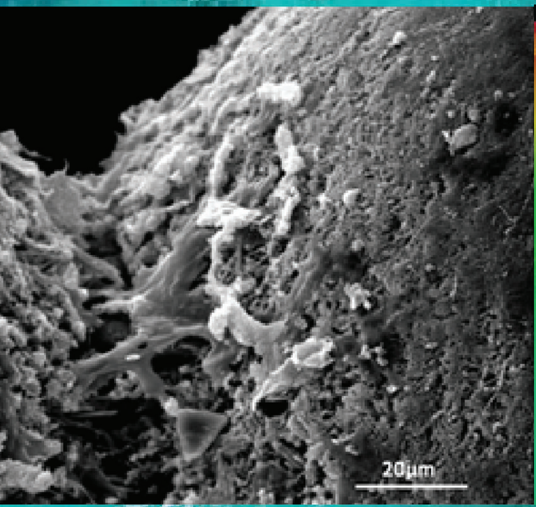
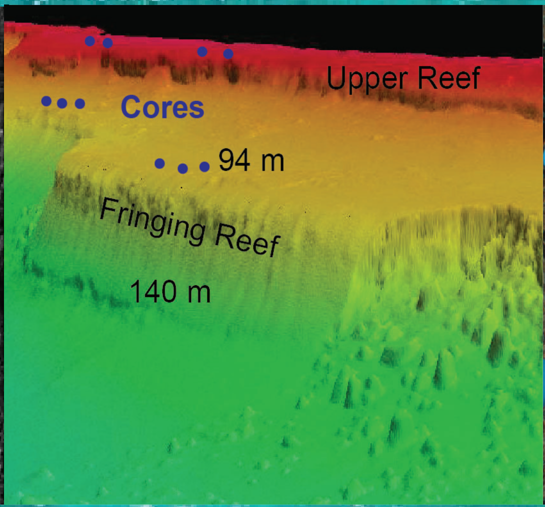
CENTER FOR CARBONATE RESEARCH

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

CSL - Center for Carbonate Research *and Education*

Prospectus 2025





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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 13 projects are divided into these main topics:

- Shallow-water carbonates: Mozambique shelf cores
- Rift basin geology
- Microbial carbonates and geochemistry
- Ichthyocarbonates
- Carbonate contourite depositional systems
- Petrophysics
- Data base of carbonate petrography

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 participatingcompanies.

In addition, we offer field seminars and in-house short courses, as well as Certificate Program in "Applied Geology" that gives geoscientists to become experts in carbonates.

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2025 RESEARCH FOCUS

In addition to our existing research projects, we expand the research inactive rift basins and start two new initiatives; one is the beginning of a **petrographic data base** and the second multidisciplinary study of a cores from a **lowstand fringing reef** offshore Mozambique that grew during the last glacial maximum. With the help of ENI, these cores were made available to us. This core analysis will be a major focus in our **shallow-water carbonate theme**. The fringing reef drowned during the deglaciation and was never subaerially exposed. Thus, these cores carry a unique record of the Indian Ocean during the last glacial maximum and giving us the opportunity to study **unaltered marine cementation** in a reefal system. In the first year, the focus will be on core description, stratigraphy, and preliminary chemical and petrophysical analysis.

Our studies in **active rift basins** in the Red Sea and the Gulf of Aqaba are ongoing with a focus on the lowstand sterilization hypothesis in the Red Sea rift brine pools. The Gulf of Aqaba is an unusual warm basin that can be compared to the Cretaceous oceans. Composition and diagenesis of samples from the deep slope will be analyzed and examined for their difference to "normal" cold ocean slope samples.

The **microbial carbonates and geochemistry** theme is addressed in three projects. The first project studies the diverse organosedimentary deposits in the Salar de Atacama in Chile to unravel the dynamic biogeochemical processes in the geological record. The second project aims to elucidate the effect of microbial communities in diagenetic processes in skeletal grains. To reach this goal, in vitro incubation experiments will be conducted with skeletal grains in the presence and absence of microbial marine communities. The third project is using the vast sample base from the Neuquén basin to measure organic and inorganic carbon variations. Key questions to be answered is if changes in $\delta^{13}C$ values proximal and/or distal behave correlative within the Neuquén Basin and their reliability as global climate proxies.

In the **diagenesis** theme, we plan to assemble a petrographic data base in carbonates with examples of all diagenetic environments. Starting point of this new initiative is our petrophsyical data base where each of the measured samples has a digital image with the diagenetic information.

Our research effort in **carbonate contourite depositional systems** continues with updating the carbonate contourite data base and with a project that investigates the importance of current deposition on continental and carbonate margin stratigraphy. The ultimate goal of this ongoing project is a sequence stratigraphic model that incorporates the facies both current and sea-level controlled deposits.

Ichythyocarbonates – fish produced carbonate grains – have proven to be important for both carbonate production in the ocean and global carbon cycle ("**blue carbon**"). A large collaborative project with biologists addresses many aspects of ichthycarbonate formation and preservation, including the importance of Ichtyocarbonates in the greenhouse world, and fractionation factors associated with the formation of biogenic HMC.

Petrophysics and Carbon Capture Utilization and Storage (CCUS) theme we continue the long-term experiments of the seal capacity of mudstone in the petrophysical laboratory with a re-design of the experimental set-up. A new project investigates why carbonate samples with similar pore geometries and high acoustic velocities but exhibit variable permeability.

Please see the detailed description of each project planned for 2025 in the prospectus.

2025 PLANNED PROJECTS

Mozambique Shelf Cores

- Research Initiative planned tasks for first year
  - Core description and age determination
  - Identification of coral and microbial assemblages in a lowstand reef
  - Start of geochemical, petrophysical, and diagenetic investigations

RIFT BASIN GEOLOGY

- Biological Persistence in an Active Rift in the Red Sea rift
- Carbonate Slopes in the Gulf of Aqaba

Microbial Carbonates and GEOCHEMISTRY

- Microbialite biogeochemistry across extreme environments: A comparative approach
- Early Marine Cementation in Holocene Skeletal Sands
- Proximal to Distal Trend of the Carbon Isotopic Composition in the Vaca Muerta Formation, Neuquén Basin Argentina

ICHTYOCARBONATES (BLUE CARBON)

- Determining the importance of ichthyocarbonate in greenhouse worlds
- Empirical definition of stable carbon isotope fractionation factors in biogenic HMC

CARBONATE DRIFT DEPOSITS

- Incorporation of Currents into Sequence Stratigraphic Models
- Atlas of Carbonate Contourites

PETROPHYSICS

- Testing Seal Capacity for Carbon Storage - an Experimental Approach – (Year 2)
- Integrating Acoustic Velocity, Electrical Resistivity, and Digital Image Analysis

DATA BASE OF CARBONATE PETROGRAPHY

- Incorporate Petrography into Petrophysical Database

2025 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:

Thursday June 24th, 2025 – 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.

Tuesday – Wednesday, October 6th - 7th, 2025 - ANNUAL REVIEW MEETING

The results of the projects detailed in this prospectus will be presented at the **Annual Review Meeting in Miami, October 6th and 7th, 2025**. We will send out information on the logistics for the meeting in the second quarter of 2025.

The **fieldtrip** from in conjunction with the annual review meeting is to **Paradox Basin**, Utah will be **October 8th – 12th, 2025.**

During the 5-day field trip we examine the upper Paleozoic rocks in the Paradox Basin of southeastern Utah that are the result of cyclic deposition of mixed carbonates, siliciclastics and evaporites. Deeply incised canyons along the San Juan River provide spectacular exposures of rocks. We will utilize these outcrops to examine the cyclic nature of Pennsylvanian strata and the vertical and lateral facies variations. We will observe the dimensions and heterogeneities of an exhumed algal mound field and relate it to subsurface data. The goals of the field trip are to illustrate fundamental processes in mixed sedimentation, high-resolution and mechanical stratigraphy. Cost and itinerary of the field trip will be provided later.

MOZAMBIQUE SHELF CORES – RESEARCH INITIATIVE

Gregor P. Eberli, Ricardo Argiolis[1], Ralf J. Weger, James Klaus, Peter K. Swart, Amanda Oehlert, and others.

1) EniProgetti SpA

PREFACE

In 2023 the CSL made a proposal to the Instituto Nacional De Petroleo (INP) of Mozambique in which we "kindly asked to have access to the shelf cores drilled in offshore Mozambique, which we intend to investigate in an integrated study that includes sedimentology, diagenesis, reef ecology, geochemistry and petrophysics".

On July 17, 2025, the Instituto Nacional De Petroleo (INP) of Mozambique granted permission to the University of Miami to analyze the cores. They had been stored in London and arrived in December in Miami. To our surprise and delight, the core material is more extensive than anticipated. It consists of 10 cores drilled at 4 sites.

In our solicitation to INP we listed the rational, projects goal and proposed a 4-year work program, which is outlined below. It is followed with a description of phase one of the initiative.

RATIONALE FOR THE STUDY

The fringing reef offshore Mozambique started to grow during the Last Glacial Maximum (LGM) at approximately 20 kyrs and drowned during the subsequent deglaciation. Such lowstand reefs have been cored in a few places around the world, including offshore the modern Barrier Reef and Tahiti. However, these borings have not achieved the level of core recovery as those of Mozambique.

The Mozambique cores will provide a unique opportunity to study lowstand reef complexes that have never been exposed to freshwater diagenesis. Given the high level of preservation, these cores are of intrinsic value as they represent an unaltered geologically record.

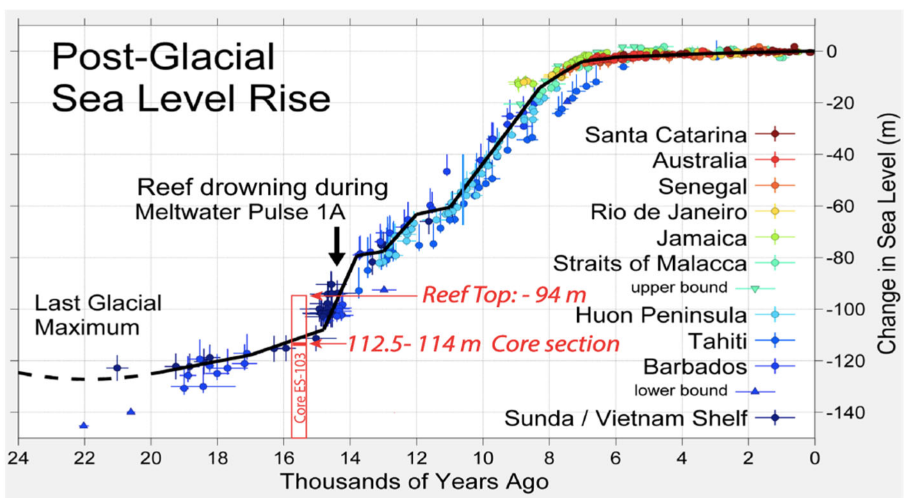

Figure 1: Position of one of the cores from Mozambique within the post glacial sea-level rise. This lowstand reef that crested at -94 m. A 2-m core section has previously been studied in Miami.

Analyses of these cores will be instrumental to address several fundamental objectives. These include: 1) the assessment of seawater composition and temperature during the LGM, 2) the timing and rate of sea level rise during the early deglaciation, 3) early marine diagenetic processes, 4) the identification of the coral species and their changes from the LGM through the early stages of the deglaciation, 5) the role of microbial crusts that have been documented as structurally volumetric components of reef environments during the LGM, and 5) relate the pore structures to the petrophysical properties of these carbonate rocks cemented solely in the marine realm.

