

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of
MARINE, ATMOSPHERIC
& EARTH SCIENCE



CSL - Center for Carbonate Research *and Education*

Prospectus 2026

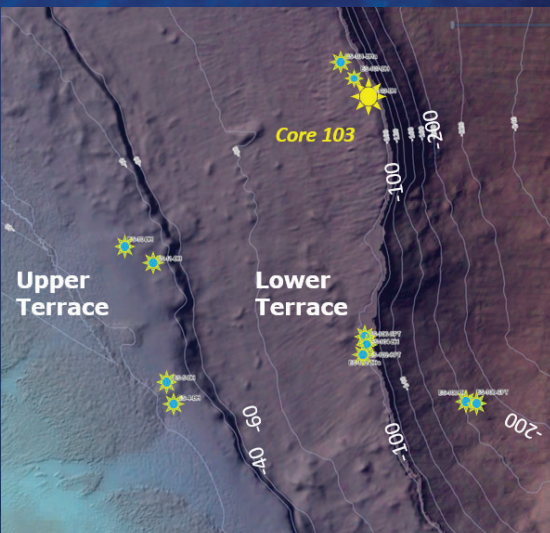


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MISSION OF THE CSL – CENTER FOR CARBONATE RESEARCH

The mission of the CSL – Center for Carbonate Research is to conduct fundamental research in carbonates and transfer the knowledge to the industrial associates.

Our research program aims to comprehensively cover carbonates exploring new approaches, techniques and emerging topics. To reach this goal, our research projects integrate geology, geophysics, geobiology, and geochemistry and combine observational, laboratory, and theoretical approaches. Most research projects are interdisciplinary, but some are designed to advance knowledge in one specific area. This year the 16 projects are divided into five main topics:

- Rift basin and microbial carbonates
- Diagenesis and geochemistry of carbonates
- Shallow-water carbonates
- Carbonate contourite depositional systems

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.

We aim to inform our industrial associates about the knowledge gained from our studies and the newest research techniques that potentially can be incorporated into the workflow of projects or help to solve longstanding problems in exploration, production or carbon sequestration.

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 associate 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.

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

PERSONNEL

Faculty and Scientists

Gregor P. Eberli	Professor, Seismic Stratigraphy, Sedimentology
Sam Purkis	Professor, Sedimentology
James S. Klaus	Associate Professor, Paleontology
Amanda M. Oehlert	Assistant Professor, Geochemistry
Ralf J. Weger	Assistant Research Professor, Petrophysics
Mara R. Diaz	Scientist, Geobiology
Mark Grasmueck	Adjunct Professor, Subsurface Imaging
Paul (Mitch) Harris	Adjunct Professor, Applied Sedimentology

Lecturer

Sara Bashah
Benjamin Ross

Post-Doc

Mingyue Wu

STUDENTS

Clément G.L. Pollier, Morgan Chakraborty, Cameron Sam, Flora Beleznav, William Wright, Merrilee Aderyn Rivers, Caroline Tran, Paulina Manekas, and Nyah Strahm, Janna Wama

RESEARCH ASSOCIATES

Jazmin Garza
Brooke E. Vitek

SCIENTIFIC COLLABORATORS

Rosario Viadora	Mozambique
G. Michael Grammer	Oklahoma State University
Adrian Immenhauser	University of Bochum, Germany
Dierk Hebblen	MARUM, Bremen, Germany
Sam Goldberg	University of Miami

2026 RESEARCH FOCUS

The **Mozambique Shelf Core Initiative** is a multidisciplinary study involving the analysis of cores and seismic data from a fringing reef offshore Mozambique that developed during the Last Glacial Maximum. Our collaborative team integrates core logging, petrography, microbialite analysis, coral taxonomy, geochemistry, GIA modeling, seismic and stratigraphic interpretation to produce the most comprehensive reconstruction to date of a Last Glacial Maximum reef system, including environmental and relative sea level changes during this important time interval. The cores – made available by the Mozambique government with the assistance of ENI – have a significantly higher recovery (86%) and better preservation than those from other drilling expeditions conducted on lowstand reefs by the Integrated Ocean Discovery Program (IODP). As such, they offer an exceptional opportunity to investigate the nature of reef development and faunal changes during the Last Glacial Maximum and the subsequent deglaciation, as well as to provide valuable constraints on the timing and magnitude of sea level change during a data-sparse time interval.

The trove of data collected in the **rift basins** of the Red Sea and the Gulf of Aqaba is another focus of the research within the CSL. In a new project, analysis of samples collected on the steep slopes in the Gulf of Aqaba aim to resolve the processes responsible for slope cementation and stabilization. A second project uses deep-water corals (DWCs) as a novel integrative archive for reconstructing Quaternary climate variability in the Middle East. Using high-resolution MC-ICP-MS, we will measure uranium-series isotopes, trace-metal concentrations, and perform U–Th geochronology within the DWC to generate a comprehensive, well-dated record of Late Quaternary hydroclimate variability in the Red Sea.

Within the **shallow-water carbonate** theme, a project is in its initial stages to develop and train machine learning algorithms for emergent pattern recognition in shallow-water carbonate depositional systems. In the course of this project, an algorithm workflow will be tested that is expandable to atolls across the world, ultimately providing a critical quantitative understanding of pattern types and their evolution.

We have explored and documented fish derived carbonates – **ichthyocarbonates** – in previous projects. This year’s study focuses on organic matter within these carbonates. Refined estimates of fish-based contributions of organic matter to the biological and carbonate pumps will enhance our understanding of carbon sequestration potential of ichthyocarbonates.

In the **diagenesis and geochemistry** theme, we conduct prolonged, in vitro incubation experiments in the presence and absence of microbial marine communities to test the hypothesis that microbial load within the grains influences the rate of cementation. We also embarked on the assembly of a database that incorporates the petrographic and diagenetic information to the petrophysical data that we have assembled over many years.

Our research effort in **carbonate contourite depositional systems** continues, with ongoing maintenance and updates to the carbonate contourite database.

For a detailed overview of each project planned for 2026, please refer to the prospectus.

2026 PLANNED PROJECTS

MOZAMBIQUE FRINGING REEF CORES – RESEARCH INITIATIVE

- Mozambique Shelf Core Research Initiative - Introduction
- Facies Architecture and Seismic Expression of a Fringing Reef System, Offshore Mozambique – Year 2
- Reconstructing Relative Sea Level Across the Last Glacial Maximum
- Investigation of Coral Communities in the Mozambique Low-Stand Reef System
- Microbialite Morphologies of the Low-stand Fringing Reef from Offshore Mozambique
- Towards a Geochemical Reconstruction of Paleoclimatic Conditions During the Last Glacial Maximum in Offshore Mozambique
- Acoustic and Electrical Properties of Coral and Microbialite Facies in the Mozambique Shelf Core

RIFT BASIN AND MICROBIAL CARBONATES

- Cementation and Aggradation of Red Sea Slopes
- Abrupt Climate Variability in the Red Sea: Insight from the $\delta^{234}\text{U}$ and U-Series Chronology of Deep-Water Corals

ICHTHYOCARBONATES

- Determining The Influence of Fish Feeding State on Ichthyocarbonate Composition and Fate
- Organic Matter Matters: Quantifying the Content and Composition of Ichthyocarbonate-Associated Organic Matter

DIAGENESIS AND GEOCHEMISTRY OF CARBONATES

- Contrasting Early Marine Cementation in Skeletal Sands and Ooid Sands
- Paleoenvironmental Reconstruction of Saline Lakes in the Salar de Llamara (Atacama Desert, Northern Chile) Informed by Sedimentological and Geochemical Indicators
- Incorporate Petrography into Petrophysical Database

SHALLOW WATER AND DEEP-WATER CARBONATES

- Emergent Patterning of Modern Atoll Reefs as an Analogue for Self-organization of Ancient Carbonates
- Atlas of Carbonate Contourites

2026 REPORTING

We will report on our research findings twice 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 October. Hopefully we will be able to meet in person. The dates for these two meetings are tentatively set at:

May 27th, 2026 – 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 12-13, 2026 - ANNUAL REVIEW MEETING

The results of the projects detailed in this prospectus will be presented at the **Annual Review Meeting in Miami, October 12-13, 2026**. We will send out information on the logistics for the meeting in the second quarter of 2026.

The **fieldtrip** from in conjunction with the annual review meeting is to mixed systems in the **Dominican Republic; October 14 -18, 2026**.

FIELD SEMINAR DOMINICAN REPUBLIC

REEFS AND MIXED SYSTEMS

OCTOBER 14 - 18, 2026

OVERVIEW

The Cibao Valley was at one time an open shelf and seaway along the northern margin of Hispaniola. Subsequent uplift of the island, associated with nearby plate boundary interactions, has exposed a relatively undeformed Miocene and Pliocene section. The uplifted sequence consists of a wedge-shaped deposit of Neogene marine sediment. Both siliciclastic and carbonate facies occur in the Cibao Basin, the siliciclastics shed from the adjacent Cordillera Central, and the carbonates mainly from *in-situ* skeletal precipitation.



This fieldtrip offers insight into some fundamental questions with respect to mixed systems.

Themes of Seminar:

1) Styles and processes in mixed-system deposition - Collectively, the Cibao Valley outcrops present a spectrum of *in situ* mixing of carbonates and siliciclastics. We will examine the three mixing styles, including coral reefs flourishing on the siliciclastic delta front and the rapid transition from clastics to carbonate clinofolds

2) Reefs in the mixed-system - Coral reefs play an important role in many tropical mixed systems both in the Tertiary, part of the Mesozoic, and the Paleozoic. The Cibao sections show several styles of reservoir-scale, reef or reef-associated lithofacies. The style of reef is largely tied to the depositional regime, which in turn is driven by changes in sea level.

3) Establishing diverse coral reefs in a siliclastic setting - The occurrence of coral reef formation in siliciclastic mud and on muddy delta fronts question the paradigm that corals need a hard substrate and cannot flourish in a muddy environment.

Cost: Approximately \$5,500; includes transportation within the Dominican Republic, accommodation, meals and course notes.

MOZAMBIQUE SHELF CORE RESEARCH INITIATIVE - INTRODUCTION

Gregor P. Eberli

PROJECT OBJECTIVES

- To decipher the initiation, growth and drowning of the fringing reef during the last glacial maximum and the subsequent deglaciation.
- Elucidate how microbialites function as an integral part of the reef complex that stabilize/cement the reef framework.
- Construct a relative sea-level curve for the interval spanning the Last Glacial Maximum, contributing to efforts to reconcile geological records with glacial isostatic adjustment models.
- To produce a comprehensive petrophysical data set of the core material, including porosity, acoustic velocity, and resistivity.
- Identify and catalog coral diversity to establish a regional baseline for reef development during the Last Glacial Maximum and the subsequent deglaciation.
- To provide a baseline for the paleoenvironmental conditions during the Last Glacial Maximum in the Mozambique Channel using stable isotopes.

