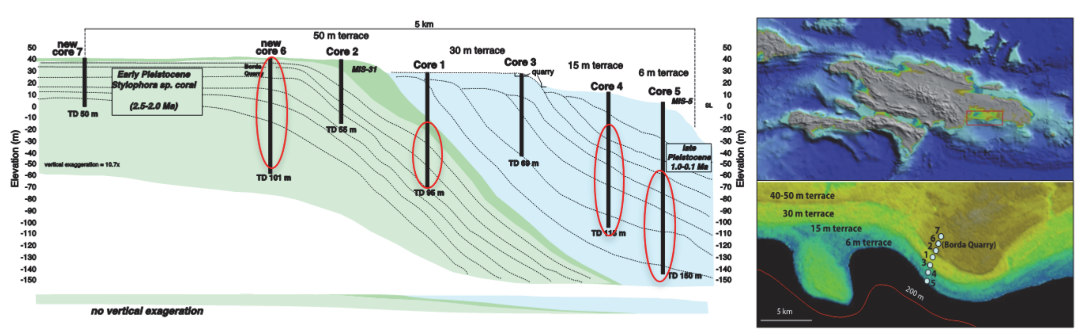

Figure 1. Cross-sectional model of Pliocene to Pleistocene reef sigmoids on the southern coast of the Dominican Republic based on seven drilled boreholes

SCOPE OF WORK

Since the initial drilling of the DR cores we have been working to develop a temporally constrained sequence stratigraphic model for the seven core transect through the Pleistocene reef deposits. Age determinations were based on biostratigraphic markers, strontium isotopes, magnetostratigraphy, and radiometric dating. A revised depositional model constrains the prograding reef system of the southern Dominican Republic to between 1.6 and 0.125 Ma. Once dated, these cores were used to assess accretion and progradation, and reconstruct fringing reef zonation and facies geometries both vertically and perpendicular to the coast.

In addition to the previously sampled cores (Ditya 2012), a further 87 one-inch diameter cylindrical plugs with variable lengths were drilled for petrophysical measurements. Plugs were sampled from the cores using a water-cooled diamond drill bit with vertical and horizontal orientation. The ends of the plugs were cut off and then polished within 0.01 mm precision (measured with a micrometer gauge) to create a flat surface for optimizing contact area between sample and sonic or electric transducers. Samples were dried at 60C for 48 hours and then stored in a desiccator for approximately 24 hours. The dry-mass of the samples were measured to the microgram using a Thomas Scientific T200S electronic scale. Chips from one end of each plug were sent to the University of Iowa's Geology Department for thin section preparation.

Petrophysical measurements will include electrical resistivity, ultrasonic velocity, porosity, permeability, and density. The petrophysical properties will be compared to assess their relationship to each other and for external comparison, for instance: porosity-permeability, porosity-acoustic velocity. The petrophysical properties will then be analyzed based on petrographic observations in order to assess any correlation between petrophysical properties and depositional / diagenetic environments.

EXPECTED RESULTS

The Dataset of petrophysical properties will be coupled to geologic parameters:

- Age
- Platform morphology (isolated, shelf, and ramp)
- Climate zone (tropical, cool-water, temperate)
- Depositional environment (top, shoal, slope, basin)
- Type of information (outcrop, subsurface)
- Texture (Dunham)
- Dominant pore type and microporosity
- Sequence stratigraphic position
- Mineralogy

The resulting dataset will be compiled with other well-studied projects to provide an unprecedented catalogue of sample set information with interconnected relationships.

ASSESSING LITHOCLAST DISTRIBUTION IN GRAINSTONE DRIFT DEPOSITS

Mark Grasmueck and Gregor P. Eberli

PROJECT OBJECTIVES

- Re-process and analyze all Madonna della Mazza 3D GPR cubes data with Pondview.
- Assess lithoclasts, their textures and distribution inside the different grainstone units based on outcrop and GPR data.
- Relate clast distribution to flow processes for a refined model for their formation within drift deposits

PROJECT RATIONALE

One of the sedimentologic characteristics of the Maiella carbonate drift delta is the continuous reworking of the bioclastic strata. Lithoclasts from reworking or “cannibalization” are subsequently transported and deposited as intraclasts in grainstone beds (Fig. 1). In outcrop these lithoclasts are reminiscent of rip up clasts in hyperconcentrated flows or sandy debrites. Yet, the arrangement in the bed and the lateral arrangement do not fit precisely to the facies that is generally related to these sedimentary processes. Assuming that bottom currents are responsible for these reworking and transportation, the observed lithoclasts laden grainstone beds could be the product of a sort of hyperpycnal hyperconcentrated flow. In the Madonna della Mazza quarry that is situated in the distal portion of the delta drift, such beds are exposed and imaged with 3D Ground Penetrating Radar, which offers a unique opportunity to examine the clast arrangement in three dimensions and potentially interpret the flow conditions of these beds and the distribution of sediment in delta drifts in general.

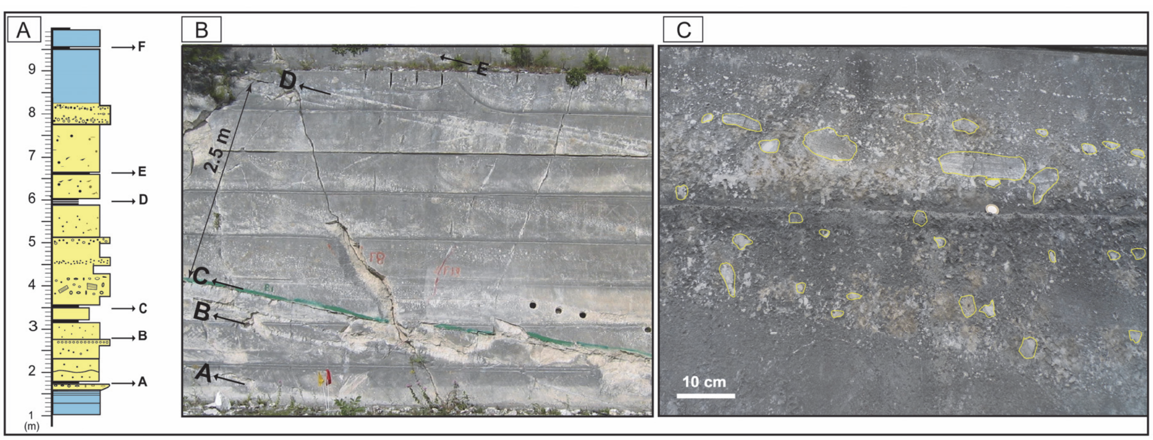

Figure 1: A) Lithologic section at the Madonna della Mazza quarry. Yellow portions are grainstone beds with lithoclasts; blue are massive grainstone beds. B) Photograph of the quarry wall with streaks of lithoclasts (white dots) between horizon A and D. C) Close-up of a lithoclasts (outlined with yellow lines) within the grainstone bed. Note that the base of the bed displays no erosional downcut.