GOALS OF PROJECT

- To decipher the timing of initiation, growth and drowning of the fringing reef during the last glacial maximum.
- To assess the composition of the reef and the contribution of microbial crusts in stabilizing the reef.
- To thoroughly analyze the diagenetic alteration in this reef that was never exposed to fresh water.
- To produce a comprehensive petrophysical data set of the core material that includes porosity, acoustic velocity, and resistivity.

WORKPLAN AND TASKS

The study of this extensive core material and large scope of the project will require four years to complete. The proposed tasks are arranged in the workplan below; roughly in a chronologic order, but once sampling is completed, several investigations will be done simultaneously by different scientists.

Work Plan

Activities: Year 1	Year 2	Year 3	Year 4
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

SUMMARY OF PROPOSED TASKS

1. Curation of core: The cores will be cut longitudinally into two halves. One half will be the archive core, which will be photographed and preserved, while the other will be used as a "working" half for a myriad of analyses, including petrographic, geochemical and petrophysical analyses.

2. Detailed core description on the archive half of the core will use Dunham classification.

3. Coral ecology: Identification of the coral species will be undertaken using morphological attributes; in addition, changes in coral community structure will be assessed as sea water composition changes during the deglaciation.

4. Quantitative analysis of core components will be undertaken by identifying textures (i.e. microbial crusts, corals, sediment grains) in core and on stitched images. The quantification will be done on adjusted images using Image J's "analyze particles" function.

5. Thin section analysis of petrographic fabrics, diagenetic alterations and grains will be conducted.

6. SEM (scanning electron microscopy) analysis of the microbial crusts and marine diagenetic cements will be undertaken.

7. Age determination using C14method on reef material and crusts will be employed to determine if they grew coevally.

8. Petrophysical studies will be done on 1-inch core plugs that are drilled vertically and horizontally into the working half of the core. Porosity will be measured with a Micromeritics AccuPyc 1330 Helium pycnometer utilizing Boyle's law. Laboratory measurements of acoustic velocity and electrical resistivity measurements will be performed on brine-saturated core plugs under variable pressures using a New England Research Autolab1000 system.

9. Geochemical analyses will consist of: 1) stable isotope analysis on regularly spaced samples in each core, 2) XRD of the same samples to determine mineralogy and 3) clumped isotope to determine the water temperature during reef growth.

10. Results from this research will be compared to previous studies conducted in Tahiti and offshore the Great Barrier Reef. The comparison will include reef composition, coral species ecology and geochemical signature.

SIGNIFICANCE

Constraining the relative sea-level (RSL) changes during the Last Glacial Maximum (LGM) is difficult because data points of sea level is limited to a few locations (Vacchi et al., 2025). Cores from offshore Mozambique will add a much-anticipated data point for establishing the timing, magnitude and rate of elative sea level changes from the onset of the LGM at ~29.5 ka BP to the beginning of the main phase of deglaciation at ~16.5 ka.

In addition, these microbially encrusted coral reefs seem to preferentially grow during deglacial periods. They typically contain large intraframe porosity yet display an extraordinary strength, thus maintaining this porosity to large burial depth and are potentially excellent reservoirs. If such microbialite/coral reefs form in a lowstand setting, they could be identified as lowstand reefs on seismic data.

MOZAMBIQUE SHELF CORES – PHASE 1: CORE CURATION AND DESCRIPTION

Gregor P. Eberli, Ralf J. Weger, Sophie Gigante, Paulina Manekas, James Klaus, and International Partners

GOALS

- To describe the composition of the cores and quantify the different components, including corals, microbialites, rubble, carbonate sand.
- Examine the difference in composition of the (older) fringing reef that grew during the Late Glacial Maximum (LGM) and the younger reef at the edge of the Upper Terrace.
- Establish a robust age frame of reef growth with C_{14} dating.
- Start a sampling campaign for a comprehensive diagenetic and petrophysical investigation of the cores and produce preliminary data set.

INTRODUCTION OF UNIQUE DATA SET

The slopes above the newly discovered giant gas fields offshore Mozambique (Fonnesu et al., 2020) revealed a long fringing reef that crested at -94 m water depth. The reef started to grow during the Last Glacial Maximum (LGM) at approximately 24 kyrs and drowned during the subsequent deglaciation (Figure 1). The reef backstepped and formed a younger fringing reef that is the edge of the Upper Terrace (Figure 1). Such lowstand reefs have been cored in a few places around the world, including offshore the modern Barrier Reef and Tahiti (Camoin et al., 2006; Heindel et al., 2012, Vacchi et al., 2025, Webster et al., 2025). What makes the cores from Mozambique unique is the number of long cores drilled into the LGM reef as well

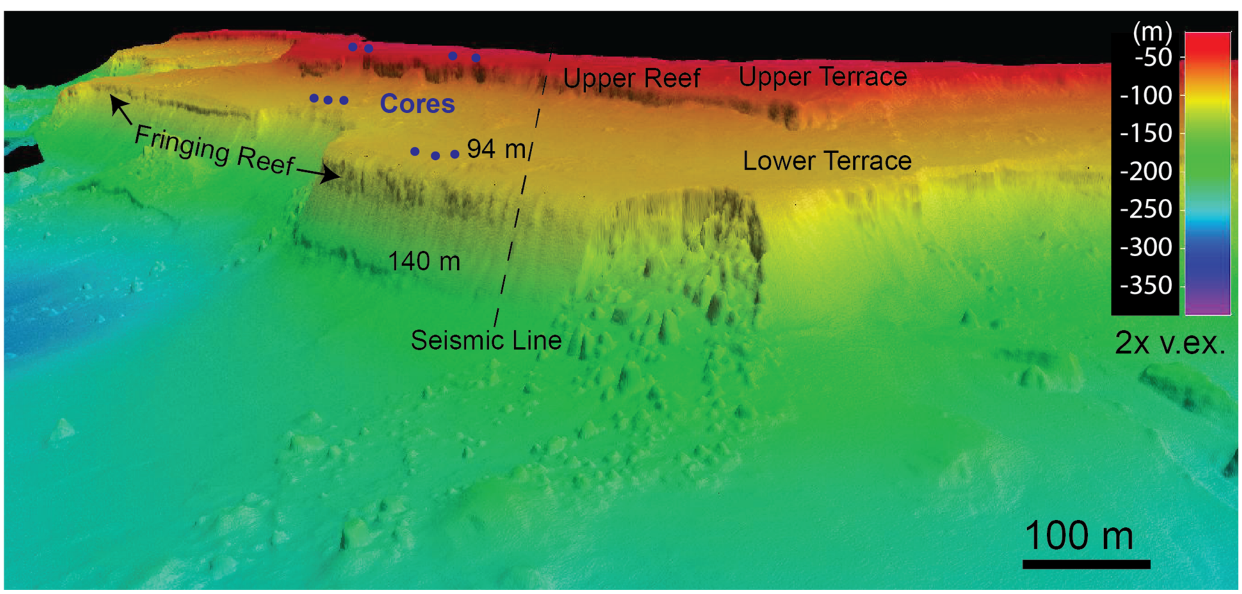

Figure 2: Approximate locations of the ten cores. Six cores were retrieved from the fringing reef along the Lower Terrace and four cores from the back-stepped reef forming the edge of the Upper Terrace.

as the cores from the Upper Terrace that retrieved a younger backstepped reef. Together these cores provide a unprecedent record of timing of LGM and the onset and rate sea level rise during the deglaciation.

INFORMATION EXPECTED FROM THE CORES

A 2 m section was made available to us a couple of years ago. It showed a diverse coral community with several species but also thick crusts of greyish microbialites, encrusting calcareous coralline algae and skeletal rudstone and grainstone (Figure 3; Tomchovska et al., 2022). Two samples collected for C-14 dating from this section yielded ages of 13,400 and 13,600 kyrs, documenting reef growth shortly after the LGM during the deglaciation and the sea-level rise event called Meltwater 1A.
The cores provided to us not only consist of two cores through the fringing reef but 10 cores from 6 sites (Figure 4). This expansive core coverage is most valuable for several reasons. First, the six long cores through the fringing reef will provide the lateral variability of the LGM reef growth and microbial encrustation but more

Component	Percentage of Surface Area
Coral	53.6%
Microbialite crust	14.1%
Calcareous coralline algae (CCA)	3.8%
Skeletal rudstone to grainstone	28.5%

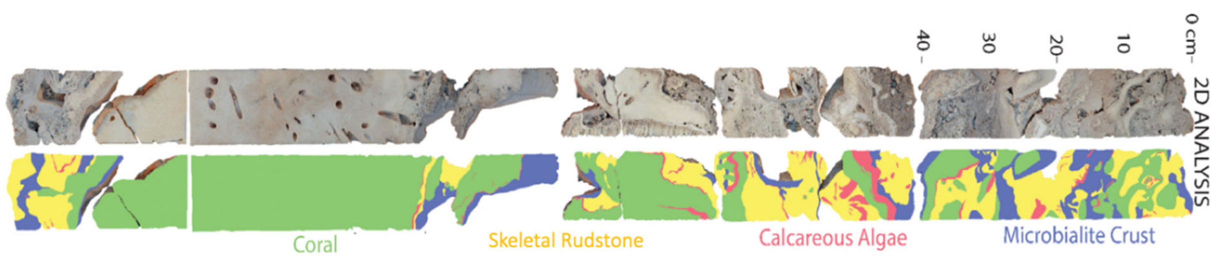

Figure 3: Quantitative analysis of the 2 m core section, displaying the four elements present and their respective abundance.

importantly will help to construct a robust time frame of the reef development during the LMG and the early deglaciation.

Second, the four cores through the younger reef on the Upper Terrace (Figure 1) offer the opportunity to examine the changes in reef composition during the Holocene sea-level rise and also to assess if the amount of microbial coating that is so prevalent in the LMG reefs (Camoin et al., 2006; Heindel et al., 2012) is decreasing with rising sea level. Furthermore, the six-fold coverage of the LGM reef allows to address many questions in a very comprehensive way, such as the evolution of the reefal community and the changes of the reef-building community towards the drowning, as well as the onset of microbial coating that is typical for LMG reefs. In addition, there will be enough material for comprehensive diagenetic and petrophysical studies.

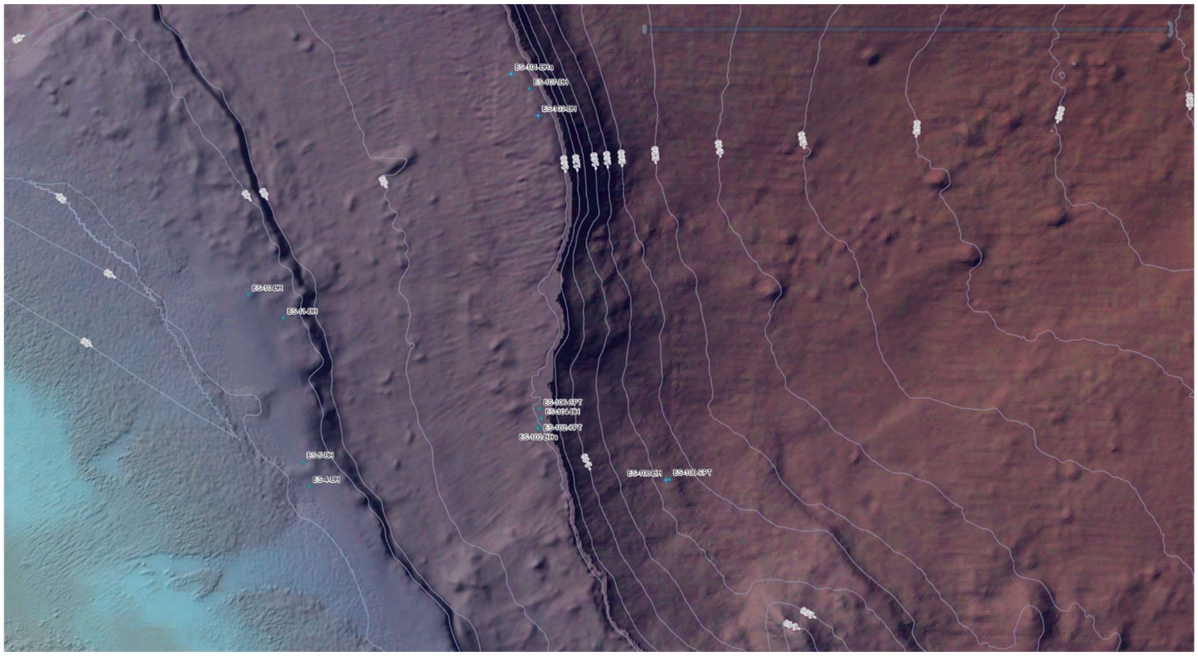

Figure 4: Bathymetry and locations of the 10 cores offshore Mozambique.