INTRODUCTION

During the Last Glacial Maximum (LGM) when sea level was about 120 m lower than today, coral reef systems established in the several ocean basins but drowned during the fast sea level rise of the subsequent deglaciation. Such submerged coral reef systems have been cored in Barbados (Fairbanks, 1989, Peltier and Fairbanks, 2006) around Tahiti (IODP expedition 310; Camoin et al. 2012) and off the Australian Great

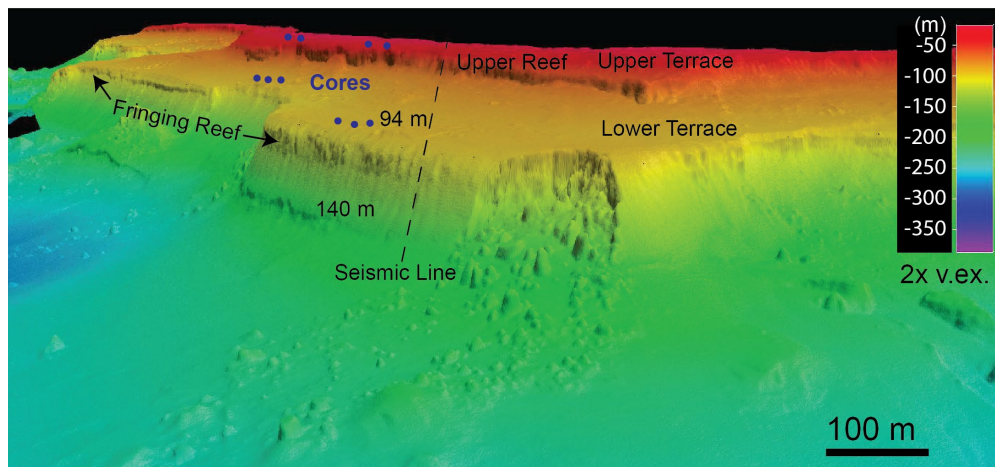


Figure 1: Approximate locations of the ten cores. Six cores (blue dots) were retrieved from the fringing reef along the Lower Terrace and 4 cores from the back-stepped reef on the Upper Terrace. The cores were drilled using a remotely operated drill rig that was positioned on the seafloor. Core barrels and drill rods for core drilling down to 120 m are stored in rotating magazine. Each core section is 1.5m in length.

Barrier Reef (IODP Expedition 325; Webster et al. 2011, Yokoyama et al. 2011) and in the surrounding Hawaii region (IODP Expedition 389; Webster et al., 2025).

An important component of these lowstand reef successions are microbialites within the reef framework. Thick microbialite successions recovered from IODP Expeditions 310 (Tahiti) and 325 (Great Barrier Reef) have been interpreted as forming alongside coral growth or shortly after deposition (Westphal et al., 2009; Seard et al., 2011; Braga et al., 2019). Microbialite formation has been attributed to a variety of environmental influences, including shifts in alkalinity, nutrient availability, and microbial activity such as sulfate reduction.

THE UNIQUE DATA SET

The data set consists of a 3D seismic data and 10 cores drilled at 4 sites (Fig. 1). All of them have an excellent recovery of over 80%. This expansive core coverage, with six closely spaced cores (60 to 120m apart) will enable documentation of lateral variability in the fringing reef. U/Th dating will help to establish a robust timeline of the reef development during the onset of the Last Glacial Maximum and the early deglaciation. The four cores from the younger reef in the Upper Terrace (Fig. 1) provide a unique opportunity to determine the timing of the backstep during the deglaciation and to examine changes in reef composition during the Holocene sea-level rise.

Access to the 3-D seismic data set is crucial for placing the cores within the depositional geometries. This 3D data set makes the Mozambique data set unique as none of the IODP drilling projects had access to 3D seismic data. The seismic data

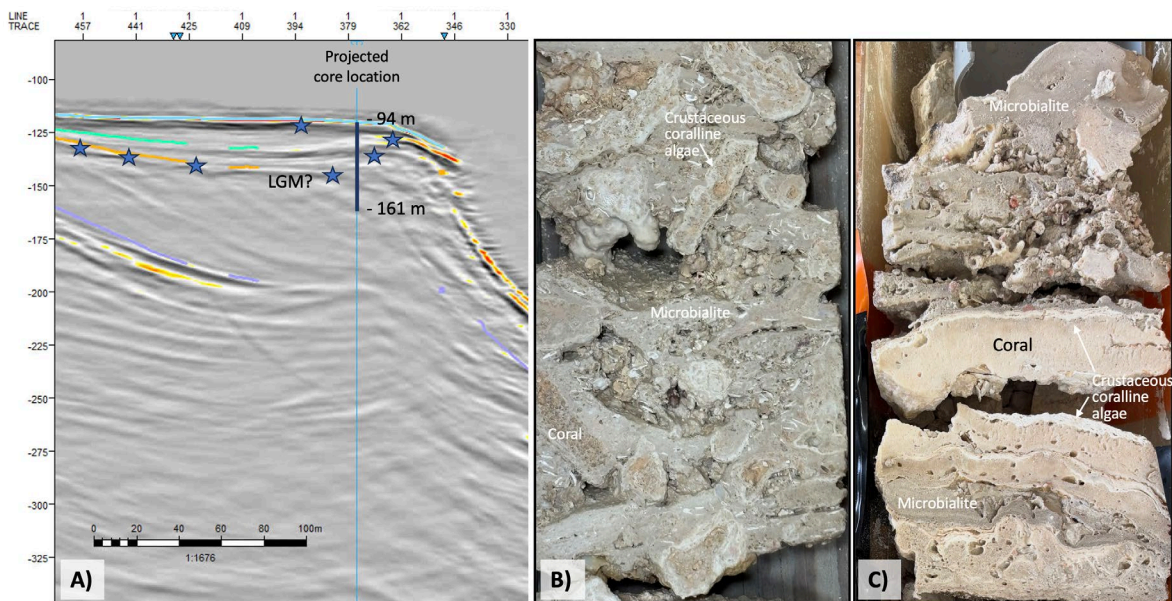


Figure 2: A) Seismic line with location and depth of the 67 m long core ES-103. The core recovered a highly diverse coral reef succession in which microbialites are an integral part of the reef edifice. The blue stars are placed at the shelf margin. B) Illustration of the excellent recovery in which coral rubble encrusted by crustacean coralline algae (CCA) and microbialite is preserved. C) Example of the typical succession of components in the core: Platy coral and other skeletal debris are encrusted by CCA and then covered by microbialite. Marine cements are mostly absent.

displays downstepping clinofolds followed by an aggrading reef front that is forming the fringing reef (Fig. 2A). This shelf margin trajectory indicates that the reef followed the falling sea-level into the Last Glacial Maximum in a forced-regression manner before transitioning to a more aggradational mode at the onset of deglaciation. The backstep of the margin prior to the drowning of the reef is likely related to a rapid sea level rise during meltwater pulse 1A.

WORK PLAN AND RESEARCH TEAM

Work Plan				
	Year 1	Year 2	Year 3	Year 4
Activities	Transportation of cores to Miami			
	Curation core, cutting, sampling			
	Description of Core	Description of Core		
	Thin section analysis	Thin section analysis	Thin section analysis	
		Quantitative component analysis	Quantitative component analysis	
		Age determination	Age determination	
		Coral ecology	Coral ecology	
		Geochemical analysis	Geochemical analysis	Geochemical analysis
		Petrophysical studies	Petrophysical studies	Petrophysical studies
			SEM analysis	SEM analysis
				Comparison to other studies
				Final Report/Papers

Figure 3: We are currently in the second year of our 4-year research effort.

We assembled a team of experts for each proposed activity. Together, these researchers will develop the most comprehensive reconstruction to date of the Last Glacial Maximum fringing reef system offshore Mozambique. Their specific goals for year 2 are shown below.

- Gregor P. Eberli, Will Wright, Jara Schnyder, Paulina Manekas – Lithologic analysis, seismic interpretation and integration of core and seismic data.
- Ralf J. Weger and student – Core curation and petrophysical analysis of lithofacies.
- James S. Klaus, Nyah Strahm and Scientists from Mozambique – Coral-reef ecology, taxonomic analysis of coral community development spanning the Last Glacial Maximum and subsequent deglaciation.
- Sam Goldberg, Merrilee Rivers – Sea level reconstruction combining age-dated corals as indicators of sea level and GIA modeling of the Mozambique margin.
- Amanda M. Oehlert and students – Stable isotopic analysis of components, benthic foraminifera and chemical analysis of microbialites.
- Benjamin J. Ross – Lecturer at UM will analyze the benthic foraminifera assemblages across the different reef environments.

SIGNIFICANCE

This study will add important and valuable information regarding sea level change, coral reef dynamics and petrophysical properties of microbialite stabilized coral-algal reefs. The cores contain the record of sea level changes during the Last Glacial Maximum for which data points of sea level are limited. Thus, the results will produce new, high-quality geological constraints on the timing and magnitude of sea-level change during the Last Glacial Maximum and the subsequent deglaciation and will contribute to broader efforts to reconcile geological records with glacial isostatic adjustment models. Geochemical analyses will provide a baseline for the paleoenvironmental conditions during the Last Glacial Maximum.

In terms of coral reef ecology, our dataset of 10 cores extends beyond a single-point record to provide a robust, regional archive that will rival established sites like Barbados and the Huon Peninsula. Understanding the "keep-up," "catch-up," and "give-up" strategies of these coral communities provides a direct record of how tropical ecosystems respond to rapid environmental changes. In addition, these microbially encrusted coral reefs typically contain large intraframe porosity yet display an extraordinary strength. The proposed petrophysical investigation will quantify their strength.

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FACIES ARCHITECTURE AND SEISMIC EXPRESSION OF A FRINGING REEF SYSTEM, OFFSHORE MOZAMBIQUE – YEAR 2

Will Wright, Gregor P. Eberli, Jara S. Schnyder¹, and Ralf J. Weger

1) Exxonmobil, Houston

PROJECT OBJECTIVES

- Document and classify reef facies of the fringing reef and reef terraces from core material based on sedimentological and petrographic characteristics.
- Interpret reef-scale architecture using seismic reflection data to define the spatial organization and geometry of the reef complex.
- Integrate core-based facies observations with seismic interpretation to develop a three-dimensional facies architecture framework for the study area.

PROJECT RATIONALE

Fringing reefs are one of the most widespread reef types globally, yet their facies architecture is still far less well constrained than that of barrier reefs or atoll systems. Much of what we understand about carbonate platform development comes from subtropical reef systems with well-developed rims and lagoonal interiors. These systems provide useful analogues, but they do not always capture the range of growth modes and architectural complexity observed in fringing reef systems.

Sedimentological and stratigraphic studies of fringing reefs have shown that these systems are often heterogeneous, both laterally and vertically (Lewis et al., 2012; Madden et al., 2013). Facies distributions and composition can vary markedly over short distances, and core-based studies commonly reveal stacking patterns that depart from simple aggradational or progradational models (Kennedy & Woodroffe, 2001). Facies relationships observed in core or outcrop alone, however, are often insufficient to resolve how these elements are organized in three dimensions.

