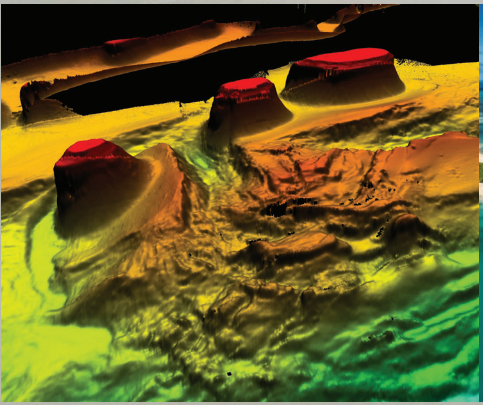
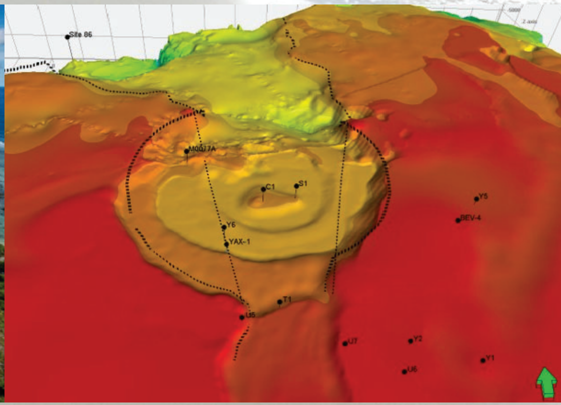
CSL
Center for Carbonate Research
and Education

Prospectus
2022





UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

CSL
CENTER FOR CARBONATE RESEARCH

TABLE OF CONTENTS

MISSION OF THE CSL – CENTER FOR CARBONATE RESEARCH

The mission of the CSL – Center for Carbonate Research is to conduct fundamental research in carbonates.

Our research program aims to comprehensively cover carbonates exploring new approaches and techniques in a variety of emerging topics. To reach this goal, the research projects integrate geology, geophysics, geobiology, and geochemistry and combine observational, laboratory, and theoretical research. Most research projects are interdisciplinary, but some are designed to advance knowledge in one specific area. This year the 19 projects are divided into six main topics:

- Shallow-water carbonates
- Rift basin and microbial carbonates
- Carbonate contourite depositional systems
- Geochemistry of carbonates
- Unconventional Reservoirs
- Carbon capture utilizations and storage (CCUS)

In addition to the fundamental knowledge gained from these studies we aim to inform our industrial associates regarding 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 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 partners through semi-annual meetings, our website, and publications.

In addition, we offer field seminars and in-house short courses.

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

We present the research results of the projects described in the prospectus in a Progress Report in the form of an executive meeting in early summer and at the Annual Review Meeting in the fall. We provide each industrial partner 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.

PERSONNEL

PRINCIPAL INVESTIGATORS

Gregor P. Eberli	Professor, Seismic Stratigraphy, Sedimentology
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2022 RESEARCH FOCUS

Our research projects cover a wide range of topics in both **shallow and deep-water carbonates,** unconventional plays, and two new projects that deal with questions in **Carbon Capture Utilization and Storage (CCUS)**. In this latter topic we rely on our expertise in petrophysical laboratory experiments and work in modern environments which store abundant quantities of organic carbon, the so-called 'blue carbon'. In the past we performed precipitation and dissolution experiments in pressure-controlled conditions and monitored the changes in velocity and chemical composition of the pore fluids. We plan a similar study on rock fluid interaction on seal rocks. In the second project we will compare the flux and the storage of organic carbon in the natural and anthropogenic altered environment of South Florida.

For the past two years, the pandemic has disrupted some field work and research expeditions but we have retrieved formidable data from the OceanX 'Deep Blue' cruise that was completed in the Fall of 2020 in the northern Red Sea. This cruise resulted in a trove of geophysical and geochemical data for the investigation of the architecture and processes in an **active rift basin.** This year the focus is on the **brine pool** and the abyssal **microbialites** in in the Gulf of Aqaba. Likewise, a short core through reef that flourished during the last glacial maximum offshore Mozambique was made available to the CSL. This core contains diverse coral species and abundant microbialites that together form a high porosity but stiff framework. To further investigate the role of microbial activity on cementation and rock stiffness we will perform an experiment in which we measure the velocity evolution during microbially induced cementation.

Two projects on **shallow-water carbonates** concentrate on the formation of ooids and Holocene islands on Great Bahama Bank, while a third one investigates how sediment is transported off the platform and also quantifies where and how much is deposited on the slope and in the basin. The question of how seaways between platforms get filled to produce a large distally steepened ramp is studied in seismic data from the Yucatan Platform, where a trough that was the site of the asteroid impact at the end of the Cretaceous gets filled with prograding clinoforms.

Several years ago, we embarked on a research effort in **carbonate contourite depositional systems** and we continue this initiative with three projects. One tests the hypothesis that increasing current speed along platforms increases that the slope angles of the platform. Another one searches for the relationship between the ichnofabrics in drifts with petrophysical properties that potentially helps discriminate coarse from fine-grained drift deposits. A third project, using 3D GPR data to visualize the sedimentary structures and reworked beds in a distal portion of the delta drift in Maiella, will elucidate the depositional processes in these drifts. In addition, we continue to assemble a database on the dimensions, composition, and petrophysical properties of carbonate drifts.

In the **geochemistry** theme, the focus is on improving the **clumped isotope method** in particular the application of Δ_{48} proxy to various aspects of carbonate precipitation. The clumped isotope method used Δ_{47} together with an empirical calibration to determine the temperature of precipitation of limestone and dolostone. The Δ_{48} proxy can now test this calibration and establish the temperature of systems which are in disequilibrium with respect to the Δ_{47} value.

After completing projects on sedimentologic process, the TOC distribution, the shelf margin trajectories, the temperature of beef formation and outcrop subsurface correlation in the **unconventional reservoirs in the Neuquén Basin** we add an evaluation assessing the burial history of the Vaca Muerta Formation utilizing clumped isotopes and elemental signature for productivity and preservation of organic matter in the basin. In addition, we extend the research to the **Agrio Formation** that contains the marine strata above the Mulichinco

Formation. What makes this formation attractive is not just the fact that also has high TOC but that the evolution is similar to the evolution in the Vaca Muerta Formation with the basin undergoing a flooding event after which conditions were established that promote the preservation of organic matter. We plan to acquire a dataset with the same detail and methodology as we did in the Vaca Muerta Formation to characterize the facies, TOC distribution, geochemical signature, and petrophysical properties of this formation.

Below we provide a detailed description of each project planned for 2022.

2022 Reporting

We will report on our research findings during the year. In a virtual meeting in June we will give a **Mid-Year Progress Report** to inform the Industrial Associates of the status of the projects and the results in hand.

The detailed results of the individual projects will be presented at the **Annual Review Meeting in Miami** in mid-October. Hopefully we will be able to meet in person. The dates for these two meetings are tentatively set at:

June 8, 2022 – Mid-Year Progress Report

Executive style presentation of the projects and results in hand followed by a discussion. The meeting will be online starting at 9 o'clock in the morning (USA-EST) and 3 pm (UTC+01:00) in continental Europe. The meeting is expected to last about 2 – 3 hours. We will send out a program and other details by early May.

October 24 - 25, 2022 - Annual Review Meeting

The results of the projects detailed in this prospectus will be presented at the **Annual Review Meeting in Miami, October 24 - 25, 2022**. We will send out information on the logistics for the meeting in the second quarter of 2022.

2022 Field Seminars

The pandemic prevented the field trip in 2020 and 2021 that is usually held in conjunction with the Annual Review Meeting. Because there is still uncertainty regarding future travel, details of the meeting field trip, together with other field trips normally offered during the year, are not included here. We will announce these field trips as soon as the situation allows.

Seismic Facies and Stratigraphy of the Cenozoic Succession in the Yucatán Platform

Elizabeth Guzmán, Gregor P. Eberli, and Sara Bashah

Objectives

1) Delineate the evolution of the Yucatán Platform that was divided into two blocks by a north-south oriented trough at the time of the asteroid impact at the end of the Cretaceous to the modern smooth platform.
2) Estimate the age of the Cenozoic sequences filling the trough and the Chicxulub crater in the Yucatán Platform.
3) Assess the progradational geometry and direction of the Cenozoic sequences to determine the influence of sea level and currents on the progradation.

Introduction

The combination of seismic, gravity, and borehole data resulted in the construction a digital terrain model (DTM) of the Yucatán carbonate platform at the end of the Cretaceous. This DTM reveals that, by the time of the Chicxulub impact event, the carbonate platform was divided into two blocks by an ~ 95–205 km wide and ~ 470 km long trough-shaped depression (Yucatán Trough), which contained the central structure of the Chicxulub impact crater (Fig. 1) (Guzmán-Hidalgo et al., 2021). The modern Yucatán peninsula and shelf are a continuous body with a flat and gently dipping surface that ends abruptly at the escarpment, which is similar to the morphology of the distally steepened carbonate ramp of West Florida.

The smothering of the uneven topography is achieved by prograding sequences that fill the trough and expand the platform to the north and east (Fig. 2). The Paleocene to Miocene sequences display prograding pulses that seem to be sea-level controlled and its progradation direction by the prevailing trade winds. In contrast, the geometry of the younger sequences bears characteristics

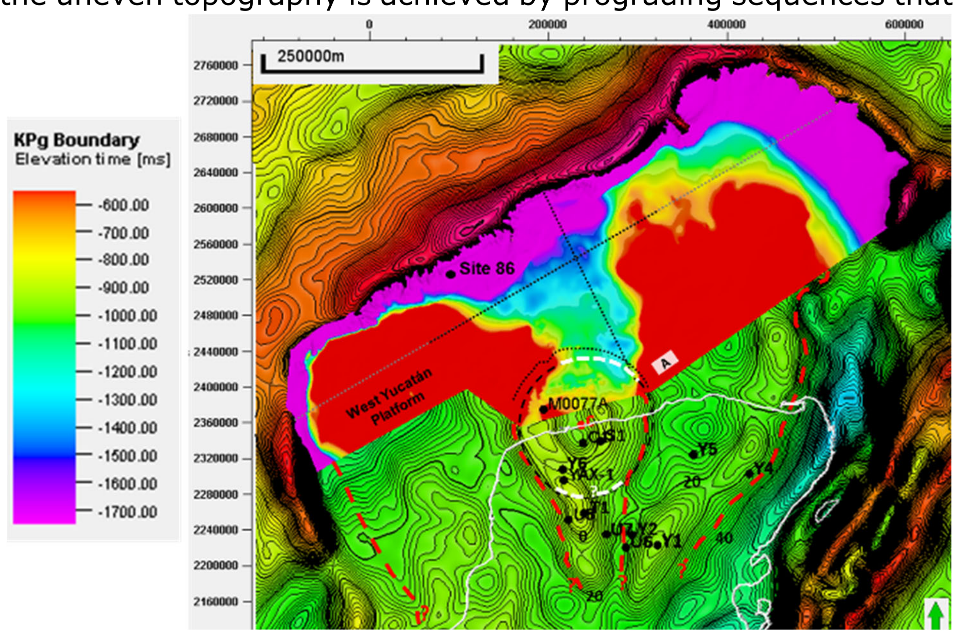

Figure 1: K/Pg boundary map constructed from seismic data and gravity anomalies in the Yucatán Platform. nYT =northern Yucatan Trough. sYT= southern Yucatan Trough.

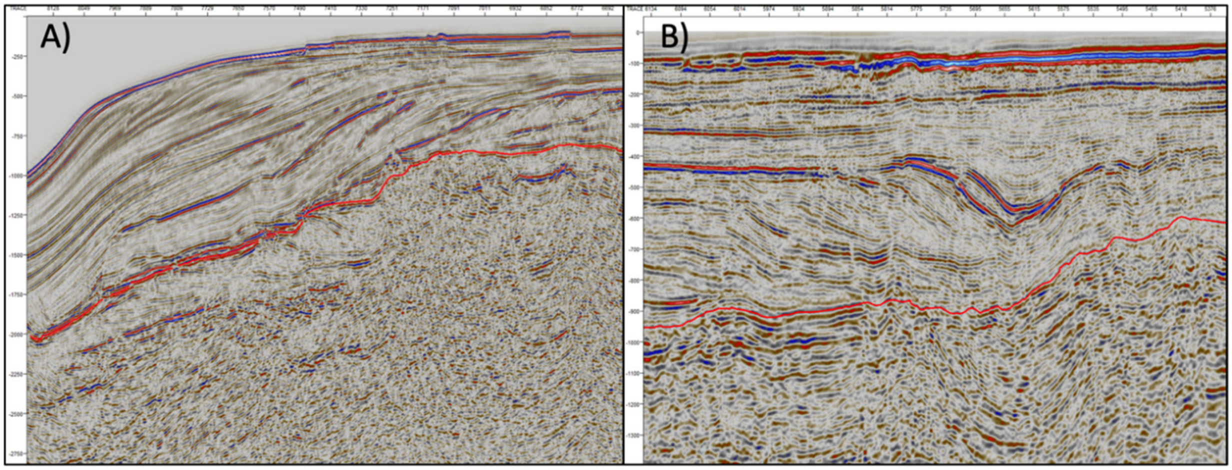

Figure 2: Examples of progradational geometries above the K/Pg boundary (red). (A) Progradation of the platform towards the north. (B) Infilling progradation in the Yucatán Trough overlain by horizontal successions.

indicative of current control. This project aims to unravel the influence and timing of sea level versus current control in the progradation that leads to the formation of the large modern Yucatán Platform.

DATA SET AND WORKFLOW

This study relies on 57 regional 2D seismic lines in the offshore Yucatán Platform and 18 boreholes with information about the lithology and ages (Whalen et al., 2013; Morgan et al., 2016).

We will identify the main surface boundaries and map them within the Yucatán Trough and correlate the boundaries to the boreholes to determine the Cenozoic ages. We will map and describe the main Cenozoic sequences observed in the offshore seismic profiles in time-domain. We will estimate the depth of these reflections using reported interval velocities in the Yucatán Platform and Bahama Bank, and project them towards the onshore boreholes. The geologic map at the surface will also be included to delimit the lateral distribution of the shallower deposits.

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EVOLUTION OF SOUTH JOULTER CAY, GREAT BAHAMA BANK – A TALE OF STORM DEPOSITION?

Paul (Mitch) Harris, [1]Juan Carlos Laya, and [2]Miles Frazer
[1)] Texas A&M University [2)] Chevron Technical Center

PROJECT OBJECTIVES

- To further calibrate the timing of key depositional events within the history of South Joulter Cay by radiometric dating of select island ridges.
- Thereby testing whether the initial ridges of the island, as well as the ridges associated with shifts between growth stages, are the results of storm deposition and resulting changes to the local hydrodynamic setting.

PROJECT RATIONALE

Our ongoing examination of South Joulter Cay (SJC), a key part of the modern Joulters ooid sand body on Great Bahama Bank (GBB) north of Andros Island, targets a better delineation of the timing and processes that formed the island. High resolution imagery and a digital elevation model (DEM) constructed from a drone survey helped to formulate a scenario for island development which emphasized growth stages reflecting variations in dispersal of ooid sands by tidal channels, wind and wave energy, and longshore and storm-related currents (Fig. 1). We are testing the hypothesis that the initial ridges of the island, as well as the ridges associated with shifts between growth stages, are the results of storm deposition and resulting changes to the local hydrodynamic setting.

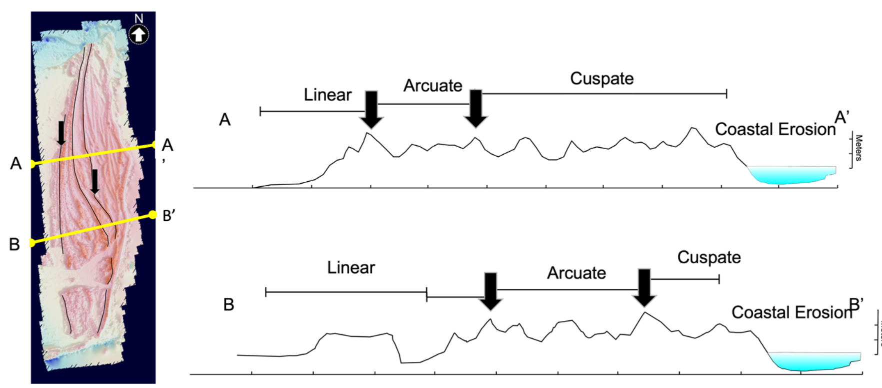

Figure 1: DEM from high-resolution drone imagery (Harris et al., 2021) annotated to show interpreted morphological stages of island growth. Stage 1 Linear Ridges represent initial island formation; Stage 2 Arcuate Ridges formed as part of an ebb tidal delta lobe related to a channel cutting the island; and Stage 3 Cuspate Ridges were deposited as multiple prograding beach ridge sets driven by longshore currents. Note the boundaries between the growth stages shown by black arrows are consistently formed by higher ridges suggesting extraordinary depositional conditions.