WORK PLAN

After viewing and sorting the core material we decided to first work on core ES 103-BH, which is located on the edge of the LGM fringing reef and has a total core depth of 63.5 m. The core sections will be photographed and subsequently described. Cores will be cut and divided into a working half and archive half. Only the working half will be sampled for further analysis. Subsequently, all the other cores will be examined the same way.

In this first phase, the main goal is to describe the cores, cut enough thin sections to produce a petrographic analysis of the lithofacies and diagenesis. The description will include the identification of the coral species to capture the potential evolution coral ecosystem during the early sea level rise and eventual drowning. In addition, extensive amounts of samples will be taken to establish the age of the reef during the LGM and the onset of the deglaciation. Furthermore, samples for geochemical and petrophysical analysis will be taken. The analyses of these samples will be the focus of phase 2 but initial results will be produced on a subset of samples.

EXPECTED OUTCOMES

With the help of international collaborators, we will provide a comprehensive description of the cores that includes

a) the amount and diversity of the coral species in the LMG and younger reef
b) the relative amounts of corals versus microbialites and reef rubble
c) age of reef during the LGM and the onset of deglaciation as well as the timing of the backstepping of the reef.
d) Initial results on the diagenesis and petrophysical properties.

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The Red Sea Survived the Last Glacial Maximum

Morgan I. Chakraborty, Arash Sharifi, Francois Tissot, Ali Pourmand, Bolton Howes, Peter K. Swart, Chaojin Lu, and Sam J. Purkis

Project Objectives

- To investigate the prevailing hypothesis of Red Sea basin-wide ecological collapse during glacial sea-level lowstands

Project Rationale

The Red Sea connects to the Indian Ocean via the Bab-el-Mandeb Strait, a narrow and shallow passage that controls water exchange between the two basins. Due to high evaporation rates and minimal freshwater input, the Red Sea is one of the warmest and saltiest marine basins on Earth. During glacial periods, lower sea levels further restricted this connection, leading to extreme salinity increases. Evidence from seabed cores shows that during the Last Glacial Maximum (LGM), when sea-level fell 110-m below present, salinity rose to at least 50 PSU, possibly making conditions uninhabitable for marine organisms (Hemleben et al., 1996; Arz et al., 2003; Biton et al., 2008). The absence of microfossils, like planktonic foraminifera, suggests that parts of the Red Sea may have undergone total ecological collapse (Reiss et al., 1980; Fenton et al., 2000). Some researchers argue that during extreme lowstands, the Red Sea functioned more like a hypersaline lake, with recolonization only occurring after sea levels began to rise back to present day levels around 15,000 years ago (Klausewitz et al., 1989).

However, the notion of complete ecological collapse is debated. Some species, such as foraminifera, coccolithophores, and pteropods, may have survived in the northern Gulf of Aqaba and southern Red Sea (Locke et al., 1988). The high level of endemism among Red Sea fish and invertebrates also suggests that at least some marine life persisted through glacial sea-level lowstands (DiBattista et al., 2016). Two main hypotheses explain these refugia: one proposes that increased rainfall at the end of the glacial period reduced salinity, while another suggests that a narrow but continuous connection to the Indian Ocean remained open (de Lattin, 1967;

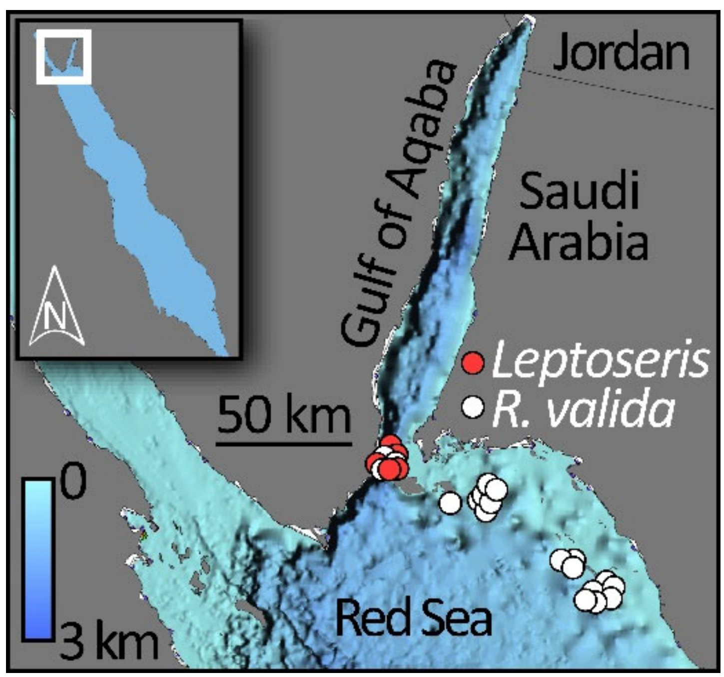

Figure 1. Locations of sampled corals and seawater in the northern Red Sea. Two coral species were collected: Rhizosmilia valida from 20 sites at depths of 400-720 m, and Leptoseris cf. striatus from six sites at depths of 80-90 m.

Bailey et al., 2007; Lambeck et al., 2011). To test these theories, we will analyze deep-water coral skeletons from the northern Red Sea, using geochemical dating and isotopic analyses. Our findings will provide critical insight into how rift-basin ecosystems respond to extreme environmental shifts and whether the modern biodiversity of the Red Sea developed only after the last deglaciation or persisted through past glacial period.

APPROACH

The study will employ a multidisciplinary approach to investigate the survival of deep-water corals in the Red Sea during the last glacial lowstand. Fossil coral skeletons of Rhizosmilia valida and Leptoseris cf. striatus have already been collected from 26 sites in the northern Red Sea using submersibles from the R/V OceanXplorer (Fig. 1). To establish the chronology of coral growth, Uranium-Thorium (U-Th) dating will be used. Geochemical analyses will be conducted to assess the environmental conditions, including clumped isotope (Δ47) thermometry to estimate past seawater temperatures, radiogenic strontium isotopes (87Sr/86Sr) to assess water-mass exchange between the Red Sea and the Indian Ocean, and stable oxygen isotopes (δ18O) to infer changes in salinity and evaporation rates.

Additionally, a meta-analysis of 27 deep-sea sediment cores from previous studies will be conducted to evaluate the presence or absence of microfossil groups, such as planktonic foraminifera, pteropods, and coccolithophores, through the last glacial period. This combined dataset will be used to test the hypothesis of basin-wide extinction during the lowstand and to explore the ecological dynamics of the Red Sea under orbital sea-level oscillations.

SIGNIFICANCE

The prevailing hypothesis suggests that life was extinguished in the Red Sea when sea level fell at least 110-m below present at the end of the Last Glacial period. This sterilization is thought to have occurred because that drop restricted the basin from the Indian Ocean, inducing a hyper-salinity crisis. If true, this scenario suggests that carbonate deposition in rift basins proceeds in a punctuated, staccato, fashion, with implications for the vertical and lateral continuity of facies belts.

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Carbonate Slopes in the Gulf of Aqaba

Ellie Barkyoumb, Ralf J. Weger, Sam Purkis, Peter K. Swart, and Gregor P. Eberli

Project Objective

- Analyze slope carbonates from the Gulf of Aqaba, with the goal of revealing what organic and inorganic mechanisms are at play to stabilize and bind sediments in this location.
- Determine the role of microbial and marine cement on the stability of the slope.
- Examine if the warm waters in the Gulf of Aqaba produce a different diagenetic cementation pattern than the marine diagenesis in cold oceans.

Project Rationale

The Gulf of Aqaba located along the African and Arabian margins, forms the southern end of the dead sea transform. This young and actively rifting basin is considered the most seismologically active region in the middle east (Abdelazim et. al, 2023). As a result, there is considerable evidence for tsunamigenic potential due to submarine landslides in the Gulf of Aqaba (Purkis et al., 2022). With rapid urbanization along the shores of the Gulf, combined with the morphological characteristics of the narrow basin and steep slopes, it is essential to understand the composition and stability of carbonate slopes in the Gulf of Aqaba.

Another unique feature of the Gulf of Aqaba is the warm water in the Gulf of Aqaba that is similar to water temperatures in the Cretaceous Ocean (Fig. 1). Water temperatures do not significantly decrease with depth but are above 21°Celsius, even at depths of 1700 meters. In addition, due to the restricted nature of the basin, the Gulf of Aqaba is hypersaline, with an average salinity of 40 psu (Purkis et al., 2022). These unique conditions dictate not only the faunal assemblages that build frameworks and create sediment, but might also influence the diagenetic processes that transform these sediments.

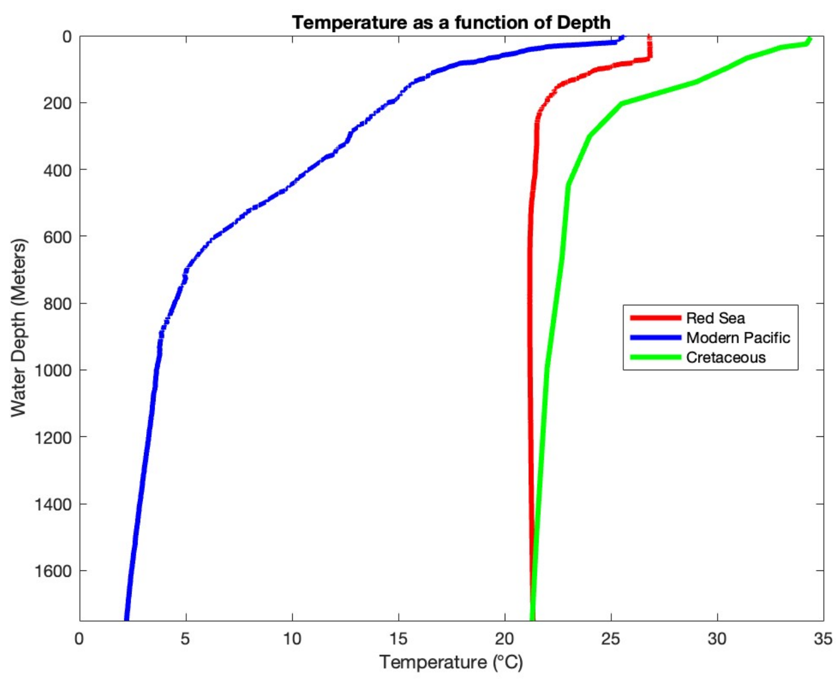

Figure 1: Temperature profile of the Red Sea, Modern Pacific and the Cretaceous. The Red Sea profile is unusual as temperature remains warm to great depth, while in most modern ocean basins temperatures decrease rapidly with depth.