Seismic reflection data provides an important means of placing sedimentological observations into a broader architectural context. Seismic profiles constrain reef geometry, thickness variations, and the relationship between reef deposits and underlying substrates, allowing facies interpretations to be evaluated at scales that cannot be captured by core data alone. When integrated with detailed sedimentological

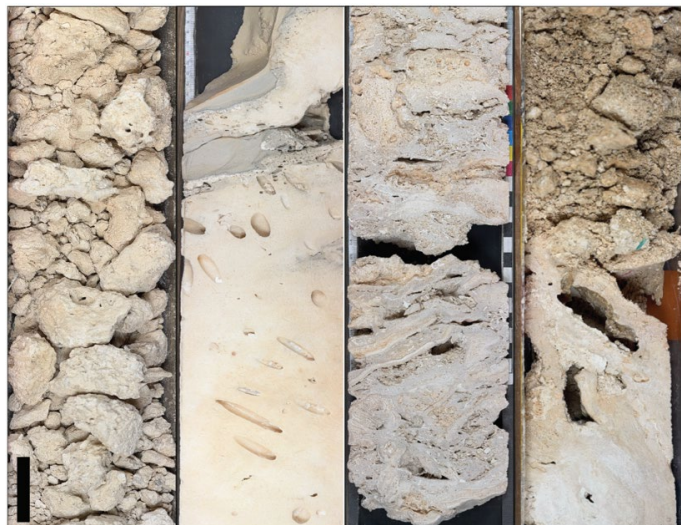


Figure 1: Representative core intervals from ES-103 illustrating major reef facies, from shallow to deep (left to right): back-reef rudstone, reef-crest framework, fore-reef framestone, and fore-reef slope skeletal sand. Scale bar = 5 cm.

analysis, seismic data offer a framework for interpreting how fringing reefs are constructed through time and space.

This project focuses on the facies architecture of a stepped fringing reef system offshore Mozambique using an integrated approach that combines core-based sedimentology with seismic interpretation. The goal is to define facies associations and their spatial organization across the reef system, providing a three-dimensional framework for understanding fringing reef development.

WORK PROPOSED

We will characterize the facies architecture of the stepped fringing reef system offshore Mozambique using integrated core-based sedimentology and seismic interpretation. Work will be completed in three phases.

Phase 1: Facies description and classification: Cores will be logged to identify lithofacies based on texture, grain composition, carbonate fabric and classification, sedimentary structures, and degree of cementation. Thin section petrography will be used to refine facies definitions and document microfacies variability. Facies associations and vertical stacking patterns will be established within and between cores.

Phase 2: Seismic interpretation: Reef-scale geometries, terrace surfaces, and major internal reflections will be identified on three-dimensional seismic reflection data. Seismic horizons and architectural elements will be mapped to constrain lateral continuity and thickness variations across the reef system.

Phase 3: Core–seismic integration: Core locations will be tied to seismic data to place facies observations within a three-dimensional architectural framework. Facies associations will be evaluated in relation to seismic geometries, allowing extrapolation of facies distributions between core control points and development of a reef-scale facies architecture model.

Phase 2 and 3 will be done in collaboration with Jara Schnyder.

SIGNIFICANCE

This work will establish a three-dimensional facies architecture framework for a stepped fringing reef system by integrating core and seismic data. The results will improve interpretation of fringing reef development and provide a robust architectural context for future stratigraphic, paleoenvironmental, and sea-level studies.

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RECONSTRUCTING RELATIVE SEA LEVEL ACROSS THE LAST GLACIAL MAXIMUM

Merrilee Rivers, William Wright, Sam Goldberg, James Klaus, Ali Pourmand, Ralf J. Weger, and Gregor P. Eberli

PROJECT OBJECTIVES

- Identify corals throughout the cores, with particular emphasis on corals preserved near notable facies and stratigraphic boundaries that help record relative sea-level.
- Assess coral preservation and diagenetic alteration before conducting uranium–thorium (U–Th) dating on well-preserved samples to generate age constraints.
- Construct a relative sea-level curve for a poorly constrained time interval spanning the Last Glacial Maximum, contributing new empirical data to improve existing sea-level reconstructions.

PROJECT RATIONALE

The Last Glacial Maximum (LGM) and subsequent deglaciation represent one of the most dynamic periods of sea-level change in Earth's history. Global sea level during the LGM was approximately 120–130 m lower than present, followed by rapid, stepwise sea-level rise driven by ice-sheet retreat (Bard et al., 1990). Studying this interval is critical for understanding ice-sheet sensitivity, meltwater pulse dynamics, and climate–sea-level feedbacks.

Coral archives provide one of the most reliable and precise methods for reconstructing past sea level, as reef-building corals grow within well-defined depth ranges and can be dated with high precision using uranium–thorium (U–Th) geochronology (Pourmand et al., 2013). Well preserved fossil corals can yield age uncertainties on the order of hundreds of years or less, making them uniquely suited for resolving rapid sea-level changes during deglaciation (Bard et al., 1990).

Coral-based sea-level records from the LGM are geographically limited leading to underrepresented intervals from preservation biases and sampling gaps (Kopp et al., 2009). This project aims to address these gaps by systematically identifying fossil corals preserved throughout a collection of sedimentary cores taken from offshore Mozambique that spans the LGM and deglaciation. Corals occurring near exposures or significant facies will be targeted for sampling when available to constrain subaerial exposures and relative sea-level

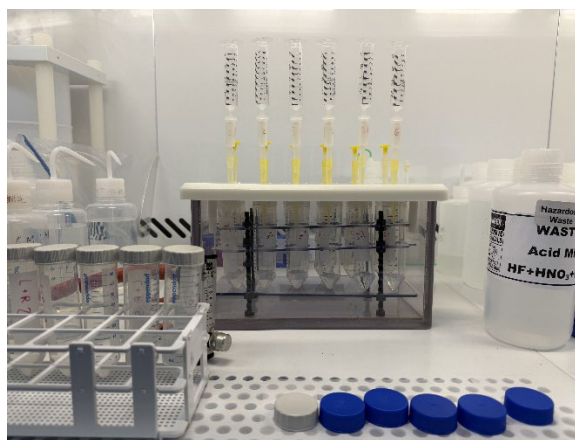


Figure 1: Set-up of Ur-Th extraction chromatography using the U/TEVA resin columns for separation and purification of U and Th prior to isotopic analysis.

stillstands (Dyer et al., 2021). By combining careful screening for diagenesis with high-precision U–Th dating, this study will generate a new set of age–elevation data points that can be used to constrain relative sea-level for this critical but data-poor interval.

WORK PROPOSED

Phase 1: Coral Identification and Stratigraphic Context: Fossil corals will be identified throughout the cores with special emphasis on corals associated with notable exposures as these features may correspond to periods of relative sea-level lowstand or exposure. Coral depths and stratigraphic positions will be carefully documented to preserve their spatial relationship within the core.

Phase 2: Diagenetic Screening and U-Th Dating: Identified coral samples will be screened for diagenetic alteration using microscopy. The best preserved samples will undergo U–Th dating to generate a robust chronologic dataset for sea-level interpretation.

Phase 3: Sea-Level Curve Construction: Coral ages will be combined with their stratigraphic positions and estimated growth position depths to construct a relative sea-level curve spanning the LGM and deglaciation. Results will be compared with existing global sea-level compilations. The final product will be a sea-level reconstruction for a time interval that currently lacks sufficient data.

SIGNIFICANCE

This project will generate new, high-quality geological constraints on sea-level change during one of the most climatically important intervals of the late Quaternary period. By targeting a period with limited existing data, the resulting sea-level curve will help reduce uncertainties in the timing and rate of deglacial sea-level rise. These results will be relevant to studies of ice-sheet dynamics, glacial isostatic adjustment, and future sea-level projections under continued climate warming.

These results will provide valuable constraints on the timing and magnitude of sea-level change before and during deglaciation and will contribute to broader efforts to reconcile geological records with glacial isostatic adjustment models in future work.

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INVESTIGATION OF CORAL COMMUNITIES IN THE MOZAMBIQUE LOW-STAND REEF SYSTEM

James S. Klaus, Nyah Strahm, Will Wright, and Gregor P. Eberli

PROJECT OBJECTIVES

- Identify and catalog coral diversity across the entire 10-core suite to establish a regional baseline for reef development during the Last Glacial Maximum (LGM) and the subsequent deglaciation.
- Reconstruct vertical biofacies successions for each core to map the spatial and temporal migration of the reef system in response to rapid sea-level rise.
- Refine regional sea-level and tectonic models by integrating coral-based depth constraints with existing seismic data and radiocarbon ages to resolve questions regarding margin subsidence and glacial isostatic adjustment (GIA)

PROJECT RATIONALE

Previous analysis of Core ES103 has demonstrated that the Mozambique margin contains an unprecedented high-fidelity archive of late Quaternary reef development (Klaus et al. 2025). Core ES103, a 65-meter section recovered from 94–159 meters depth, revealed a diverse and continuous coral record spanning the last glacial maximum and deglaciation. A total of 328 coral specimens were identified, representing 22 genera. *Acropora* was the dominant genus (53% abundance), particularly in its tabulate and branching forms, alongside common occurrences of *Porites* and *Montipora*. The core captured a distinct shallowing-upward progression, transitioning from a forereef slope environment (characterized by *Leptoseris* and *Oxypora*) to a reef crest (*Acropora* and *Montipora*) and finally a backreef lagoon (characterized by *Galaxea* and mound *Porites*).

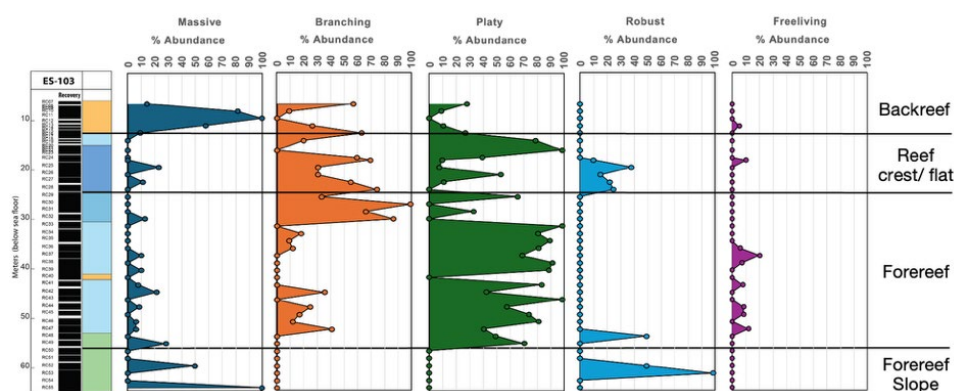


Figure 1: Plot showing vertical changes in coral growth forms in core ES103. Changes reflect varying reef environments associated with reef accretion and sea level change.

These results provided critical environmental constraints. Because different coral communities occupy specific depth and energy niches, their presence in the fossil record allows for precise water-depth reconstructions. This data is essential for interpreting the sea-level signatures found in the core.

WORK PROPOSED

This project proposes a systematic analysis of the remaining nine cores secured from the Mozambique margin, following the established workflow utilized for Core ES103.

Taxonomic and Biofacies Analysis: Following the methodology used for Core ES103, each core will be examined in 1.5-meter intervals. This will include:

- Detailed taxonomic identification of coral specimens to the genus level (and species where possible).
- Quantification of growth forms (massive, branching, platy, robust, and free-living) to determine relative abundance and community structure.