APPROACH

From observing the impacts of recent hurricanes, we believe that major storms proximal to Joulters and delivering east to west energy and sediment transport are most likely to have played a role in island development, but that a single storm by

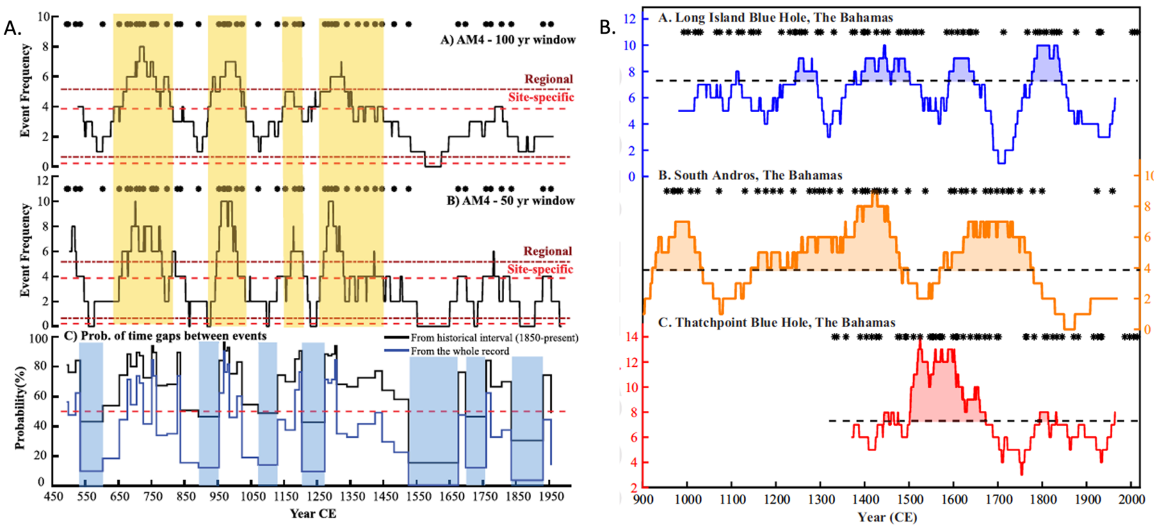

Figure 2: (A) from Wallace et al., 2019, shows results from sediment coring in a blue hole on South Andros to assess timing of storm deposits and therefore storm frequency. Yellow highlighted portions of plot indicate four periods of intense hurricane activity. (B) from Wallace et al., 2021, zooms in on the South Andros data as well as results from two other Bahamas sites to better delineate multi-decadal periods of intense storm activity.

itself may be insufficient to cause change. Instead, it is more likely that multi-decadal periods of intense storm activity as determined for the last 1100-1500 years by recent sediment coring and dating from several blue hole sites on GBB (Fig. 2) provides the type of collective storm activity that can relate to the initiation and growth change variability observed at SJC.

Significance

This study has relevance to facies interpretation and correlation within subsurface grainstone reservoirs as well as the interpretation of their sequence stratigraphic and diagenetic development. The development of islands like SJC introduces an element of spatially constrained facies variation and meteoric diagenesis. Thus, at the EOD scale, islands like SJC add significantly to complexity and potential localized heterogeneity within a broader development of reservoir quality grainstone. Assessing the impact of storms in forming the island and changing ridge morphology will continue to help refine our understanding of the broad suite of controls over shallow carbonate platform facies patterns.

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THE ORIGIN OF PELOIDAL NUCLEI IN BAHAMIAN OOIDS

Mara R. Diaz and Gregor P. Eberli

PROJECT OBJECTIVES

- Determine the provenance of the nucleus in the ooid shoals in the Bahamas.
- Test the hypothesis that the peloidal nuclei are produced on the shoal itself.

PROJECT RATIONALE

Ooid shoals require high energy environments to form that are accomplished in tidal regimes or along beaches. The largest ooid shoals form at the end of embayments in the platform where the tidal wave is focused (Fig. 1). Despite the fact that these areas are mud-deprived, the predominant nucleus of the ooids in these sand bodies has been reported to consist of peloids (Harris et al., 2019). Micritic grains that are called peloids can form by micritization of skeletal grains and older ooids but it is generally assumed that most of the modern peloids on Great Bahama Bank are pelleted mud. Filter-feeding organisms like shrimps and worms are producing pellets. The question is how the peloids are transported into the active portions of the ooid shoals where ooids preferentially form? Storms do not bring peloids to the shoal areas but it is well-documented that storm surges laden with mud deposit a mud layer on the shoals (Fig. 2; Major et al., 1996). It is our hypothesis that the pellets are subsequently produced from this mud directly on the shoal.

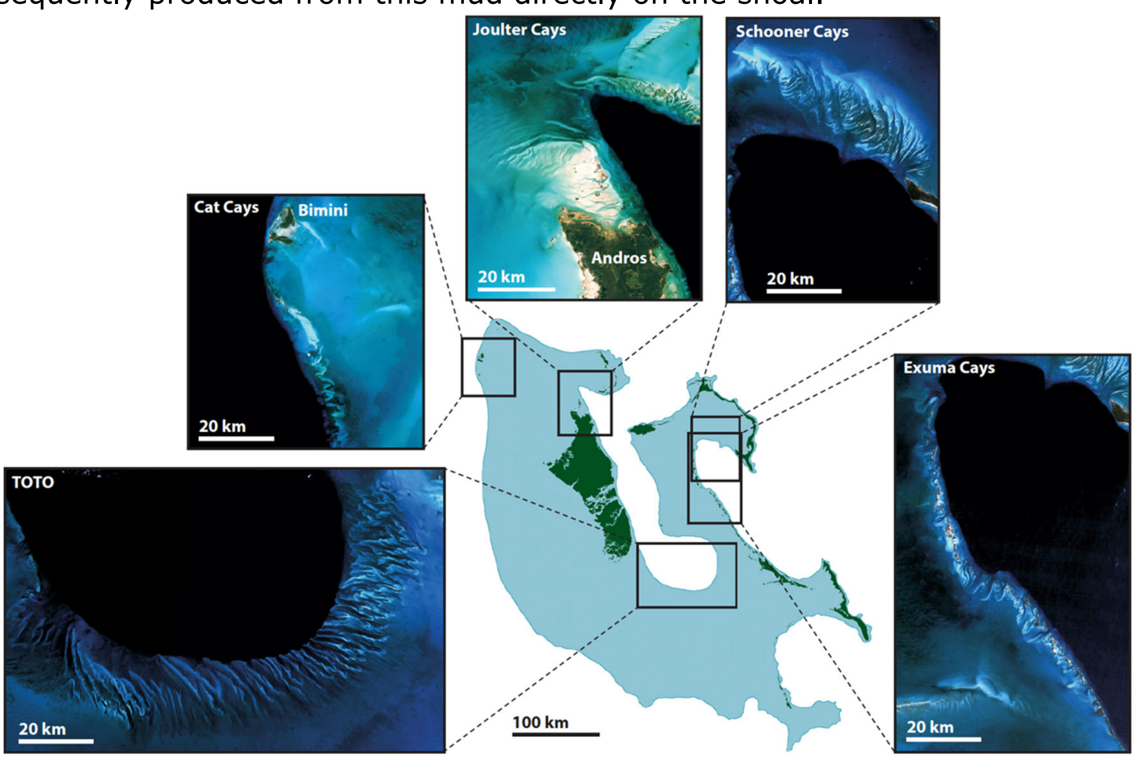

Figure 1: Map of Great Bahama Bank and landsat images of the largest ooid shoals at the end of embayments on the bank top: the Cat, Joulter, Schooner, and Exuma Cays and the Tongue of the Ocean (TOTO). Figure adapted from Purkis and Harris (2017) as published in Harris et al. (2018).

Figure 2: Discontinuous mud layer deposited on a well-sorted ooid shoal on Joulter Cays after Hurricane Andrew (Major et al., 1996). The photograph was taken several days after the hurricane had passed. The mud is then utilized by shrimps to stabilize their burrows. See below.

APPROACH

To test the hypothesis a quantitative analysis of the abundance of peloidal nuclei on the ooid shoal is needed. Microscopic inspection of modern ooids will be conducted to identify the various nuclei. Point-counting will give the quantification of the different nuclei. SEM images will be used to document the process of hardening of the ooids to reach the induration needed for movement in the tides and the accumulation of the cortices.

IMPLICATION AND SIGNIFICANCE

Validation of our hypothesis will imply that the large accumulations of modern ooid sands are facilitated by storm activity. This might also help to explain why large ooid shoals are missing in tropical areas where hurricanes do not exist.

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Over the Edge: Linking On-Platform Processes to Deposition Off the Margin of the Great Bahama Bank

Cecilia Lopez-Gamundi, Paul (Mitch) Harris, Gregor P. Eberli, and Sam Purkis

Project Objectives

- To assess the Great Bahama Bank (GBB) sediment budget.
- Reconcile platform-top sediment production and transport with off-platform deposition.

Project Rationale

Since reflooding of the platform top ~6 ky ago during the Holocene transgression, Great Bahama Bank (GBB) has yet to fill its accommodation space (Purkis and Harris, 2016). This situation flouts conventional sequence stratigraphic principles. Given our estimates of GBB's ability to over produce sediment, how can accommodation be regionally unfilled during the Holocene highstand? Our hypothesis is simple – sediment transport.

To test this hypothesis, we must compare sediment production and transport against the volumes of sediment actually deposited off the platform's flanks (Fig. 1). Here, sediments residing on the slope, show substantial along-strike variability in their sedimentary facies (Anselmetti et al., 2000; Mulder et al., 2012). However, it remains unclear whether this heterogeneity is due to the variation in sediment producers which inhabit the margin, or can

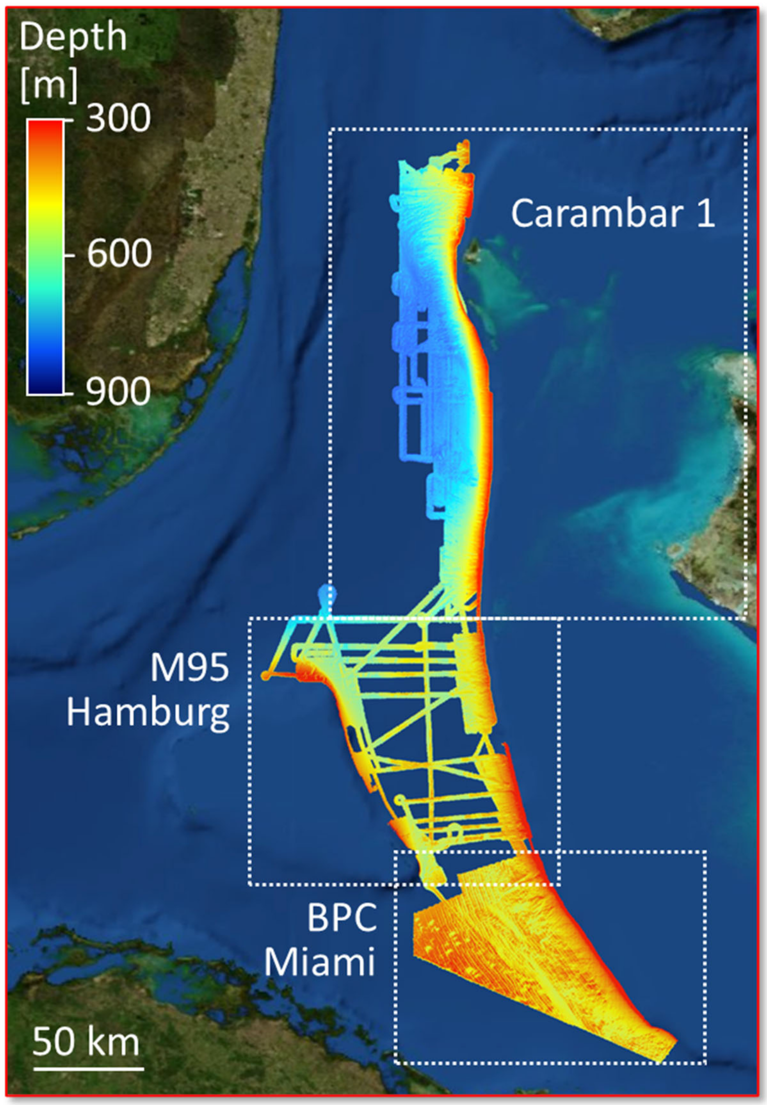

Figure 1: Bathymetry and CHIRP seismic surveys on the western margin of the Great Bahama Bank. Datasets will be used to assess off-platform sediment volumes and facies.

be attributed to the mosaic of producers atop the platform, which link to the slope via lengthy transport pathways.

Atop the platform, our hydrodynamic model indicates sediment can be transported up to 300 km/yr under fair-weather conditions. Further simulation of Category 4 Hurricane Matthew (Oct. 5^{th}, 2016) suggests that sediment transport can be amplified by a factor of four during the two days that the storm raged, as compared to a full year of fair-weather conditions. The extended cross-platform transport of sediment implied by the modelling is capable of delivering substantial quantities over the platform margin, onto the slope of GBB, and beyond. Such loss of material from the platform-top is an essential ingredient of any comprehensive sediment budget and is the motivation for this study. Building off the decades of research conducted by our CSL collaborators, past and present, we intend to marry our platform-top hydrodynamic modelling with off-platform geophysical data. The intended outcome is an elevated understanding of the drivers of facies heterogeneity on the flanks of the GBB.

APPROACH

Satellite-retrieved water turbidity measurements will be compared to model outputs during fair- and storm-weather conditions to quantify their ability to loft and transport sediment. Next, the quantity of sediment lost from the platform in our model will be compared to seismic-derived volumes that have accumulated on the western margin of GBB.

SIGNIFICANCE

Accurate knowledge of sediment production and water movement atop GBB is paramount to understanding the volumetric significance of sediment dispersal. All these processes influence platform-top sedimentation, slope architecture, and facies anatomy.

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THE NEOM BRINE POOL – THE FIRST DISCOVERY IN THE GULF OF AQABA

Sam Purkis, Hannah Shernisky, Gaëlle Duchâtellier, Amanda Oehlert,
Peter K. Swart, and James Klaus

PROJECT OBJECTIVES

- To characterize the physical and chemical characteristics of this new type of pool.
- Based on coring and radiometric dating, our second aim is to quantify its stratigraphic setting.
- Our final aim is to describe the eukaryote and prokaryote life which thrives in the harsh brine environment.

PROJECT RATIONALE

Deep sea brine pools are formed by the dissolution of buried evaporites and the stable accumulation of these hypersaline solutions in seabed depressions. Earth has three classic venues for such accumulations – the Gulf of Mexico, the Mediterranean, and the Red Sea. Of these, the Red Sea boasts the most numerous pools and, prior to this study, they fell into one of two categories.

In the first category, there are at least 25 complexes of brine pools developed along the axial trough of the Red Sea (Fig. 1). These 'axial' pools are all anoxic, and, being associated with the hydrothermal system of the basin's spreading axis, are 'hot', meaning that they are substantially warmer than ambient seawater. To date, there are only two examples in the second category, which encompasses pools located away from the axial trough on the coastal shelf. Both examples situate offshore Saudi Arabia – the Thuwal Seeps at 860 m water depth and the Afifi Brine Pool at 350 m. Like the axial pools, this pair are both anoxic, but their hypersaline waters are not substantially warmer than ambient. Colloquially, these are termed 'cold' pools.

Here, we report our discovery of the NEOM Brine Pool (Fig. 2), named eponymously after the NEOM-facilitated 2020 research cruise with OceanX. Different to all previous discoveries, the NEOM pool situates in the Gulf of Aqaba. The first discovery outside the Red Sea proper. As for the axial pools, the NEOM pool is situated at abyssal depth (1770 m), yet like the much shallower Afifi pool and Thuwal seeps, the discovery is cold (its waters are only 1 °C warmer than ambient; Fig. 3). The final feature that sets the NEOM pool apart is its 2 km proximity to the coast. Of all the other Red Sea pools, the most shore-proximal is the Thuwal Seeps which situates 25 km offshore. Based on these differences, we propose our discovery constitutes a meaningful variation on the category of cool coastal-shelf pools, but arguably represents an altogether new category of Red Sea brine pool.

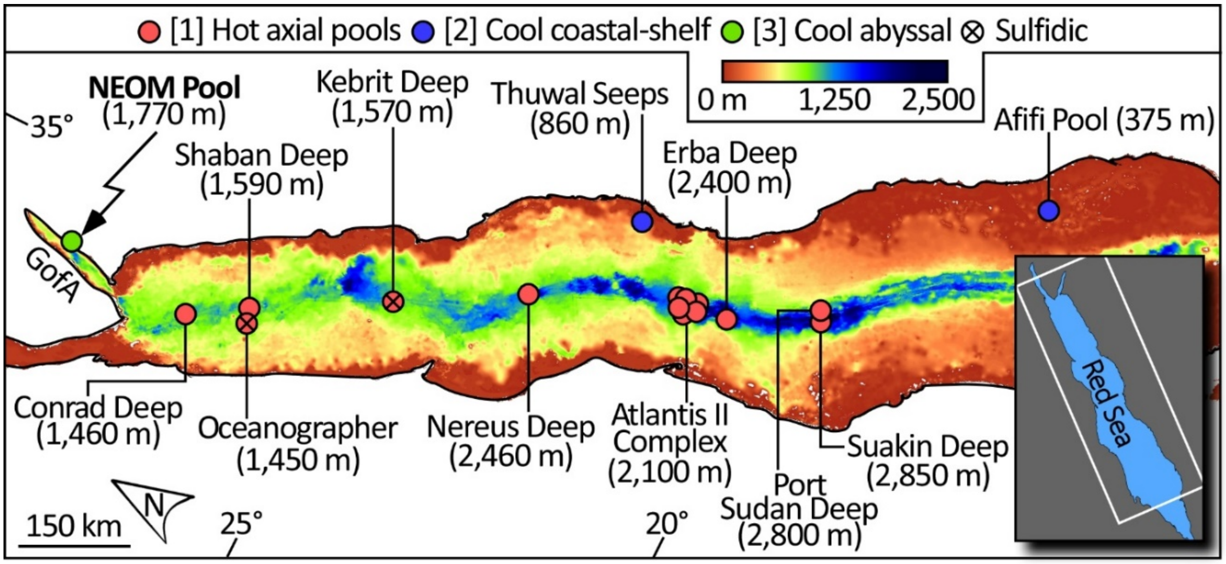

Figure 1: Brine Pools of the Red Sea. Based on the depths at which the brine pools locate and their temperature, the basin's population of pools logically split into three categories. [1] Hot pools in the deep axial trough associated with hydrothermal flow at the rift spreading axis (red dots). [2] Cold pools, meanwhile, situate on the shallow coastal shelf (blue dots). [3] The NEOM Brine Pool, the first discovery in the Gulf of Aqaba (GofA), is cold, and neither located on the spreading axis nor the continental shelf (green dot). Two hot axial pools, Oceanographer and Kebrit, are sulfidic, meaning their brines contain stable measurable concentrations of dissolved sulfide.