Sample Set and Methodology

We plan to analyze a total of 30 rock samples that were collected from varying depths, ranging from 0 to 700 meters water depth, using the ROV Neptune, deployed on research cruises aboard R/V OceanXplorer in 2020 and 2022 (Fig. 2).

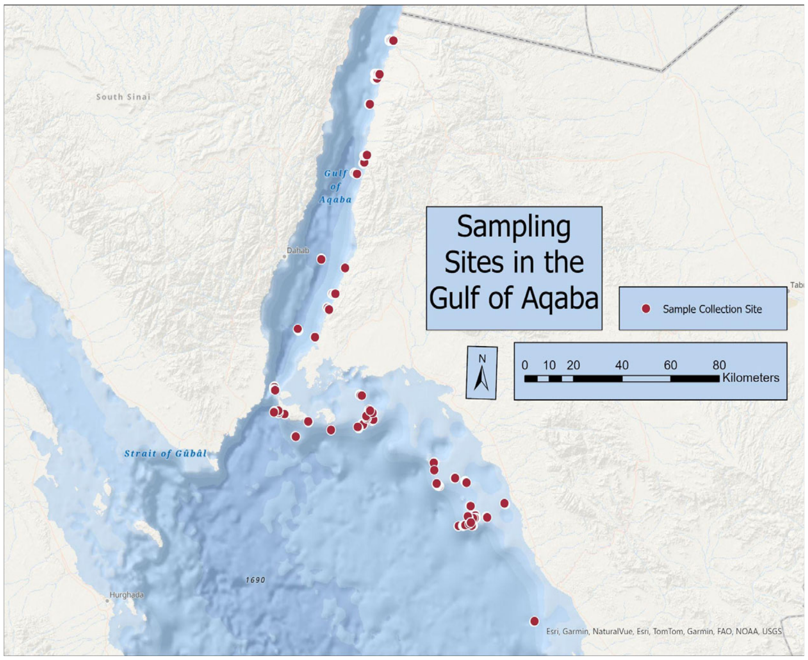

Figure 2: Sample collection by ROV Neptune in the Gulf of Aqaba and surrounding areas.

The sample set will be studied in regard to their composition and how sediments are bound and cemented. Mineralogical composition will be determined using X-Ray diffraction. Geochemical analysis will include stable isotope analysis. Visual inspection and description of the samples will be followed by the analysis of thin sections with a petrographic microscope to determine grain composition and diagenetic alterations. Initial results of the thin sections reveal abundant microbial cement (Figure 3). Consequently, characterization of microbialites will be carried out using Scanning Electron Microscope (SEM) analysis following the procedure outlined in Diaz and Eberli (2022).

Initial Results

Petrographic analysis has shown the diverse composition of this sample set. At both shallow and deep depths (30 to 396 meters water depth), scleractinian corals represent an important agent of slope construction, commonly encased with abundant crustose coralline algae and other encrusting organisms (Figure 3 a, c). Abundant encrustation foraminifera and calcareous red algae of coral fragments but also on hardground surfaces is common. The abundance of serpulids points to the importance of serpulids in bioconstructions in the Gulf of Aqaba. Below 500 meters water depth, foraminiferal packstone represent the majority. In few samples, quartz and felspar are admixed (Figure 4), documenting the occasional input of sediment from the rift shoulder. Many samples are covered by a thin iron-manganese crust, conforming the notion that the "Red Sea is an under-supplied marine rift basin" (Taviani 1989).

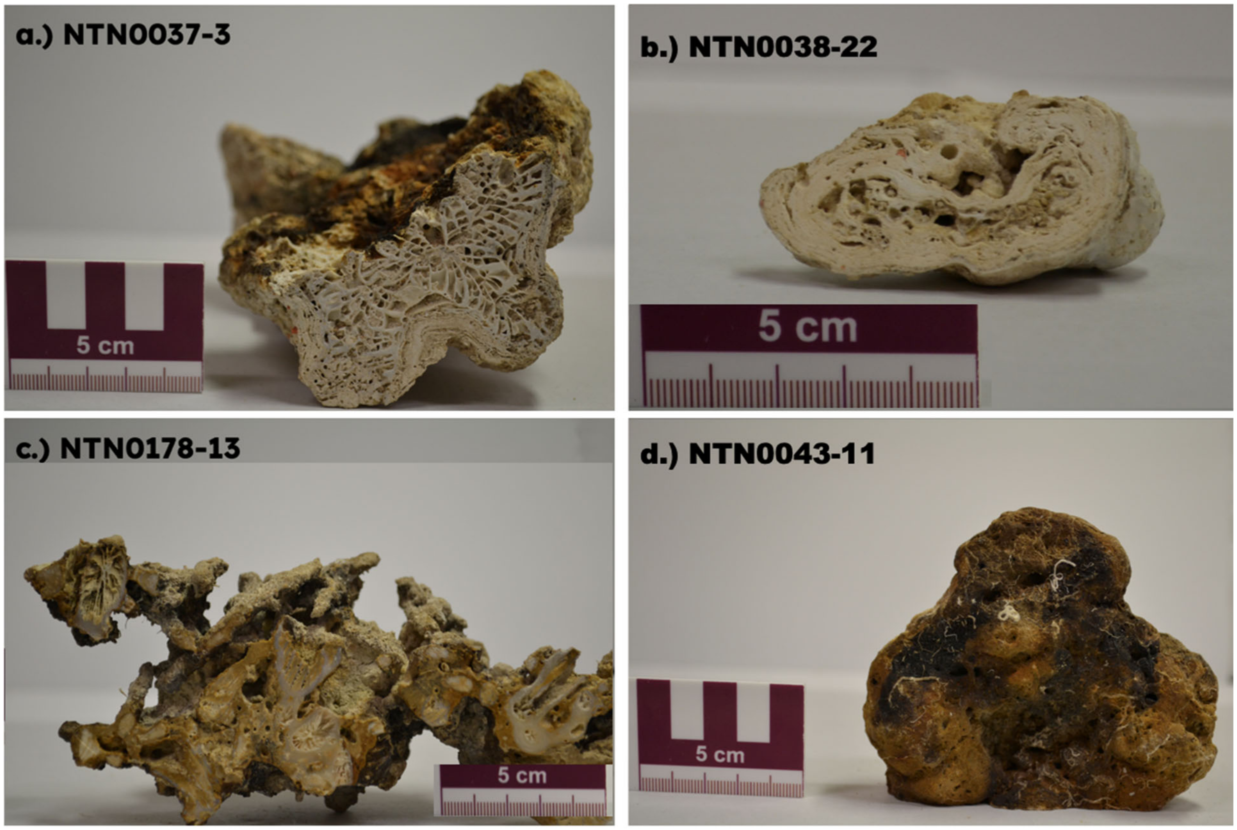

Figure 3: a.) Sample NTN0037 coral with encrusting organisms. b.) NTN0038-22 serpilud encrusted with calcareous red algae. c.) Assembly of rugose coral rubble. d.) Hardground on foraminiferal packstone with with serpulids.

Cementation of the samples is dominated by dark micritic cement that is some cases fills even large cavities (Figure 4a) and can be the only cement inside of grainstones (Figure 4c). Another unique characteristic is the occurrence of large fibrous splays and botryoids (Figure 4).

SIGNIFICANCE

The composition of carbonate slopes in the Gulf of Aqaba has the potential to provide vital information on the risk of slope failure and tsunamis in the region as it undergoes rapid urbanization. In addition, understanding the composition of carbonate slopes in the Gulf of Aqaba gives insight into how slopes are deposited and altered in an actively rifting basin with unique temperature and salinity conditions.

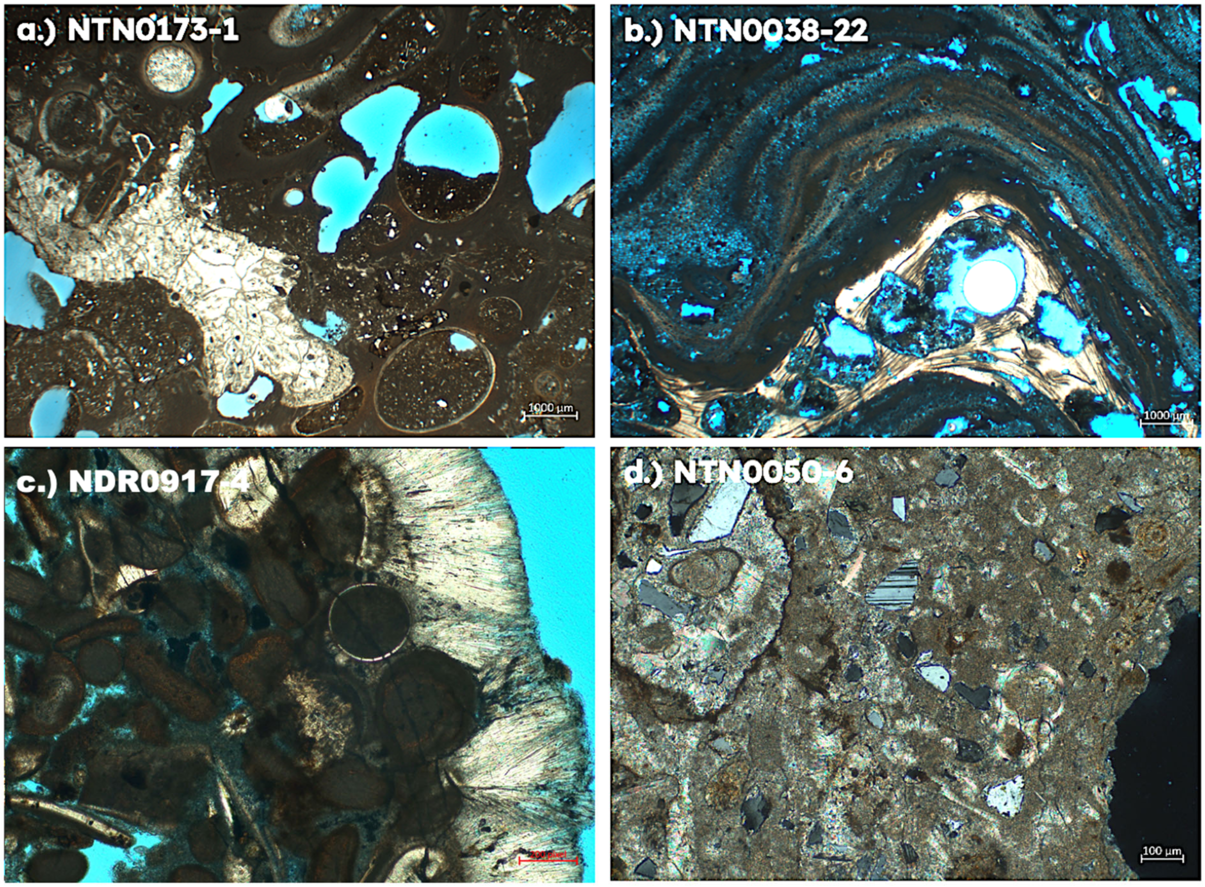

Figure 4: a.) Thin section of sample NTN0173-1, with a bryozoan and serpulid tubes filled with fine sediment and cemented by dark micritic cement. b.) Thin section of NTN0038-22 displaying coral fragment with encrusting foraminifera. c.) Skeletal grainstone with micritic cement and splays of fibrous aragonite on the outside. d.) Skeletal packstone with admixtures of quartz and feldspar.