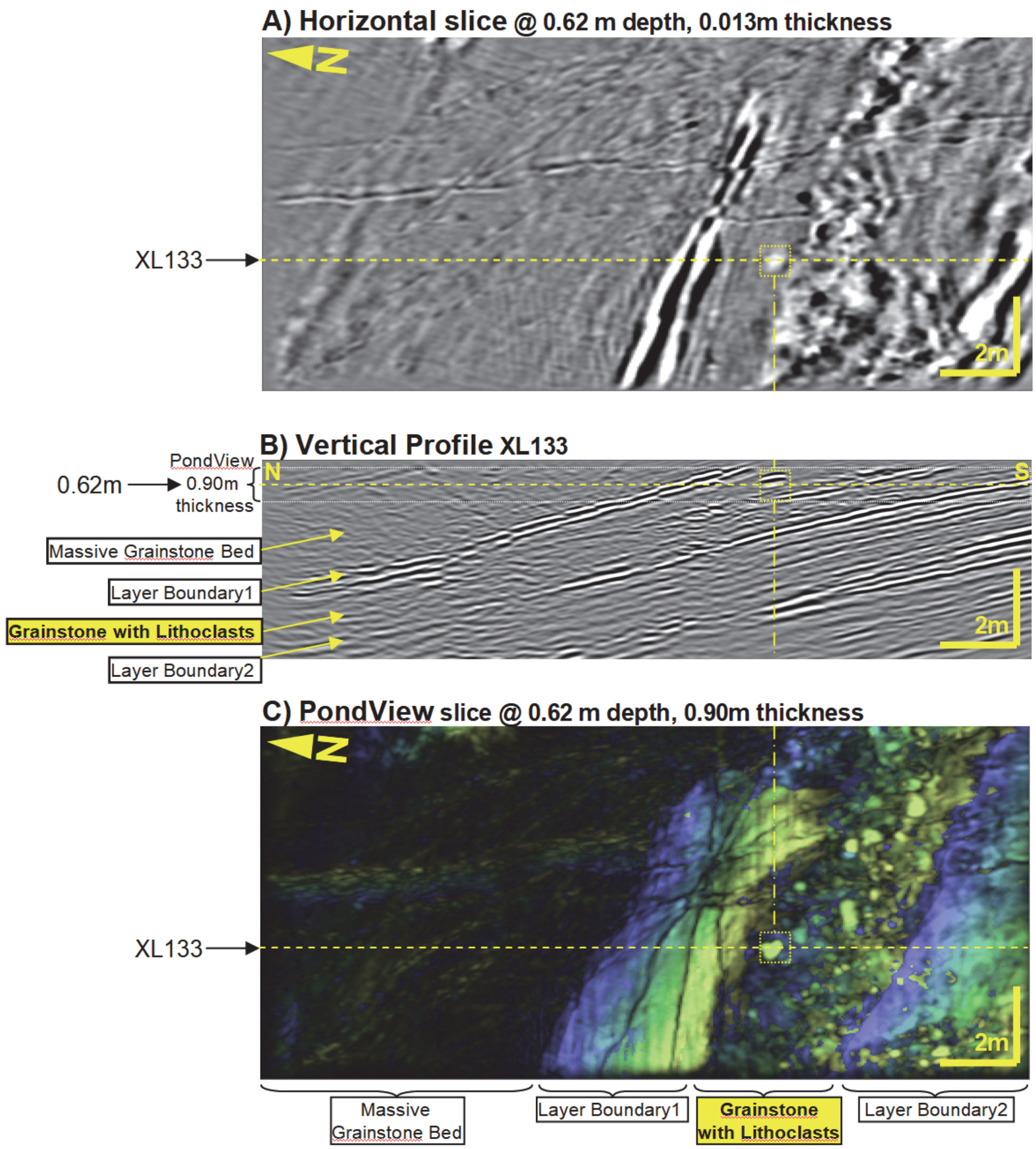

Figure 2: A) Single sample thin horizontal 3D GPR slice extracted at a depth of 0.62 m below the floor of the Madonna della Mazza quarry. Yellow square marks the response of a prominent lithoclast B) Vertical Profile XL133 crossing the marked lithoclast. The lithoclast is located in a North dipping grainstone layer. The profile is plotted without vertical exaggeration. C) PondView covering the same area as shown in A) but incorporating data over a 0.9m thick interval centered at 0.62 m depth. The lithoclast distribution is now clearly visible. Yellow shades are located shallower than green and blue shades. Colors are similar to objects submerged in a clear pond illuminated by the sun from above. The NE dipping layer interfaces contain fracture patterns. The massive grainstone in the northern half or the area only shows low amplitude curved signatures of deformation bands and contains no lithoclasts.

APPROACH

Most 3D Seismic and GPR data interpretation focuses on interfaces separating beds. To assess the lithoclast distribution in grainstones, the layer content between the bounding interfaces have to be visualized and interpreted. Preliminary tests on a 400 m2 3D GPR survey acquired in the center of the Madonna della Mazza quarry, show how thin horizontal slices and vertical profiles (Fig. 2A and 2B) do not give an interpretable view of the lithoclast distribution. However, our recently developed PondView application (Grasmueck and Viggiano, 2018) gives a clear map view of the lithoclasts inside the grainstone bed (Fig. 2C). The yellow-green-blue color coding shows the relative depth and vertical distribution of lithoclasts within the imaged slice thickness. At the same time Pondview also precisely shows fracture discontinuities and dipping bed interfaces.

SCOPE OF WORK

The next steps to further investigate the lithoclast distribution in the grainstone drift deposits of the Madonna della Mazza quarry are:

- Use horizon flattening to remove dip and to visualize lithoclast distribution of entire grainstone beds.
- Process and visualize the Madonna della Mazza 3D GPR data collection covering 2300 m2 quarry floor.
- Compare Pondview results with other geobody visualization approaches available in commercial 3D interpretation software.
- Integrate lithoclast distribution results obtained from 3D GPR data with Outcrop observations and refine the flow process model for drift deposits containing lithoclasts.

SIGNIFICANCE AND EXPECTED RESULTS

The sedimentary processes and the related genetic facies or difficult to interpret in the drift delta as the flow mechanisms are poorly understood. These beds are likely the result of a complicated transformation from bedload to suspended flow and/or supercritical flow. Because this study will produce a 3D clast distribution within a bed it potentially helps decipher the flow processes in such beds.

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THE EFFECT OF MICROBIAL MEDIATED PRECIPITATION ON ROCK PHYSICS

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

PROJECT OBJECTIVES

- To elucidate the involvement of microbes in ooid cementation processes and their potential effect on the acoustic properties of un-cemented ooid sandstone at low pressures.
- Compare the influence of microbial mediated versus inorganic precipitated cements on acoustic velocity and rock strengths of carbonates.

PROJECT RATIONALE

Carbonates can undergo diagenetic alterations, which often results in drastic changes in the petrophysical properties of the grain as newly formed cements may completely occlude or partially line the pores. This process can exert profound changes in the strength of granular rocks as it can increase the stiffness of a particulate aggregate, especially if the new cement precipitates at the grain-to-grain contacts (Bernabe et al. 1992; Dvorkin and Nur, 1996). These cements not only have a concomitant effect on the stiffness/shear stress behavior but can greatly affect compaction, bulk and shear modulus. Our previous in vitro precipitation studies have shown that inorganic carbonate crystal precipitation at grain contacts can occur in few weeks when ooids are incubated with supersaturated solutions of $CaCO_3$ (Fig. 1). Ongoing precipitation can also lead to overgrowth by needle structures that can embed the ooid surface. However, contrary to grain-to-grain contacts, which lead to an increase in rock stiffness and acoustic velocity, needle crystals reduce porosity but have a negligible effect on acoustic velocity.

Recent evidence, however, suggests that cementation is not a strictly inorganic process as microbial binding in micritic bridging and fringing cements has been documented, strengthening the notion that microbes are involved in

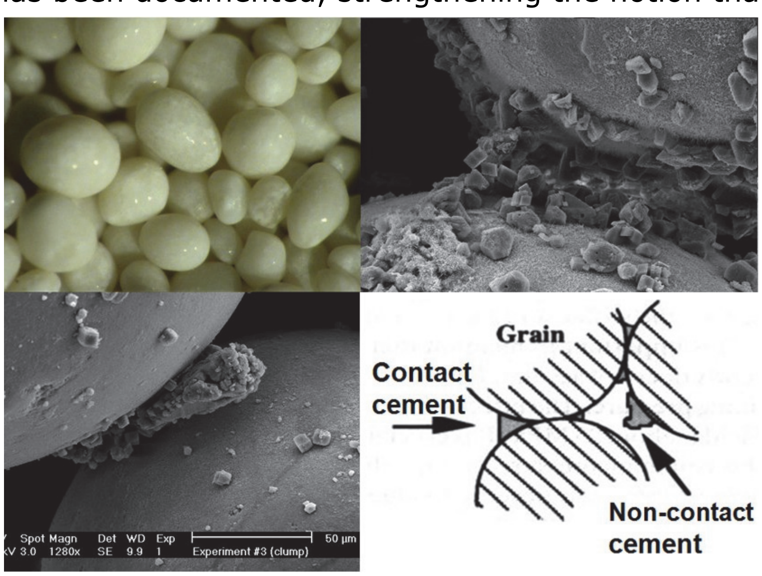

Figure 1: Results of inorganic precipitation study. Top right, clean ooids before experiment. Top right and bottom left, calcium carbonate crystals precipitated during the experiment. Precipitation occurs preferentially at the ooid-to-ooid grain contacts. Bottom right, illustration of contact vs. non-contact cement (from Dvorkin and Nur, 1996).

the initial cementation and stabilization of sediments. Our observations are further supported by preliminary experiments that use in-vitro incubations of ooids in the presence of indigenous microbial populations. Based on the growing evidence supporting the biological mediation theory, this study aims to address the involvement of microbes in early cementation processes and their impact on the elastic properties that leads to grain compaction and cementation. In particular, we will address whether microbial cementation can trigger increases in the stiffness of granular soils and how it affects velocity and compaction. Toward this end, experiments that quantify both the chemical changes in the fluids and the diagenetic and petrophysical changes (i.e. acoustic velocity and permeability) will be undertaken. Special attention will be given to the differences between microbial and inorganic precipitation. These measurements will be complemented with SEM observations.

APPROACH AND WORK FLOW

In order to improve our understanding of the impact of microbial precipitation on rock-physics experiments will be tailored to:

Quantify the chemical changes in the fluids and the diagenetic and petrophysical changes in the rocks during different types of precipitation, including inorganic and microbial mediated precipitation. While inorganic precipitation experiments will be undertaken in incubation chambers inoculated with sterilized ooids – to remove any potential microbial involvement in the calcification process – microbially mediated carbonate precipitation experiments will use an inoculum of freshly collected ooids.

Determine the presence and potential involvement of biofilm extracellular polymeric substances (EPS) in carbonate precipitation at grain-to-grain contact loci and non-contact areas of the grains. The presence of EPS will be determined with SEM image processing analysis and confocal laser scanning microscopy (CLSM). The CLSM analysis will allow visualization of EPS distribution in the grains via specific binding of lectins to EPS-carbohydrates.

Determine if ACC nanograins can act as precursors of cementation processes in ooids. Detection of ACC will use morphological attributes based on SEM image analysis.

KEY DELIVERABLES

A data set will be generated capturing changes in acoustic velocity and fluid flow permeability generated by microbially induced precipitation. High-resolution images using SEM will provide insights on the precipitated material and preferential location within the rock framework.