APPROACH

A comprehensive geophysical dataset acquired in the Gulf of Aqaba will be interrogated to examine the syn-rift carbonates of the northern Red Sea and the brines that accumulate in the basin's abyssal deeps. Geochemistry, genomics, and sequence stratigraphy will be used to divine the source of the brine, the microbial life which thrives in the harsh brine environment, and the unique sedimentary record which deposits beneath the brine (Fig. 4). Emphasis will be placed on disentangling the controls on plan-view morphology of rift carbonates and internal stratal patterns of the deposits, with a view to developing a modern analog to Tertiary rift basins in the South China Sea and Mesozoic basins of the South Atlantic.

SIGNIFICANCE

Syn-rift carbonate platform strata can form important petroleum reservoirs within syn-rift basins. They also provide critical records for understanding the tectonic evolution and depositional history of rift systems. This unique dataset from the Red Sea has the potential to provide enhanced understanding in such settings.

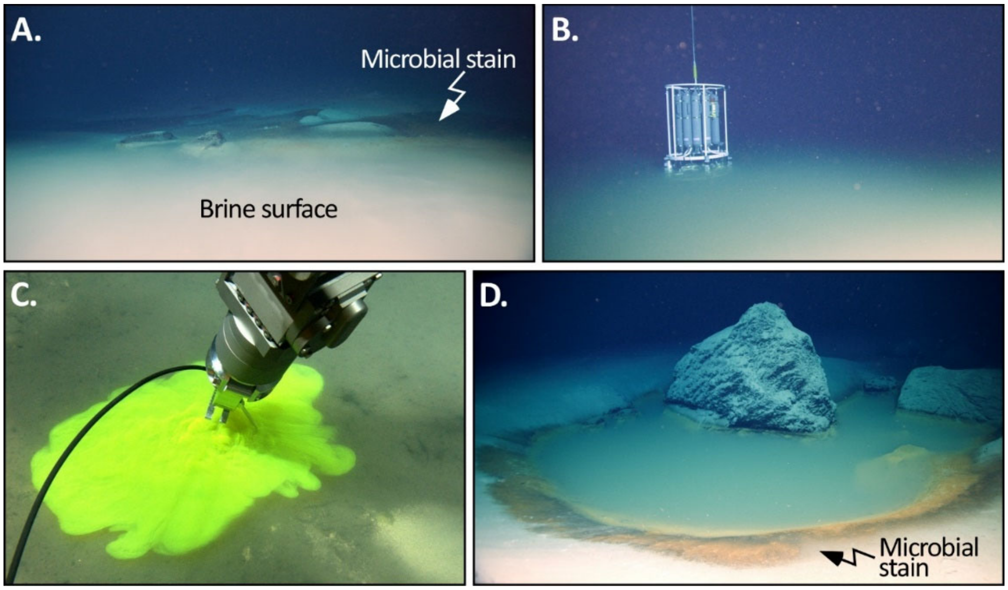

Figure 2: Photographs of the NEOM Brine Pool. (A) Brine surface in the foreground onlaps the 'beach' which is characterized by a rich microbial community (orange-to-gray in color). In (B) the Sea-Bird CTD system is lowered through the brine-seawater interface, a transition which can be emphasized via injection of biodegradable dye (C). (D) Shows a small brine pool situated 50 m to the west of the main pool. Boulders shed from the nearby reef slope have excavated a seabed depression on the abyssal plain that has subsequently filled with brine. As for the main pool, the microbial community stains the beach around this diminutive pool.

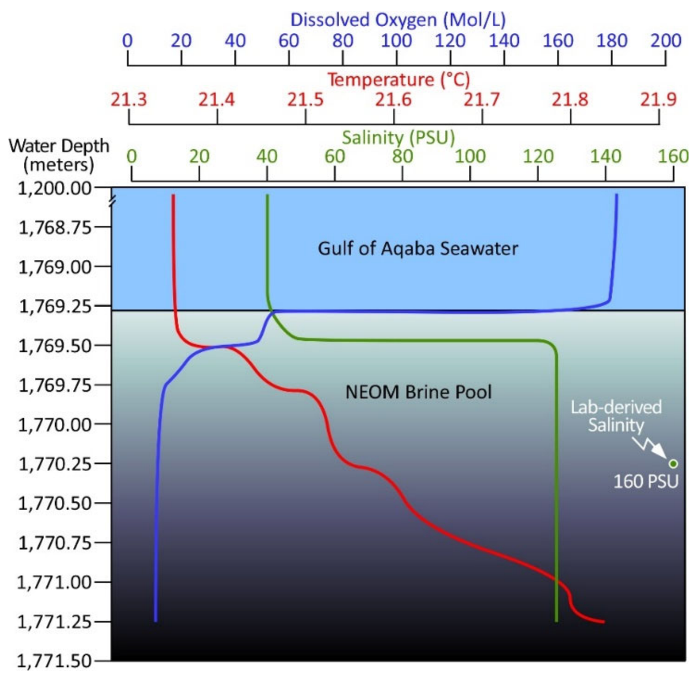

Figure 3: Dissolved oxygen, temperature, and salinity profiles into the NEOM brine pool. The brine-seawater interface situates at 1769.26 m water depth, demarked by the abrupt decrease in dissolved oxygen concentration and increase in salinity. Note that the CTD conductivity probe saturated at 120 PSU and the true brine salinity was determined in the lab to be 160 PSU. The temperature differential between the brine and overlying seawater is modest at 1 °C.

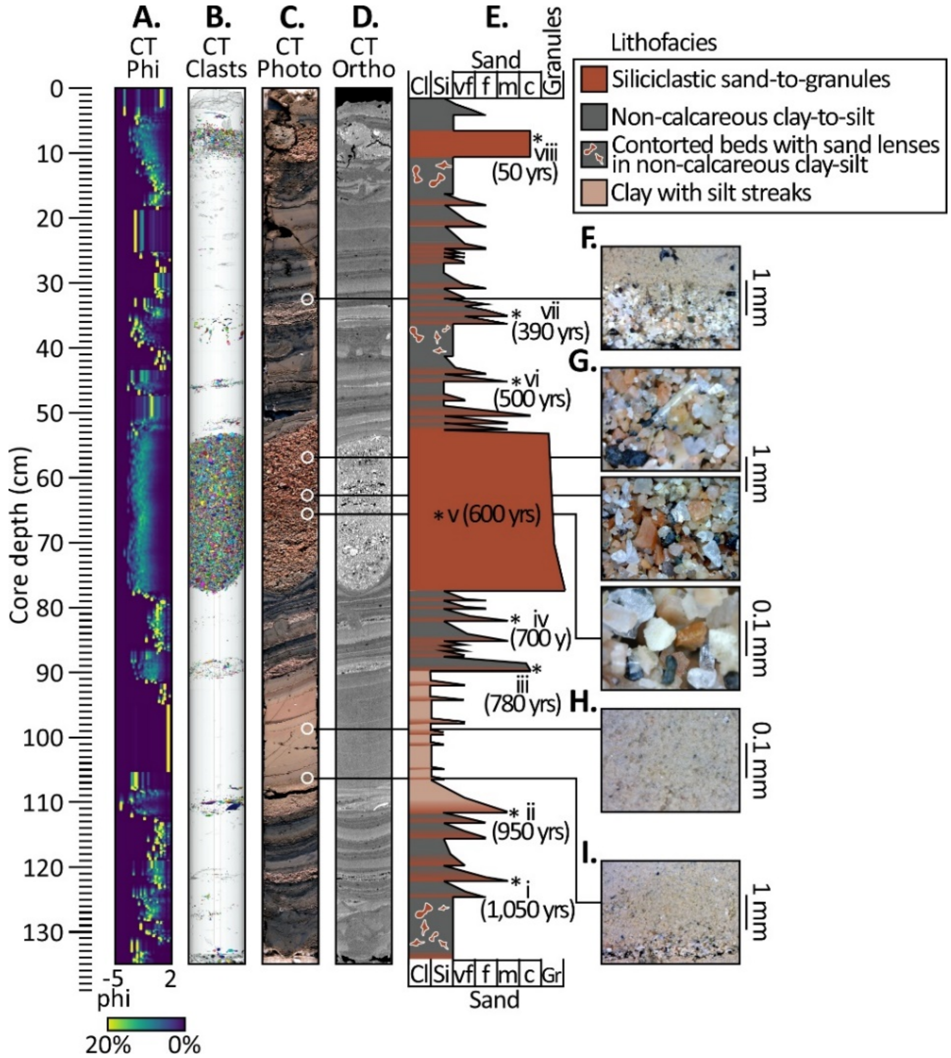

Figure 4: Stratigraphy of the long core pushed into the bed of the brine pool. (A) Clast size analysis derived from computed tomography (CT) scanning of the core computed at 1 cm intervals via a moving window. In this histogram plot, the left border is -5 phi (i.e., coarse clasts) and the right border is 2 phi (fine clasts). The color scale varies from 0% occurrence of a given phi in each 1 cm interval in blue, up to 20% by volume in yellow. Using random colors, (B) identifies the occurrences of individual clasts which could be separated in the CT scan. This 3-D visualization excellently emphasizes the eight prominent siliciclastic intervals. (C) Is a high-resolution digital photo-scan of the archive half of the split core and (D) is the equivalent grayscale orthoslice reconstructed from CT. (E) Is the core description capturing grainsize and lithofacies. Asterisks demark the eight prominent siliciclastic intervals recorded in the cores and their ages as derived from the Bayesian age model. Of these, the most prominent is 'v' which dates to ~600 yrs. BP. (F) through (I) are photomicrographs which detail the fining-upwards arrangement of the turbidite deposits (F), the coarse siliciclastic interval (G), and the clay deposit with silt streaks during times of uninterrupted deposition (H) and also interspersed with fining-upwards turbidite deposits (I).

ABYSSAL MICROBIALITES IN THE GULF OF AQABA

Hannah Shernisky, James Klaus, and Sam Purkis

PROJECT OBJECTIVES

- The NEOM brine pool is at 1770 m water depth and the main pool is 260 m long and 70 m wide.
- The NEOM pool has the lowest sulfate/chloride ratio yet documented in the Red Sea-Gulf of Aqaba system, emphasizing the activity of sulfate-reducing bacteria that contribute to the pool's rich microbial fauna.
- At the periphery of the pool, the interface between normal marine waters and the anoxic brine delivers a niche in which a rich microbial community develops, stratified by the preferred metabolisms of its occupants.
- Abyssal chemosynthetic stromatolites are conspicuous facies in the stratigraphy of the brine pool and its surroundings.

PROJECT RATIONALE

Microbial buildups are generally considered a shallow-water phenomenon. Here, we present the discovery of diverse microbial communities associated with a 10000 sq. m brine pool in the Aragonese Deep of the Gulf of Aqaba at 1770 m depth (Fig. 1). A diverse prokaryotic fauna stratifies into a series of niches characterized by high salinity, low oxygen, lowered pH, and modestly warmer temperature, as compared

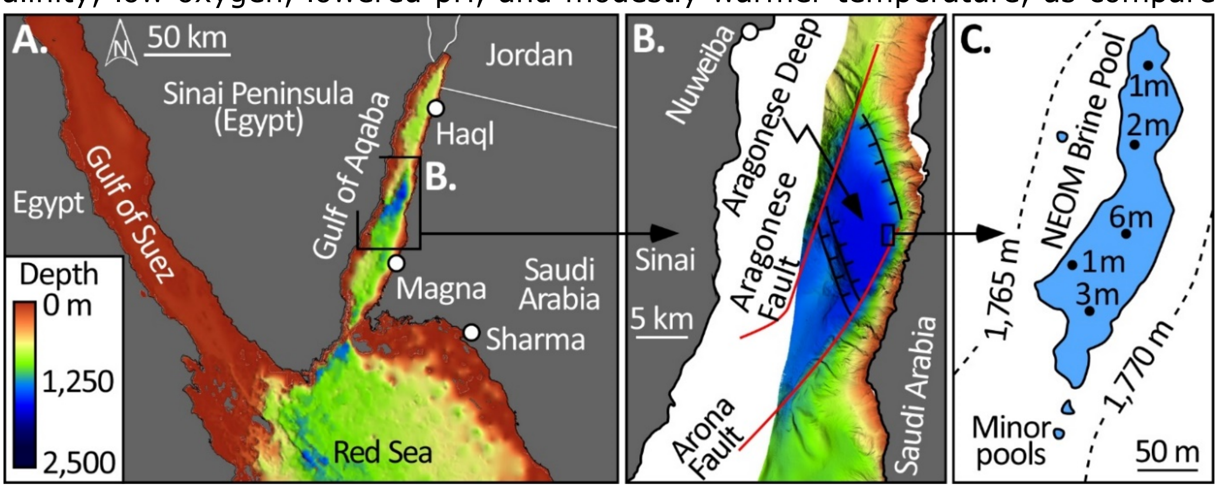

Figure 1: Bathymetric and tectonic setting of the NEOM Brine Pool in the Gulf of Aqaba. (A) The General Bathymetric Chart of the Oceans (GEBCO) provides regional context to the multibeam data acquired during the OceanX-NEOM research cruise (B). The brine pool locates at the toe-of-slope of the Saudi coastal margin in the Aragonese Deep, a pull-apart basin and the deepest point in the Gulf of Aqaba. This basin is bounded by the strike-slip Arona and Aragonese faults (red lines) which connect via normal faults (black lines). The NEOM Brine Pool situates at the junction between the coast-parallel Arona Fault and the NNW-trending normal fault that extends to demark the northern margin of the basin. (C) The brine-seawater interface is at 1770 m depth and the main pool is 260 m long, 70 m wide, and covers an area of 10000 m^2. Spot soundings (black dots) indicate a maximum thickness of the brine to be 6 m in the center of the pool. Three minor pools, each <10 m^2 in area were discovered within 50 m of the main pool, one to its west and two to its south.

to ambient. The microbes develop thick mats which trap and bind sediment, delivering expansive chemosynthetic deep-water stromatolites, which, in some cases, are sufficiently lithified to justify application of the term 'microbialites'. The overall goal of this study is to characterize the microbial communities in terms of their genetics and sedimentology to better understand the formation of abyssal stromatolites in rift basins and beyond.