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Mineralogical and Sedimentological Controls on Biosignature Incorporation in Organosedimentary Deposits of the Salar de Atacama (Chile)

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Project Objectives

- Characterize the mineralogical and sedimentological compositions of diverse organosedimentary deposits in the Salar de Atacama.
- Assess how variations in facies characteristics of organosedimentary deposits influence trace element enrichments and stable isotope fractionation patterns.
- Develop a conceptual model using facies-specific elemental partition coefficients and isotope fractionation factors to improve the interpretation of biosignatures over geological time.

Project Rationale

Microbes have influenced and/or induced the formation of sediments since at least 3.5 Ga, forming a long-standing sedimentological archive. Organosedimentary deposits are composed of carbonate, evaporite, and silicate minerals, as well as organic matter (Reid et al., 2024). Each of these compositional fractions in organosediments can be an archive for trace elements (e.g., As, Zn, Cu, Fe, Mn) and stable carbon and sulfur isotope ratios, the incorporation of which may be affected by microbial processes (i.e., Sforna et al., 2014). However, interpreting enrichment

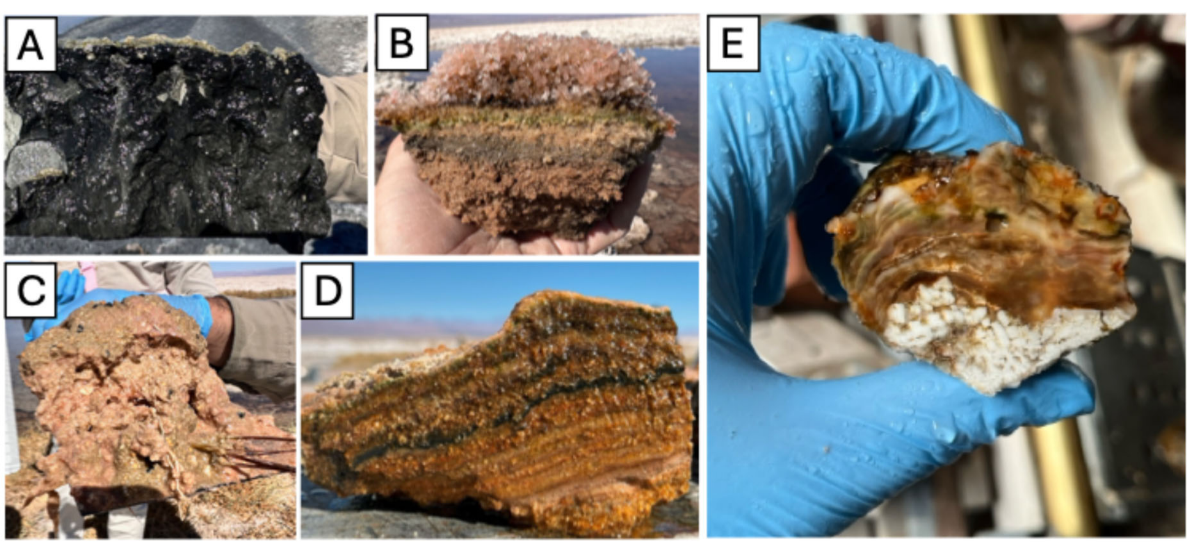

Figure 1: Organosediments observed in the Soncor and Aguas de Quelana marginal lake systems, locally known as lagoons, in the Salar de Atacama. (A) Mud, (B) Evaporite, (C) Granular sediment, (D) Unlithified microbial mat, and (E) Lithified microbial mat.

patterns or stable isotope ratios as chemical biosignatures is complicated by uncertainty about how changes in the proportion, spatial distribution, and mineralogy of the fractions comprising organosedimentary deposits influence the incorporation of trace element patterns and stable isotope ratios.

APPROACH

We investigated modern sedimentary deposits in the saline lakes, locally referred to as lagoons, along the eastern margin of the Salar de Atacama (Chile), where mud, granular sediment, evaporite, and microbialite deposits coexist (Fig. 1). We collected 101 samples from these diverse facies, and integrated bulk geochemical, mineralogical, and microscale imaging analyses to characterize their composition. Sequential leaching experiments quantified the proportions of the organic, evaporite, carbonate, and siliciclastic fractions, while FIB-SEM nanotomography revealed their spatial distributions, and X-ray diffraction confirmed mineralogical composition. Compositional characteristics of each organosedimentary deposit was related to trace element enrichment patterns and stable carbon and sulfur isotope ratios. Finally, we contextualized these results with complementary analyses of lake water chemistry, establishing elemental partition coefficients and fractionation factors for each organosedimentary deposit.

SIGNIFICANCE

Sedimentological characteristics, mineralogy, and the chemical conditions under which each organosedimentary deposit form exert an influence on their elemental enrichment patterns and stable carbon and sulfur isotope ratios. Consequently, mud, granular sediments, evaporites, and microbialites of varying degrees of lithification each capture unique information about the environmental conditions and microbe–mineral interactions. We propose a conceptual model that can be applied more broadly to compare geochemical datasets across multiple facies of organosedimentary deposits, offering multi-faceted evidence for identification of chemical biosignatures. Because organosedimentary deposits often exhibit vertical and lateral facies transitions, this model facilitates a more continuous reconstruction of biosignatures within a given stratigraphic sequence compared to interpretations based on individual facies in isolation. The expanded perspective proposed here is anticipated to enhance understanding of the dynamic biogeochemical processes that drove the formation of heterogeneous organosediments in the geological record. Additionally, advancing our knowledge of sediment formation in the Salar de Atacama will be useful in refining conceptual models of ancient microbial carbonate deposits in analogous continental evaporitic systems (*i.e.,* Virgone et al., 2013).

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Early Marine Cementation in Skeletal Sands

Flora Beleznay, Mara R. Diaz, Gregor P. Eberli and Ralf J. Weger

Project Objectives

- To elucidate the effect of microbial communities in diagenetic processes that lead to the cementation of skeletal grains.
- Toward this end, *in vitro* incubation experiments will be conducted with skeletal grains in the presence and absence of microbial marine communities.
- To determine whether microbial exudates of exopolysaccharide substances (EPS) influence agglutination and early cementation of skeletal grains.
- To document the development of inter/intragranular cements and identify textural forms and mineral microstructure composition of early marine cementation areas using petrographic thin-sections and SEM/EDS.

Project Rationale

Many micritic early marine cements display microbial fabrics consistent with microbial mediation (Dravis, 1979; Hillgärtner et al.,2001; Diaz and Eberli 2022). Based on recent studies with a cohort of field collected samples from the Bahamas and Hamelin pool, we hypothesize that initial cementation and stabilization of carbonate sediments result from the interplay of metabolic activities and passive processes influenced by extracellular polymeric substances (EPS) and entombment of cells. Results from *in vitro* experiments undertaken with ooids in the presence and absence of native microbial communities support this hypothesis (Diaz and Eberli, 2022). We have shown, for instance, that early cements and grapestone formation is a fast process (30 to 60 days), primarily assisted by exudates of microbial EPS, microbial filaments and metabolic activities within the sedimentary grains. We also speculated that the mircrobial community responsible for the early cements are indegenous to the ooids that carry a highly diverse microbial community (Diaz et al. 2023). The scarcity of grapestone and intraclasts in skeletal carbonate sands might be the direct result of the limited micorbial community in skeletal sand.

In this new experiment, we plan to test this hypothesis and establish whether early cementation in skeletal grains follow a similar trend and rate of cementation. Given that ooids harbor an astonishing rich diversity of micro-organisms we expect cementation of skeletal grains to occur at a reduced rate.

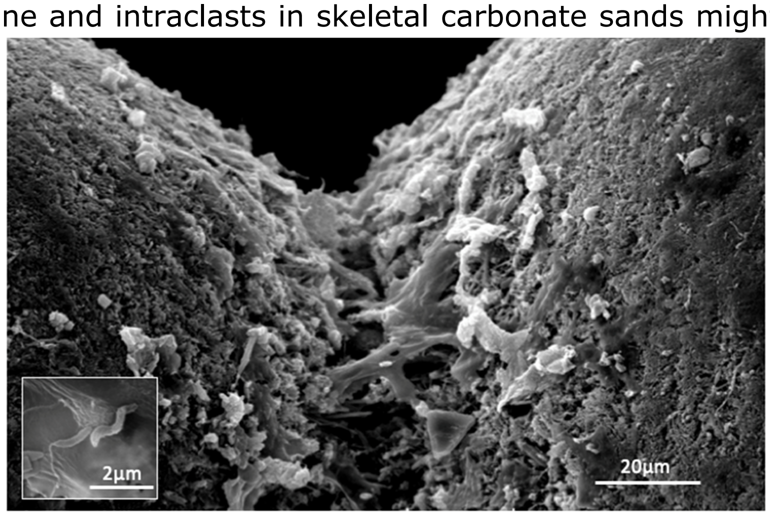


Figure 1. Example of agglutination of ooid grains assisted by EPS and biofilm bacteria after 30 days incubation (from Diaz and Eberli, 2023).

Sample Site

We will collect samples from the White Sands in the Florida Reef Tract and repeat the experiment following the protocol of the ooid study (Diaz et al., 2023).

Figure 2: The Florida Reef Tract is a patchwork of coral reefs and high-energy skeletal sands (White Sands). Well-sorted skeletal sands will be collected using a protocol that preserves the indigenous microbial communities (Diaz et al., 2023)

Approach and Methodology

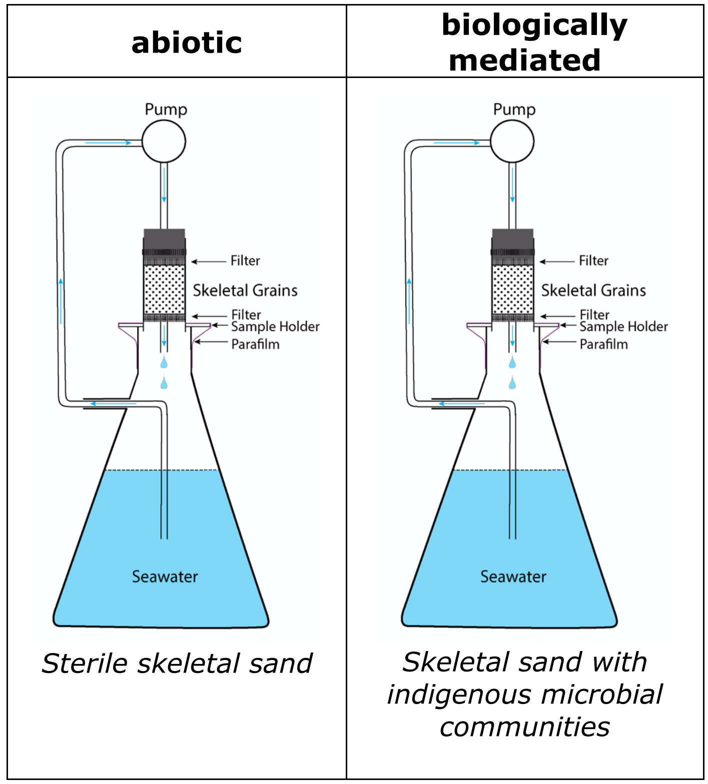
The experimental approach: We will use two sets of incubations - representing abiotic and biologically mediated precipitation (see inset). In vitro experiments will be undertaken in chambers containing skeletal grains that have undergone sterilization (to ensure axenic or microbial free conditions), whereas microbially mediated precipitation will use freshly collected skeletal grains with their native flora. The packed grains are sealed with two porous disks, permitting the inflow/outflow of seawater through the sleeve. A continuous inflow of sterilized seawater (seawater not enriched with nutrients) will be applied. The samples will be subject to alternating cycles of daylight and dark conditions to allow 12 hours photosynthetic processes and 12 hours darkness to stimulate heterotrophic activity under low oxygen conditions.