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LITHOLOGIC AND GEOCHEMICAL CALIBRATION OF THE BASAL CLINOFORMS IN THE SIERRA DE LA VACA MUERTA, NEUQUÉN BASIN, ARGENTINA (YEAR 2)

Laura E. Rueda, Gregor P. Eberli, Max Tenaglia, Ralf J. Weger, Donald F. McNeill, Larry Peterson, and Peter K. Swart

PROJECT OBJECTIVE

- Reconstruct in detail the geometry of the early to late Tithonian clinoforms in the southern, proximal portion of the basin in the Sierra de la Vaca Muerta that contain the first high TOC interval in the Neuquén Basin.
- Place the mixed carbonate-siliciclastic facies into the shelf-margin clinoforms and produce a detailed model of the depositional processes.
- Correlate high-resolution geochemical logs with lithological logs in the different depositional sub-environments to produce a geochemical calibration of the various facies.

PROJECT RATIONALE

The dynamics of sedimentation in muddy mixed carbonate-siliciclastic systems, especially those that form unconventional reservoirs, is still in an exploratory phase. The Vaca Muerta (VM) Formation in the Neuquén Basin is one of these systems. In this mixed carbonate-siliciclastic prograding system the carbonate content, the total organic carbon, and the motif of the depositional cycles vary throughout the basin in a systematic manner (Leanza et al., 2011; Zeller et al., 2015). Outcrops in the Sierra de la Vaca Muerta (SdlVM) expose the early to late Tithonian clinoforms that fill the basin in a southeast to northwest direction (Fig. 1). A 3D terrain model using high-resolution, digital elevated satellite imagery allows the calculation of vertical

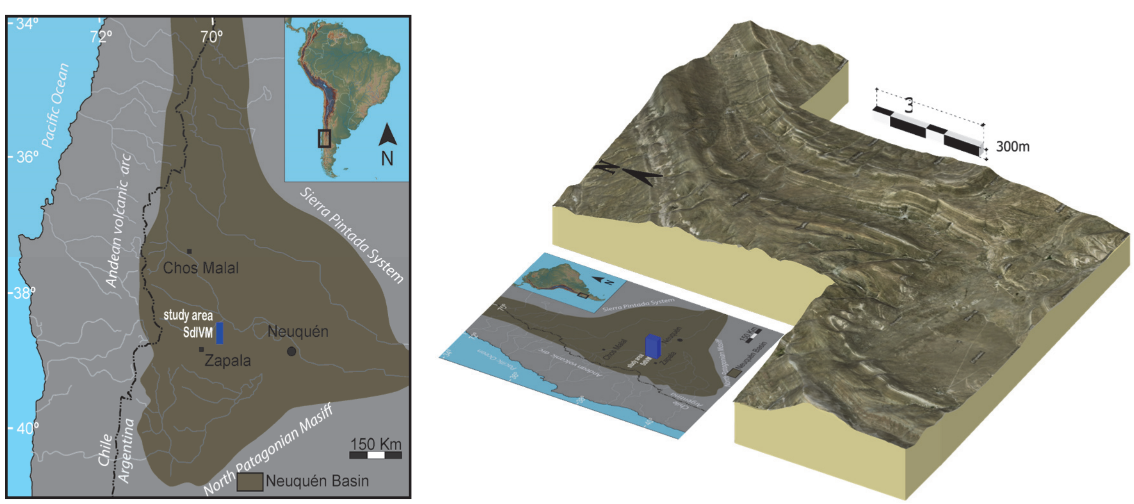

Figure 1: Left: Location map of the study area in the Sierra de la Vaca Muerta (Blue box). Right: 3D terrain model of the outcrop area in which clinoform geometry, and their lithologic and geochemical content, will be studied.

and lateral distances, improving the assessment of lateral and vertical variations of bed thicknesses and depositional geometries within these clinoforms. Previous sedimentologic studies of outcrop and subsurface data produced various depositional models, in which the interpretation of the depositional environment and the mode of sediment transport of the Vaca Muerta- Picun Léufu-Quintuco system varies widely. In this study of the lithological and geochemical variations in clinoforms exposed in the SdlVM we expect insights into other controls beyond the sea-level fluctuations that generated this mixed-system of prograding clinoforms.

PROJECT DESCRIPTION

In this study, the lithological and geochemical characteristics of the shelf margin clinoforms are analyzed within a detailed geometrical framework derived from a 3D terrain model (Fig. 1). The digital terrain model is constructed from high-resolution satellite imagery collected by DigitalGlobe satellites and stitched using the *Sketchup* software.

Nine sections within the terrain model serve as the calibration for a transect that covers ~25 km and a vertical succession of 716 m in a downdip direction of the oldest clinoforms. For the chemical calibration, 733 samples were analyzed for carbonate (%$CaCO_3$), total organic carbon (%wt TOC) content, and for organic $\delta^{13}C$ and $\delta^{15}N$ isotopes. A total of 985 samples (including duplicates) were studied for mineral composition using the ASD TerraSpec Halo mineral identifier, a near-infrared portable spectroscope. Correlations between the detailed logs and core descriptions, and the geochemical findings, will aid in the definition and interpretation of facies and cycles.

PRELIMINARY FINDINGS

The prograding shelf-margin clinoforms in the Sierra de la Vaca Muerta exhibit a sigmoidal geometry that, together with their low angles, controls the sediment partitioning into and across the basin. Clinoforms that exhibit relatively steep shelf edges are capped with carbonate-rich beds and are associated with large mass-transport complexes. In contrast, clinoforms with low angles that are made of calcareous-mudstones and sandstones contain small slumps. The clinoforms are fronted by mud-dominated bottomsets. Sedimentary structures and lateral thickness variation of the bottomset indicate bottom currents. Siliciclastic and carbonate mineral assemblages display a cyclicity that reflects sequence stratigraphic divisions.

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Stratigraphic and Lateral Distribution of TOC in the Vaca Muerta Formation

Max Tenaglia, Ralf. J Weger, Gregor P. Eberli, Peter K. Swart and the Vaca Muerta Team

Project Objectives

- Determine depositional and temporal trends in accumulation of organic-rich strata in the Neuquén Basin from over 4000 outcrop samples.
- Refine thickness maps of TOC-rich intervals.
- Correlate geochemical measurements of outcrop samples to log measurements and petrophysical values.

Rationale

One reason why the Vaca Muerta Formation in the Neuquén Basin is the most prolific unconventional play in South America is the long-lived nature of organic-rich strata accumulation. Deposition of strata rich in Total Organic Carbon (TOC) occurred during the Late Jurassic – Early Cretaceous in the basal portion of a time-transgressive prograding shelf system. Due to the prograding nature and the evolving fill of the basin, TOC content is variable laterally and also temporally constrained. High TOC intervals are most prominent in the basal components of prograding clinoforms. In the southern part of the basin, only the oldest clinoforms are indicative of this basal component. Outcrops provide the record of the evolving basin and its organic-rich strata.

In years of field work, over 2000 m of sections in six zones along the western margin of the basin were examined. Within these sections, approximately 4000 samples were taken and analyzed for TOC, carbonate content, $\delta^{13}C_{org}$, and γ– log. Together, these data allow for a comprehensive assessment of the distribution, and both the lateral and temporal variability of the organic-rich intervals in the Neuquén Basin.

Age	Interval	PL		SdlVM		Loncopue		PC		AT		All Outcrops		El Trapial	
		Avg TOC	MAX TOC	Avg TOC	MAX TOC	Avg TOC	MAX TOC	Avg TOC	MAX TOC	Avg TOC	MAX TOC	Avg TOC	MAX TOC	Avg TOC	MAX TOC
Valanginian	**V3-V4**	N/A		N/A		N/A		0.90%	**2.82%**	1.11%	**2.56%**	0.94%	**2.82%**	N/A	
Valanginian	**V2-V3**	N/A		N/A		N/A		1.28%	**4.07%**	1.50%	**4.92%**	1.38%	**4.92%**	N/A	
Valanginian	**V1-V2**	N/A		N/A		N/A		1.41%	**4.31%**	1.12%	**2.69%**	1.30%	**4.31%**	N/A	
Valanginian	**B4-V1**	N/A		N/A		N/A		2.60%	**9.19%**	2.16%	**6.27%**	2.48%	**9.19%**	4.34%	**10.77%**
Berriasian	**B2-B4**	N/A		N/A		N/A		2.60%	**6.77%**	3.16%	**6.61%**	2.74%	**6.77%**	4.92%	**8.35%**
Berriasian	**B1-B2**	N/A		N/A		N/A		2.45%	**6.53%**	2.41%	**4.88%**	2.41%	**6.53%**	N/A	
Berriasian	**T5-B1**	N/A		N/A		1.76%	**2.62%**	2.98%	**9.69%**	2.71%	**5.99%**	2.77%	**9.69%**	4.83%	**9.58%**
Tithonian	**T3 - T5**	N/A		0.80%	**6.00%**	3.03%	**5.51%**	2.28%	**6.01%**	2.72%	**6.95%**	1.64%	**6.95%**	6.04%	**10.52%**
Tithonian	**T1 - T3**	1.45%	**11.82%**	2.65%	**16.26%**	4.03%	**9.47%**	2.30%	**7.24%**	3.75%	**11.69%**	2.69%	**16.26%**	6.47%	**11.51%**

Table 1. TOC values (average and maximum) of seismic intervals, arranged by outcrop. Intervals of high TOC indicated by darker color shading.