Data Integration: Coral biofacies data from all 10 cores will be correlated with existing industrial 3D seismic data. By mapping these biological markers across the seismic volume, we will create a four-dimensional model of reef growth and drowning during the last deglaciation.

SIGNIFICANCE

The continued study of Mozambique coral communities is significant for both regional geological history and global climate science. Shallow-water reefs are instrumental in constraining sea levels during glacial lowstands (Montaggioni and Faure 1997, Camoin and Webster 2014). By expanding our dataset to 10 cores, we will move beyond a single-point record to a robust, regional archive that rivals established sites like Barbados (Peltier and Fairbanks, 2006) and the Huon Peninsula. Understanding the "keep-up," "catch-up," and "give-up" strategies of these coral communities provides a direct record of how tropical ecosystems respond to rapid environmental change (Kennedy and Woodroffe 2002). The preliminary data from Core ES103 shows potential discrepancies between predicted facies and recorded sea levels. A comprehensive analysis of the full core suite is the only way to determine if these anomalies are due to reef drowning events during meltwater pulses, regional tectonic subsidence, or glacial isostatic adjustment.

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MICROBIALITE MORPHOLOGIES OF THE LOW-STAND FRINGING REEF FROM OFFSHORE MOZAMBIQUE

Paulina Rae Manekas, William Wright, Gregor P. Eberli, Ralf J. Weger, and Amanda Oehlert

PROJECT OBJECTIVES

- Classify the microbialites in a 65 m core of a fringing reef that grew during the Last Glacial Maximum (LGM).
- Log the distribution of individual morphologies in the core to assess the volume of microbialites and morphologies and determine their relationship to the lithofacies. microbialite-coated debris (MCD), structureless, digitate, laminated, intraporal, and microbialite layers.
- Relate color and stable isotopic composition to microbialite morphologies.

PROJECT RATIONALE

Coral reefs of the LGM and subsequent deglaciation events serve as archives of reef responses to extreme environmental changes, particularly shifts in ocean chemistry resulting from sea level fluctuations. A 65 m core (ES-103-BH) of a coral-microbialite reef that grew during the Last Glacial Maximum (LGM) recovered a suite of diverse microbialites with distinct morphologies and colors. In a 2m subset of ES-103-BH, microbialites were volumetrically significant (>18%) and found to provide a pervasive structural framework to the coral reef (Tomchovska et al., 2022). In these samples, the microbialite acts as a cavity filler, a sediment binder, an encrusting agent, and an overall bio-stabilizer

throughout the core. Prior work showed that microbialites in deglacial reefs in Tahiti developed a few hundred years after coralgal communities in shallow-water environments and found that they are a key structural element to the stability of the coral reef (Seard et al.,

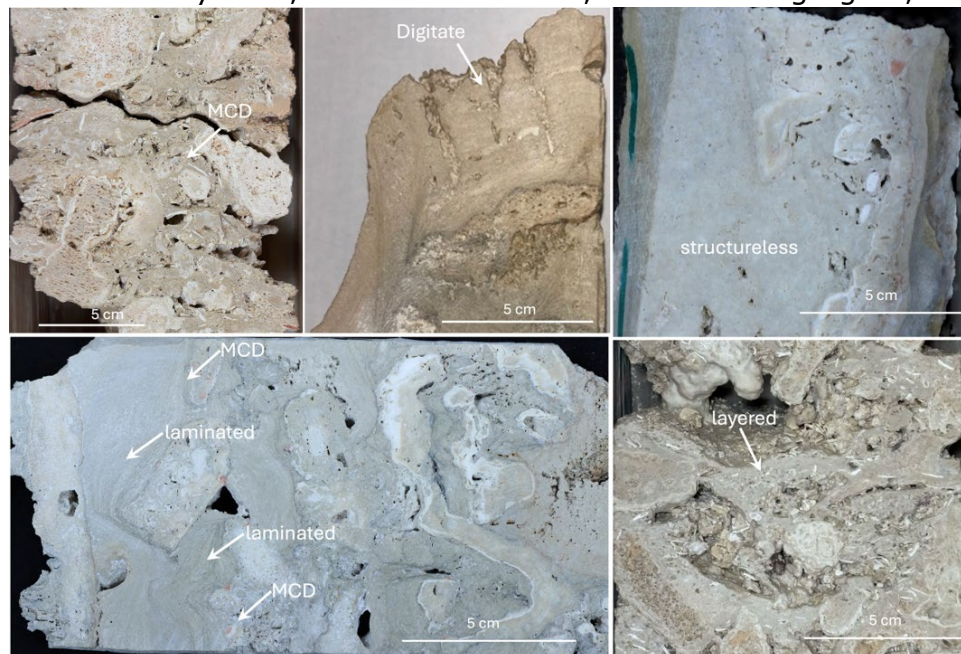


Figure 1: Examples of five microbialite types identified in the Mozambique fringing reef core. A sixth type is an intrapore microbialite recognized in thin sections that is not depicted here.

2011). In all recovered LGM cores, the microbialites have several distinct morphologies and colors. In the Mozambique core studied here, we have recognized six microbialite morphologies (Fig. 1). The environmental conditions required for such unique microbialite morphologies to accumulate are still unknown.

Stable carbon and oxygen isotope ratios can be useful for interpreting the contributions of microbial processes like phototrophy and heterotrophy to the formation of carbonate minerals (e.g., Andres et al., 2006). By combining a detailed classification of specific microbialite-dense cores and high-resolution stable isotope geochemistry, this project will provide a clearer model for interpreting microbialite accretion resulting from environmental changes during the last deglaciation.

WORK PROPOSED

Multiple steps have been defined throughout this project to test the hypothesis that microbialite morphologies and colors are landmarks of environmental changes. Meticulous core logging and high-resolution core photography are pertinent to defining each morphology and color of the microbialite morphologies. Based on the microbialite maps, samples will be taken from each location while defining the color of each sampling location.

Stable carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$) isotope values of the microbialite samples will be measured using a Gas Bench + Delta Q to investigate the influence of external (seawater chemistry) and internal (bacteria community) changes, and correlate morphology and color with these aspects. Finally, a model will be constructed that links environmental conditions to each morphology, color, and stable isotopic composition.

SIGNIFICANCE

This study will establish whether microbialite morphologies, color, or stable carbon and oxygen isotope ratios are paleoenvironment and/or paleoclimate proxies in Core ES-103-BH. By integrating microbialite morphology and color with stable isotope geochemistry, this research provides an important model for the interpretation of microbialite morphologies associated with corallgal reefs throughout the geological record.

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TOWARDS A GEOCHEMICAL RECONSTRUCTION OF PALEOCLIMATIC CONDITIONS DURING THE LAST GLACIAL MAXIMUM IN OFFSHORE MOZAMBIQUE

Amanda M. Oehlert, Jazmin Garza, Ben Ross, James Klaus, and Gregor P. Eberli

PROJECT OBJECTIVES

- Measure the stable carbon and oxygen isotope composition of bulk sediments and sedimentary allochems to develop a multiproxy paleoclimatic reconstruction of temperature and ice volume.
- Assess the mineralogical and elemental composition of selected samples from ES103 to reconstruct sea water temperature and salinity

PROJECT RATIONALE

Reefs are key archives of changing paleoenvironmental conditions and rates of sea-level rise, especially over the Quaternary (Camoin and Webster, 2014). Fossil reefs from Barbados provide foundational perspective into the substantial changes in ice volume, temperature, and sea-level that occurred during the Last Glacial Maximum (e.g., Broecker et al., 1968), however, regional sea-level reconstructions may vary substantially due to factors like Glacial Isostatic Adjustment (Clark and Mix, 2002), creating uncertainty about the rates and timing of ice melting during this time period (Woodroffe and Webster, 2014). Sediment cores from the Mozambique Channel provide a unique opportunity to investigate the evolution of paleoclimatic conditions during the Last Glacial Maximum because they contain a series of lowstand reef successions containing multiple sedimentary allochems that exhibit near continuous deposition through this important period in Earth history. Geochemical measurements like stable carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$) isotope ratios can be applied to such well-preserved sedimentary archives in order to support reconstructions of changes in temperature and ice-volume using both bulk sediment and allochem-specific measurements (e.g., Rohling et al., 2009). Initial results indicate that ES103, our study core collected from the fringing reef terrace, has yet to be subaerially exposed and thus is unlikely to have experienced meteoric

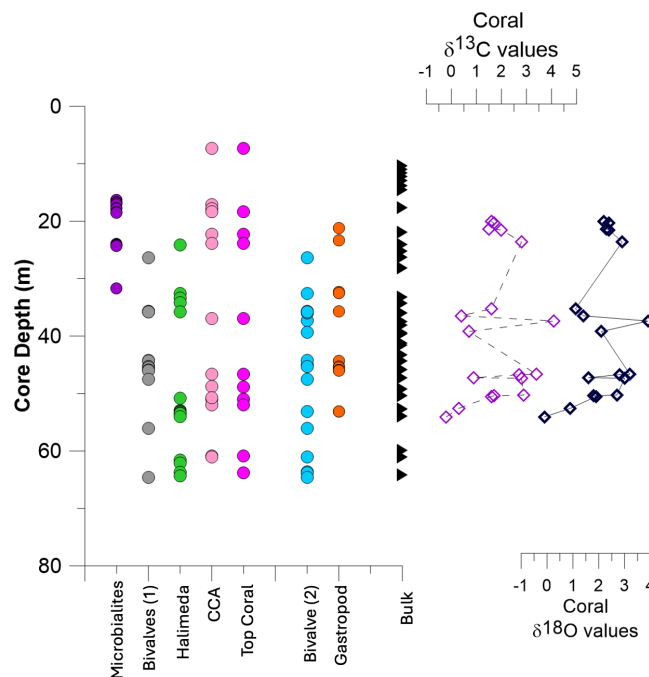


Figure 1: Depths of samples collected for suite of bulk sediments and sedimentary allochems to be analyzed in this study.

diagenesis. Consequently, results from these sediments are expected to provide a robust perspective into environmental changes during the Last Glacial Maximum.

WORK PROPOSED

In this study, we will contribute detailed geochemical characterization of both bulk sediments and eight sedimentary allochems to investigate differences in paleoclimatic and paleo-environmental information preserved in a suite of sedimentary archives. A team of undergraduate and graduate students enrolled in MGS 513/613 Introduction to Geochemistry in Fall 2025 subsampled Core ES103. To investigate the information preserved in the geochemical composition of various sedimentary allochems, students collected samples of bulk sediment as well as a suite of sedimentary allochems, including benthic foraminifera, microbialites, bivalves, *Halimeda*, crustose coralline algae, coral fragments, and gastropods (Figure 1). Samples were collected either by isolating the allochem and grinding with an agate mortar and pestle, or powders were collected from specific allochems using a hand drill. More than 150 samples were ground and weighed. Samples are currently being analyzed for the stable carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$) isotope ratios using a GasBench Plus and Delta Q IRMS. Initial results from measurements of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values from coral skeletons are presented in Figure 1. XRD measurements will be conducted at the College of Engineering, and elemental composition will be assessed using ICP-QQQ.