Visual inspection of contact areas to identify grain binding and microbial colonization will be conducted at different time intervals (0 to 4 months) using petrographic thin sections and SEM analysis. SEM-EDS analysis will also be used to document and characterize the mineralogy of early cements as well as the potential involvement of extracellular polymeric substances (EPS) and presence of ACC as a precursor to cementation processes.

Characterization of microbes associated with the evolution of cements will be carried out using SEM analysis. Characterization of the skeletal grains and cements will be done on epoxy-impregnated thin sections.

SIGNIFICANCE

This study will provide insights on the role of microbes and associated EPS in cementation processes in carbonate skeletal sands. In addition, the results will reveal how much the rate of cementation in skeletal sands differ from those in ooid sands that contain a high-diversity microbial community. There are indications from other studies and in the geologic record that the rate of cementation might be lower in skeletal sands. Grammer et al. (1999) conducted a cementation experiment with ooid samples that were suspended above the sea floor at various depth across the margin of Great Bahama Bank. Partial lithification by fibrous aragonite cement was observed within 8 months in water depths of up to 60 m and complete lithification in 20 months (Grammer et al. 1999). The experiment also included skeletal sand but the cementation was minimal over the same time intervals and was not reported (Grammer pers. comm.), indicating a reduced rate of cementation compared to the ooid samples.



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. It has been speculated that early removal of aragonite prevents the early cementation so that lithification is delayed until substantial burial and chemical compaction (James et al., 2005). Another characteristic of (temperate) skeletal sands is the near absence of micritic envelopes that are formed by endolithic borers (Betzler et al., 1997). The absence of micritic envelopes might also indicate a smaller role of microbial organisms in the cementation process compared to the one in ooid sands. Together, decreased microbial activity and delayed cementation produce highly porous and permeable rocks with excellent reservoir quality (Ehrenberg et al. 2006).

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Carbon Isotopic Composition of Proximal and Distal Sediments in the Vaca Muerta Formation, Neuquén Basin Argentina (Year 2)

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

Project Objectives

- Evaluate the ability to use $\delta^{13}C$ values from organic material to correlate between different sections within the basin, sections kilometers apart, in both proximal and distal positions.
- Reevaluate the reliability of carbon isotopic values ($\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$) for reconstructing Late Jurassic–Early Cretaceous climatic signals.
- Confirm that $\delta^{13}C$ values of organic material can be used to correlate coeval sections within a basin more accurately than the $\delta^{13}C$ values of carbonate.
- Assess the impact of diagenetic processes and localized sedimentary influences on $\delta^{13}C$ records.
- Integrate legacy ocean drilling core data (NSF Proposal) to understand and resolve existing discrepancies and enhance the reliability of carbon isotopic values to understand global climate of the past.

Project Rationale

Understanding the Earth's past climate is critical for deciphering the complex interactions between geochemical cycles and environmental change. Carbon isotopic compositions recorded in sedimentary deposits have long served as proxies for global climatic conditions. However, depositional processes, diagenetic alterations, and localized basin effects can obscure these primary signals, leading to significant discrepancies with the global record.

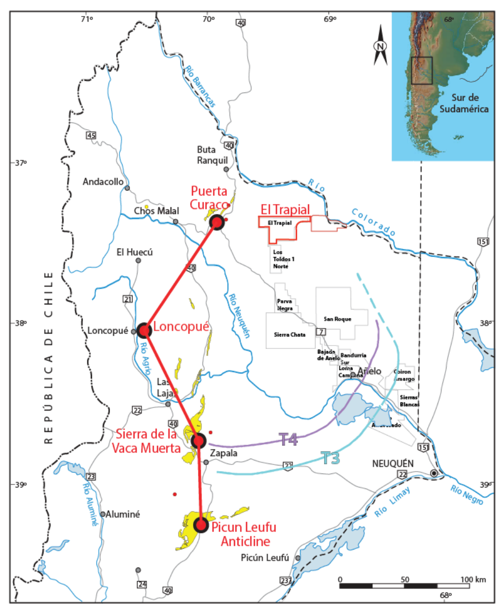

Figure 1: Location of outcrops in the Neuquén Basin.

$\delta^{13}C$ values of carbonate and organic material within sedimentary deposits have been studied extensively and variations have been interpreted principally as changes in the rates of organic carbon production relative to burial and preservation (Hayes et al., 1999). We have studied the $\delta^{13}C$ values of organics and carbonates from 800 m of continuous, Late Jurassic to Early Cretaceous strata (~ 15 Myrs) exposed in the Neuquén Basin, Argentina (Rodriguez Blanco et al., 2020; Tenaglia et al., 2020). The data provided a unique opportunity to compare this high-resolution $\delta^{13}C_{org}$ record to other published organic carbon isotope records from the same time period sourced in Atlantic, Arctic, and Tethyan sections. The data from the Vaca Muerta showed correlation to several globally distributed locations that show a large negative isotopic excursion of organic carbon ($\delta^{13}C_{org}$) of over 4‰ (V-PDB) and to a minimum of −30.3‰; an anomaly that has been named the 'Volgian Isotopic Carbon Excursion' (VOICE).

WORK PROPOSED

We have obtained additional samples from approx. 350m of measured section of outcrops at the Picun Léufú anticline, the Tithonian portion of the Vaca Muerta Formation in a proximal setting. We plan to compare these new samples from proximal locations within the Neuquen Basin to the basinal portions of the Vaca Muerta Formation the re have previously analyzed (Rodriguez Blanco et al., 2022; Weger et al., 2023). In addition, we just submitted a NSF proposal that, if funded, will expand this project and include the analysis of samples from legacy ocean drilling cores alongside those from the Neuquén Basin to re-evaluate the reliability of carbon isotopic values ($\delta^{13}C_{org}$ and $\delta^{13}C_{org}$) for reconstructing global Late Jurassic–Early Cretaceous climatic signals.

SIGNIFICANCE

This study represents a combined study of the $\delta^{13}C$ values of organic and inorganic material found within the Neuquén Basin in Argentina. The $\delta^{13}C_{org}$ values appear to be unrelated to the global patterns in $\delta^{13}C_{carb}$ values, but they show similarity to patterns seen in $\delta^{13}C_{org}$ values at several boreal localities. This study will provide a detailed comparison of $\delta^{13}C$ values of carbonate and organic carbon and their variations between coeval distal and proximal locations. Key questions to be answered is if changes in $\delta^{13}C$ values proximal and/or distal behave correlative within the Neuquén Basin and their reliability as global climate proxies.

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DETERMINING THE IMPORTANCE OF ICHTHYOCARBONATE IN GREENHOUSE WORLDS

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PROJECT OBJECTIVES

- Determine whether changing seawater chemistry influences ichthyocarbonate production rates
- Assess composition of ichthyocarbonate produced by fish acclimated to Cretaceous seawater chemistry
- Predict how ichthyocarbonate fate may have changed through geological time

PROJECT RATIONALE

Marine bony fish produce significant quantities of magnesium-rich carbonate (ichthyocarbonate; Grosell and Oehlert, 2023). With an annual production magnitude estimated to rival that of foraminifera or coccolithophores, marine fish are one of the top carbonate producers in the oceans today (Oehlert et al., 2024). The only marine vertebrates who consistently drink seawater to stay hydrated, marine fish precipitate ichthyocarbonate to maintain internal salt and water balance and continuously excrete these precipitates to the environment (Grosell and Oehlert, 2023).

In the modern oceans, ichthyocarbonate is typically comprised of carbonate polymorphs such as (very) high magnesium calcite (HMC) and amorphous calcium magnesium carbonate (ACMC) with high dissolution rates, potentially limiting significant accumulations of ichthyocarbonate to shallow and tropical sedimentary environments (Wilson et al., 2009). Throughout the Phanerozoic, environmental conditions have varied substantially, with significant changes in temperature, pCO_2, and seawater chemistry occurring over time (Fig. 1). Factors like temperature, salinity, and pCO_2 are known to increase ichthyocarbonate production rates (Wilson et al., 2009; Genz et al., 2011; Heuer et al., 2012, 2016). Similarly, increased pCO_2 was shown to increase base excretion by > 34% (Heuer et al., 2012). However, little is known about how

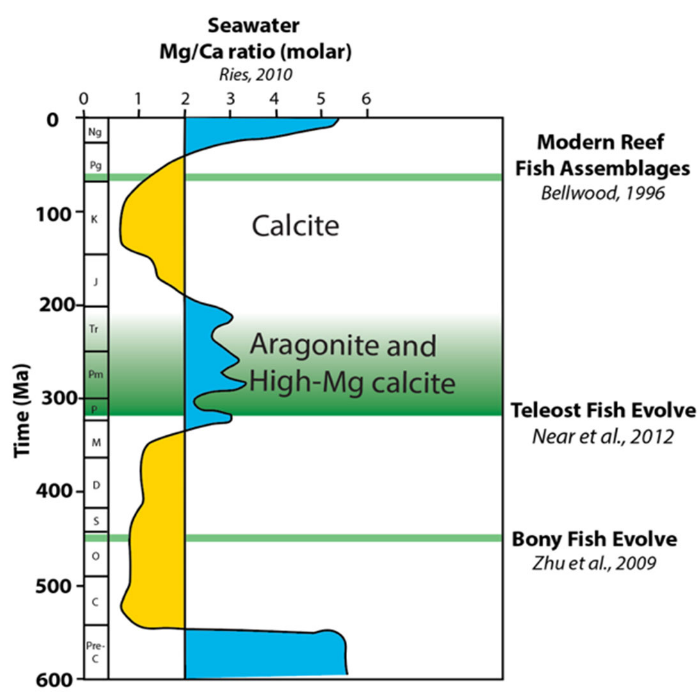

Figure 1. Changing seawater chemistry (Mg/Ca ratio) and evolutionary milestones of marine bony fish.

seawater chemistry impacts the production and preservation potential of ichthyocarbonate. Secular changes in the ionic composition of Phanerozoic seawater have resulted in mineralogical shifts in inorganic carbonate precipitates (Fig. 1). Transitions between Calcite and Aragonite Seas occurred as many as 3 times since the rise of bony fish, suggesting marine fish have had to adapt to changes in seawater chemistry.

APPROACH

We acclimated triplicated tanks holding Gulf toadfish (*Opsanus beta*) in modern seawater and synthetic seawater with ionic composition similar to Cretaceous oceans, (Mg/Ca ~1; sulfate ~9 mM; alkalinity ~2 mM). Production rate was assessed daily by collecting wet masses of ichthyocarbonate normalized to fish biomass in the tanks. Differences in ichthyocarbonate size were determined using a Python-based morphological analysis, and mol%$MgCO_3$ of the ichthyocarbonate were measured using ICP-QQQ. pH stat approaches were used to determine dissolution rates.

SIGNIFICANCE

Results suggest that marine fish acclimated to Cretaceous seawater produce ichthyocarbonate 3.6x faster and with 2.5x lower mol%$MgCO_3$. The dissolution rate of ichthyocarbonate produced by toadfish acclimated to Cretaceous seawater was ~3x slower than modern controls, suggesting ichthyocarbonate was more likely to reach sediments. We conclude that marine fish likely played an even more prominent role in Mesozoic carbon cycling than today.