APPROACH

Sampled via a transect of five push cores (Fig. 2), a defining characteristic of all the pools in the NEOM complex are the four concentric zones which develop around their rims. The outermost zone in this series is the abyssal mud which constitutes the seabed of the Aragonese Deep. As the brine pool is approached, the second zone encountered is characterized by its rich microbial community which stains the seabed dark gray. This second zone (akin to a beach in a coastal setting) is temporarily inundated by brine when even minor waves are induced into the surface of the pool. The gray zone is typically 1-2 m wide, depending on local topography at the edge of the pool. Third in line, inboard of the gray zone, lies the orange 'swash' zone which situates immediately at the brine-seawater interface. The orange color is also induced

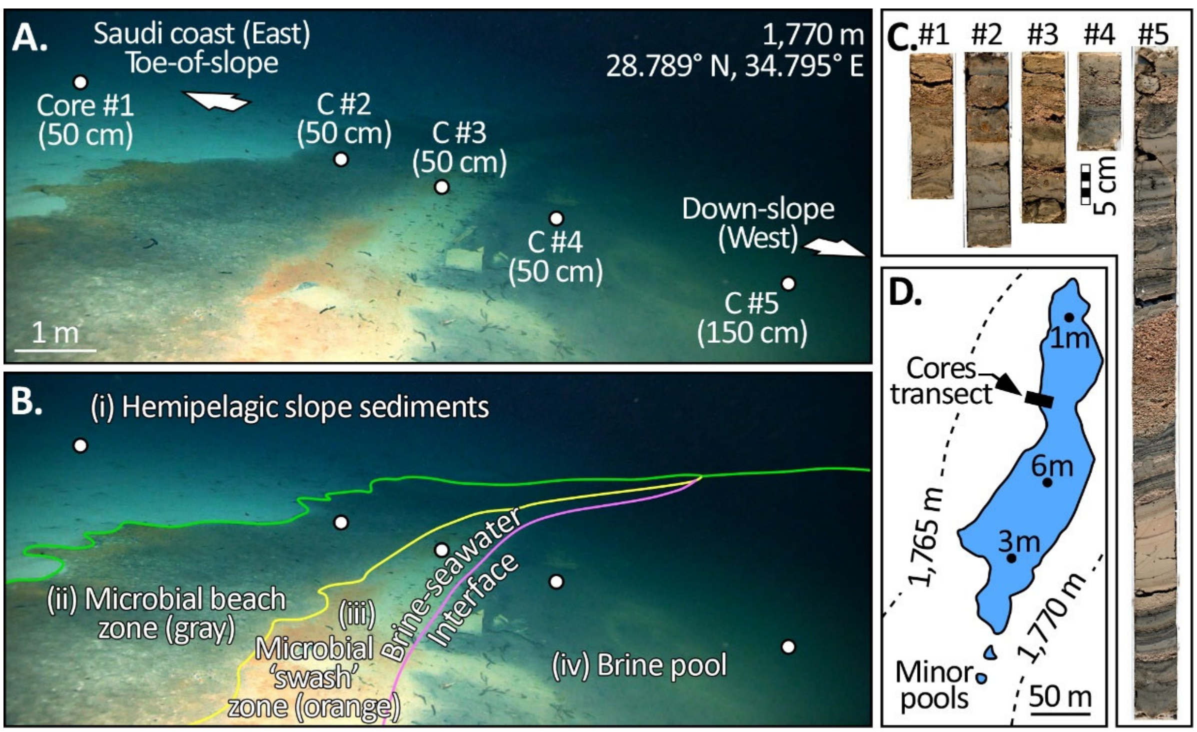

Figure 2: Location and photo-scans of the four short cores and one long core retrieved from the bed of the NEOM Brine Pool. (A) Shows the western margin of the NEOM brine pool. Cores #1 through #4 were pushed to 50 cm depth sub-seabed, whereas Core #5 was acquired with a longer barrel and pushed to 150 cm (the depth of refusal). The transect of cores was set to sample the four zones which develop as the brine onlaps the surrounding seabed (B). (C) Shows the five cores. Note the increase in fine-grained dark intervals, indicative of reduced conditions, for the cores acquired beneath the brine. (D) Maps the geometry of the NEOM Brine Pool and the location of this transect of cores on its western margin.

by a dense microbial community. The bivalve *A. muriatica* densely inhabits both the gray and orange zones. The fourth zone in the sequence is located within the brine pool proper, which we define as permanently submerged beneath brine.

The five cores were extensively sampled for their microbial communities using 16S rRNA sequencing. The fidelity of the sequencing was sufficient to identify seven classes of prokaryotes whose per-core relative abundances were tallied to reveal gradients in the prokaryotic community in and around the brine pool (Fig. 3).

The outermost core in the transect (Core #1) penetrated the hemipelagic mud constituting the broader seabed of the Aragonese Deep. Preliminary genomic analysis from the core tops reveals that more than 75% of the microbes in this zone adopt an aerobic metabolism, with the majority identified as Gammaprotobacteria, with minor contributions from Alphaprotobacteria, and clade SO85 (Fig. 3). The second core, which sampled seabed darkened in color by a rich microbial fabric (the gray zone),

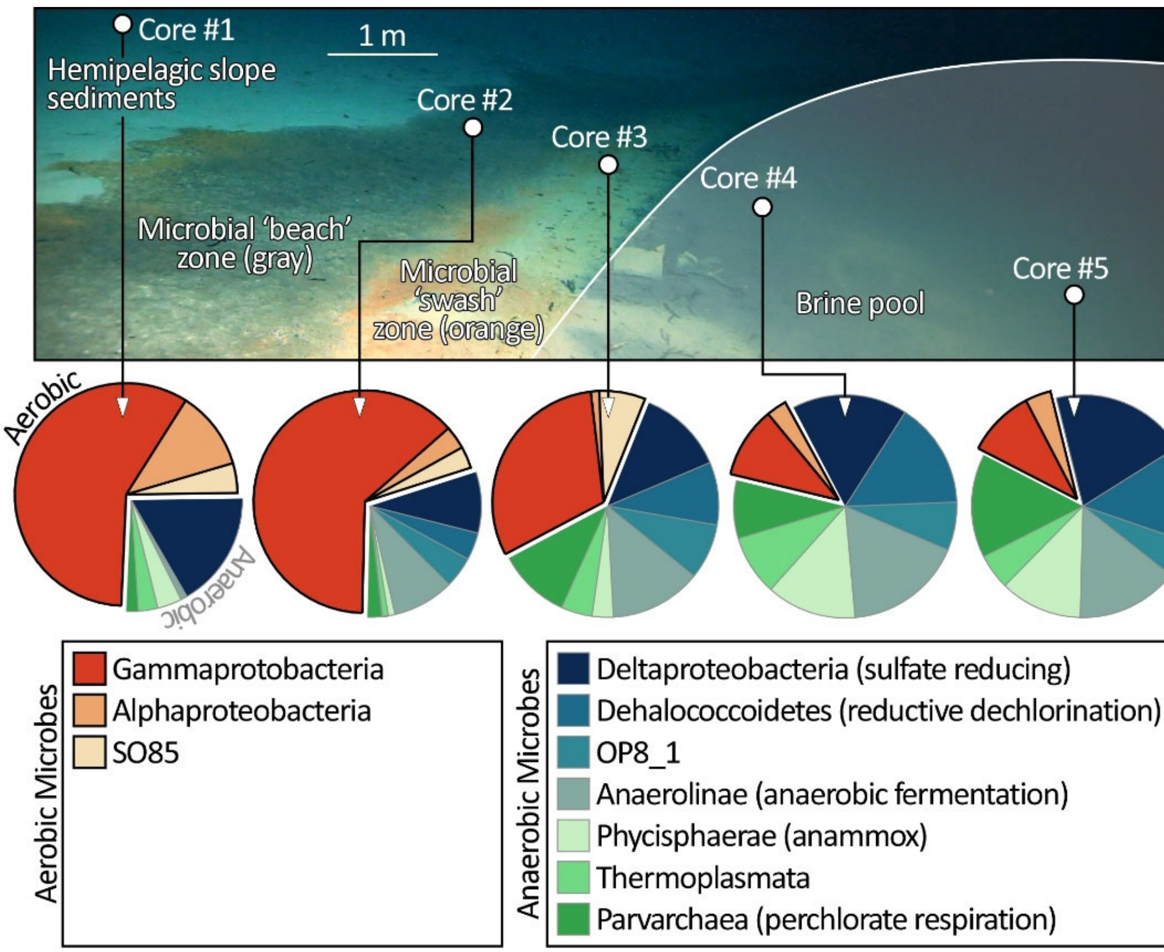

Figure 3: Lateral distribution of prokaryote communities in and around the NEOM Brine Pool. 16S rRNA sequencing of the top 20 mm of the five cores reveal that the microbes inhabiting the background sediment (Core #1) and gray microbial beach zone (Core #2) are 75% aerobic and 25% anaerobic. Moving closer to the shoreline of the pool, this distribution between aerobic and anaerobic metabolisms is reversed in the orange microbial swash zone. For the samples obtained from within the brine pool (Cores #4 and #5), only 10% of the sequenced microbes are aerobic with the remaining anaerobes splitting near equally into seven classes of chemolithoautotrophs.

boasted a similar community of prokaryotes. By contrast, ~75% of the microbes identified in Core #3, which penetrated the orange swash zone situated immediately outboard of the brine-seawater interface, were anaerobic, adopting a broad spectrum of metabolisms spanning sulfate reduction, reductive dichlorination, fermentation, and perchlorate respiration (Fig. 3). The dominance of anaerobic prokaryotes surpassed 85% of the total community sequenced in the final pair of cores (#4 and #5) which penetrated the bed of the brine pool. The abundance of sulfate reducers occupying the bed sediments of the brine pool squares with the depleted SO_4^{2-}/Cl^- ratio measured within the overlying brine.

SIGNIFICANCE

Syn-rift microbialites associated with abyssal brine pools broadly accumulate in the Gulf of Aqaba. The hypersaline anoxic environment favors extremophile prokaryotes. Among these, the metabolism of sulfate-reducing bacteria delivers brine with the lowest sulfate/chloride ratio yet documented in the Red Sea-Gulf of Aqaba system. Subsea hypersaline anoxic brine pools are among the most extreme habitable environments on Earth that offer clues to first life and life on other planets.

MICROBIALITES WITHIN A LOWSTAND CORAL REEF, OFFSHORE MOZAMBIQUE

Iva Tomchovska, Gregor P. Eberli, James Klaus, Peter K. Swart,
and Amanda Oehlert

OBJECTIVES

- To investigate the unique coral and microbial assemblages of a core section dated between 13400 to 13600 kyrs that formed in the last glacial period.
- Quantify the respective amounts of corals, microbialites and allochems in the reef framework.
- Reconstruct seawater chemistry and (anoxic or oxic?) conditions for microbial crust formation.
- Investigate the role of microbial binding in the early marine diagenesis and test the strength of these microbial bindings.

INTRODUCTION

The analysis of the slopes above the newly discovered giant gas fields offshore Mozambique (Fonnesu et al., 2020) revealed a long, approximately 40 m thick fringing reef that crested at -95 m water depth. A 2 m section of a core that was drilled through the reef displays a diverse coral community with several species from the genus *Montipora* and a few *Porites*, *Galaxea*, *Pocillopora*, and *Platygyra* but also thick crusts of greyish microbialites (Fig.1) and microbial pellets inside the coral frame (Fig. 2). Two samples collected for C-14 dating from this section yielded ages of 13400 and 13600 kyrs, documenting reef growth shortly after the Last Glacial Maximum during the deglaciation and the accelerated sea-level rise event called Meltwater Pulse 1A.

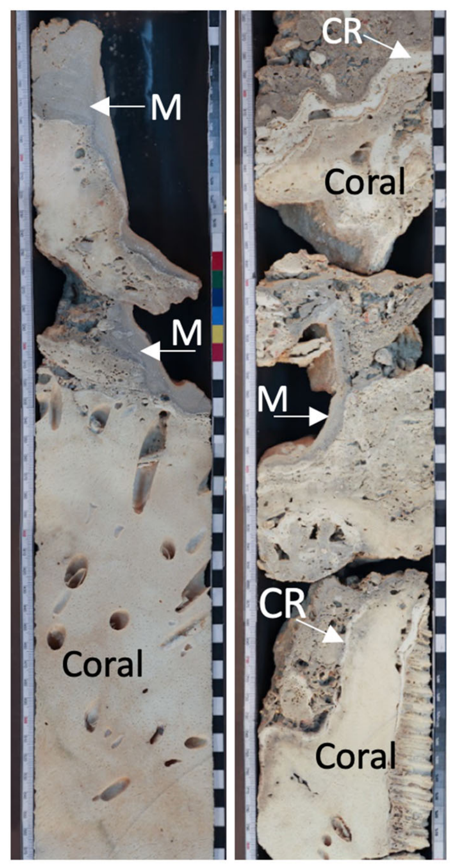

Figure 1: Core section lowstand reef with a diverse coral community and encrustations of microbialite (M) as well as calcareous red algae (CR).

Similar microbialites in reefal environments have been documented in other Last Glacial Maximum and deglacial reefs in Tahiti, the Great Barrier Reef and the Maldives (Camoin et al., 2006; Heindel et al., 2012). In these publications, the microbialite has been interpreted to reflect the environmental change stemming from the deglaciation. In addition, the thickness of the crust has been attributed to the various amounts of fertilization from chemical weathering of volcanic rocks that stimulated primary productivity and microbialite formation. Based on lipid markers and chemical analysis Heindel et al. (2012) propose that sulfate

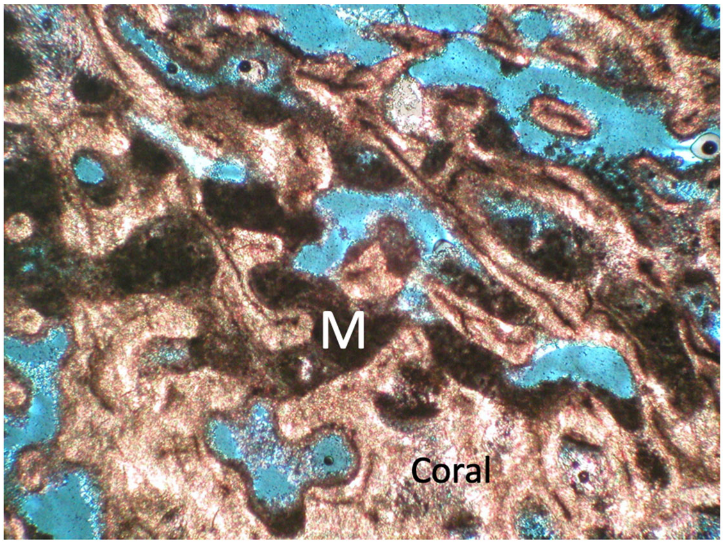

Figure 2: Thin section photomicrograph illustrating the occurrence of microbial micrite in the coral frame.

reducing bacteria play a crucial role in the precipitation of the microbial carbonate. The goal of this study is to test if similar mechanisms operated in the formation of the microbialites. In addition, we intend to estimate how much the microbialites contribute to the strength of the reef framework.

PROPOSED ANALYSIS

We will investigate the unique coral and microbial assemblages within a 2 m section using both visual inspection of the core, the thin section and SEM images. Color-coding of the various components and quantitative analysis using Image J will quantify the respective amounts of corals, microbialites and allochems. Chemical analysis will include XRD analysis of mineralogy, stable isotope analysis of the various components and rare earth elements (REE) for determining the oxidation stage during microbialite formation. C-14 ages will help to determine the age difference between corals and microbialite.

SIGNIFICANCE

Microbially encrusted coral reefs contain large intraframe porosity yet display an extraordinary strength, thus maintaining this porosity to large burial depth. If such microbialite/coral reefs form preferentially during deglacial periods, they could be identified as lowstand reefs on seismic data.

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EARLY MARINE CEMENTATION PROCESSES AND VELOCITY EVOLUTION

Mara R. Diaz, Ralf J. Weger, Peter K. Swart, Qian Ding[1], and Gregor P. Eberli

[1)] *Petroleum Exploration & Product Research Institute of SINOPEC*

PROJECT OBJECTIVES

- To investigate the role of microbes in ooid lithification processes that leads to the formation of grapestones and rocks.
- Compare the influence of biologically mediated versus inorganically precipitated cements on acoustic velocity and rock strength of carbonates.

PREFACE

This project was planned for 2021 but travel restrictions and new policies and research permits in the Bahamas have delayed the execution of the project. We expect policy changes that would allow us to retrieve samples this year.

PROJECT RATIONALE

Diagenetic alterations can trigger drastic changes in the petrophysical properties of carbonate grains. Newly formed cements can occlude or partially line pores which results in changes in the strength of granular rocks. When the new precipitates form at grain-to-grain contacts, an increase in stiffness and shear stress behavior is often foreseeable, affecting compaction, bulk and shear modulus (Bernabe et al., 1992; Dvorkin and Nur, 1996). The induction period for inorganic carbonate crystal precipitation at grain contact and non-contact areas – based on *in vitro* experiments with supersaturated solutions of $CaCO_3$ – can occur in as little as a few weeks (Fig. 1), while in the marine-realm, cementation processes can take place on a scale of a few months or years.

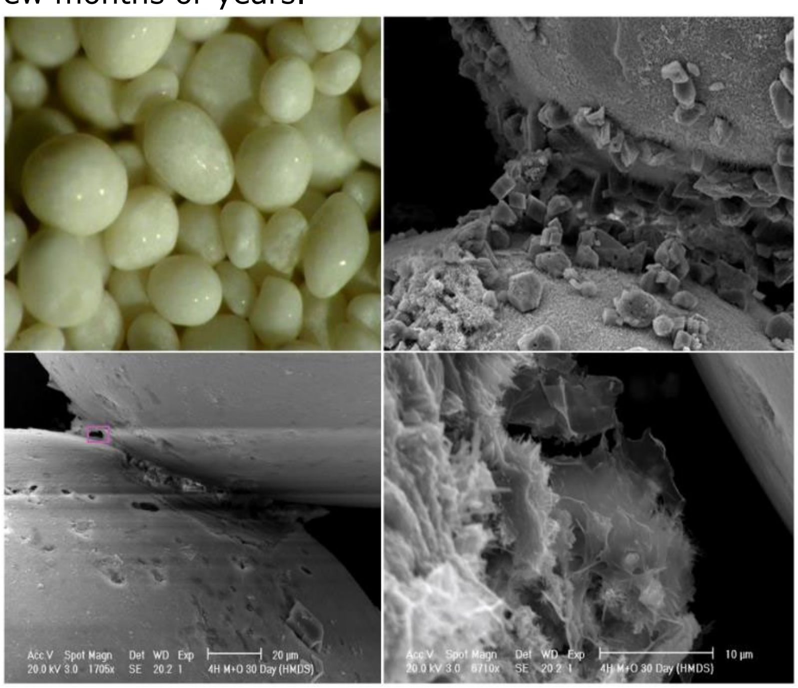

Figure 1: Results of inorganic and microbially mediated precipitation study. Top right, clean ooids before experiment. Top right, calcium carbonate crystals precipitated during the experiment. Precipitation occurs preferentially at the ooid-to-ooid grain contacts. Bottom right, illustration of microbially induced cementation after 30 days. Note the EPS at grain contact area.