Approach and Workflow

Two easily identifiable, laterally extensive, high TOC intervals, commonly refered to as "Kitchen" are found in the Middle Tithonian (T1-T3) and the Upper Berriasian (B2-B4). In outcrop, the average TOC value for the Tithonian "Kitchen" is 2.69% (Table 1), compared to 6.47% in the subsurface. In the stratigraphically higher, chronologically younger Berriasian "Kitchen," averaged outcrop values are 2.74% TOC, with 4.92% in the subsurface. Multiple individual sections that span these key time intervals will be examined to determine small scale variability of TOC, as well as determining the association of organic richness to refined depositional geometries and slope angles.

For correlating the various outcrop sections to determine time-equivalent strata we produce a sequence stratigraphic analysis in each section and combine it with biostratigraphic information. This sequence stratigraphic framework is tied to reflection horizons that cut the outcrop surface (Masaferro et al., 2014) and extrapolated to the subsurface stratigraphic horizons identified in the "Transecta Line" (Sattler et al., 2016). From this correlation, two transect lines are used to constrain the sections into the overall framework. Detailed stratigraphic logs were compiled together, and incorporated into our basinal stratigraphic framework that can now be populated with all of our geochemical measurements.

Expected Outcome of TOC Variability across the basin

It is known that organic carbon is not concentrated at a unique horizon within the basin but the positioning of organic-rich intervals becomes stratigraphically higher and chronologically younger towards the basin center. The results presented will document the repeated occurrence of organic-rich strata in outcrops and subsurface at multiple horizons. By placing the data into a seismic and refined sequence stratigraphic framework, our latest understanding will produce a map detailing the lateral extent of TOC-rich zones on the scale of 10s to 100s of kilometers. The latest advancements in our understanding of the basin dynamics will be incorporated into our depositional model to produce a refined map documenting the extent, and thickness of high TOC strata within the Vaca Muerta Formation.

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INTRA-FORMATIONAL FLOW AND FRACTURE BARRIERS – CRYSTAL STRUCTURE & POROSITY OF STRATIGRAPHIC CONCRETIONS, VACA MUERTA FORMATION

Donald F. McNeill

PROJECT OBJECTIVES

- Assemble data on concretion strength.
- Characterize nature of calcite cements and porosity in concretion beds.

PROJECT RATIONALE

Concretionary beds are an integral part of mud-rich deposits, many of which form in unconventional reservoir systems. In both siliciclastic- and carbonate-rich mudstones, bedded "stratigraphic" concretions can form relatively low-permeability beds that form early in the burial sequence (Fig. 1). Pervasive cementation forms beds with low permeability that can act as a fluid baffle and a mechanically stiff layer. This study addresses the microstructure of the concretion beds and how cementation forms relatively strong units early in the burial history.

APPROACH

This study will employ two main analytical techniques. Concretion microstructure will be analyzed by SEM imaging of ion micromilled surfaces (Fig. 2). Concretion strength will rely on simple uniaxial compression testing (horizontal and vertical oriented plugs) to provide a measure of rock strength.

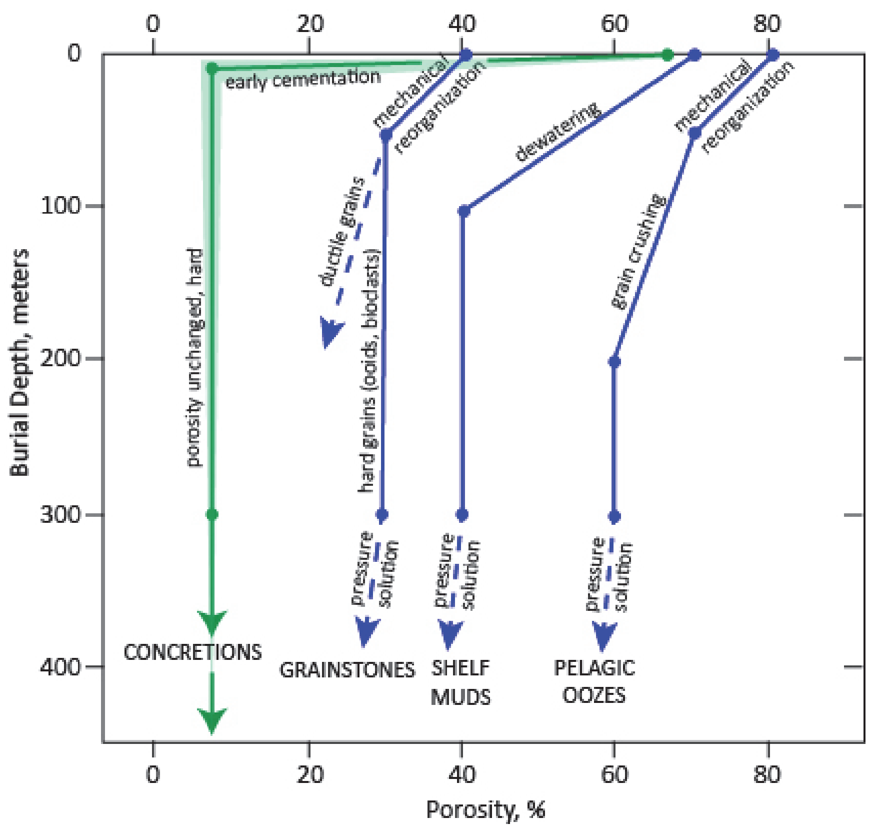

Figure 1. Porosity versus shallow burial depth for different types of carbonate lithologies (blue lines) based on fig. 9.5 of Moore (1989). Concretions show a distinct early cementation trend different from most carbonate and siliciclastic sediments.

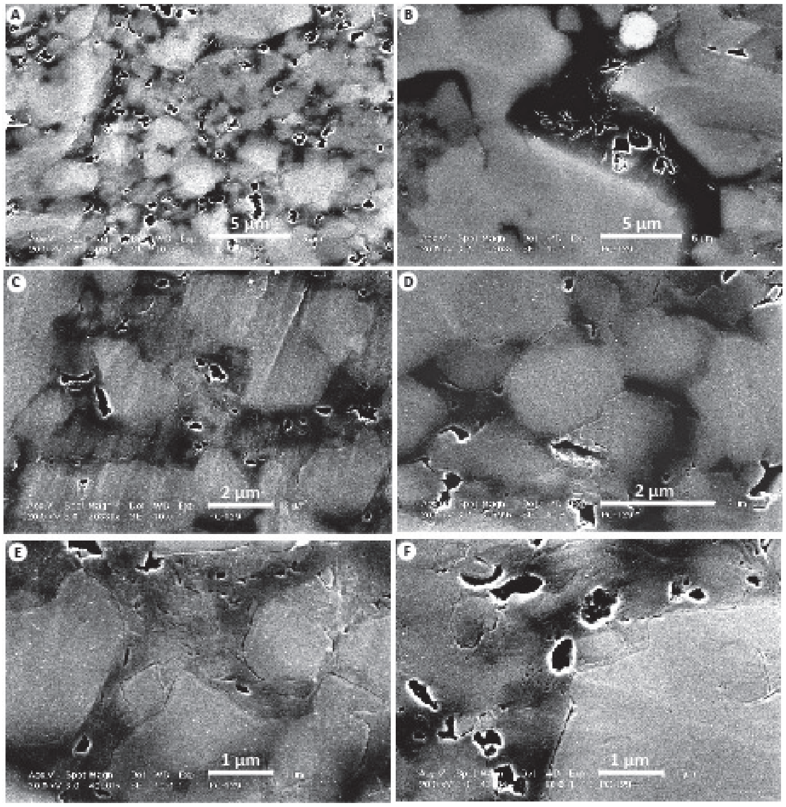

Figure 2: SEM photomicrographs of micromilled Vaca Muerta concretion surfaces showing calcite crystals (mostly light gray) and pore spaces (mostly black with white rims from electron charging at edge of pore).

Some inter-crystalline area is likely composed of organic matter and contains intraparticle organic pores. A) Overview image of calcite crystals and pores; B-D) typical oval to equidimensional pores that occur at the intersection of calcite crystals within the cement matrix. The dark matrix is likely organic matter and contains intraparticle pores; E-F) view of pores that also include elongate pores that occur at the boundary between calcite crystals or detrital grains. All images are from SC-PC03-129 at ~25 cm.

INITIAL RESULTS - CONCRETION CRYSTALLINITY & POROSITY

Scanning electron microscopy was used to examine ion-micromilled surfaces of Upper Jurassic concretions. Results indicate that the dominant crystal size is 1-3 μm (mean 2.08 μm microns; S.D. = 1.42 μm). Pores were formed at the intersections of calcite crystals by the constriction of the fluid-filled interstitial space, likely prior to dewatering and initial compaction. These (micro) pores are of the "Type III, fitted fused" variety. Two-dimensional pore shapes analyzed on micromilled surfaces are near equidimensional (length/width = ~1-1.5), oval (length/width = 1.5-5), and elongate (length/width = >5) forms. Equidimensional and oval pores occur at the intersections of calcite crystals (along with clay minerals and organic material). Elongate pores of uncertain origin are found at the boundaries between adjacent calcite crystals. Helium pycnometer porosity of the plugs associated with the Upper Jurassic micromilled sample is consistent with a relatively low total porosity, with values of 0.38, 0.58, and 0.82%. The size and shape of cement crystals and pores suggests that relatively early, rapid, and pervasive precipitation produced a homogeneous mass of calcite and small isolated pores.