SIGNIFICANCE

Alongside ongoing work focused on coral reef ecology, sedimentological and stratigraphic descriptions, and the development of radiometric age constraints, geochemical analyses proposed here will contribute to a better understanding of paleoenvironmental changes during the Last Glacial Maximum. In concert, these results are expected to provide a key new constraints on sea-level and ice volume from “far-field” regions that are less influenced by local effects of ice volume (e.g., Yokoyama et al., 2018), like Mozambique.

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ACOUSTIC AND ELECTRICAL PROPERTIES OF CORAL AND MICROBIALITE FACIES IN THE MOZAMBIQUE SHELF CORE

Ralf J. Weger, William Wright, and Gregor P. Eberli

PROJECT OBJECTIVES

- Quantify acoustic velocity and electrical resistivity of distinct lithologies (corals, microbialites, and associated facies) from the Mozambique shelf cores.
- Evaluate the influence of pore structure and diagenetic overprint on petrophysical properties.
- Establish lithology-specific petrophysical signatures to improve log and seismic interpretation.

PROJECT RATIONALE

The Mozambique Shelf Core project represents a unique opportunity to investigate a well-preserved fringing coral reef that developed during the Last Glacial Maximum (LGM). The lithological diversity within the Mozambique cores—including massive coral framestones, laminated microbialites, and interbedded carbonate sands—offers a rare chance to study the petrophysical behavior of distinct reefal components that only experienced early marine diagenesis. In the absence of downhole geophysical logs, laboratory-based petrophysical measurements become essential for characterizing these lithologies. Acoustic velocity and electrical resistivity data are critical not only for generating synthetic seismograms and seismic calibration but also for interpreting diagenetic overprints, porosity evolution, and the mechanical integrity of the reef framework. This project aims to provide a robust dataset of acoustic and resistivity properties for the key lithologies present in the Mozambique cores.

PROPOSED WORK

Approximately 50 representative core samples from the Mozambique Shelf cores will be selected to capture the full range of lithological variability, including coral framestones, microbialites, and associated carbonate sands. Each sample will be prepared as a 1-inch diameter core plug, oriented both vertically and horizontally where possible, to account for anisotropy in rock properties.

Porosity of each plug will be measured using a Micromeritics AccuPyc 1330 helium pycnometer.

Acoustic velocity measurements (both P-wave and S-wave) will be conducted on brine-saturated plugs under a range of confining pressures using a New England Research AutoLab 1000 system. This apparatus allows simulation of subsurface stress conditions, ensuring that velocity measurements (in m/s) reflect in-situ conditions.

Electrical resistivity will be measured concurrently on the same saturated core plugs, using a four-electrode (Wenner array) configuration.

All measurements will be complemented by detailed petrographic analysis (thin section microscopy) and digital image analysis of pore structures. This integrated approach will allow us to correlate the measured physical properties with pore

architecture and lithofacies attributes (Weger et al., 2009; Weger et al., 2023). By linking quantitative pore metrics to velocity and resistivity, we aim to better understand how specific pore geometries (such as moldic vs. interparticle porosity) control acoustic and electrical responses.



Figure 1: Examples of representative 1-inch core plugs from ES-103 illustrating the complexity of rock types in the different reef facies, and the challenges they represent for measuring acoustic velocity and resistivity.

SIGNIFICANCE

The petrophysical characterization of the Mozambique Shelf core lithologies holds significant implications for both academic research and applied geoscience. Acoustic velocity measurements provide insights into the elastic properties of reefal carbonates, which are essential for constructing accurate synthetic seismograms and improving seismic-to-well ties in the absence of borehole logs.

Electrical resistivity measurements complement the acoustic data by providing information on pore fluid content, pore connectivity, and saturation state (Verwer et al., 2011).

By integrating the petrophysical data with petrographic, and geochemical analyses, this project contributes to a holistic understanding of reefal and microbialite systems. Extensive microbialites are typical for lowstand reefs but are also common on the Paleozoic slopes and other times of the Earth history. The knowledge gained will enhance, establishing clear links between lithology, pore structure, and petrophysical properties in the Mozambique shelf cores will improve our ability to predict rock properties in analogous carbonate reservoirs elsewhere.

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ABRUPT CLIMATE VARIABILITY IN THE RED SEA: INSIGHT FROM THE $\Delta^{234}\text{U}$ AND U-SERIES CHRONOLOGY OF DEEP-WATER CORALS

Morgan I. Chakraborty, Haoyu Li, Francois Tissot, Arash Sharifi, Ali Pourmand, and Sam J. Purkis

PROJECT OBJECTIVES

- Quantify the $\delta^{234}\text{U}$ and trace metal variability in Red Sea deep-water corals to reconstruct Quaternary climate extremes
- Improve resolution of Red Sea coral geochronology using a larger sample set
- Compare deep-sea-derived signals with Arabian paleoclimate archives

PROJECT RATIONALE

The aim of this study is to understand how Quaternary climate variability in Arabia is recorded by Red Sea deep-water corals (DWCs). The Red Sea occupies a climatically sensitive position at the intersection of the African monsoon, the Mediterranean westerlies, and the Afro-Asian dust belt. Its semi-restricted connection to the Indian Ocean renders the Red Sea highly responsive to shifts in atmospheric circulation and regional hydroclimate, establishing it as a natural laboratory for investigating climate extremes in rift basins.

Building on the framework from Chakraborty et al. (2025), we explore the potential of uranium-series disequilibria in DWC's as a proxy for terrigenous input and hydroclimate. By quantifying the sensitivity of the $^{234}\text{U}/^{238}\text{U}$ ratio to weathering, riverine discharge, and aeolian dust flux, we develop a framework linking atmospheric circulation, Arabian rainfall, and seawater $\delta^{234}\text{U}$, and apply U-Th geochronology to resolve Late Quaternary climate variability. Together, these advances position Red Sea DWC's as a robust deep-sea archive for reconstructing abrupt hydroclimate events in a dynamically forced region.

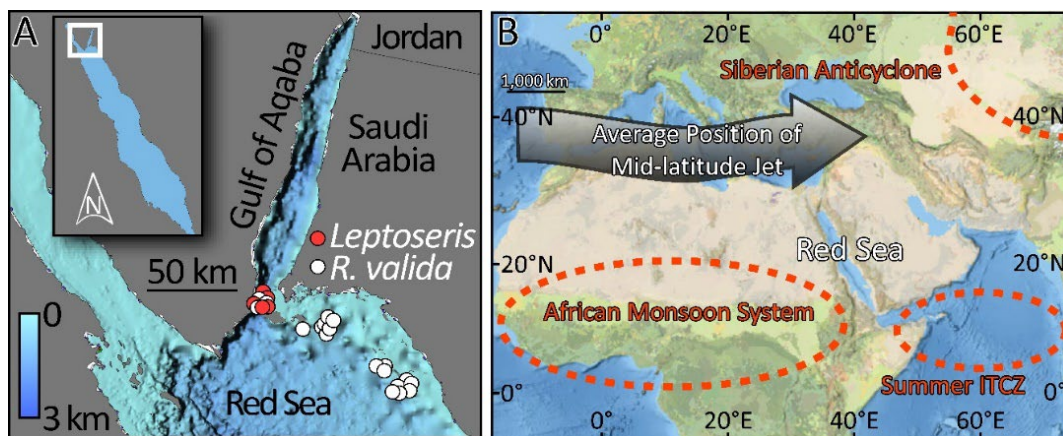


Figure 1: Regional map and sample location. (A) Displays the location of the sampled corals atop multibeam bathymetry data acquired during three research cruises. (B) Set-up of the large-scale atmospheric circulation systems which moderate Arabian climate.

APPROACH

We will expand the existing dataset from Chakraborty et al. (2025) by analyzing an additional 17 DWCs collected from the northern Red Sea. These samples will increase temporal resolution and extend the record beyond 17.8 kya, the age of the oldest coral analyzed to date. Using high-resolution MC-ICP-MS, we will measure uranium-series isotopes, trace-metal concentrations, and perform U–Th geochronology to generate a comprehensive, well-dated record of Late Quaternary hydroclimate variability in the Red Sea.

The resulting coral-based record will be evaluated alongside existing terrestrial and atmospheric archives from Arabia, including records of monsoon intensity, dust flux, and regional precipitation from speleothems. By integrating seawater $\delta^{234}\text{U}$ variability with independently constrained atmospheric circulation proxies, we aim to identify the timing, magnitude, and mechanisms of abrupt hydroclimate events and assess how shifts in large-scale circulation systems are transmitted from the atmosphere to the marine environment and archived in DWCs.

SIGNIFICANCE

Deep-water corals (DWCs) are valuable archives of past U-isotope compositions. The Red Sea offers a unique opportunity to exploit this archive, as we have in hand fossil DWCs, recovered using submersibles and remotely operated vehicles (ROVs) from depths and settings inaccessible to traditional sedimentary records (>250 m water depth). These samples enable direct reconstruction of past seawater $\delta^{234}\text{U}$ in primary skeletons which have not been exposed subaerially during the last sea-level lowstand.

We contend that when the $\delta^{234}\text{U}$ value deviates from the global average (Chen et al., 2016), it provides evidence for changes in terrigenous input into the basin, as mediated by aeolian dust and ephemeral rivers, which reciprocally vary during wet and dry climate shifts. Arabian climate is controlled by the interplay of Hadley Cell systems around the Red Sea, including the African Monsoon System (AMS), Mediterranean westerlies, and the Afro-Asian dust belt. We aim to disentangle how these atmospheric systems regulate Arabian rainfall (Purkis et al., 2025). This project investigates how coupled atmospheric and hydrologic processes interact in the marine system and are then archived in DWCs. By linking atmospheric circulation, hydroclimate, and seawater $\delta^{234}\text{U}$, this work bridges processes across Earth's atmosphere and hydrosphere establishing DWCs as a novel integrative archive for reconstructing Quaternary climate variability in the Middle East.

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CEMENTATION AND AGGRADATION OF RED SEA SLOPES

Morgan I. Chakraborty, Gregor P. Eberli, and Sam J. Purkis

PROJECT OBJECTIVES

- Characterize slope facies and lithification processes along the Gulf of Aqaba margin.
- Determine the mechanisms for early cementation and diagenesis responsible for slope stabilization, distinguishing between microbially-mediated micrite precipitation, abiotic cementation, and a hybrid sedimentation–diagenetic processes.

PROJECT RATIONALE

The Gulf of Aqaba hosts some of the steepest and tallest marine carbonate slopes in a warm-water ocean basin (Ben-Avraham et al., 1979). These slopes are characterized by a wide mesophotic reef zone extending to about 150 m water depth, followed downslope by laterally continuous ledges that persist to the seafloor. These ledges are composed of micritic limestone that is lithified, iron-stained, and pervasively bored by sponges and bivalves, imparting a hardground-like character, albeit vertical. This morphology and mineralogy are reminiscent of microbialites, or cemented carbonate slopes observed in other systems, like Chub Cay (Ginsburg et al., 1991) and the Belize Barrier Reef (Rützler et al., 1982). However, petrographic and SEM analyses do not reveal diagnostic microbialite fabrics, leaving the origin of these deep cemented slope deposits uncertain.