There is increasing evidence that cementation is not a purely abiotic process as organomineralization processes – mediated by microbes and EPS biofilms – can induce many forms of early cements, including micrite envelopes, micritic bridges, meniscus cements and fringing cements. This implies that microbes are important in the initial cementation and stabilization of sediments. This notion is supported by our observations on interclasts from the Bahamas and Hamelin Pool, Australia (Diaz and Eberli, 2021) and in-house experiments with *in-vitro* incubations of loose ooid sands in the presence and absence of native microbial populations. Under the presence of microbial flora, our experiments show that the initial stages of grain consolidation can occur at 30 days with more advanced stages at 60 days. In contrast, sterilized ooids remain unconsolidated after 60 days (Fig. 1).

This study addresses the role of microbes in cementation and their impact on the elastic properties following cementation and rock formation. Of special interest is determining whether microbial cementation enhances the stiffness of loose sands and how it influences velocity and compaction.

APPROACH

Experiments will be tailored to determine the extent to which microbial precipitation affects rock-physics. To this end, the experiments will quantify both the chemical changes in the fluids and the diagenetic and petrophysical changes within the sediments (i.e. acoustic velocity and permeability).

To assess differences in petrophysical properties and the effect of microbial colonization on lithification, two sets of incubations - representing abiotic and biologically mediated precipitation - will be undertaken in chambers containing ooids that have undergone physical and chemical sterilization (to ensure axenic or microbial free conditions), whereas microbially mediated precipitation will use freshly collected ooids with their native microbial flora. Visual inspection of grain contact areas will use petrographic thin sections to identify grain binding, porosity and microbial colonization. SEM-EDS analyses will be used to document the involvement of extracellular polymeric substances (EPS) and the presence of ACC as a precursor to cementation processes.

KEY DELIVERABLES

A data set will be created capturing changes in acoustic velocity and fluid flow permeability generated by microbially and non-microbially induced precipitation. High-resolution images using SEM will provide insights on the role of microbes and associated EPS in precipitation and their location within the rock framework.

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Carbonate Contourite Drift Systems – The Ongoing Research Initiative

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1) Instituto de Geología, Universidad Nacional Autónoma de México,
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Project Objectives

- Investigate the role and influence of ocean currents on the architecture of shallow-water carbonate ramps, shelves and isolated platforms.
- Refine depositional models and current processes in coarse-grained drift systems.
- Assess the petrophysical characteristics of current-controlled deposition for improved interpretation of carbonate contourites and contourite drifts.
- Continue assembling dimensions of carbonate contourite systems for a comprehensive data base of such systems.

Project Rationale and Goals

Many depositional and stratigraphic models in off-bank carbonates assume that most sediment transport is gravity driven. In particular, slope depositional models commonly consider variable mass gravity flows as the main factor in determining variable slope deposition (Playton et al., 2010; Reijmer et al., 2015). The recognition of the ubiquity of bottom currents in shallow and deep basins and their ability to move sediment requires adding currents as an important control on deep water carbonate sedimentation in addition to sea-level controlled production and gravitational export. This interaction between mass gravity flows and bottom currents can increase reservoir quality, as is the case in the giant reservoirs offshore Mozambique. In carbonates, current controlled deposits that are large reservoirs

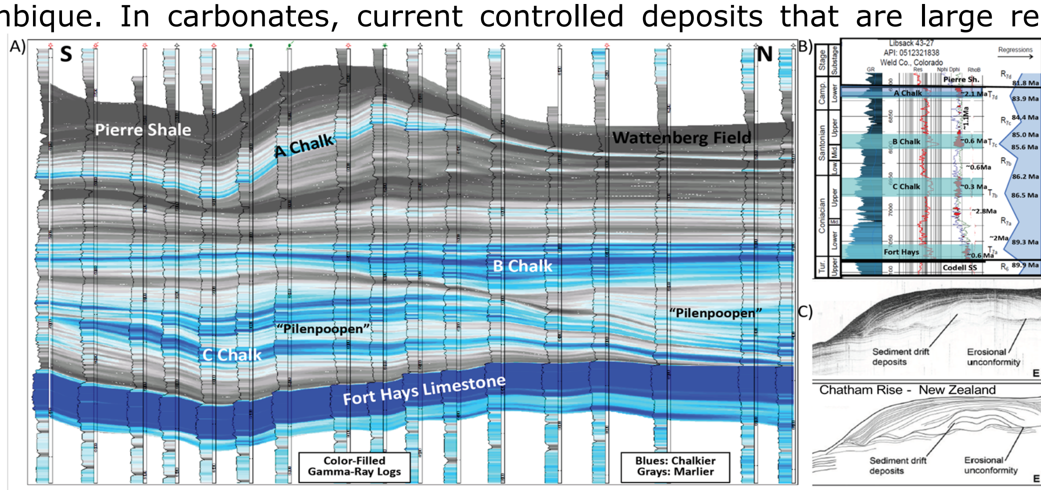

Figure 1: Revisiting the Upper Cretaceous Niobrara petroleum system with the aim of recognizing current control in the 30 mile cross-section across the Wattenberg Field Area, revealing that the chalk benches in the Niobrara are not nearly as blanket-like as Longman et al. (1998) inferred. Instead, considerable lensing of both the chalks and intervening marls is apparent, particularly in the C chalk, indicating that the system is basically a carbonate contourite drift (from Longman, 2020).

occur in the Upper Cretaceous chalk fields in the Central Graben of Denmark (Megson,1992). More recently, other carbonate plays in chalky facies have been re-interpreted as carbonate contourite drifts, like the Niobrara petroleum system in the western interior seaway (Fig. 1; Longman, 2020).

The influence of ocean currents on shallow-water carbonate systems is generally minimal but is important for platform drowning (Ling et al., 2021). Consequently, periods of widespread platform drowning can be taken as indicators of strengthening of the global circulation as is the case in the late middle Miocene in Southeast Asia (Eberli et al., 2010; Ling et al., 2021) and in the mid-Cretaceous when several platforms in the Pacific, Atlantic and Mediterranean realm drowned (Schlager, 1981).

The goal of this research initiative within the CSL is to identify current controlled from sea-level controlled deposition. It is our working hypotheses that some carbonate contourite drift systems have reservoir potential, although they are generally considered a risky play. Equally important is the role of currents in the drowning of isolated carbonate platforms and their sealing by fine-grained sediments. This research initiative aims to elucidate both the deposition and the erosion/non-deposition of carbonates due to ocean currents.

PROJECT PROGRESS AND FUTURE PLANS

In the past years, we have described three carbonate-specific types of contourite drifts that develop because of a feedback (Eberli and Betzler, 2019) and started to examine the current influence on the flank architecture of isolated platforms (Betzler and Eberli, 2019). This year we investigate the influence of currents on slope morphology, the role of currents to fill seaways between platforms, relating depositional processes to sedimentary structures, and the influence of ichnofabrics on petrophysical properties.

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The Relationship Between Carbonate Slopes and Contour Currents - Year Two

Sara Bashah and Gregor P. Eberli

Working Hypotheses

- Current strength along carbonate ramps, shelves and isolated platforms determines the
  - dip of the platform flanks
  - dip of the mounded contourite drift
  - grain size of the contourite drift.
- Carbonate slopes steepen worldwide in the late Middle Miocene after the onset of modern ocean currents at approximately 13 Ma.

Project Rationale

It has been proposed that carbonate slope architecture is controlled by the amount of deposition, by-pass or erosion of mass gravity flows (Schlager and Camber, 1986) and by the fabric of the slope material (Kenter, 1990). The flanks of carbonate platforms around the world after 13–10 Ma have, however, not only been constructed by mass gravity deposits, but equally by contourites with distinct drift and moat geometries. This style of flank architecture is typical of tropical carbonate platforms growing in the Neogene icehouse world. Ocean currents reduce sedimentation by particle sorting or winnowing and even by eroding slopes (Betzler and Eberli, 2019). In this project we will document the evolution of carbonate slopes in the Bahamas,

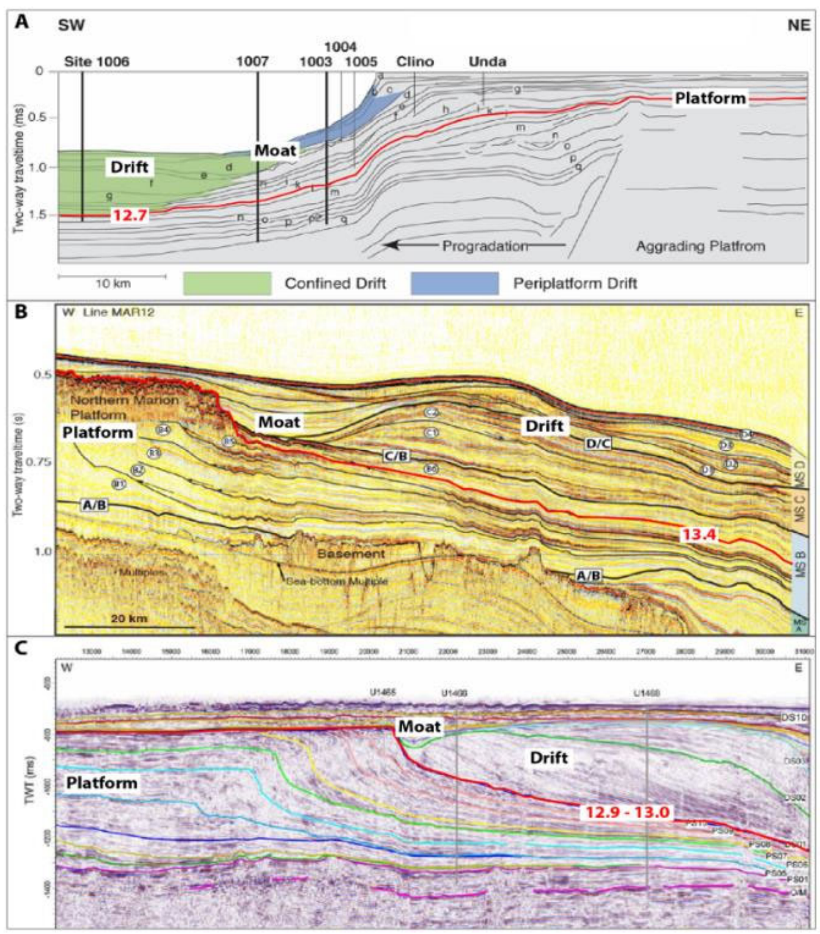


Figure 1: Selected seismic lines from (A) Great Bahama Bank, Atlantic. (B) Marion Plateau, northeast Australia. (C) Maldives, Indian Ocean.

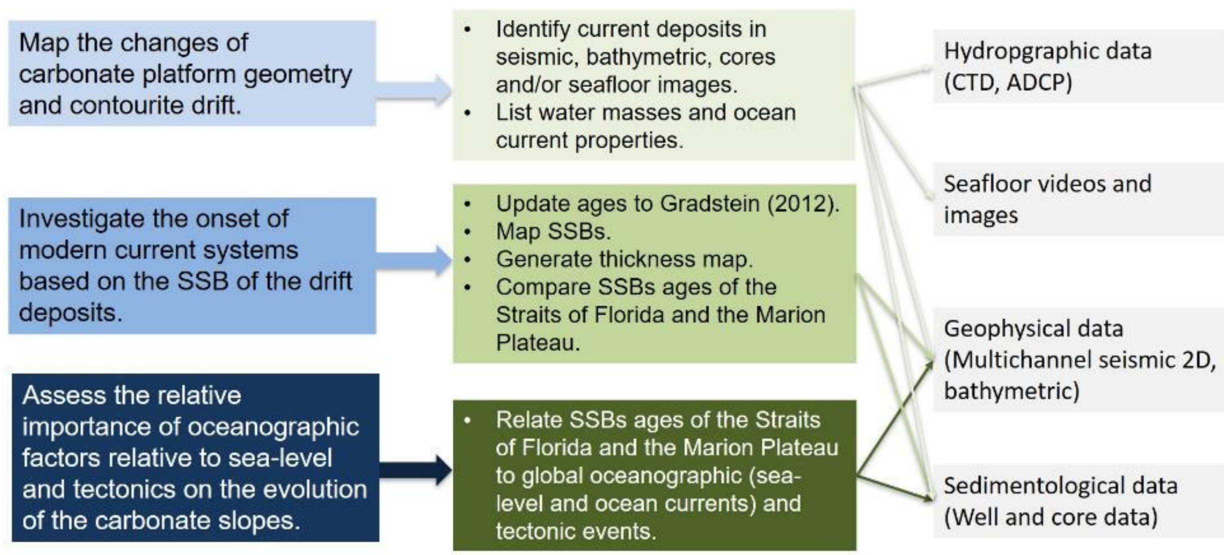
on the Marion Plateau, and in the Maldives, and their relationship with the along slope sediment transport by contour currents. These platforms show an abrupt onset of current activity along their slopes (red lines in Fig. 1).

DATA SETS

For this study, four data sets consisting of seismic, cores, and log data, from ODP Leg 194, ODP Leg 133, ODP Leg 166, and IODP Expedition 359 are analyzed. Age models are based on biostratigraphy and Sr-isotope dating from these ODP and IODP sites.

APPROACH AND WORKFLOW

To achieve the goals regarding the influence of contour currents on the carbonate platform slopes, we use the following workflow:



SIGNIFICANCE

The outcome of this study will improve our understanding of the influence of currents on carbonate platform architecture. The results will prompt a revision of facies models of carbonate platform slopes that have been based mostly on the assumption that they have been constructed by mass gravity flow deposits. This knowledge potentially helps discriminate current-influenced platforms from those evolving during times with less ocean circulation.

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ICHNOFABRIC CONTROL ON PETROPHYSICAL SIGNATURE IN CARBONATE CONTOURITE DRIFTS

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[1)] *Universidad de Granada, Spain*

PROJECT OBJECTIVES

- Test the hypothesis that different ichnofabrics in carbonate contourite drifts have distinct petrophysical properties.
- Compare ichnofacies and petrophysical signatures of slope deposits to those in carbonate contourite drifts to produce discriminating criteria.
- Incorporate these results into a more general catalogue for discriminating slope/basin deposits from carbonate contourite drifts using petrophysical logs.

BACKGROUND AND PROJECT RATIONALE

Bioturbation is common in contourite drifts. In fact, some researchers consider bioturbation to be a diagnostic feature that differentiates contourites from associated facies such as turbidites (e.g. Wetzel et al., 2008), while others have used the different ichnofacies solely as a paleoenvironmental indicator (e.g. Rodríguez-Tovar and Hernández-Molina, 2018, Rodríguez-Tovar et al., 2017). The integration of grain size, mineralogy, and ichnology define the ichnofabric of a rock. Ichnofabric analysis is, thus, an excellent tool to incorporate original sedimentary features (i.e. grain size, texture, and composition) with biodeformational aspects such as diversity, size, tiering, and cross-cutting relationship of ichnotaxa (Reolid and Betzler, 2018; Reolid, 2021).

In carbonate contourite drifts three main types of ichnofabrics are recognized: 1) coarse-grained and completely bioturbated sediment typical of delta drifts; 2) intensely bioturbated fine-grained deposits that may or may not exhibit discrete trace

Figure 1: One inch plugs of fine-grained wackestone with tiers of Zoophycos that is one of the typical ichnogenera for carbonate contourite drifts.

fossils out of the mottled background (Fig. 1); and 3) sediment with present to absent trace fossils and preserved sedimentary structures (Reolid and Betzler, 2018). The working hypothesis is that these different ichnofabrics can be separated by their petrophysical signature.

APPROACH AND DATA SETS

In the assessment of the relationship between ichnofabric and petrophysical signature we will begin with the large number of plugs from cores retrieved from the carbonate drifts of the Maldives (IODP Expedition 359). These plugs, which display variable amounts of bioturbation (Fig. 1), will be sorted out into the different ichnofabrics defined by Reolid and Betzler (2018). Porosity, permeability, sonic velocity and resistivity have been measured in all these plugs. Likewise, a similar, albeit a bit smaller, data set exists from the slope deposits that underlie the drift in the Maldives.

Cores through the Santaren Drift in the Bahamas were retrieved during ODP Leg 166. The Miocene portion of this drift is superbly preserved with excellent core recovery. Here, core photographs will be studied for the various ichnofabrics and, based on this analysis, we will request samples from the ODP core repository for laboratory measurements that would cover the same petrophysical properties as the ones from the Maldives.

In both study sites, contourite drifts and slope carbonates are deposited in and retrieved from the cores, allowing for a comparison of the petrophysical properties of these two systems. Kenter et al. (2002) measured the slope sections in the Bahamas, while Emma Giddens measured the slope carbonates in the Maldives.

GOAL

The goal of this study is to explore the potential for discriminating between depositional variations in carbonate drifts recorded in the ichnofabrics using petrophysical properties. If successful, these results will be incorporated into the comprehensive petrophysical database of carbonate contourite drifts that we are assembling at the CSL.

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3D-GPR Stratal Slicing of Sedimentary Structures in a Carbonate Contourite Deposit - The Next Steps

Mark Grasmueck and Gregor P. Eberli

Project Objectives

- Extract 3D sedimentary structures imaged in the 3D-GPR cube to refine the depositional model in the distal portion of the coarse-grained delta drift in the Maiella mountains.
- Refine the Geomodel used for stratal slicing by using a denser fault network and noise reduction in improved 3D-GPR migration.
- Ground-truth the Geomodel with drilling of short cores and outcrop.