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EMPIRICAL DEFINITION OF STABLE CARBON ISOTOPE FRACTIONATION FACTORS IN BIOGENIC HIGH MAGNESIUM CALCITE

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PROJECT OBJECTIVES

- Measure the $\delta^{13}C$ values of intestinal fluid and ichthyocarbonate
- Calculate the fractionation factor (ε) for ichthyocarbonate formation
- Assess the relationship of ε with mol%$MgCO_3$ content

PROJECT RATIONALE

Ichthyocarbonate is a magnesium-rich carbonate mineral produced in the intestine of marine teleost fish (Wilson et al., 2009). Through ichthyocarbonate production and excretion to the environment, marine fish contribute to both the biological and carbonate pumps, processes which are important controls on atmospheric carbon dioxide concentrations (Grosell and Oehlert, 2023). Ichthyocarbonate is composed of significant proportions of both dietary carbon and seawater dissolved inorganic carbon (DIC; Oehlert et al., 2024), in contrast to other marine calcifiers which principally use DIC. Notably, no value for the fractionation factor between intestinal fluid and ichthyocarbonate has been reported, creating uncertainty in estimates of intestinal fluid δ13C values, and thus the contribution of dietary carbon to ichthyocarbonate formation (Oehlert et al., 2024). Previously, ε was assumed for ichthyocarbonate based on measurements conducted on high magnesium calcite with varying magnesium contents formed in inorganic precipitation experiments (i.e. Jimenez-Lopez et

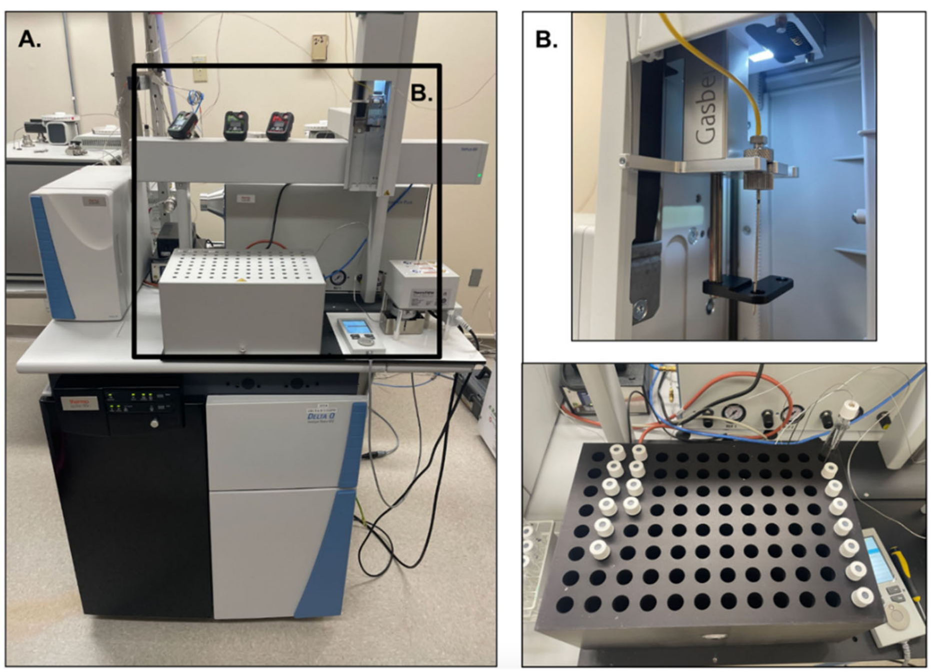

Figure 1: (A) The ThermoFisher Delta Q IRMS + EA Isolink CNS allows for stable isotopic analysis of carbon, nitrogen, and sulfur, (B) The Gasbench Plus allows for measurements of the stable carbon isotopic composition of evolved CO2 gas from acidification of intestinal fluids with H3PO4.

al., 2006) and natural dolomite (Sheppard and Schwarcz, 1970). Based on the high mol%MgCO3 content of ichthyocarbonate (14 – 50‰; Heuer et al., 2012; Salter et al., 2012), the predicted range of ε is + 0.9 – 2.2‰ with increases in ε expected with increasing mol%$MgCO_3$ (Oehlert et al., 2024).

APPROACH

Here we will empirically determine ε by measuring the $\delta^{13}C$ values of intestinal fluid and ichthyocarbonate collected from Gulf toadfish (*Opsanus beta*). Gulf Toadfish were fasted for 3 days, then ichthyocarbonate and intestinal fluid were collected via dissection, along with samples of seawater and excreted ichthyocarbonate. Muscle samples were also collected to fully parameterize the mixing model, which were analyzed on an EA Isolink CNS + Delta Q. The $\delta^{13}C$ values of intestinal fluid, seawater, and ichthyocarbonate were analyzed using the Gasbench Plus + Delta Q. By subtracting the $\delta^{13}C$ values of intestinal fluid from the $\delta^{13}C$ values of ichthyocarbonate, we calculated for the first time the fractionation factor for ichthyocarbonate formation. Additional work to measure the mol%$MgCO_3$ content of ichthyocarbonate and the Mg/Ca ratio of intestinal fluid is underway.

SIGNIFICANCE

We performed the first measurements of paired ichthyocarbonate and intestinal fluid $\delta^{13}C$ values, while developing novel methods for the processing and analysis of intestinal fluid. Additionally, our preliminary analyses suggest the mineralogical fractionation factor of ichthyocarbonate is + 1.62‰. This new measurement will enable researchers to refine estimates of dietary carbon incorporation in ichthyocarbonate, which is one of the top three sources of global marine carbonate production (Wilson et al., 2009; Oehlert et al., 2024) and will provide insight into fractionation factors associated with the formation of biogenic HMC more generally.

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Incorporation of Currents into Sequence Stratigraphic Models

Gregor P. Eberli

Goals of Project

- Provide examples of the contribution of currents to continental margin sequence architecture.
- Delineate criteria for recognition of contourite drifts in a depositional sequence.
- Outline a sequence stratigraphic model that incorporates the facies both current and sea-level controlled deposits.
- Make a case that unconformity-based sequence stratigraphy is better suited to incorporate current-derived deposits than other sequence stratigraphic methods.

Rationale

Eustatic sea-level change, subsidence, sediment supply and climate have traditionally been considered the controlling factors for the sequence architecture on continental margins (Galloway et al., 1989). More recently these factors have been narrowed down to varying rates of coastal accommodation increase and decrease (δA) relative to the rate of sediment flux (δS) (Neal & Abreu 2009, Catuneanu et al. 2009). All the sequence stratigraphic methods consider the (clastic) sediment supply as a function of sediment production and gravity driven dispersal. Yet, ocean currents have a major control on sediment distribution, especially at the shelf edge and beyond where they can accumulate contourite drifts. In fact, they can produce successions that resemble sea-level controlled sequences (Betzler et al., 2013). In addition, current controlled deposits (contourite drifts) can be misidentified as lowstand systems tracts (Bashah et al., 2024), or rollover points of prograding and elongated contourite drifts are misidentified as prograding shorelines or as prograding sub-aqueous clinoforms. In addition, currents can produce abrasive terraces that resemble geometries observed in forced regressions. Yet, sequence stratigraphic models continue to explain the strata and geometries mostly by gravity-dominated

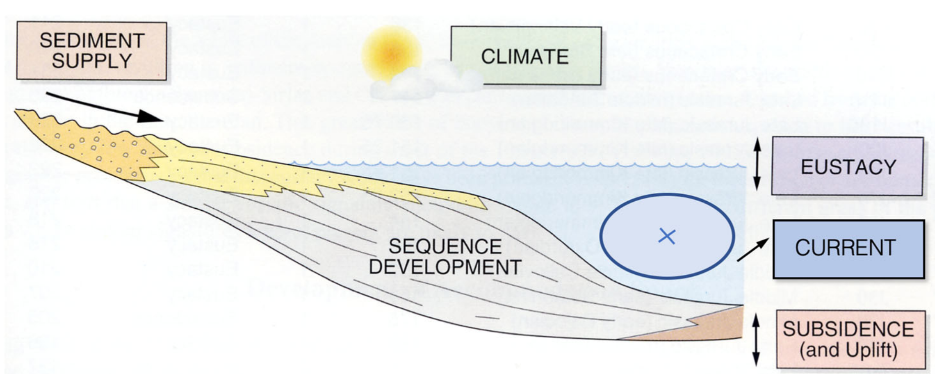

Figure 1: The controlling factors for the sequence architecture on continental margins have been sediment supply, climate, eustasy and subsidence. This project explores the contribution of the currents to the sequence development and its consequences for sequence stratigraphy.

sediment distribution within the context of fluctuating sea level. This project tests the hypothesis that current erosion and deposition are important for sequence evolution and consequently an adjustment of sequence stratigraphic models is required.

Approach and Method

We examine the architecture of carbonate and mixed carbonate/siliciclastic sequences in three areas where current activity is well documented. We will make a sequence stratigraphic interpretation, using both the traditional unconformity-based sequence stratigraphy and more recent sequence stratigraphic methods (Neal and Abreu, 2009; Catuneanu et al., 2009). In particular, we will analyze the systems tracts interpretation in regard to potential misidentification as current deposits. Furthermore, we will interrogate the interpretations of the stratigraphic surfaces when a current contribution is considered. This will lead to a test of which stratigraphic method is better capable of incorporating current deposits into the sequence stratigraphic model.

Significance

If the hypothesis that currents are a controlling factor in sequence development is proven, stratigraphic models need to be adjusted to be accurate in predicting facies distribution in the subsurface. Correct identification of the facies in the different system tracts is also paramount to building reliable static models from geometries extracted from seismic data.

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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.

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.

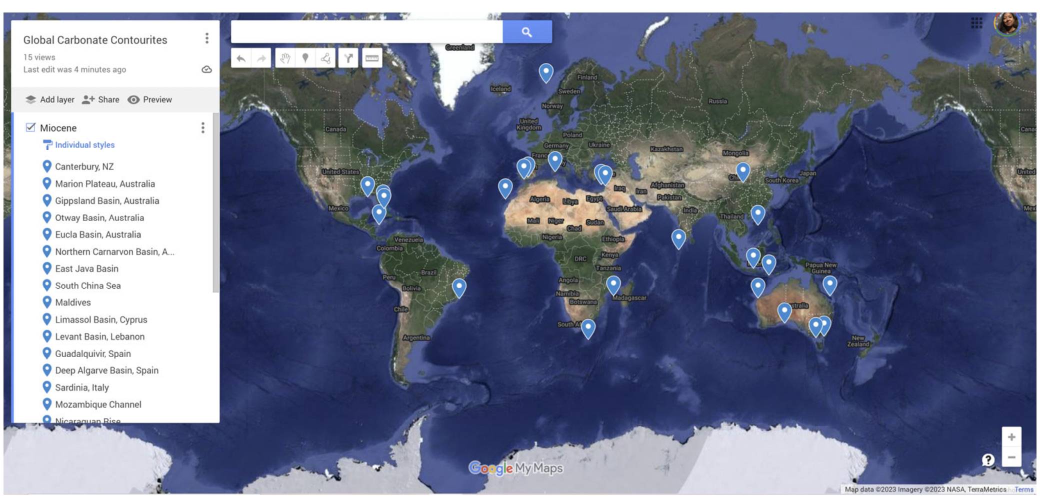

Figure 1: Google Maps showing the location of Miocene carbonate platforms with existing contourites studies.