Figure 1. Morphology of cemented carbonate slope deposits in the Gulf of Aqaba (400–700 m). Photos taken from the ROV and submersibles of laterally continuous ledge structures and carbonate facies along steep mesophotic to deep-water slopes. Top: Close-up view of lithified micritic substrate characterized by dense boring traces and hardground-like textures. Middle: Elevated mound or ledge morphology composed of consolidated carbonate material with sparse benthic colonization, highlighting relief development along the slope. Bottom: Downslope perspective showing laterally continuous terrace-like ledges and irregular cemented blocks forming a stepped geomorphic profile.

This new project seeks to resolve the processes responsible for slope cementation and stabilization in the Gulf of Aqaba, with a particular focus on the depth interval between 400 and 700 m, where we suspect microbial influence is present. By integrating facies analysis, microfabric characterization, and geochemical constraints, this study will distinguish between microbial, abiotic, and hybrid mechanisms of early lithification and slope accretion.

APPROACH

Using slope samples collected during multiple research cruises, we will analyze slope facies at 50 m depth intervals from the surface to 750 m water depth. Polished slabs and petrographic thin sections will be examined to characterize micritic textures down the slope. Scanning electron microscopy (SEM) will be used to resolve crystal habits, micritic fabrics, and potential microbial associations at the micro- to nanoscale. X-ray diffraction (XRD) analyses will constrain cement mineralogy, with particular emphasis on distinguishing high-Mg calcite from aragonite phases. Stable oxygen and carbon isotope measurements will infer cement precipitation conditions and evaluate deviations from expected marine signatures. Where feasible, elemental ratios will provide additional constraints on cementation pathways and diagenetic processes.

SIGNIFICANCE

Understanding how steep carbonate slopes form and persist in the Gulf of Aqaba has implications beyond the Red Sea region. Many ancient carbonate margins exhibit steep slopes that are commonly interpreted as microbial or cemented in origin, based on morphology alone. By resolving the mechanisms responsible for slope formation in a modern analogue, this project will provide critical constraints for interpreting carbonate slope deposits in the rock record and improve reconstructions of past oceanographic and diagenetic conditions.

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DETERMINING THE INFLUENCE OF FISH FEEDING STATE ON ICHTHYOCARBONATE COMPOSITION AND FATE

Caroline L. Tran, Sydney M. Cloutier, Bret Marek, Cameron Sam, Sarah Walls, Martin Grosell, and Amanda M. Oehlert

PROJECT OBJECTIVES

- Evaluate how the feeding state of fish influences ichthyocarbonate composition, morphology, mineralogy, and size.
- Characterize the crystallite morphology, mineralogy, and grain size of fed and fasted Gulf Toadfish (*Opsanus beta*).

PROJECT RATIONALE

Marine bony fish are one of the top contributors to marine biogenic carbonate production through the formation and excretion of ichthyocarbonate, carbonate precipitates formed in the intestine as a product of osmoregulation (Oehlert et al., 2024a). The production and excretion of ichthyocarbonate is an important component of the global carbon cycle, as ichthyocarbonate contributes to oceanic alkalinity budgets through dissolution and to the flux of carbonate to the deep ocean by seafloor deposition (Folkerts et al., 2024; Oehlert et al., 2024b; Saba et al., 2021; Woosley et al., 2012). Work predicting ichthyocarbonate fate employs measurements of composition, mineralogy, morphology, and grain size of ichthyocarbonate to inform models estimating the contributions of fish to the carbon cycle (Folkerts et al., 2024; Grosell et al., 2025; Oehlert et al., 2024a). However, most studies done on ichthyocarbonate composition and fate have been conducted on fasted fish, resulting in estimates that may not be representative of the contribution of wild fish to the carbon cycle.

Little is known about the influence of feeding state of fish on the mineralogy, morphology, and size of ichthyocarbonate. This project aims to determine how the feeding state of fish influences the composition and fate of excreted ichthyocarbonate by characterizing the crystallite morphology (Fig. 1), mineralogy, and grain size of ichthyocarbonate produced by fed and fasted fish, allowing for improved estimates of the contribution of wild fishes to the global carbon cycle.

WORK PROPOSED

An experiment will be conducted using Gulf toadfish (*Opsanus beta*). One group of fish will be fed raw squid twice weekly, and one group will be fasted. The excreted ichthyocarbonate will be

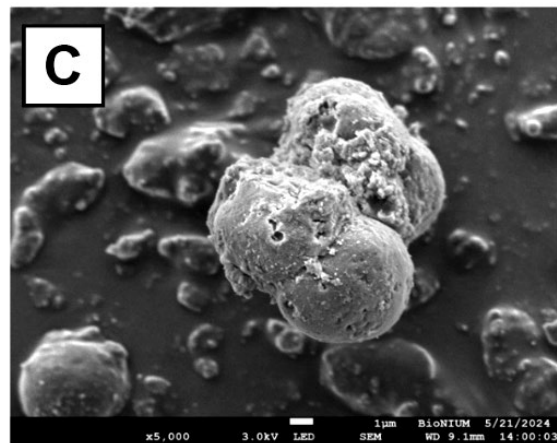


Figure 1: Example of a scanning electron photomicrograph of an ichthyocarbonate crystallite (Grosell et al., 2025).

siphoned daily from the tank bottoms for 12 days. The ichthyocarbonate samples will be photographed in seawater with a scale bar to conduct a grain size analysis using a binary image morphometrics analyzer app (Cloutier & University of Miami, 2026; CC BY-NC-SA 4.0). A few grains from each sample will be fixed to characterize the crystallite morphology using scanning electron microscopy (SEM). The remainder of each sample will be rinsed briefly with MilliQ water to remove seawater and left to dry. The mineralogy of the dried samples will be analyzed using x-ray diffraction (XRD). Together, these measurements will enable us to better predict the behavior and fate of ichthyocarbons produced and excreted by fed and fasted fish. We anticipate that these results will be more representative of ichthyocarbonate excreted by fish in the wild.

SIGNIFICANCE

This work will address the uncertainty from estimations of the contribution of ichthyocarbonate to the carbon cycle using data from fasted fish. Understanding how feeding state influences ichthyocarbonate composition, mineralogy, morphology, and grain size can allow us to update current models and improve our predictions of ichthyocarbonate fate. By refining our estimates of the ichthyocarbonate contribution to oceanic alkalinity budgets and to the carbon fluxes to the deep ocean, we can improve our understanding of the role of marine bony fish in the global carbon cycle.

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ORGANIC MATTER MATTERS: QUANTIFYING THE CONTENT AND COMPOSITION OF ICHTHYOCARBONATE-ASSOCIATED ORGANIC MATTER

Cameron Sam, Sarah Walls, Bret Marek, Martin Grosell, and Amanda M. Oehlert

PROJECT OBJECTIVES

- Determine the effects of fish lifestyle, size, and feeding state on the content and composition of ichthyocarbonate-associated organic matter.

PROJECT RATIONALE

Marine fish are significant drivers of carbon flux out of the ocean's euphotic zone through the production of organic carbon, including fecal material and deadfall, and through the excretion of inorganic carbon in the form of HCO_3^- and a magnesium-rich carbonate (Saba et al., 2021) called ichthyocarbonate (Grosell and Oehlert, 2023). Ichthyocarbonate is predominantly composed of a high-magnesium calcite mineral produced in the intestine of marine teleost fish as a product of osmoregulation (Wilson et al., 2002). Ichthyocarbonate is associated with substantial quantities of organic matter (OM), ranging from ~3 – 40%, representing another source of particulate organic carbon (POC) by marine fish to the biological pump (Oehlert et al., 2024b). By shielding ichthyocarbonate from dissolution in seawater, organic matter plays a vital role in promoting the persistence of sinking ichthyocarbonate that may sequester carbon in the deep oceans by dissolution and

alkalinization or by deposition in seafloor sediments

(Oehlert et al., 2024b).

Likewise, the denser mineral fraction of ichthyocarbonate helps shuttle embedded organic matter to depth, thereby increasing its sequestration potential relative to other fish produced POC like fecal matter

(Oehlert et al., 2024b). Despite

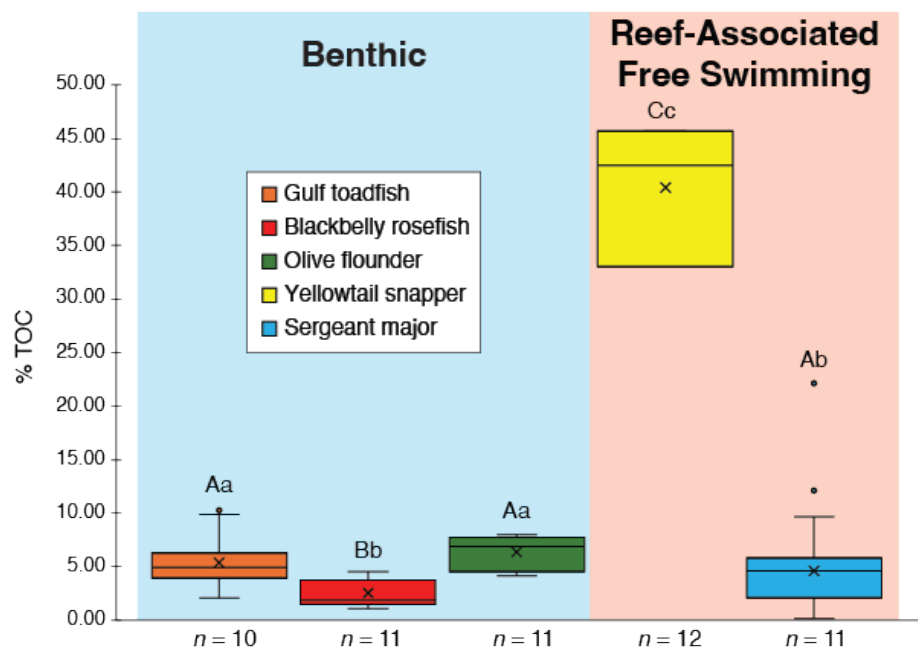


Figure 1: %TOC in ichthyocarbonate collected from gulf toadfish and sergeant major (this study), blackbelly rosefish (Grosell et al., 2025), and gulf toadfish, olive flounder, yellowtail snapper. (Oehlert et al., 2024a).

the importance of ichthyocarbonate-associated organic matter to the biological pump, knowledge gaps exist regarding the content and composition of this organic matter and how this varies by fish characteristics like size, feeding state, and fish lifestyle.

Here, we measured the effects of fish size, feeding state, and lifestyle on the amount associated organic matter. We collected ichthyocarbonate from tanks holding gulf toadfish (*Opsanus beta*), a benthic and sedentary species, and sergeant major (*Abudefduf saxatilis*), a reef-associated, free-swimming fish. We then dissolved ichthyocarbonate samples in 1% nitric acid (HNO₃), filtered out the remaining organic matter, and ran it in a CNS elemental analyzer and DeltaQ continuous-flow isotope ratio mass spectrometer. Comparing our results with those of Oehlert et al. (2024a), we found that % TOC varies by fish species and lifestyle and that there is no correlation between the two factors (Figure 1). In this project, we will explore how fish size impacts $\delta^{13}\text{C}_{\text{org}}$ values and molar C/N ratios in sergeant majors and % TOC in gulf toadfish. We will also investigate the impact of feeding state on $\delta^{15}\text{N}$ values of ichthyocarbonate collected from gulf toadfish.