Lateral Variability of the Vaca Muerta Formation

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

Project Objectives

- Assess the degree of lateral variability between different sections only separated by a few kilometers.
- Use sedimentological, stratigraphic, petrophysical and geochemical changes between these sections to demonstrate the presence of current dominated deep basin processes.

Project Rationale

Over the last several years, the Vaca Muerta Formation has proven its unconventional resource potential. The CSL has assembled a complete reference section at Puerta Curaco (PC) by splicing together the best-exposed segments of the formation. In 2017, we measured a new section to assess the lateral variability between PC and Aguada de los Tamariscos (AT), approximately 5 km north of Puerta Curaco. Last year, we measured an additional section at Pampa Trill (PT), another 15 km further north east.

We presented the differences between the measured sections in Puerta Curaco (PC) and Aguada de los Tamariscos (AT) in 2017, illustrating subtle indications of current driven depositional differences and an overall increase in carbonate content over the just 5km distance between PC and AT. Additional data from a presumably more proximal setting 15 km further NE will provide insight into the basin evolution on the far north-eastern end of the Neuquén Basin.

Figure 1: Location of the compared sections at Puerta Curaco, Aguada de los Tamariscos, and Pampa Trill

Approach

In the areas of Puerta Curaco, Aguada de los Tamariscos, and Yesera del Tromen we measured 12 different sections with a total length of 1850 meters. In addition to the lithologic log, spectral gamma ray was measured every meter and a sample for geochemical analysis was collected at each gamma ray location. Geochemical analyses included total organic content (TOC), carbonate content and isotopic analysis of the organic and inorganic carbon. In the Puerta Curaco area, nine individual sections were spliced into a composite reference section that covers the stratigraphic column from Tordillo up to the Mulichinco Formation. The section in Puerta Curaro was correlated (lithologic and gamma ray) to the section at Aguada de los Tamariscos and ammonite zonation from Aguirre Urreta et al. (2014) provided clear age constraints for the first 120 m, and the younger parts of the sections were age correlated to wells in the El Trapial Block (Chevron) via spectral gamma ray. A more detailed explanation can be found in Rodríguez Blanco (2016). Now we have measured an additional section 570 m in length, collecting gamma ray and samples for geochemical analysis every meter.

SIGNIFICANCE

The lithologic sections display many similarities, but are different with regards to thickness, carbonate content, presence of calcite 'beef', and TOC. All three sequences are correlated based on lithological characteristics and gamma ray signature. Substantially higher carbonate content, and noticeably less horizontal, stratigraphically aligned calcite veins (beef) and volcanic intercalations have been observed in PT.

These observed variations between the sections can be explained with a proximal – distal trend but more importantly by the presence of currents that dominate the deep basin processes. Indications of current driven depositional differences are the thickness variations and the strong increase in carbonate content over a distance of just a few kilometers between PC, AT, and PT. The chemical data (carbonate content, TOC, isotopes) suggest a more proximal depositional setting at PT, only 15 km NE of PC.

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GEOCHEMICAL FACIES OF THE BAHAMAS REVISITED

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PROJECT OBJECTIVES

- To explore geochemical variations in the surface sediments of the Great Bahama Bank and relate these to sedimentary facies.
- To apply this information to core material from the Bahamas and other carbonate platforms, both in the Neogene and ancient carbonates.

PROJECT RATIONALE

The Great Bahama Bank (GBB), a large (>100,000 km^2) shallow-water carbonate complex situated to the east of the Florida Straits, has built up over at least the last 100 myrs (Eberli and Ginsburg, 1987; Schlager et al., 1988) as a result of the activities of carbonate secreting organisms and the inorganic precipitation of calcium carbonate (Purdy, 1963a, b; Traverse and Ginsburg, 1966). In order to calibrate the geochemical signal of these sediments, a series of cruises collected material from the western portion of Great Bahama Bank between 2002 and 2005 (Fig. 1). This work resulted in the publication of a series of sediment facies and geochemical maps (Reijmer et al., 2009; Swart et al., 2009) which were used to calibrate remote sensing images which in turn allowed facies to be mapped in areas of GBB not previously sampled (Harris et al., 2015). This study will concentrate on the areas of GBB not sampled previously.

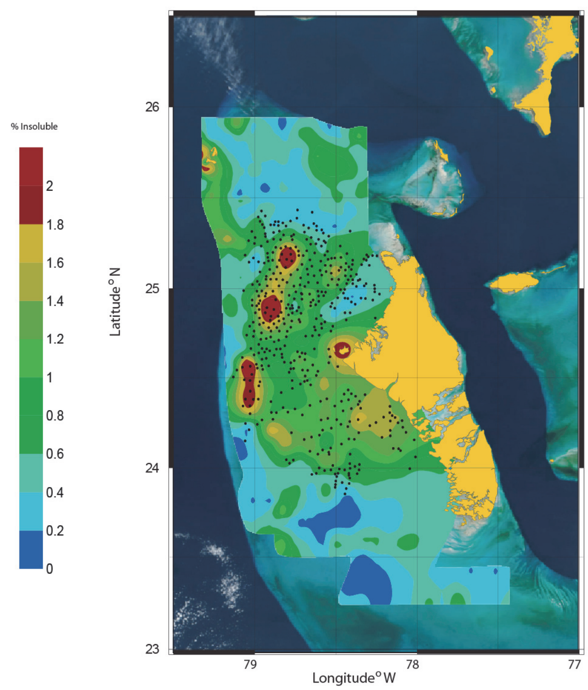

Fig. 1: The percentage of insoluble material in sediment samples collected in cruises between 2002-2006 and the location of whitings.

SCOPE OF WORK

The proposed work will sample the surface sediments of the Bahamas (to the west and south of the island of New Providence and in the southern area of GBB), which were not only not sampled during our previous efforts, but were also largely ignored in the studies of Purdy (1963a) and Traverse and Ginsburg (1966). In these areas we propose two three week cruises, one in 2019 and one in 2020. During these cruises we will collect water and sediment samples on a grid and characterize bottom sediment types using video. Samples will be classified during the cruise using the textural features outlined in Dunham (1962). Once the samples are returned to Miami we will carry out a range of geochemical analyses. These analyses will include stable isotopes of C, O, N, Ca, Mg, Cr, and trace elements on the inorganic components, together with C and N and carbon content analysis of the organic components.

SIGNIFICANCE

Our previous studies provided valuable geochemical data with which to calibrate the sedimentary record. One example of this was the identification of high concentrations of insoluble material linked to the fertilization of GBB by African dust (Swart et al., 2014). This in turn encouraged the activity of cyanobacteria, drawing down the concentration of CO_2 and promoting the precipitation of $CaCO_3$ as whitings. We propose that the new suite of surface sediment samples will provide new information, both expected and surprising, and be useful in the interpretation of the formation of carbonate sediments and their diagenesis.

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New Approaches to Constraining the Temperature vs. Clumped Isotope Calibration for Dolomite

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Project Objectives

- Measure the difference between the Δ_{47} produced at 25 and 90°C for dolomites with different initial Δ_{47} values
- Use this information to constrain the clumped isotope equation for dolomite

Project Rationale

The recognition that clumped isotopes of CO_2 are solely dependent upon temperature and not on the isotopic composition of the fluid from which they are formed has opened significant possibilities in unraveling the temperature and water signal as applied to diagenetic carbonates. At the University of Miami we have two working clumped isotope mass spectrometers and are investigating a range of problems involving both the calibration of the method as well as its application to geological problems. For example in the study of Staudigel et al. (2018) we precipitate calcite samples at 10 different temperatures and developed our own calibration line (Fig. 1). In a second study we have been measuring exchange rates between the CO_2 and the phosphoric acid in an effort to understand error and artifacts

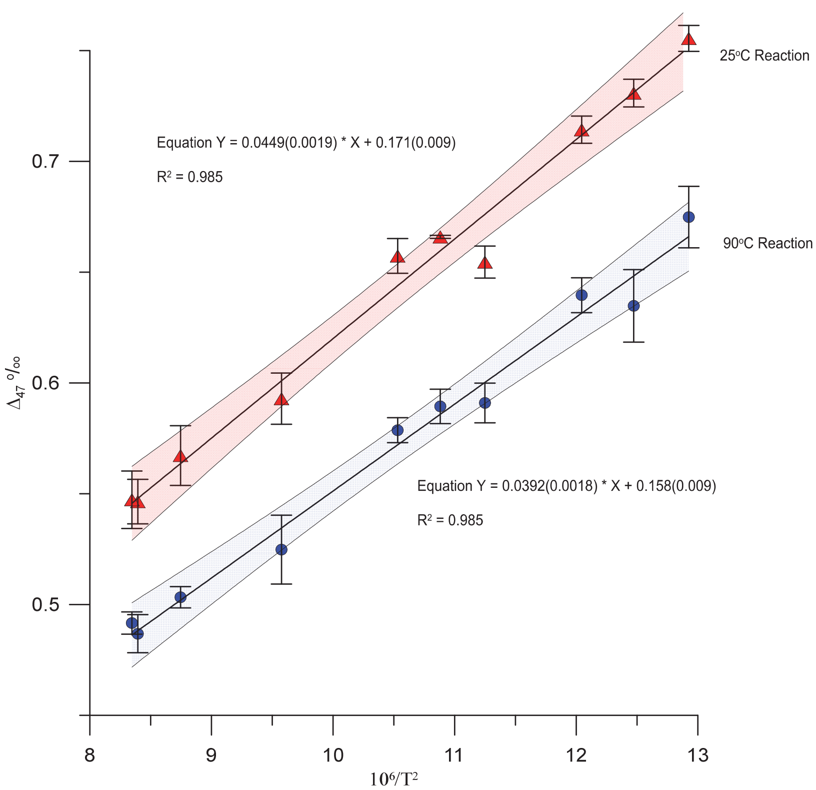

Figure 1: Comparison of the calibration lines between Δ_{47} and temperature for calcites precipitated in the laboratory and reacted at 25 and 90°C. Notice the difference in slopes between the two lines.