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PERMEABILITY VARIATIONS IN SIMPLE PORE GEOMETRIES: INTEGRATING ACOUSTIC VELOCITY, ELECTRICAL RESISTIVITY, AND DIGITAL IMAGE ANALYSIS

Ralf J. Weger and Gregor P. Eberli

PROJECT OBJECTIVES

- Investigate why carbonate samples with similar pore geometries (large, simple pores: high DomSize, low PoA) and high acoustic velocities exhibit variable permeability.
- Correlate electrical resistivity and permeability in these samples to identify microstructural controls (e.g., microporosity, cementation, pore connectivity).
- Develop a predictive model to distinguish high- vs. low-permeability zones in carbonates with high velocity and simple pore structures using integrated acoustic, resistivity, and DIA data.

PROJECT RATIONALE

Carbonate reservoirs units with simple pore geometries (e.g., oomoldic rocks and grainstones) often display high acoustic velocities due to stiff frameworks but sometimes show drastic permeability variability. In most cases, regions that exhibit high acoustic velocity and simple pore geometry also show high permeability. There are, however, exceptions to this rule. Oomoldic rocks, completely inverted ooid grain stones, are an example of high acoustic velocity rocks with simple pore geometry that sometimes lack any connectivity at all (e.g. Anselmetti and Eberli, 1999). High electrical resistivity correlates in many cases with low permeability (e.g., cemented zones), but Verwer et al. (2011) revealed that high-permeability samples can also exhibit high resistivity if pore structures limit electrical connectivity (e.g., isolated vugs). This paradox complicates reservoir characterization and water saturation calculations but might be exploitable in combination with acoustic velocity.

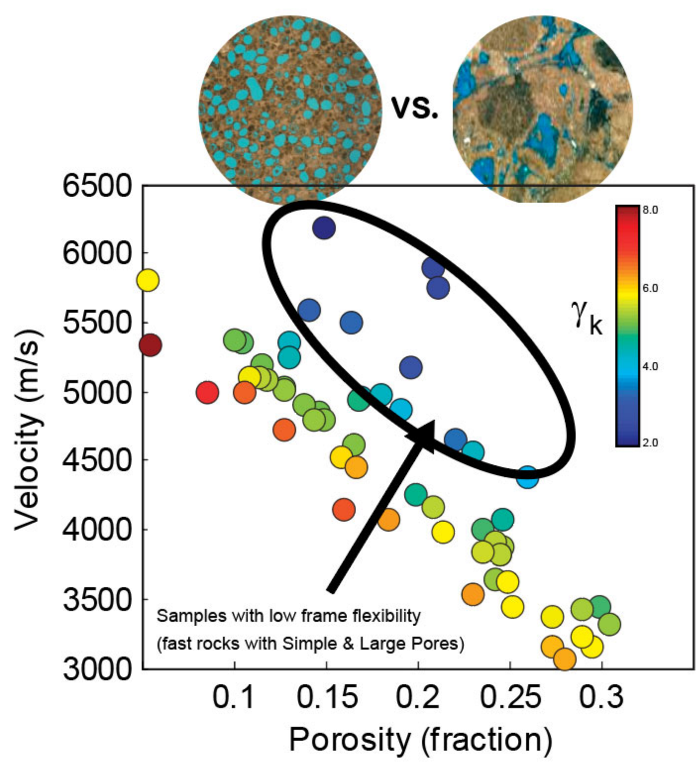

Figure 1: velocity-porosity cross plot with samples colored by γ_k. Low γ_k samples (large DomSize and low PoA) frequently have high permeability but are sometimes completely disconnected (oomoldic).

DATA/METHODOLOGY

This study will re-analyze representative samples to resolve conflicting relationships between velocity, resistivity, and permeability in simple-pore carbonates, leveraging Digital Image Analysis (DIA) to quantify microstructural controls. We plan to measure ~30 carbonate core plugs with high DomSize (>300 μm) and low PoA (<50 mm^{-1}) (simple pores) that are expected to show high acoustic velocity (>4,500 m/s) but variable permeability (0.1–1,000 mD). We will incorporate a variety of different rock types to provide a diverse range of applicability (e.g., microbialites, grainstones, travertines, ...).

APPROACH AND METHODOLOGY

We will address the lack of understanding of how microporosity, pore geometry, and overall connectivity influence permeability in rocks with macroscopically similar pore structures and re-evaluate the existing ambiguities. The Challenge is to separate rocks with simple pore space geometries (stiff rocks) that have connected pore networks and most often high permeability (Weger et al., 2024) from those with less connected (or unconnected) pore networks. Both have low PoA and high DOMSize and they show high velocities for their given porosity resulting in low $\gamma_{k.}$ But, samples with a high number of pores connections and lower tortuosity show more effective transport of ionic charge (Norbisrath et al., 2015).

SIGNIFICANCE

This study will resolve ambiguities in log-based permeability prediction, enabling better identification of high-permeability zones in carbonates with simple pore structures. By integrating resistivity measurements with acoustic velocity and pore geometry data, this project will enable more accurate discrimination of samples with fewer pore connections (e.g., isolated vugs or large, poorly connected pores) that will exhibit high resistivity but may have low permeability from samples with well-connected pores will show lower resistivity and higher permeability. This advancement will improve reservoir models, enhance log-based permeability predictions, and refine water saturation calculations, ultimately supporting better decision-making in exploration and production, particularly in complex carbonate reservoirs like microbialites or pre-salt plays.

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Testing Seal Capacity For Carbon Storage - an Experimental Approach – (Year 2)

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

Project Objectives

- Re-Design an experimental set-up that allows for CO_2-Brine saturation prior to CO_2 injection
- Evaluate how the pre saturated CO_2-Brine mixture alters the seal capacity of mixed carbonate-siliciclastic samples.
- Run experiments to assess the amount of dissolution and possible breach of samples.

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 (Weger et al., 2012) addressing the potential changes in the seal rocks resulting from CO_2 injections.

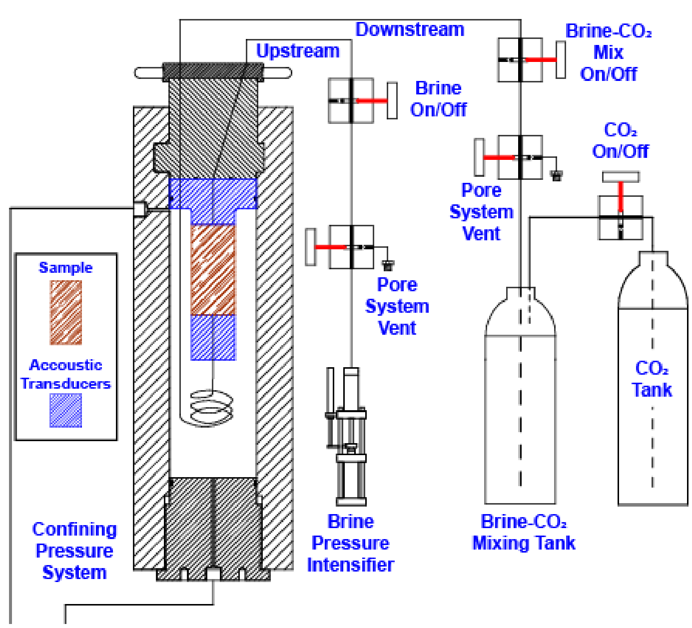

Figure 1: Set-up of proposed dissolution experiments using the Autolab 1000 which allows for pre-CO2-Brine saturation.

WORK PROPOSED

Phase 2 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 examined 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 proposed equipment re-design lis expected to produce better results as the previously used method. 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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INCORPORATE PETROGRAPHY INTO PETROPHYSICAL DATABASE

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

GOALS OF PROJECT

- Assemble a petrographic data base 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 pores 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 setting is not captured in the petrophysical data base. 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?".

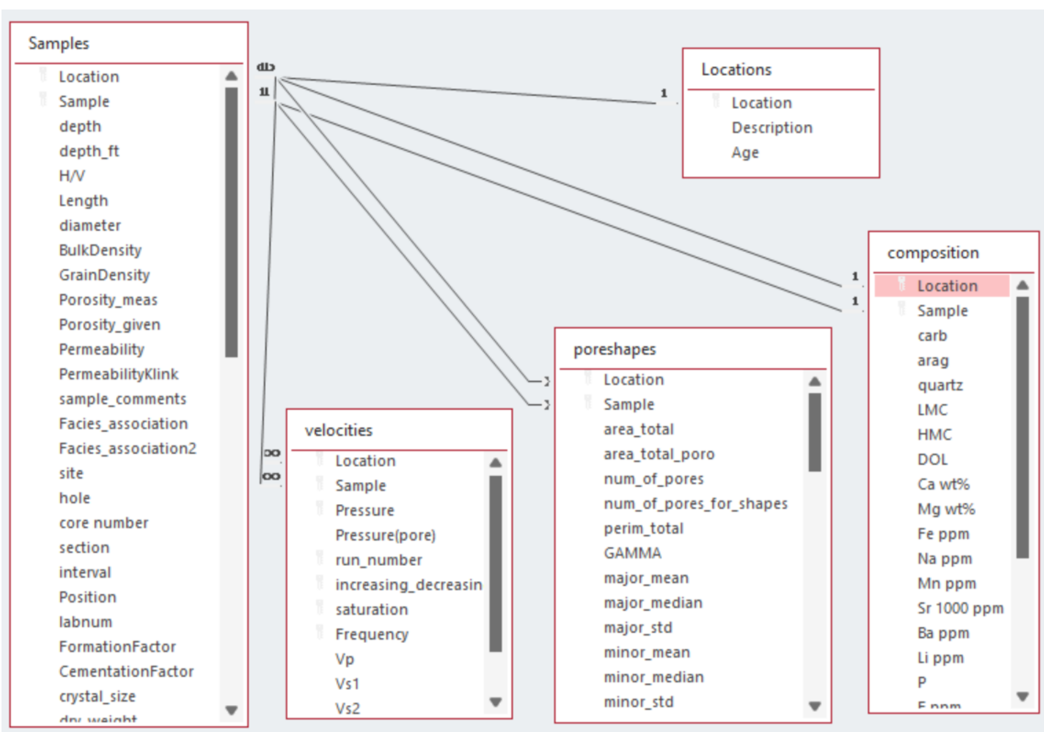

Figure 1: Organization of the CSL Carbonate Data Base.

APPROACH AND TASKS

We will add features to the existing database (Figure 1) that will increase the applicability for general comparison. These additions include:

1. Geographic location and formation name
2. Formation name and age
3. Depositional setting
4. Diagenetic alterations

The geographic location will help to place the sample in a geographical framework. The formation name and age will place it in a 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 the 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)

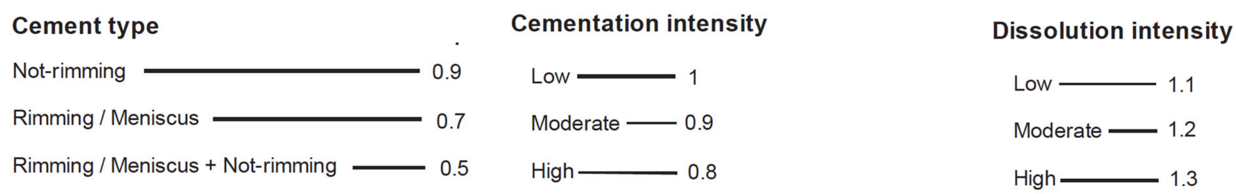

Figure 2: Determination of cement type, cementation and dissolution intensity from Tonietto et al (2014)

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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