SIGNIFICANCE

Updated metrics of $\delta^{13}\text{C}_{\text{org}}$, $\delta^{15}\text{N}$, % TOC, and molar C/N ratios will allow researchers to better characterize and quantify the organic matter embedded within ichthyocarbonate and its effects on ichthyocarbonate dissolution. Additionally, measuring impacts of fish lifestyle, size, and feeding state on ichthyocarbonate-associated organic matter will produce more accurate estimates of how ichthyocarbonate production varies across different fish populations. Refined estimates of fish based contributions to the biological pump and carbonate pumps will further understanding of carbon sequestration potential by ichthyocarbonate.

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CONTRASTING EARLY MARINE CEMENTATION IN SKELETAL SANDS AND OOID SANDS

Mara R. Diaz, Gregor P. Eberli, G. Michael Grammer¹, and Ralf J. Weger

1) Oklahoma State University, Stillwater

PROJECT OBJECTIVES

- Compare the rate of early marine cements in skeletal and ooid sands using prolonged, *in vitro* incubation experiments in the presence and absence of microbial marine communities.
- To test whether the microbial community composition differs between the two carbonate sands using DNA molecular analysis.

PROJECT RATIONALE

In a landmark study, Grammer et al. (1999) quantified rates of early marine cementation by deploying different types of carbonate sand in various water depth off the Great Bahama Bank. The deployed ooid sands were cemented to oolitic grainstone in 20 months, and the measured cement growth rates are now used by geochemists to model diagenetic processes. Not reported in the publication was the slower and spatially uneven (patchy) cement observed in the deployed samples of skeletal grains. Incubation experiments on ooid sands revealed that indigenous microbial community within the ooids is responsible for the fast early cementation (Diaz and Eberli, 2022). The newly formed microbial cements were the result of both active (microbial metabolism) and passive mechanisms, involving an amorphous ACC phase that forms along the edges of decaying EPS and/or microbial cell walls acting as matrices for crystal nucleation and growth (Diaz et al., 2023).

In a new experiment, we began testing the hypothesis that microbial load within the grains is influential on cementation by exploring if early cementation in skeletal grains follow a similar trend as in the microbially loaded ooids. Some of the preliminary results of this second set of incubation experiments were already reported in the fall meeting.

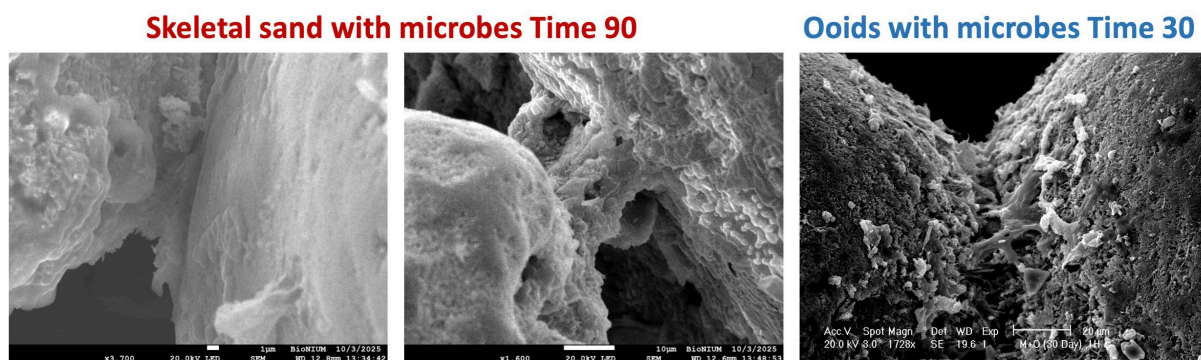


Figure 1. SEM images skeletal sands (left two images) after 90 days of incubation and ooids after 30 days of incubation. Despite the longer incubation, skeletal sands have only sparse and small content of micritic bridging cements, while ooids grains are thoroughly fused by microbially induced micritic cement after 30 days (from Diaz and Eberli, 2023).

As predicted, the rate and extent of cement formation in the skeletal sands were significantly lower compared to the ooids (Fig. 1). One possible explanation is that the microbial communities inhabiting ooids and skeletal grains differ in both diversity and microbial composition. Consequently, we plan to conduct DNA-based analysis of the skeletal sands and compare their microbial assemblage to those of ooids. In addition, we will conduct thin section and SEM analyses in the skeletal sands to generate data sets comparable to those available for ooids.

APPROACH AND METHODOLOGY

The experimental set up for both, ooids and skeletal grains, was identical with two sets of incubations - representing abiotic and biologically mediated precipitation but the duration varied. Due to the slower rate of cementation, the incubation period for the skeletal grains was extended to 120 days, which represents twice the duration of the ooid experiment.

To document the development of inter/intragranular cements and to identify textural forms and mineral microstructure composition of early cement "hot spots" we will conduct petrographic thin-sections and SEM/EDS analyses, complemented by DNA-based analysis.

SIGNIFICANCE

This study will provide insights on the role of microbes and associated EPS in cementation processes in ooids and carbonate skeletal sands. The variable rate and amount of early marine cements potentially have implications for reservoir quality. The reduced amount of early cement in skeletal carbonate shoals could preserve more primary porosity and allow for a higher permeability. Even when the marine and burial diagenesis continues, the originally preserved porosity renders a rock with high permeability as is documented in Miocene skeletal grainstone succession in the cool-subtropical Marion Platform (Ehrenberg et al., 2004). In the geological record, neritic skeletal sands, especially in cool-subtropical and cool-water settings, can be loosely cemented even when they are many million years old.

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PALEOENVIRONMENTAL RECONSTRUCTION OF SALINE LAKES IN THE SALAR DE LLAMARA (ATACAMA DESERT, NORTHERN CHILE) INFORMED BY SEDIMENTOLOGICAL AND GEOCHEMICAL INDICATORS

Zachary Adams, Arash Sharifi, Clément G.L. Pollier, Reid Jansen, Hannah Heath, Ali Pourmand, L. René Daza, Alvaro T. Palma, R. Pamela Reid, and Amanda M. Oehlert

PROJECT OBJECTIVES

- Provide a new stratigraphic history of the Salar de Llamara and identify temporal changes in bottom types and environmental conditions
- Integrate core descriptions, U-Th dating, and total elemental analysis to define facies indicative of distinct paleoenvironments

PROJECT RATIONALE

The shallow saline lakes of the Salar de Llamara are known to respond to complex biogeochemical processes in the hyperarid Atacama Desert, but our understanding of the response of these systems to changing conditions over recent geologic time is yet to be evaluated. Modern lakebed composition is driven primarily by ranges in electrical conductivity of the overlying lake waters, with more saline lakes being dominated by evaporite mineral bottom-types, as opposed to microbially-dominated bottom-types found in the lower conductivity lakes (Reid et al., 2021; Oehlert et al., 2022). The morphology of gypsum crystals within saline lakes varies depending on whether there is a microbial presence during their formation, or if crystal precipitation is due to physical/chemical processes (Vogel et al., 2009). Total elemental analysis can further these interpretations by providing geochemical distinctions between facies and employ proxies for past salinity and detrital input.

This project aims to provide the first high-resolution stratigraphic and geochemical history over the Holocene in two crystalline-bottom lakes in the Puquios of the Salar de Llamara. Our evaluation of gypsum crystal morphology and the associated elemental trends throughout sediment cores will inform a paleoenvironmental reconstruction of the two lakes and qualify the influence of biological versus physical/chemical parameters on sediment characteristics.

WORK PROPOSED

Sediment cores taken in two of the evaporite-dominated lakebeds and through a dome-shaped evaporite structure will be investigated to characterize all modern lakebed structures. A sedimentological and stratigraphic description of the cores will define several facies based on mineralogy, grain size, shape, and crystal terminations.

Each facies will be sampled and digested to facilitate the evaluation of the ages of sedimentary gypsum using U-Th radiometric dating, and to perform total elemental analysis on an ICP-QQQ (Sharifi et al., 2024; Pollier et al., 2025). Statistical analyses

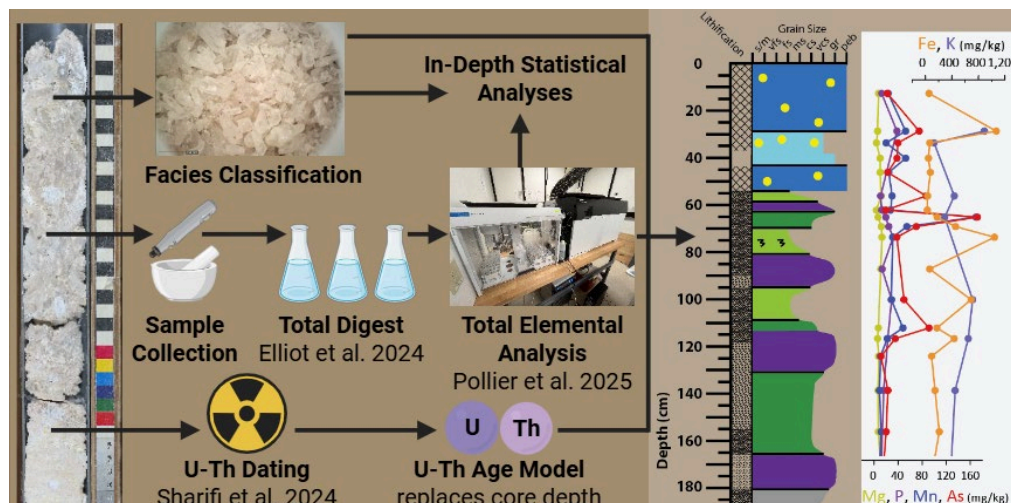


Figure 1: Proposed methodology to produce U-Th dated stratigraphic columns with associated elemental data. Created in BioRender.

such as principal component analysis will be used to determine whether significant chemical differences exist between facies.

SIGNIFICANCE

Characterizing the dynamic nature of saline lakes over centennial to millennial timescales will document the Holocene history of this salar and will provide a set of sedimentological and geochemical characteristics. These attributes will be useful in diagnosing paleoenvironmental conditions that could be applied to the other ~80 saline lake environments in northern Chile, Argentina and Bolivia (Vignale et al. 2022), filling a notable gap in evaluating the long-term evolution of saline lakes in extreme environments like the Atacama Desert.

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INCORPORATE PETROGRAPHY INTO PETROPHYSICAL DATABASE: YEAR 2

Gregor P. Eberli, Ralf J. Weger, and others.

GOALS OF PROJECT

- Assemble a petrographic database in carbonates that includes,
 - Geographic location
 - Formation and age
 - Diagenetic alteration
 - Petrophysical properties (porosity, velocity, permeability and resistivity)
 - Pore type and quantitative digital image analysis parameters of the pore structure.

RATIONALE

The CSL has an extensive petrophysical data base that includes velocity, permeability, resistivity, porosity and pore types (also expressed as digital image parameters) of a wide variety of different types of carbonates. These petrophysical properties and pore structures are the combined result of original deposition and diagenetic alterations. The diagenetic aspect has so far not been added to the database. Likewise, formation and age and depositional settings are not captured in the petrophysical database. We decided to include this information to make the data base a more comprehensive source of information for questions along the line: “What kind of porosity/pore types can I expect in Eocene carbonates?”.