arising from the extraction method (Swart et al., 2019). In addition to method development we have applied the clumped isotope method to a range of geological problems (Müller et al., 2017; Murray, 2016; Murray et al., 2016; Staudigel et al., 2018; Swart et al., 2016; Vahrenkamp et al., 2014). In one of these studies (Murray et al., 2016) we noticed that the difference between the Δ_{47} of dolomite reacted at 25 and 90°C is not the same as for calcite (Swart et al., 2019) (Fig. 2). This is important because it has recently been proposed that the calibration between temperature and Δ_{47} for dolomite is the same as that for calcite (Bonifacie et al., 2017). However, if our observation is correct then this suggests that the calibration lines for dolomite and calcite are probably not the same.

SCOPE OF WORK

For over 50 years researchers have struggled to derive an equation linking the □18O value of dolomite to temperature which is realistic at sedimentary temperatures (Clayton et al., 1968; Land, 1980). The problems with the nine equations which have been published so far is that they were either theoretical, derived at high temperature and extrapolated to low temperature, or derived on materials which were in fact not actually dolomite, but rather calcian or proto dolomite (Murray and Swart, 2017). As far as the Δ47 values of dolomite are concerned, the one equation which exists at the present time suggests that there is no difference between dolomite and calcite (Bonifacie et al., 2017). However, not only are there a number equations for calcite, which if applied to a specific sample would yield quite a wide range of temperatures, but the dolomite equation suffers from the same problem as the previous equations involving the □18O value of dolomite in that the low temperature end is mainly constrained by extrapolation from high temperature. We present a new approach which is based on two observations made during our study of the temperature dependence of the Δ47 value in calcite. First, the slope between temperature and Δ47 for calcite depends upon the temperature at which the samples were reacted. Samples reacted at 25oC have a steeper relationship with respect to formation temperature than those samples reacted at 90oC. Hence, with increasing formation

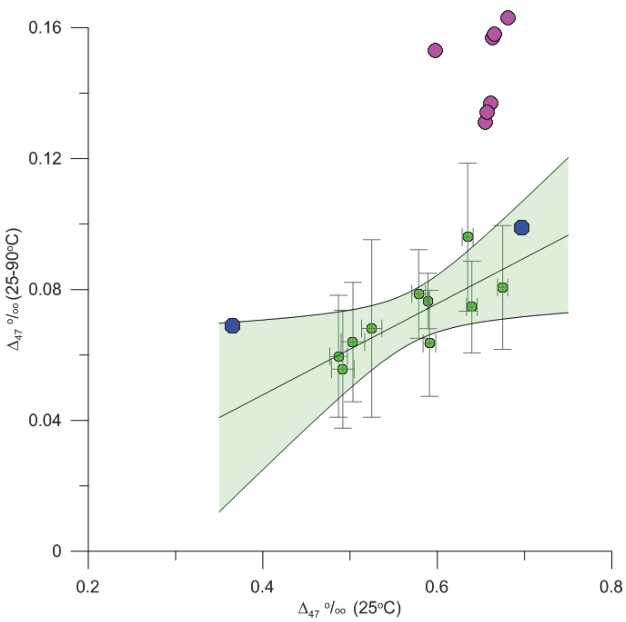

Fig. 2: Differences between 25 and 90°C reactions as shown in Fig 1 as a function of the 25°C clumped isotope value. Also shown are data from Murray et al. (2016) which show large acid fractionation for dolomite (purple dots) as well as acid fractionation for two natural calcites (blue dots).

temperature the calibration lines converge. The explanation for this trend is that at high formation temperature the Δ47 values are further away from theoretical equilibrium with the phosphoric acid at 90oC (Swart et al., 2019). During the reaction the CO2 equilibrates with the acid at a rate which is proportional to the difference between its initial value and the equilibrium value. Hence, samples formed at high temperature tend to exchange with the acid more. The second observation is that the difference between dolomite and calcite reacted at 25 and 90oC is different than that for calcite (Fig. 2). These two observations are incompatible with the notion that the calibration line for dolomite is the same as that for calcite. In order to confirm this observation we are remeasuring the difference between dolomite and calcite using the NIST-88b as measured by Murray et al. (2016). We also intend to repeat these experiments using dolomites with much lower Δ47 values. We propose two models, one in which there is a constant difference between calcite and dolomite irrespective of the initial Δ47 of the sample, and one in which the difference becomes smaller as the Δ47 of the sample become more stochastic (Fig. 3).

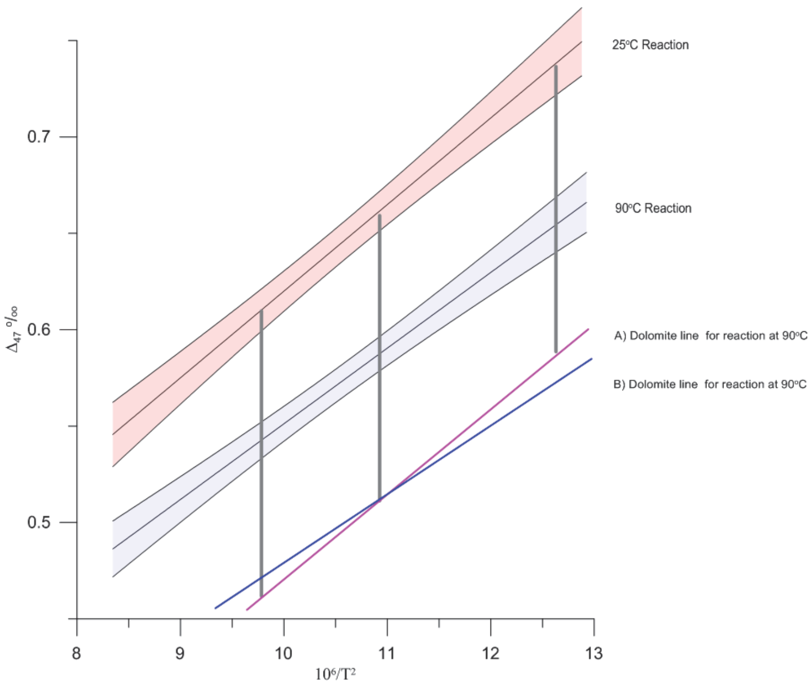

Fig. 3: Proposed position of the calibration line for dolomite based on the measured acid fractionation of 0.12‰. The proposed line is either parallel to the 25°C reaction line or the 90°C reaction line.

SIGNIFICANCE

The clumped isotope proxy has already shown that it is a powerful tool in reconstructing depositional temperatures, temperatures of diagenesis, and burial histories. In conjunction with the conventional $\delta^{18}O$ value it is also able to provide information on the $\delta^{18}O$ values of the fluids involved in deposition and/or diagenesis. While initial work has suggested that the Δ_{47}-temperature equation is similar for dolomite and calcite, there are discrepancies in the behavior of dolomite and calcite which suggest that there may be some differences in the equation linking temperature to the Δ_{47} value. The identification of such differences is crucial to enable the equation to be successfully used for dolomites and to provide information on dolomitization.

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CLUMPED ISOTOPIC VARIATIONS IN MODERN CARBONATE SEDIMENTS

Megan E. Smith and Peter K. Swart

PROJECT OBJECTIVES

- Determine the relationship between Δ_{47} and temperature for a range of different carbonate allochems.
- Analyze a wide range of bulk carbonate sediments in order to ascertain the extent of deviation from their expected temperature of formation.

PROJECT RATIONALE

The variation of multiply substituted "clumped" isotopologues in calcium-carbonate, measured as the Δ_{47} of CO_2, has been found to be a precise and reliable indicator of formation temperature (Ghosh et al., 2006). The use of this technique has a major advantage over the most common paleothermometers because it does not require any knowledge of the original solution from which the carbonate was precipitated. This is because the multiple substitution of isotopes into a molecule is strongly dependent on temperature and is not reliant upon the oxygen or carbon composition within the solution. The use of clumped isotopes as a paleothermometer opens up a new realm of possibilities in the variety and age of samples that can be measured and will aid in any project that has been hindered by a lack of knowledge of the isotopic composition of the precipitating solution. A further advantage is that once the temperature has been determined, it will be possible utilizing the $\delta^{18}O$ value of the carbonate to calculate the $\delta^{18}O$ value of the fluid involved in precipitation or diagenesis.