Project Rationale

The Madonna della Mazza quarry near Pretoro (Italy) is cut into the distal portion of the Upper Cretaceous Orfento Formation, which has been identified as coarse-grained delta drift (Eberli et al., 2019). In the proximal portion of the delta drift, outcrops expose successions containing sedimentary structures that are characteristic for three main depositional processes 1) high density turbidity current deposits, 2) transitions from subcritical to supercritical turbidity currents, and 3) hyperpycnal flows. In the distal portion, the outcrops are more uniform and in thick, massive grainstone beds but reworked clasts give evidence of erosive traction currents (Fig. 1). 3D-GPR data, however, reveal a more diverse spectrum of sedimentary structures that include migrating carbonate sand waves, small-scale mass transport complexes and fluid escape structures (Grasmueck and Eberli, 2021). These diverse structures indicate the evolution of the depositional processes from the proximal to the distal

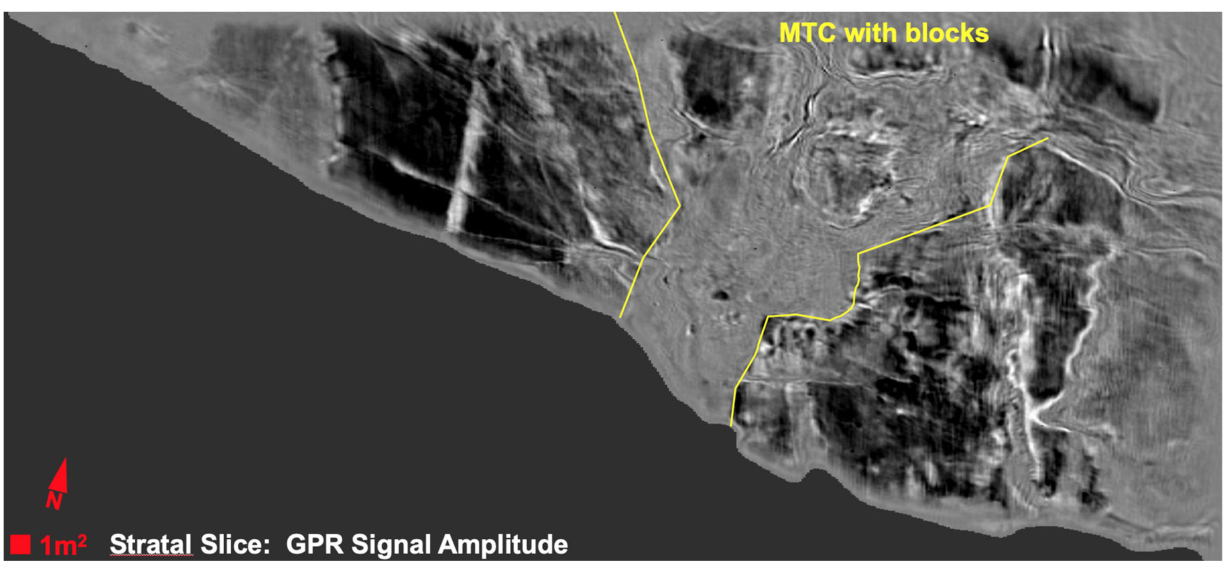

Figure 1: Stratal slice within the GPR cube of the Madonna della Mazza quarry displaying a small-scale mass transport complex with blocks floating in a grey grainstone matrix (modified from Grasmueck and Eberli, 2021).

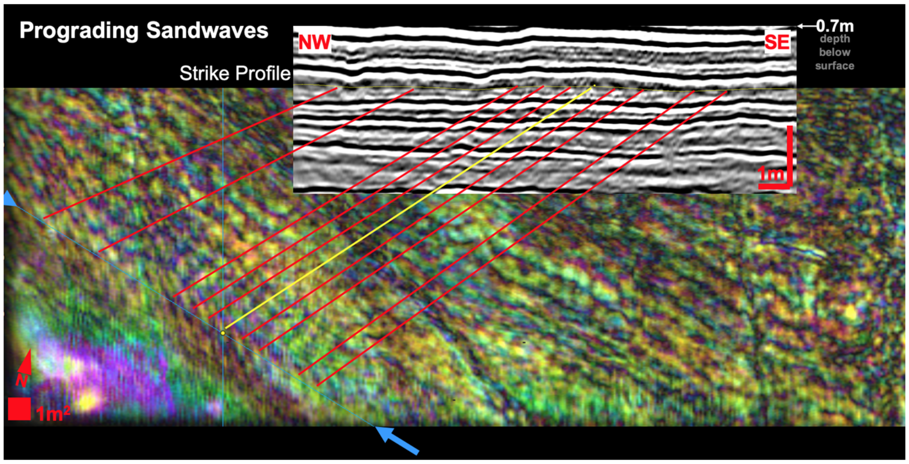

Figure 2: Stratal slice within the GPR cube of the Madonna della Mazza quarry in which spectral decomposition reveals the prograding sand-waves in the distal portion of the delta drift (modified from Grasmueck and Eberli, 2021).

portion of the carbonate contourite drift. Visualizing the sedimentary structures is paramount in deciphering these processes and their products.

Approach for Visualization and Interpretation of Sedimentary Structures

To visualize the strata, we use the 200 MHz 3D-GPR data that were acquired with a grid spacing of 0.1 m × 0.05 m over an area of 64.7 m x 27 m. Following data processing that included a 3D migration with a constant velocity of 0.09 m/ns, we constructed a Geomodel using Paleoscan, which resolves the individual horizons of the quarry succession (Grasmueck et al., 2021). The horizons can be populated with the original GPR signal amplitudes or any data derived attribute. So far, we have tested blended spectral decomposition attributes known from seismic imaging to enhance the visibility of subtle channels (Partyka et al., 1999) (Fig. 2).

The following steps are planned to further improve the visualization. 1) Do another migration of the data with noise reduction. And 2) refine the Geomodel with a denser fault network. In addition, we plan to incorporate other GPR volumes from the quarry. To improve the interpretation of the observed features in the GPR data we will revisit the outcrop and drill short cores into areas that are interesting on the GPR data. Other quarries and outcrops in the area will be visited for outcrop analogs.

Significance

This study visualizes, for the first time, sedimentary structures in the rock record in three dimensions. This third dimension offers a better quantification of the sedimentary product from the flow processes in this carbonate contourite drift.

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ASSESSING THE THERMAL HISTORY OF THE NEUQUÉN BASIN USING CLUMPED ISOTOPES

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

PROJECT OBJECTIVES

- Assess the geothermal history of the Vaca Muerta Basin using the Δ_{47} proxy.

PROJECT RATIONALE

The Vaca Muerta Basin, located in Central Argentina is a mixed carbonate-siliciclastic mudstone succession with interbedded limestone, mass transport deposits and volcaniclastic beds. Its lower portion is organic-rich and was deposited under anoxic conditions. This interval serves not only as the source rock for hydrocarbon deposits in the Neuquén Basin, but also is an unconventional play (Minisini et al., 2020). The thermal history of the basin, which is important for understanding the maturation of the organic material, has been ascertained using a combination of fluid inclusions (Ukar et al., 2020) and clumped isotopes of calcite veins known as 'beefs' (Weger et al., 2019).

While the study of Weger et al. (2019) was pivotal in determining the formation temperature and origin of the beefs, these samples do not provide the burial history throughout the 800 m of section. We compare the Weger et al. (2019) data to the modeled temperatures using the models of Henkes et al. (2014) and Stolper and Eiler (2015) (Fig. 1). Although the Weger et al. (2019) data is broadly in agreement, additional measurements need to be made which are not biased towards the calcite within calcite veins. To rectify this, we propose to analyze samples throughout the entire section.

WORK PROPOSED

We have collected over 2000 samples from ~ 800 m of section and constructed a composite section extending from the Early Tithonian to the Early Valanginian (149-135.5 Ma). The carbonate content of these samples varies, but generally increases towards the top of the section and mirrors the transition from anoxic to more oxic conditions. There are also a few intervals that contain dolomite. Our approach will be to take between 20-30 bulk samples throughout the entire section as well as samples from dolomitized intervals and fractures. These will be processed for the measurement of their Δ_{47} and Δ_{48} values using methods established at the University of Miami (Murray et al., 2016; Swart et al., 2019). The Δ_{47} values will be modeled using various approaches presented by a number of workers (Hemingway and Henkes, 2021; Henkes et al., 2014; Stolper and Eiler, 2015) to determine the burial history of the basin. As dolomite and calcite have different blocking temperatures, we can use these to tune the burial and diagenetic history.

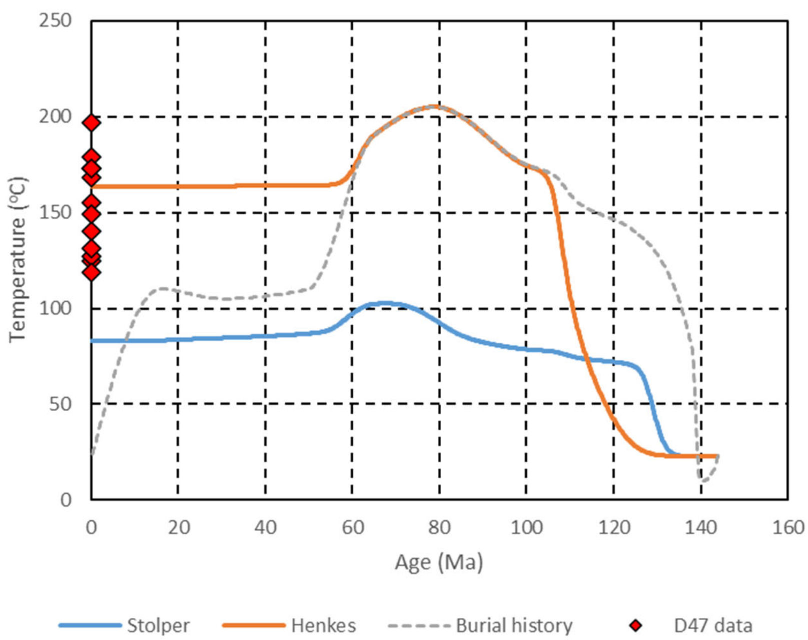

Figure 1: Estimate of the temperatures expected in the calcite samples using two of the solid-state models compared with the temperatures estimated using the clumped isotope data from Weger et al. (2019).

Significance

The measurement of the Δ_{47} values from the Vaca Muerta will enable us to compare the burial history of the Vaca Muerta calculated using fluid inclusions with that estimated from clumped isotopes. The addition of the Δ_{48} proxy will allow a comparison of its performance as an indicator of solid-state reordering relative to the values obtained using Δ_{47}. This will help us understand the maturation in the basin.

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Characterization of The Agrio Formation, Neuquén Basin, Argentina

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

Project Objectives

- Characterize the facies, TOC distribution, geochemical signature and petrophysical properties of the Agrio Formation in the Neuquén Basin.
- Compare these data with the existing data set in the Vaca Muerta Formation to assess similarities and differences in these two marine stages of the basin following terrestrial conditions.

Project Rationale

During the late Jurassic and early Cretaceous, the Neuquén Basin in Argentina experienced three similar sedimentary cycles of continental to marine successions (Fig. 1). In the Tithonian, terrestrial and lacustrine environments were rapidly inundated by marine waters, forming a basin that was subsequently filled with organic-rich clinoforms of the Vaca Muerta Formation. Following a relative sea-level fall in the early Valanginian, sedimentation was limited to the central part of the Neuquén Basin, with the deposition of a predominantly clastic, continental to shallow marine wedge (Schwarz et al., 2006). Renewed flooding in early Late Valanginian times, re-established marine conditions and resulted in deposition of the organic-rich mudstones of the Pilmatué Member of the Agrio Formation. Another dramatic sea-level fall resulted in terrestrial and aeolian conditions over most of the Neuquén Basin before a third flooding re-established marine conditions and deposition of the Agua de la Mula Member of the Agrio Formation (Fig. 1).

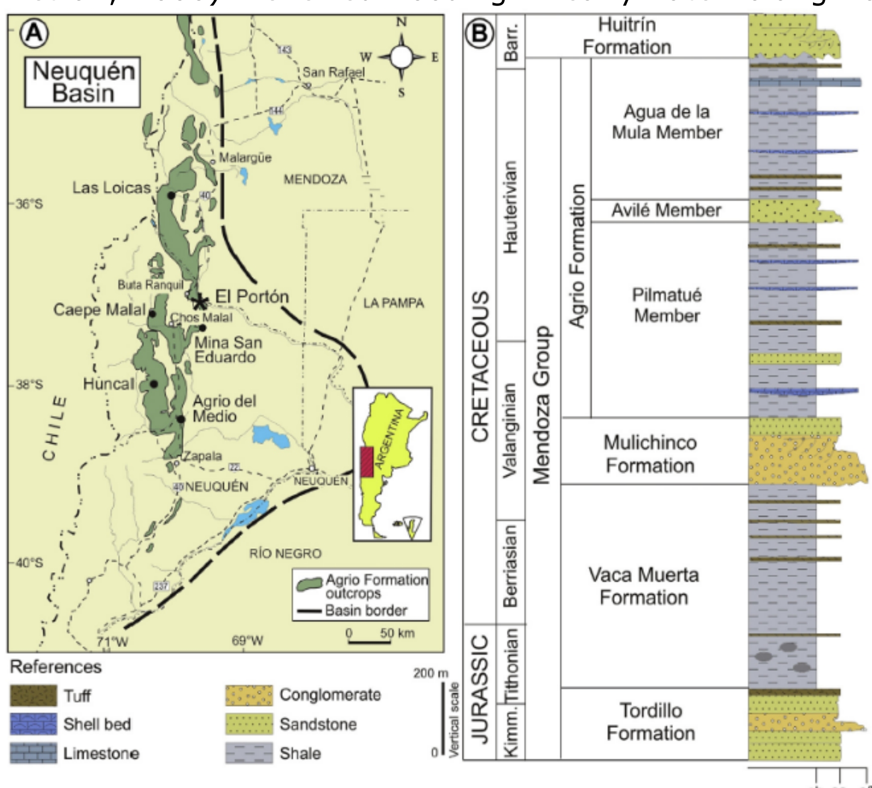

Figure 1: Location of Agrio Formation outcrops (A) and stratigraphic column of the Medoza Group (B) (Aguirre-Urreta et al., 2017)

After each marine flooding event organic-rich strata was deposited. The

Vaca Muerta Formation is more enriched in total organic carbon (TOC) than the younger Agrio Formation with the latter containing 2-5% TOC in a 50-400 m thick section (Legarreta and Villar, 2011). The facies associated with each formation, however, vary, indicating that the sedimentary system changed slightly. To capture the variability and similarities between formations we plan to characterize the Agrio Formation as we did with the Vaca Muerta Formation i.e., with detailed lithologic sections that are accompanied by geochemical sample analysis and gamma ray measurements every meter. Subsequently, these two data sets are compared to quantitatively assess the differences.

APPROACH

In the areas of Puerta Curaco, Aguada de los Tamariscos, Yesera del Tromen, and Pampa Tril we measured over 20 different sections of the Vaca Muerta Formation with a total length of over 2000 m, covering the stratigraphic column from the Tordillo, through the Quintuco up to the Mulichinco Formation to characterize facies and geochemical signatures. The Mulichinco Formation separates the Vaca Muerta Formation from the overlying Agrio Formation. We plan to measure through the Mulichinco Formation with low sampling rates (5 m spacing) to provide a representation of this interval, but then continue with 1 m spacing in the Agrio Formation. At the Puerta Curaco location, only the lower portion of the Pilmatue Member (Fig. 1) is well exposed, but a high-resolution lithologic log, spectral gamma ray, and geochemical samples every meter will provide the basis for correlation to other, better exposed outcrop locations of the Agrio Formation. Some scouting will be required, but well exposed outcrops of the Agrio Formation have been documented by several authors (Uliana and Legarreta, 1993; Aguirre-Urreta et al., 2017, 2019).

SIGNIFICANCE

These new lithologic sections and analyses will provide the required high-resolution data necessary to characterize the Agrio Formation for comparison with the Vaca Muerta Formation. These observed differences and similarities between the two formations will aid in assessing the potential of the Agrio Formation.

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ELEMENTAL SIGNATURES OF PRODUCTIVITY AND PRESERVATION IN THE VACA MUERTA FORMATION

Amanda Oehlert, Gregor P. Eberli, Ralf J. Weger, Laura Rueda, and Peter K. Swart

PROJECT OBJECTIVES

- Conduct laboratory-based measurements of elements that were poorly resolved in XRF dataset, including Ba, U, and Mo using ICP-QQQ.
- Calculate enrichment factors, elemental ratios, and conduct rolling window regression analysis using integrated dataset.
- Refine interpretations for differences in the origin (enhanced productivity and/or preservation) of high %TOC intervals in Upper Tithonian and Lower-Middle Berriasian aged cores from the Vaca Muerta Formation.

PROJECT RATIONALE

The Vaca Muerta Formation in the Neuquén Basin is one of the largest unconventional reservoirs in the world, yet consensus on the geological controls of intervals with high total organic carbon (TOC) content has yet to be established. Understanding the distribution of TOC within the basin has been a theme of major research and application of elemental proxies for paleoproductivity and preservation have provided new insight into potential controls on high TOC intervals. Prior work in the southern sub-basin has identified zones of both oxic and anoxic bottom waters in proximal depositional environments. In contrast, paleoenvironmental studies incorporating elemental signatures in the northern sub-basin are limited in spatial extent and support periodic transitions from anoxia to euxinia.