We will add features to the existing database (Figure 1) that will increase the applicability for general

APPROACH AND TASKS

We will add features to the existing database (Figure 1) that will increase the applicability for general

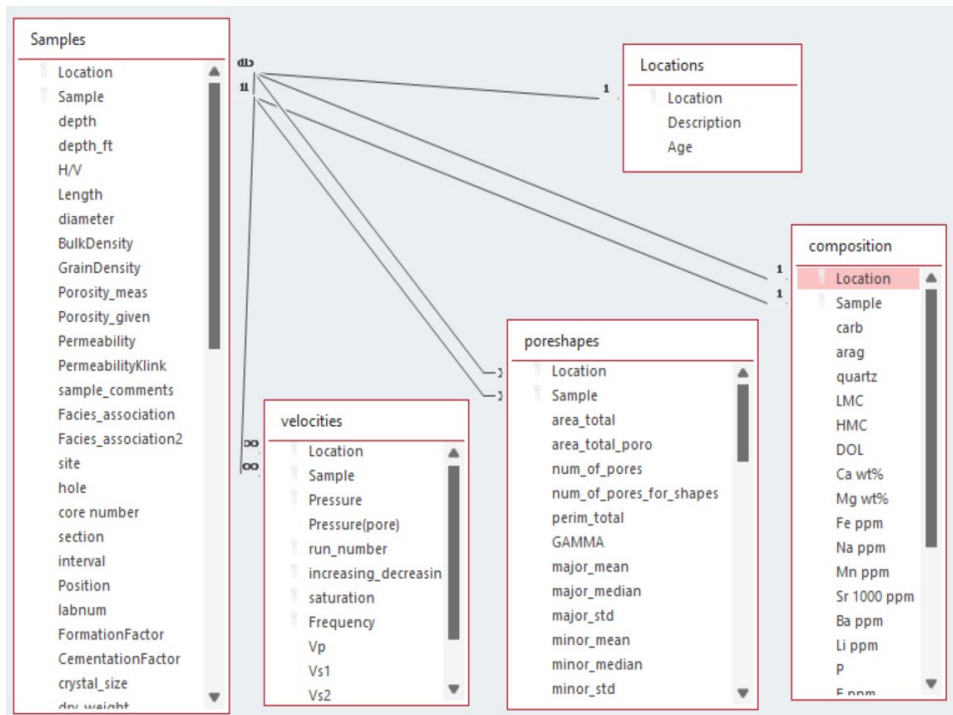


Figure 1: Organization of the CSL Carbonate Data Base.

comparison. These additions include:

- Geographic location and formation name
- Formation name and age
- Depositional setting
- Diagenetic alterations

The geographic location will help to place the sample in a geographical framework. The formation name and age will place it in stratigraphic context. Determining the precise age will rely on the precision of the dated interval in outcrop or in a core. Likewise, the precise determination of the depositional setting will be dependent on the geologic information provided by the scientist who provided the sample to the database. The biggest task is to capture the diagenetic alteration in a consistent and concise manner so that it can be retrievable in the database. We plan to use some of parameters that Tonietto (2014) and Tonietto et al. (2014) used for determining the diagenetic coefficient. These include a cement type, cementation intensity and dissolution intensity (Fig. 2)

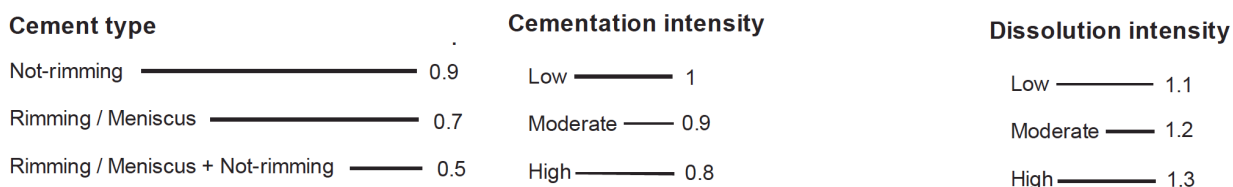


Figure 2: Determination of cement type, cementation and dissolution intensity from Tonietto et al (2014)

SIGNIFICANCE

This combined petrographic and petrophysical database will be of great value to as a comparison database for coeval deposits worldwide. It can be interrogated both from the geophysical side as well as from a geological side and as such should be a versatile tool for estimating geological and petrophysical properties of little-known strata in a frontier region.

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EMERGENT PATTERNING OF MODERN ATOLL REEFS AS AN ANALOGUE FOR SELF-ORGANIZATION OF ANCIENT CARBONATES

Flora Beleznav, Gregor P. Eberli, and Sam J. Purkis

PROJECT OBJECTIVES

- Develop and train machine learning algorithms targeted towards emergent pattern recognition in shallow-water carbonate depositional systems
- Develop a quantitative reef-evolution classification scheme utilizing the latent embeddings and covariance matrices of dimensionally reduced outputs from the machine learning model
- Deploy this analysis pipeline across multiple modern systems to understand the diversity of emergent patterns in Earth's modern carbonates

PROJECT RATIONALE

Reef-building organisms have changed markedly through geologic time, yet they have repeatedly occupied a similar functional niche as ecosystem engineers in shallow-marine carbonate settings. Across both modern systems and ancient analogues, reefs commonly exhibit coherent, emergent spatial patterning consistent with spatial self-organization, in which large-scale order arises from localized biotic–abiotic interactions (Rietkerk et al., 2004). One mechanistic expression of this process is an activator–inhibitor framework (Turing, 1952), which can be formulated as coupled partial differential equations and has been used to reproduce the emergent patterns adopted by more than 30% of modern reefs (Xi et al., 2025). Developing a quantitative classification scheme to encompass the diversity of these patterns would provide a rigorous basis for testing and refining subsurface predictions. This scheme would also enable machine-learning comparisons between modern reef patterns and equivalent architectures preserved in the ancient record. In this way, spatial patterning in modern atoll reefs may serve as a measurable biosignature that strengthens interpretation and prediction of ancient carbonate depositional systems.

WORK PROPOSED

This project is the initial stage of a broader tool development effort aimed at building pattern recognition platforms with extensive algorithm training tuned to recognize and quantify emergent carbonate facies patterns. We build upon previously derived modeling work that explains reef distribution patterns through Turing activator–inhibitor feedbacks (Xi et al., 2025). The primary training and validation database being utilized for this launch phase of the project is the Alacranes Reef platform located in the Gulf of Mexico, whose geomorphology has already been very well studied, mapped, and understood (Purkis et al., 2015). A binary representation of the reticulated reef patterns that occupy the lagoon of Alacranes Reef will be created from satellite imagery, then subset into 1×1 km tiles. Prior to being used in our AI

model, those tiles will then be translated through multiple orientations to reduce anisotropy in model performance and prevent directional bias. Next, these data will be input into a dimensionality-reduction learning framework to generate latent embeddings, which will be clustered to other segments of similar pattern characteristics. Clustering will be run until global optimal center values are obtained. This algorithm workflow will be expandible to atolls across the world, ultimately providing a critical quantitative understanding of pattern types and their evolution.

SIGNIFICANCE

Patterns within various marine environments have been notably observed from centimeter- to meter-scale reticulation, as seen in intertidal mussel beds on the Dutch Tidal flats (van de Koppel et al., 2005), to kilometer scale coral reef patterning (Schlager and Purkis, 2015). Yet, the origins of these patterned distributions are often ambiguous due to similar geometries arising from external (allogenic) forcing versus internally generated (autogenic) dynamics (Burgess, 2006). By quantifying reef pattern evolution in modern atolls and assessing the role of spatial self-organization, this project will establish a mechanistic framework for reef-pattern formation. These modern systems will serve as a prelude analogue for ancient depositional environments, improving interpretation of how ordered and irregular carbonate buildups form, persist, and stack in the geologic record.

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ATLAS OF CARBONATE CONTOURITES

Sara Bashah and Gregor P. Eberli

PROJECT OBJECTIVES

- Provide a database of global carbonate contourite depositional systems.
- Analyze the geometry and dimensions of the various contourite depositional systems.

PROJECT RATIONALE

120 major contourite areas have been recognized worldwide (Rebesco et al., 2014). Recognition of these contourite systems has influenced not only paleoclimatology and paleoceanography studies but also geological hazard assessment and hydrocarbon exploration. In carbonate environments, platforms are substantial barriers in the way of ocean currents; hence drifts are a frequent component of carbonate platform depositional systems. In addition, sizable carbonate contourites have been recognized in various settings (such as continental platforms and seaways) and ages (Eberli and Betzler, 2019). We aim to provide a catalog of global carbonate contourites depositional systems based on existing studies presented in a user-friendly Google Maps format.

APPROACH

Each carbonate contourite depositional system location will be pinned on Google Maps with specific coordinates. For each location, a description of the carbonate contourite system and a link to the scientific articles will be provided. Users can choose to view information on either the Miocene and/or Cretaceous carbonate contourites depositional systems.

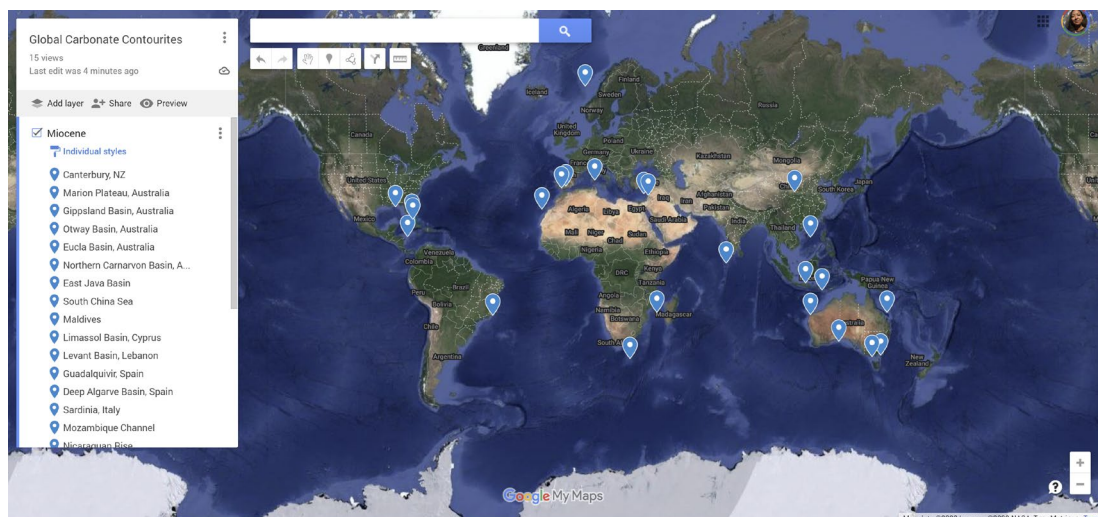


Figure 1: Google Maps showing the location of Miocene carbonate platforms with existing contourites studies.

SIGNIFICANCE

The carbonate contourite database will provide easy access to information on the available literature, geometry, and dimensions of carbonate contourites around the world to aid exploration involving carbonate depositional systems.

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