Although the original calibration involved several different types of carbonate materials, raising the hope that there was one universal calibration which could be applied to all carbonate materials, this hope has been dashed over the past 10 years as it has become obvious that many different carbonates fractionate the Δ_{47} differently. For example, corals give temperatures which are much lower than expected (Saenger et al., 2012), while echinoderms give higher than expected temperatures (Davies and John, 2018). As the sediments contributing to the sedimentary record are usually composed of a range of different allochems it will be important to calibrate different type of Modern sediments to see how faithfully the bulk compositions track the Modern temperatures.

SCOPE OF WORK

We propose to analyze the (i) Δ_{47} value of a range of carbonate allochems from environments with well constrained temperatures, these will include different green calcareous algae (*Halimeda* sp., *Penicillus* sp., *Acetabularia* sp.), red calcareous algae, molluscs, echinoderms, and benthic foraminifera, ooids, peloids, and mud components (bottom sediment and whiting materials), (ii) a range of different bulk sediments from the Bahamas, Florida, Belize, Maldives, and the Persian Gulf. In addition to measurements of the Δ_{47} values, we will characterize the mineralogy of the samples as well as other bulk geochemical parameters ($\delta^{13}C$, $\delta^{18}O$, and trace element geochemistry). As a start we will build on the work of Atasoy (2014) who analyzed the Δ_{47} values in samples collected during a survey of the stable isotopic composition of bulk surface sediments from the Bahamas (Swart et al., 2009). This will be supplemented by samples in hand from a survey of sediments from the Maldives (Swart et al., 2019), Belize(Gischler and Lomando, 1999) and Florida. We will also collect new samples this year during a cruise to the eastern portion of Great Bahama Bank.

SIGNIFICANCE

Many applications of the clumped isotope method have already utilized bulk samples from throughout the Phanerozoic. The basic assumption in all of these studies is that the bulk sediments reflect the original depositional temperature. The proposed work outlined is important as it will confirm whether such interpretations are correct.

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THE ROLE OF DIAGENESIS IN THE CONTROL OF B, S, AND CLUMPED ISOTOPES: THE ROLE OF EARLY DIAGENESIS

Evan Moore, Sean T. Murray, and Peter K. Swart

PROJECT OBJECTIVES

- To constrain the behavior of the stable isotopes of boron (^{11}B and ^{10}B), sulfur (^{32}S and ^{34}S), and clumped isotopes during marine and meteoric diagenesis.

PROJECT RATIONALE

In this project we will investigate the behavior of three isotopic systems (clumped isotopes of CO_2 (Δ_{47}), boron isotopes, and sulfur isotopes) during early meteoric and marine diagenesis. Despite the fact that the fundamental behavior of these systems has not been studied under well-constrained diagenetic conditions, these geochemical systems have already been widely applied to ancient geological problems. The ratio of $^{11}B/^{10}B$ ($\delta^{11}B$) has been used as a proxy of pH during well-known global carbon isotope events such as the P-T boundary and the Marinoan glaciation (Clarkson et al., 2015; Ohnemueller et al., 2014). Sulfur isotopes ($\delta^{34}S$) of carbonate associated sulfate (CAS) have been widely used in conjunction with carbon isotopes as indicators of anoxia (Lyons and Gill, 2010) and clumped isotopes have been used to ascertain the temperature of the Precambrian oceans (Bergmann et al., 2018).

SIGNIFICANCE

The application of all three of these proxy systems has the potential to dramatically change the interpretation of significant events which have occurred during Earth's history. For example, one interpretation of the dramatic change in carbon isotopes which has been widely documented at the P-T boundary, was that massive amounts of isotopically negative carbon was released from the oxidation of clathrates which in turn lowered the pH of the oceans. Hence, the interpretation of changes in the $\delta^{11}B$ values of carbonates at the P-T boundary apparently supported this hypothesis (Clarkson et al., 2015). However, later work has shown changes in the $\delta^{11}B$ values of equal magnitude associated with meteoric alteration (Stewart et al., 2015). These changes take place as a result of the degradation of organic material at the interface between the vadose and fresh-water phreatic zone and the concomitant reduction in pH. Of similar importance is whether changes in the $\delta^{34}S$ values of carbonate associated sulfate are related to anoxia or simply a product of bacterial sulfate reduction (BSR) associated with carbonate recrystallization (Swart, 2015). During burial BSR usually takes place. Under closed system conditions, the concentration of sulfate is drawn down. As a result of the large fractionation of S during this process, the $\delta^{34}S$ values of the pore fluids are elevated. If carbonates are recrystallized at the same time, the newly formed carbonate will incorporate the more positive signal. Failure to recognize this process will result in a misinterpretation of geochemical signals. Finally, the recognition that the clumped isotope signal present at mass 47 can give an indication of temperature has radically improved the interpretation of the formation of carbonates. However, the question remains whether changes in Δ_{47} reflect original temperatures or are a product of diagenesis (Staudigel, 2018).

PROPOSED WORK

We propose to study the behavior of these three isotope systems in well-studied marine and meteoric diagenetic regimes.

Meteoric: As an example of meteoric systems we will use core material from the Bahamas and the Dominican Republic. Both of these archives have well established diagenetic histories and we will examine the behavior of diagenetic systems associated with exposure surfaces, the vadose zone, the freshwater phreatic zone and the mixing zone.

Marine: Marine diagenesis will be studied using both the marine portions of cores from the Bahamas as well as material from various ODP and IODP drilled expeditions. These will include Leg 166 and Expedition 359.

SIGNIFICANCE

Many of the geochemical signatures which are now being taken as evidence of changes in the original environment may in fact be artifacts of diagenesis. If true, while these geochemical proxies may not be able to provide information on the original environment of deposition, understanding the diagenetic signal may allow use of these proxies to better understand carbonate diagenesis and the development of carbonate reservoirs.

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Relationships Between the Carbon values of Inorganic and Organic Material from the Maldives, Bahamas and the Nicaraguan Rise

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Project Objectives

- To determine the nature of the changes in the $\delta^{13}C$ values of organic material relative to $\delta^{13}C$ values in carbonate sediments.

Project Rationale

A positive covariance between the $\delta^{13}C$ values of inorganic ($\delta^{13}C_{carb}$) and organic carbon ($\delta^{13}C_{org}$) has long been suggested to be proof that such signals were original and indicative of changes in the global carbon cycle (Knoll et al., 1986). However, not only do the relationships between $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ values vary depending upon whether carbonates are pelagic, peri-platform, or mainly platform derived (Oehlert et al., 2012), but both meteoric and marine diagenesis can also alter the covariance (Oehlert, 2014; Oehlert and Swart, 2014). The purpose of this work is to examine controls on the relationship between $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ and to ascertain under what circumstances covariance reflects variations in the global carbon cycle and other factors which may alter the covariance.

Scope Of Work

As the initial work on this problem was carried out using samples drilled off the margin of Great Bahama Bank during Ocean Drilling Program Leg 166 (Eberli et al., 1997), we intend to examine material collected from cores drilled in sediments surrounding other carbonate systems. For this study we will concentrate on two carbonate buildups, The Nicaraguan Rise, drilled during ODP Leg 165 (Sigurdsson et al., 2000) and The Maldives (Betzler et al., 2016), drilled during IODP Expedition 359. In the Maldives a set of well-dated cores were collected which extend from the Modern to the late Oligocene. We have already performed a high-resolution study of the $\delta^{13}C$ values of the carbonate component (Swart et al., 2019) in four of the cores from the Maldives as well as completing measurements of the $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ values on samples from Site 1000 situated on the Nicaraguan Rise. While samples from both the Maldives and the Nicaraguan Rise show changes in the $\delta^{13}C_{carb}$ values which appear to be synchronous with changes in the global carbon cycle during the Monterey Event as recorded in the benthic record of Zachos et al. (2001), the record from the Maldives may be reflecting varying contributions from the adjacent platforms in a mechanism similar to that proposed in the Bahamas (Swart and Eberli, 2005). As of yet we have not carefully examined the data from Site 1000 to see if similar processes are in effect. We intend to use the same samples from the Maldives to conduct a high resolution study of the variations in the $\delta^{13}C_{org}$. If the changes in the $\delta^{13}C_{carb}$ values in the Maldives are related to the Monterey Event, then we should see similar changes in the $\delta^{13}C_{org}$

values and therefore ascertain whether our original hypothesis regarding the origins of the isotopic variations in the $\delta^{13}C$ values of these samples was correct. The data from the Maldives will then be compared with data from the Bahamas and the Nicaraguan Rise.

SIGNIFICANCE

The study of variations in the $\delta^{13}C$ values of carbonates and organic material has been vital in understanding the global carbon cycle and allowing such variations to be used as a stratigraphic tool. However, there has been a fundamental misinterpretation regarding the meaning of many of the changes observed. The proposed research will help to clarify and decipher some of this unresolved confusion.

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GEOCHEMICAL SIGNATURES OF HAMELIN POOL STROMATOLITES

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PROJECT OBJECTIVES

- Characterize the geochemical signatures of microfabrics of Hamelin Pool stromatolites.
- Relate stable isotope, rare earth element and trace element geochemistry of stromatolite microfabrics to formation mechanism and environmental geochemistry.