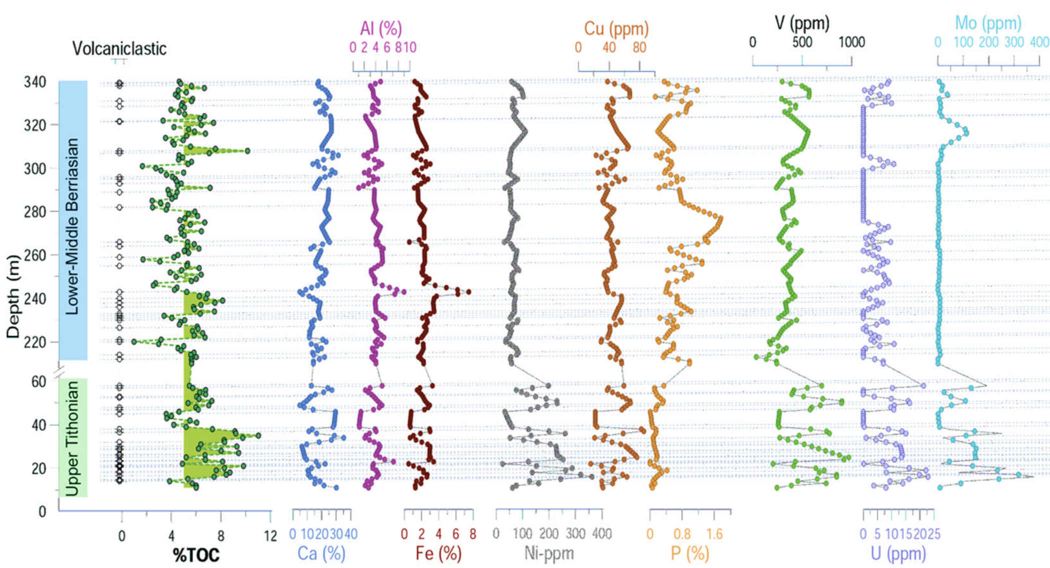

Figure 1: Variability in elemental concentrations of cored intervals from the Upper Tithonian measured by handheld Goldeneye XRF versus depth in meters above the base of the Vaca Muerta Formation. %TOC was previously measured and reported by Tenaglia et al., 2020. Occurrences of volcaniclastic materials are denoted as dashed grey lines across the plot.

In our recent analysis of elemental proxies for productivity and preservation in cores from the Upper Tithonian and Lower-Middle Berriasian intervals of the Vaca Muerta at El Trapial, potentially important differences in geological controls on high TOC (>5%) intervals were observed. Based on XRF measurements of Ni, Cu, and P, the Upper Tithonian high TOC intervals were interpreted to have originated from enhanced productivity, possibly linked to volcaniclastic input of limiting nutrients. Analysis of redox proxies like V, Mo, and U suggested that the Upper Tithonian was also characterized by high preservation potential driven by anoxic-euxinic bottom waters (Fig. 1). The Lower-Middle Berriasian interval lacked elevated concentrations of productivity indicators Ni and Cu but contained elevated concentrations of P. Paleo-redox proxies like Mo, U, and V were limited by XRF detection limits, requiring further analysis using instrumentation with sub-ppm level detection limits. Here, we will report on new analyses of productivity and redox sensitive elements, such as Ba, Cr, Co, W, Cd, Mo, U, and V/Mo, using discrete samples of the Vaca Muerta Formation at El Trapial.

APPROACH

We will accomplish these new measurements using ICP-QQQ technology, which will allow for characterization of these elemental concentrations at three orders of magnitude lower than XRF. Using this improved dataset, we will present calculations of enrichment factors (*sensu* Tribovillard et al., 2006) using the Post Archean Australian Shale values for normalization following previous studies in the basin at Puerta Curaco and Covunco. Finally, we will conduct rolling window regression analysis (Oehlert and Swart, 2019) of this dataset to investigate high-resolution changes in productivity and paleo-redox proxies in both intervals to refine our interpretation of paleoenvironmental conditions during the deposition of the Vaca Muerta Formation.

SIGNIFICANCE

Better understanding of the controls on high TOC intervals in the Vaca Muerta Formation will improve understanding of paleoenvironmental and paleo-redox controls in one of the largest unconventional reservoirs in the world.

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APPLICATION OF THE Δ_{48} PROXY TO THE REAL WORLD

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PROJECT OBJECTIVES

- Application of the Δ_{48} proxy to geological materials with constrained histories.
- Apply the Δ_{48} proxy to materials which are known to have formed in isotopic disequilibrium with respect to the Δ_{47} value.

PROJECT RATIONALE

While there are many reasons for the development of an additional clumped isotope proxy such as the Δ_{48} value, the most important is that it provides a method for resolving instances in which kinetic behaviour affects the Δ_{47} value. However, the measurement of Δ_{48} values is significantly more problematic than that of the Δ_{47} values, not only as a result of the abundance of mass 48 being approximately 10 times lower than that of mass 47, but also because all the variation at mass 48 is principally caused by variations in oxygen and as such is much more sensitive to exchange with H_2O. With the introduction of the generation of instruments such as the Thermo 253-plus, it has been possible to measure abundances of mass 48 and establish a framework similar to the carbon dioxide equilibrated scales (CDES) as developed by Dennis et al. (2011) and the Intercarb CDES (I-CDES) established by Bernasconi et al. (2021) for mass 47 (Fiebig et al., 2016). Finally, the last piece of the puzzle was put in place by developing an empirical calibration between temperature and the Δ_{48} value. This was accomplished by measuring the Δ_{48} values in carbonates precipitated at known temperatures and which had been previously calibrated with Δ_{47} values (Staudigel et al., 2018; Swart et al., 2019). This work (Swart et al., 2021) also agreed with the theoretical line of Hill et al. (2014) and various carbonate minerals which were considered by Bajnai et al. (2020) to have formed in isotopic equilibrium (Fig. 1).

APPROACH

Once the basic framework of using the Δ_{48} values has been established the next task is to ascertain whether the temperatures suggested by the empirical calibration can be duplicated in materials for which the Δ_{47} proxy appears to give values close to equilibrium, and also whether systems such as corals and speleothems which form carbonates out of equilibrium with respect to Δ_{47}, behave similarly with respect to Δ_{48} values.

WORK PROPOSED

Equilibrium: We have already established a calibration line between the Δ_{48} values and temperature (Fig. 1). We now propose to examine many of the skeletal and non-skeletal components that have been reported to form in equilibrium with respect to Δ_{47} and ascertain whether this is also true for the Δ_{48} value.
Non-equilibrium: We propose to examine the Δ_{48} values in scleractinian corals which form skeletons with Δ_{47} values lower than expected (Saenger et al., 2012) and Δ_{48} values in speleothems which have Δ_{47} values higher than expected. We will use the

model of Guo and Zhou (2019) to model the Δ_{47} and Δ_{48} values and ascertain whether a combination of the two proxies can resolve the original temperature using the approach outlined by Bajnai et al. (2020).

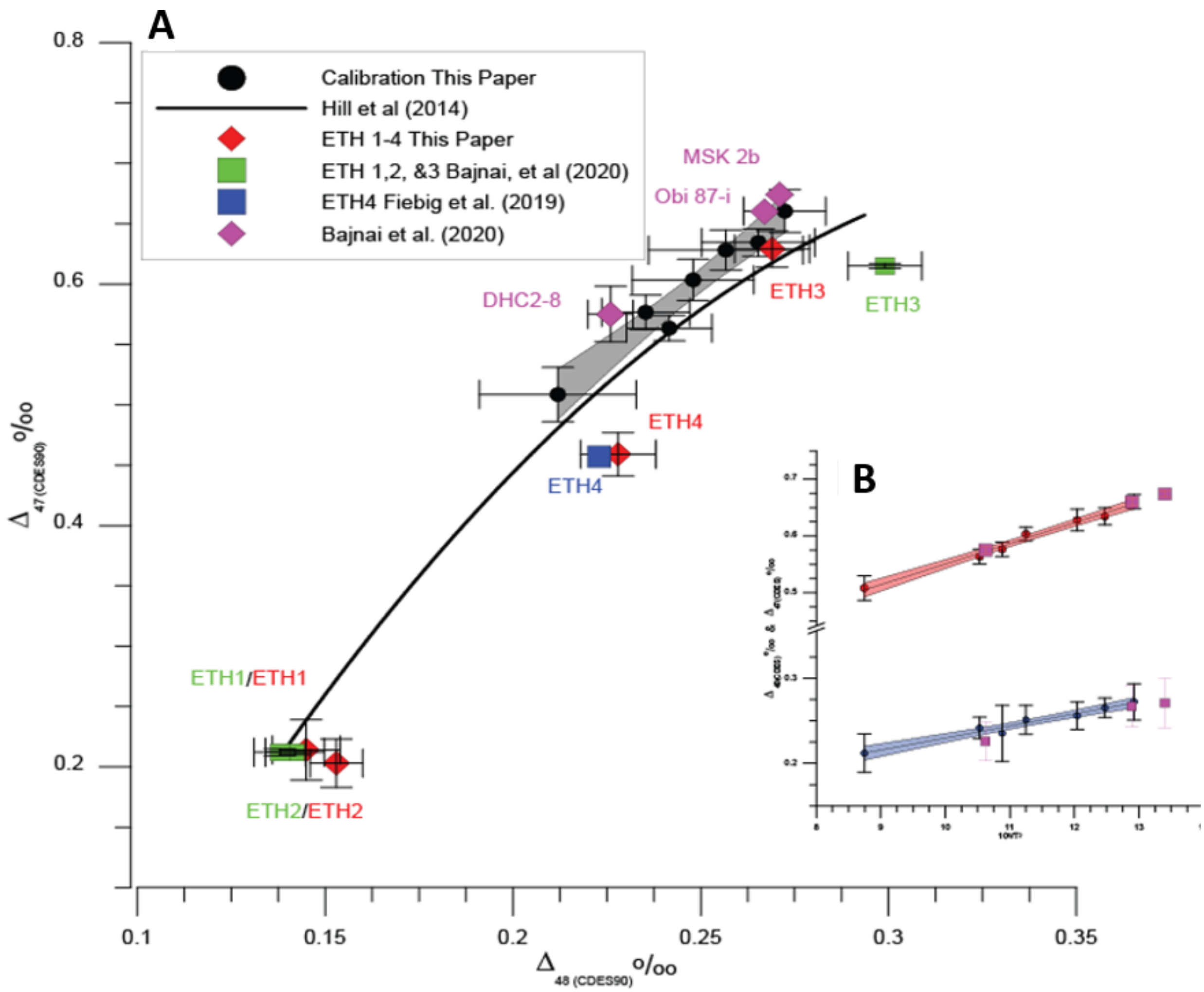

Figure 1: (A) Relationship of Δ_{48} and Δ_{47} values measured on the calibration presented by Swart et al. (2021) (black circles) and ETH samples (red diamonds) compared to the theoretical line from Hill et al. (2014) and the data from Fiebig et al. (2019)(ETH4) (blue square) and (ETH1, 2, and 3) (green squares). The DHC2-8 sample reported to have formed close to 33.7°C (Coplen, 2007) has Δ_{48} and Δ_{47} values that fall within error of the calibration. Other values reported by Coplen (2007) for Obi-87i and MSK 2b fall within error of the calibration line.

(B) Shows the Δ_{48} and Δ_{47} values of DHC2-8, Obi-87i, and MSK 2b samples plotted relative to the calibration lines. Note that Δ48 and Δ47 values for MSK, OBI and DHC2-8 were not processed using equilibrated gases directly, but using long-term CDES values obtained for ETH standards. All values fall within the 95% confidence limits of the analyses and the calibration line.

Figure from Swart et al. (2021).

SIGNIFICANCE

There are many applications of the Δ_{48} proxy. These include:

1- Confirming whether temperatures derived from the Δ_{47} values agree with those derived from Δ_{48} value.
2- Establishing the temperature of systems which are in disequilibrium with respect to the Δ_{47} value.
3- Establishing the blocking temperature of the Δ_{48} proxy and, if different, combining the two clumped proxies to better understand the burial history of a depositional sequence.

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CHARACTERIZATION OF SEAWATER CONDITIONS FAVORABLE FOR MICROBIAL HYDROCARBON SOURCE-RESERVOIR SYSTEMS IN THE ANCIENT PRECAMBRIAN

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PROJECT OBJECTIVES

- Examine the organic features related to microbial activities and assess the potential of hydrocarbon source rocks in the Ediacaran Doushantuo Formation.
- Analysis of the microbialite types, microbial relics, and reservoir porosity within the microbialite system in the Ediacaran Dengying Formation.
- Explore the Precambrian oceanic conditions and the controls operating on the development of microbe-related source rocks and microbialite reservoirs.
- Establish a model for microbial source-reservoir assemblage systems in the Precambrian.

BACKGROUNDS AND PROJECT RATIONALE

Several commercial Precambrian petroleum systems have been discovered worldwide. Various types of microorganisms have been identified in Precambrian successions contributing to the development of high-quality hydrocarbon source rocks and microbialites with high reservoir porosity (Nutman et al., 2016). However, there are still some key issues which need to be thoroughly explored. For example, what is the role of microbes and which oceanic conditions lead to the development of organic-rich hydrocarbon source rocks and microbialite reservoirs?

Fortunately, widespread black shale source rocks in the Edicaran Doushantuo Formation, and the directly overlying Dengying Formation microbialite reservoirs in the Sichuan Basin (China), provide the ideal material to address these key issues (Fig.1). The Doushantuo Formation sediments were deposited in shallow to deep water environments, and black shales are distributed within the second and fourth members. The Dengying Formation was deposited in a shallow platform and consists mainly of “algal dolomite” with abundant dissolution pores, especially in the second member (Liu et al., 2016; Zhu et al., 2020).

WORKPLAN

To achieve the project objectives, some future work will be arranged as follows. Black shales from several representative outcrops of the Doushantuo Formation will be investigated and sampled in detail, to measure their TOC, TS, Ro, carbon isotope values, and elemental composition. Palynomorphs in shales will be identified on acidified thin sections. Microbialite samples will be polished and thin sectioned, to identify their petrological, mineralogical and morphological features. SEM-EDS analysis will be conducted to study the potential influence of microbes and associated organic exudates i.e. extracellular polymeric substances (EPS) in these formations. Microbial identification will be based on morphological traits (i.e. size, cell shape, surface structure), whereas EPS detection will use morphological attributes based on those established in the literature. Crystal dolomite characterization will use SEM-EDS analysis. Porosity and permeability, and micro CT analysis for the Dengying Formation microbialites will be conducted to clarify the features of the reservoir spaces. All acquired data will be used to illustrate the hydrocarbon potential, microbial types, reservoir porosity and Precambrian oceanic geochemistry. Finally, we will propose a model for the microbial source-reservoir system.

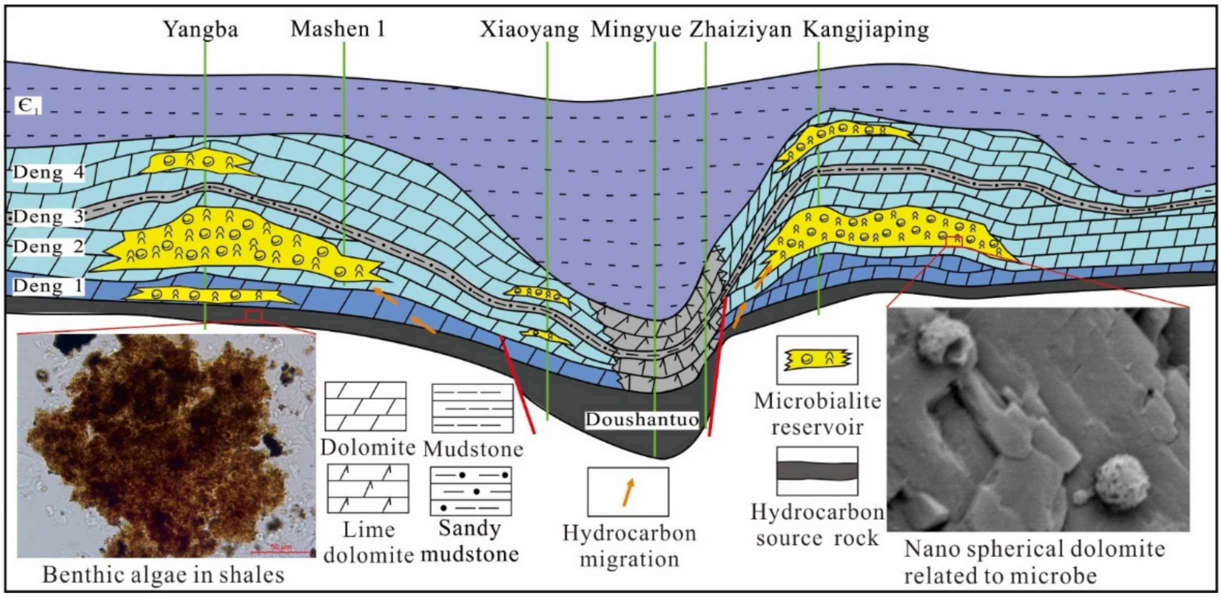

Figure 1: Models of assemblages of source rocks and microbialite reservoirs in Sichuan Basin

SIGNIFICANCE

This study focuses on the development mechanism of both the high-quality hydrocarbon source rocks and microbialite reservoirs in the Sichuan Basin, China. It provides an opportunity to establish the significance of microbes and oceanic conditions on the formation of Precambrian source rocks and microbialite reservoirs.

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TESTING SEAL CAPACITY FOR CARBON STORAGE - AN EXPERIMENTAL APPROACH

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

PROJECT OBJECTIVES

- Design an experimental set-up that allows testing how CO_2 injection alters the seal capacity in carbon storage sites.
- Run experiments to assess the dissolution and potential leakage of strata that seal storage reservoirs.
- Monitor chemical and physical changes in the rock
  - Document and quantify amount of dissolution and/or precipitation from injection of CO_2 saturated fluids into these rocks.
  - Assess changes in acoustic velocity resulting from injection of CO_2 saturated fluids.

PROJECT RATIONALE

Carbon Capture Utilization and Storage (CCUS) will be a crucial component in reducing global CO_2 emissions in the coming years. Although the utilization of the captured CO_2 is an important component, it is likely that carbon capture with permanent storage will play a more important role in achieving faster, large-scale reduction of CO_2 emissions. Permanent storage requires natural reservoirs with a seal that resists dissolution by CO_2 saturated fluids. Many theoretical modeling studies dealing with such rock-fluid interactions have been published in recent years (André et al., 2007; Gaus et al., 2005; Yuan et al. 2019; amongst many others) but actual laboratory experiments are rare. Luquot and Gouze (2009) have shown that CO_2 injection triggered dissolution increased permeability, while inducing only minimal modification of porosity.

Changes in elastic properties resulting from the removal of the smaller particles (i.e., those with highest surface area), the creation of pits of dissolution on the grain surfaces, and changes at grain contacts such as grain welding caused by injection of CO_2 saturated solution have been reported by Vialle and Vanorio (2011). This project aims to contribute to the experimental side of rock fluid interaction for carbon storage by building on past precipitation/dissolution experiments that we conducted in carbonate rocks (Fig. 1; Weger et al., 2012) addressing the potential changes in the seal rocks resulting from CO_2 injections.

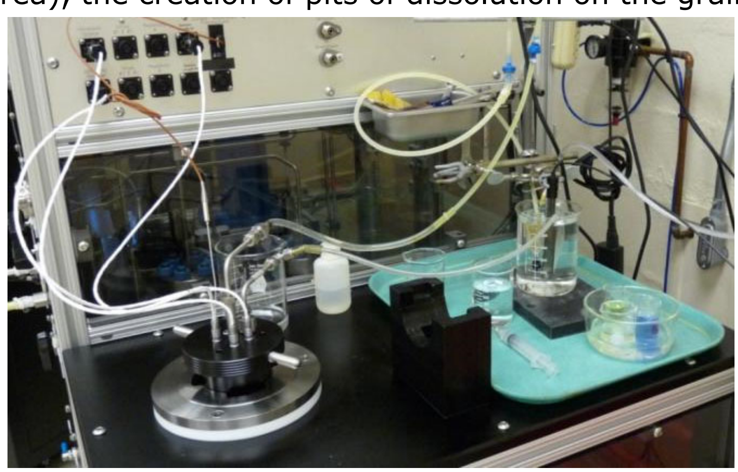

Figure 1: Set-up of previous dissolution experiments using the Autolab 1000 where the fluid composition is constantly monitored.

WORK PROPOSED

Phase 1 of the project is the design and testing of the experimental setup. The following workflow will be tested first on various rock samples in our New England Research Autolab 1000 system. We will be using a semi-closed system experimental design where pore fluid with predetermined geochemical composition is emplaced in the sample, CO_2 pressure is established, and only the existing fluid volume within the intensifiers (~5-10 pore volumes of the sample) will be used to create flow of fluid within the sample. This limited fluid injection will ensure that any chemical reaction of the fluid with the rock proceeds before the system reaches equilibrium with the host and the chemical reaction halts.

Monitoring of possible reactions that result in dissolution or mineralogy changes is a crucial element in the experiment. We plan to monitor physical changes with time series measurements of velocity. For this, the upstream pore fluid connection is closed. Five MPa pore pressure is installed at 60 MPa confining pressure, resulting in 55 MPa Ep. Time series measurement of VP and VS will be conducted for 72 hours (3 days) taking an acoustic measurement each hour.

After each three-day reaction time, the pore fluid will be extracted and chemically analyzed. In addition, all samples will be documented using SEM and CT scans before and after the experiment.

SIGNIFICANCE

This work will improve our understanding of how rock-fluid interaction changes microstructure and its elastic properties when CO_2 enriched fluids are injected in rocks with seal capacity. The quantification and high resolution image documentation of the resulting rock alterations will further enhance our understanding of the rate of changes resulting from CO_2 injection.

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BLUE CARBON: A CASE STUDY IN SOUTH FLORIDA

Peter K. Swart, Amel Saied, Greta J. Mackenzie, Michael Lutz, and Chaojin Lu

PROJECT OBJECTIVES

- Compare the flux and the storage of organic carbon in a relatively natural portion of the South Florida Ecosystem with one which has been heavily anthropogenically affected.

PROJECT RATIONALE

There can be little doubt that the increase in the concentration of CO_2 in the atmosphere which has taken place over the past 300 years has resulted primarily from the combustion of fossil fuels. This is recorded in atmospheric changes made since ~ 1960 as well as records contained in the $\delta^{13}C$ values recorded in the skeletons of organisms such as sclerosponges and CO_2 trapped in ice cores. Figure 1 for example, shows records from two long-lived sclerosponges from the Caribbean and from two Antarctic ice cores. All show the tremendous decrease in $\delta^{13}C$ values starting in the 18th century. Initially these decreases were a result of the burning of coal, but by the start of the 20th century they were augmented by emissions from the internal combustion engine. Carbon stored in coastal ecosystems in the form of seagrasses, mangroves, salt marshes, and other coastal ecosystems, also known as blue carbon, does not have the ability to eliminate this increase, but can modify the rate of future change. While terrestrial forests and grass lands (green carbon) have historically been thought of as the most important temporary storage site of carbon, it has gradually become apparent that coastal areas may be more significant. This realization necessitates a reexamination of the

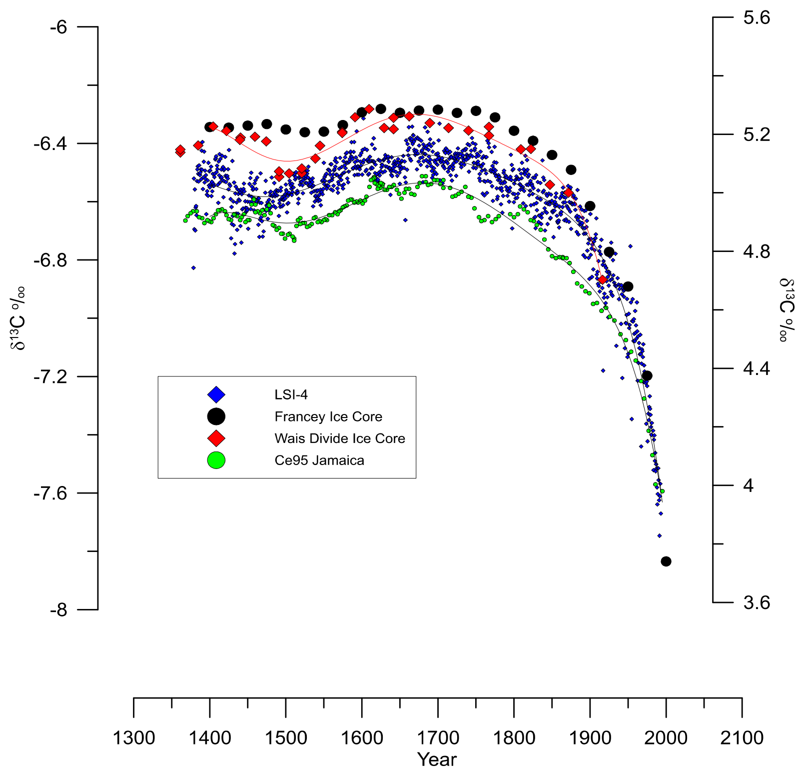

Figure 1: The $\delta^{13}C$ values measured in two sclerosponges, one from the Bahamas (LSI-4) (Waite, 2011; Waite et al., 2020) and one from Jamaica (Ce-95) (Böhm et al., 2002) (scale on right axis) together with $\delta^{13}C$ values of CO_2 from gas trapped in ice cores from the Antarctic (Bauska et al., 2015; Francey et al., 1999). Superimposed on the anthropogenic trend there are variations in the $\delta^{13}C$ values attributed to variations in the organic productivity.

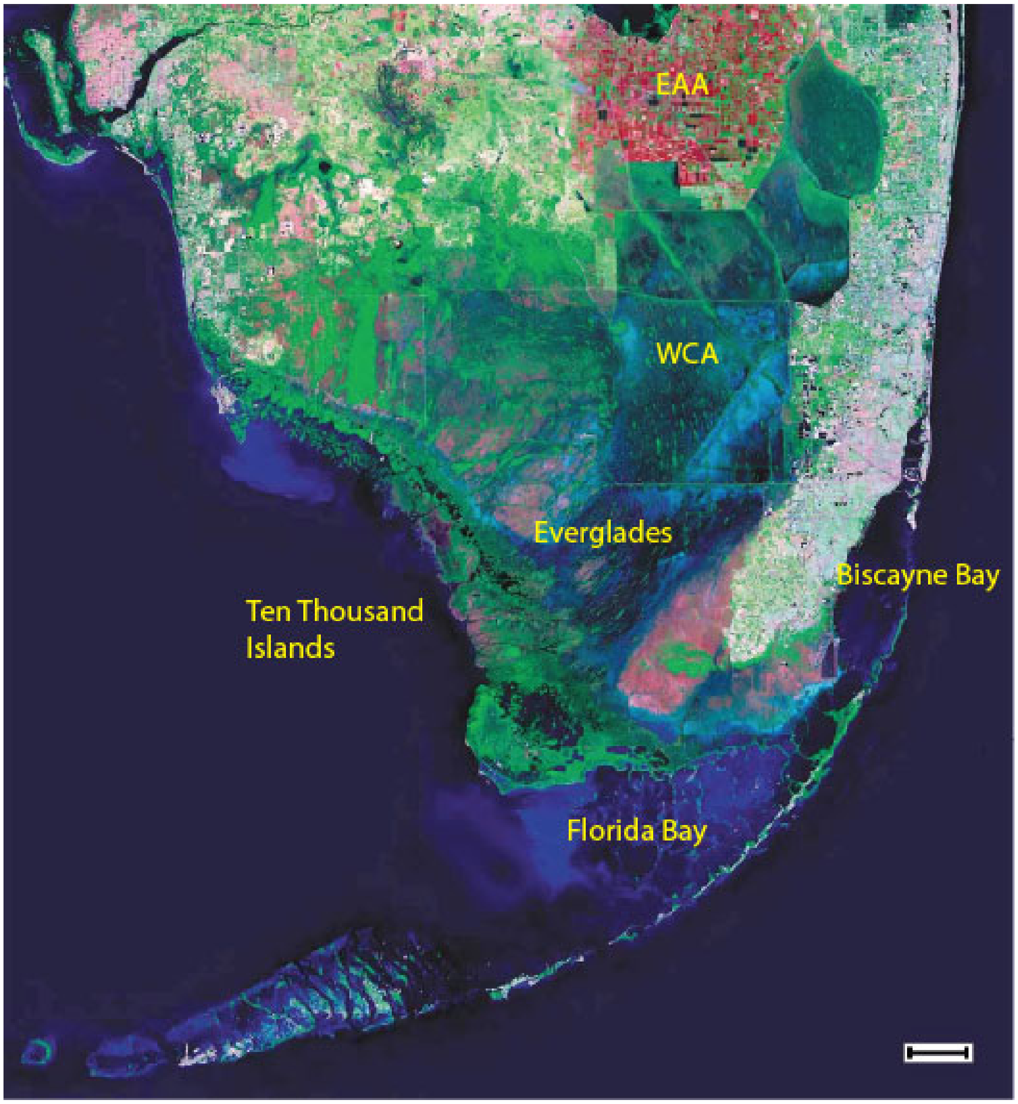

Figure 2: Satellite image of South Florida showing the Everglades, Everglades Agricultural Area (EAA), Water Conservation Area (EAA), Biscayne Bay, Ten Thousand Islands, and Florida Bay. Most of the population is concentrated on the coastal ridge, the white area, between Biscayne Bay and the Everglades.

anthropogenic influences on such fluxes and storage. In this project we will assess the storage and flux of carbon in the coastal ecosystems of South Florida and examine how this has been impacted by anthropogenic activity.

APPROACH

South Florida is not only home to some of the most important calcium carbonate producing systems, but also to large amounts of organic-rich environments in the form of seagrass beds, mangrove forests, and coastal wetlands that merge seemlessly into terrestrial environments such as the Everglades. Superimposed on this transition is a metropolitan area, home to several million people and the accompanying destruction of natural ecosystems.

The unmodified landscape of South Florida was originally an area of significant blue and green carbon storage. This study aims to investigate fluxes between the terrestrial and marine environments and to compare the natural habitat with the modified anthropogenic system.

WORK PROPOSED

Over the past 30 years we have been investigating carbon fluxes into the marine environment. A large amount of these data are contained in the work of Lutz (1997) and the measurements of the concentrations of organic material made in water samples collected by the Southeast Environmental Research Center at Florida International University (Briceño, 2008). A record of changes is recorded in cores taken in Florida Bay (Halley and Roulier, 1999; Prager and Halley, 1999) as well as in the skeletons of scleractinian corals (Anderegg et al., 1997; Hudson et al., 1989; Smith et al., 1989; Swart et al., 1999, 1996)

(Anderegg et al., 1997; Hudson et al., 1989; Smith et al., 1989; Swart et al., 1999; Swart et al., 1996)(Fig. 2). More data will be collected starting in 2022 targeting the anthropogenic component of the system mainly targeting Biscayne Bay. Water and sediment samples will be analyzed from a wide range of locations and compared with the fluxes previously measured in Biscayne Bay and the more natural portions of the system.

SIGNIFICANCE

This study will provide an assessment of the impact of major anthropogenic development on blue and green carbon storage. Such an assessment will be important not only for South Florida, but also for many other areas where there is exploitation of the coastal environment for purposes of human settlement and industrial development.

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UNIVERSITY OF MIAMI ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Department of Marine Geosciences
University of Miami

CSL CENTER FOR CARBONATE RESEARCH

CERTIFICATE PROGRAM
APPLIED CARBONATE GEOLOGY

PURPOSE AND GOALS OF THE CERTIFICATE PROGRAM

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 for an advanced knowledge and understanding of carbonate systems.

OVERVIEW AND COSTS

A Certificate in Applied Carbonate Geology requires the successful completion of 16 course credits assembled from 11 courses in the program (see back). 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 2022. The student/geoscientist will be in residence for 6 months. The current tuition fee is $2,000/credit.

REQUIREMENTS FOR ADMISSION AND REGISTRATION

A bachelor degree or equivalent degree is required but can be offset by years of working experience. No GRE or TOEFL are required. Registration for the Certificate Program started in the summer of 2016 and is handled by the Graduate Studies Office of RSMAS.
Registration for the Certificate Program opens each year in June for classes in the following year. Registration is online using the UM-RSMAS graduate program website.

LEARNING OUTCOMES OF THE CERTIFICATE PROGRAM

Learning Outcome 1:

Geoscientists/students will gain a broad knowledge of carbonate geology and geophysics.

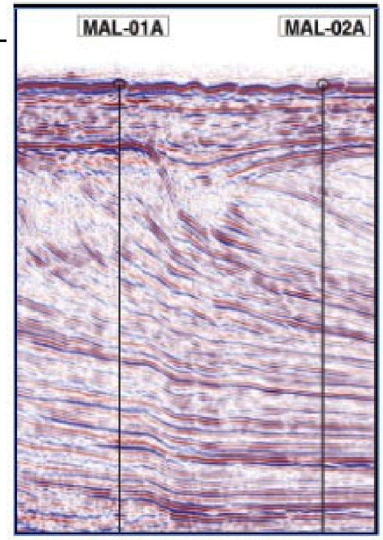
Learning Outcome 2:

Geoscientists/students will learn to incorporate the acquired knowledge and available data and tools into the workflow of applied projects.

Learning Outcome 3:

Geoscientists/students will learn oral and written communication skills and will be able to communicate their ideas and findings to peers, managers, and administrators.

INSTRUCTORS IN THE PROGRAM



Gregor P. Eberli	Seismic Sequence Stratigraphy
Peter K. Swart	Carbonate Geochemistry
James S. Klaus	Paleoecology, Geomicrobiology
Donald F. McNeill	Sedimentology, Stratigraphy
Mara R. Diaz	Molecular and Geomicrobiology
Ralf J. Weger	Petrophysics
John Dolson	Carbonate Petroleum Geology
Greta Mackenzie	Petrography
Paul M. (Mitch) Harris	Carbonate Geology

OFFERED COURSES

MGS 611 3 Cr Earth Surface Systems
MGS 641 2 Cr Field Evaluation of Fossil Platforms, Margins, and Basins
MGS 601 1 Cr Seminar in MGS
MGS 678 2 Cr Field Seminar: Facies Successions on Great Bahama Bank
MGS 688 2 Cr Field Seminar: Heterogeneity of a Windward Margin
MGS 784 2 Cr Seismic Interpretation of Carbonate Systems
MGS 526 2 Cr Petrophysics of Carbonates
MGS 686 2 Cr Microbial Carbonates
MGS 726 2 Cr Carbonate Diagenesis and Petrography
MGS 527 2 Cr Analysis in Carbonate Cores
MGS 789 2 Cr Petroleum Geology in Carbonates

For additional information about the
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