PROJECT RATIONALE

Hamelin Pool stromatolites are a key living analogue for ancient microbialite deposits. Understanding the processes that contribute to the formation of the microfabrics, or internal structures of the stromatolites, should provide insight into the relative roles of environmental and microbial processes active in stromatolite accretion (Trompette, 1982; Ginsburg, 1991; Suosaari et al., 2019). Thirteen microfabrics have been identified in Hamelin Pool stromatolites and interpreted as fingerprints of the microbial mats that formed them (Hagan, 2015). Our recent work suggests that the stable isotope signatures of carbon and oxygen ($\delta^{13}C$ and $\delta^{18}O$) of these microfabrics exhibit trends that may be related to microbial metabolism, with more positive $\delta^{13}C$ and $\delta^{18}O$ values associated with unlaminated/clotted microfabrics (army green and gray), while more negative $\delta^{13}C$ and $\delta^{18}O$ values are associated with well-laminated microfabrics (red and yellow). The $\delta^{13}C$ and $\delta^{18}O$ values of well-laminated microfabrics are also associated with more trapped and bound grains, as evidenced by the overlap between $\delta^{13}C$ and $\delta^{18}O$ values for red and yellow

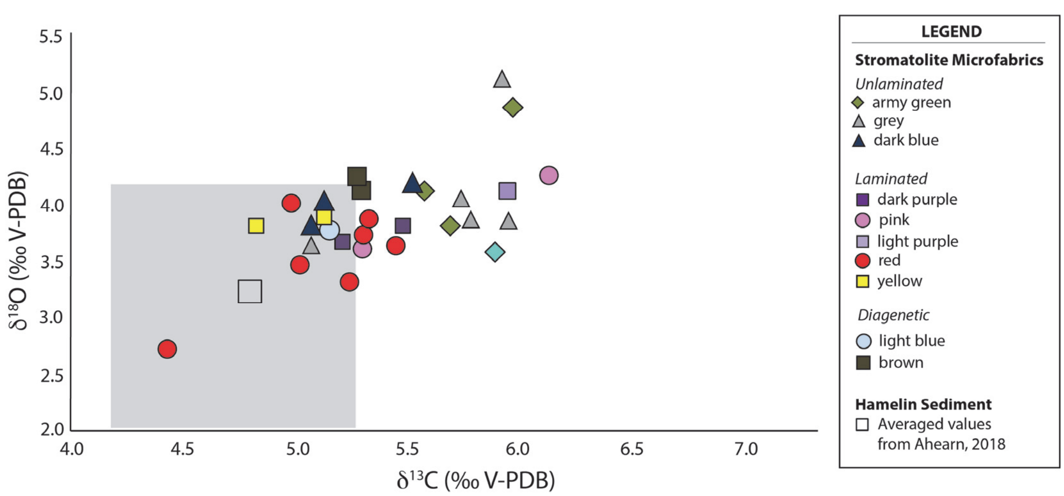

Figure 1: Cross-plot of $\delta^{13}C$ and $\delta^{18}O$ values of stromatolitic carbonate from Hamelin Pool. The large grey box represents the range and the small square is the average $\delta^{13}C$ and $\delta^{18}O$ composition of Hamelin Pool sediments from Ahearn (2018).

microfabrics and the range of sediment compositions in Hamelin Pool (Fig. 1, grey box). These observations are consistent with the interpretation that some of the Hamelin Pool stromatolites are formed by both trapping and binding as well as in situ precipitation of microbial carbonate (Reid et al., 2000; Hagan, 2015.

Recent studies suggest that specific patterns of rare earth element (REE) concentrations in stromatolites can indicate the role of life in the formation of laminated carbonate structures in the geological record (Corkeron et al., 2012). In contrast, other studies suggest that microbialites, such as stromatolites, record environmental REE concentrations allowing for paleoenvironmental reconstructions (Webb and Kamber, 2000), such as the oxygenation status of the water during the time of carbonate formation.

APPROACH

In this study, we expand the Hamelin Pool dataset by increasing the number of $\delta^{13}C$ and $\delta^{18}O$ measurements, and incorporate mineralogical (X-ray diffraction), trace element, and REE analyses of each microfabric.

SIGNIFICANCE

Better understanding of the geochemical characteristics of modern stromatolites formed by both trapping and binding, as well as direct precipitation in a well constrained depositional environment, will provide new insight into the significance of geochemical signatures in microbialites through geological time. If REE signatures in microbialites prove to record initial seawater chemistry, paleoenvironmental conditions can be reconstructed from stromatolites throughout geological time.

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EXAMINING THE ROLE OF MICROBIAL CONTRIBUTION TO CEMENTATION

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PROJECT OBJECTIVES

- Determine the potential contribution of microbes to cementation processes on carbonate slopes and reefal boundstone deposits.
- Describe and interpret sedimentary structures and textures within reefal boundstone deposits.

PROJECT RATIONALE

The strong control of cyanobacteria, algae and fungi in binding carbonate grains and triggering cementation in the form of micritic meniscus cement (Fig. 1) is well documented in the formation of grapestones, aggregate grains and firmground crusts and hardgrounds in the vicinity of high-energy carbonate sand bodies (Fabricius, 1977; Hillgärtner et al., 2001). This early microbial binding often precedes the typical marine cementation, including acicular and fibrous aragonite or bladed rinds. Extensive microbial binding is also identified as the controlling factor for early stabilization of carbonate slopes that, in combination with subsequent rapid cementation, maintains the steep slope angles around carbonate platforms and shelves (Reolid et al., 2017).

Some Silurian reef slope deposits at the Pipe Creek Union Quarry in Indiana are notable for their unusual inclined-flank-beds lithofacies that dip at an angle of around 45° (Santiago et al., 2018). Although marine cements are recognized as an important slope stabilizer, the contribution of syndepositional microbially-derived cement cannot be excluded, as microbial binding can be an important contributor to slope stabilization and reef maintenance.

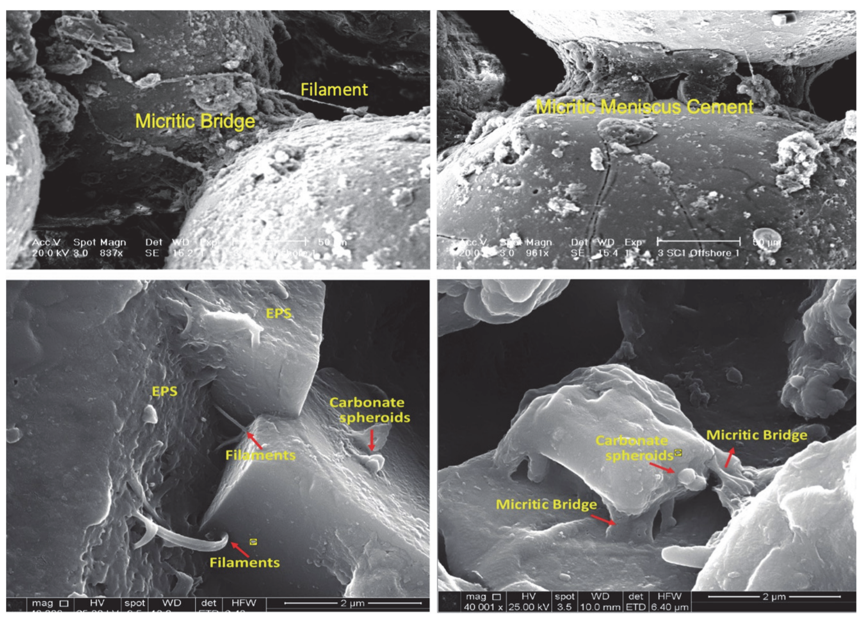

Figure 1: SEM images of modern micritic cements in intraclasts from ooid shoals at Schooners Cay and fossilized filamentous structures (interpreted as mineralized cyanobacterial filaments), fossilized EPS, carbonate spheroids, and micritic bindings in reefal boundstone deposits from the Michigan Basin (from Santiago et al., 2018).

Likewise, microbial micrite and binding cement play a role in reef maintenance, and in preventing reefs from being overwhelmed by rubble (Leinfelder, 1992). Amid the growing number of studies supporting the role of microbes in binding and trapping, and precipitation of micritic cements, this study aims to characterize signatures of microbial fingerprints that potentially denote *in situ* production and syndepositional lithification processes.

APPROACH AND DELIVERABLES

To elucidate the potential contribution of microbial cementation in the maintenance and stabilization of ancient reefal slopes, thin section petrography, SEM analysis, and confocal microscopy analyses will be conducted in Holocene sediments from Great Bahama Bank and Silurian upper slope deposits from Pipe Creek Jr., Indiana. Identification of microbes will be based following microscopic and microbial morphotypes. Special attention will be given to fossilized remnants of extracellular polymeric substances (EPS) given their strong preservation potential and utility as predictors of microbial life. Moreover, EPS is one of the key components for organomineralization. We will document any lithologies consistent with microbial influence such as micritic coatings around skeletal grains and/or, fibrous calcite cement around organic material, patterns of lamination and occurrence of micropeloidal fabrics, etc.

IMPLICATIONS

Results from this project will assist in elucidating whether abiotic or microbial cementation dominates the reefal boundstone in the modern and ancient and whether reservoir modifications can be partially attributed to syndepositional microbially-derived cement. This will have important implications for the oil industry as reef-related marine cementation is a key player in the porosity evolution of economically important ancient reefs.

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