2024 RCRL Research Prospectus

Carbonate Reservoir Characterization Research Laboratory

Carbonate Reservoir Characterization Research Laboratory (RCRL)

Mission

The Carbonate Reservoir Characterization Research Laboratory (RCRL) mission is to use outcrop and subsurface geologic, geophysical, and petrophysical data from carbonate reservoir strata as the basis for developing new and integrated methodologies and concepts to better explain and describe the 3D-reservoir parameters, and to improve discovery, production, and storage of gas and fluids in carbonate rocks in the subsurface. In addition to this research mission, RCRL researchers are dedicated to technology transfer and education, continuously offering state-of-the-art training in short courses, field seminars, in-house reviews of selected assets, and extensive graduate student supervision and guided research.

Overall Research Goals

RCRL approaches reservoir characterization through three main scales of investigation, using both outcrop and subsurface datasets: (1) platform-to-basin-scale stratigraphy; (2) reservoir architecture and pore network distribution, including both matrix and non-matrix systems (e.g., fractures and paleokarst); and (3) structural and geomechanical properties characterization related to stratigraphic framework.

Membership and Funding

We invite your company to participate in the continuation of the RCRL Carbonate Reservoirs Research Program for 2023. In 2023, the annual RCRL Industrial Associates contribution to the program will be $65,000 per sponsor per year. To encourage sponsors to commit to a 2-year agreement so that we can better plan a longer-range research program and reduce the time and effort in securing agreements, we offer a 2-year (2023 and 2024) rate of $60,000 per year. Participating sponsors will sign a Memorandum of Agreement (MOA) for the 2-year commitment, payment being due in January of each year.

Membership Benefits

Industrial sponsors receive new research results at annual review meetings, in short courses, during mentoring activities, in prepublications, and on the continually updated, member only RCRL website database (http://www.beg.utexas.edu/rcrl/members/). Our searchable website protects the investment in RCRL research and makes previously presented material easy to locate. The data area contains digital presentations, including archived video and annotated presentations, core workshop books, and fieldtrip guidebooks. Supplemental data, such as maps, core photos, porosity and permeability data, and digital outcrop reservoir models, are available through our password-protected database for RCRL members.

Interaction

We host an Annual Review Meeting and an associated Fieldtrip and Core Workshop, in addition to a core-based training opportunity offered in the spring in Houston. These workshops are interactive, utilizing subsurface data, along with applicable outcrop analogues to emphasize applications of key elements that are important in understanding carbonate systems and their importance to hydrocarbon production. All presentations from our annual meetings and workshops are presented via Teams and are recorded and available on our member website.

Carbonate Reservoir Characterization Research Laboratory (RCRL)

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RCRL Research Topics in 2024

Reservoir Characterization

Salt Creek Field Characterization and Regional Framework of the Canyon-Cisco Setting from Isolated Platforms to Basinal Cline Shale to Eastern Shelf

The Horseshoe Atoll with its >4 Bbbl cumulative production from shallow-water platform top and slope strata of Late Pennsylvanian (Missourian-Virgilian) age, is one of the biggest of the conventional reservoir systems in the Permian Basin and the Lower 48. This same time interval equates to one of the active unconventional resource plays in the Midland and to a lesser extent the Delaware Basins, the Cline Shale. The Canyon-Cisco interval currently lacks a true high-resolution shelf to basin framework that would match across the isolated platforms of the Horseshoe, into the basinal strata, and up onto the Eastern Shelf and across the Midcontinent USA. This project will focus on the Salt Creek Field initially, by completing another 10-15 detailed core descriptions including digitizing core-based facies and translating these into a 3D facies/petrophysical model for the field. Once that is complete and a better understanding of cycle and sequence-scale framework is established, then we will collaborate with MSRL to correlate into the basinal Cline strata adjacent to the Atoll. From there we will progress landward towards King County where the STARR program has developed a detailed framework for the late Canyon through Cisco interval leveraging 3D seismic, logs, and limited core data. The resulting model will provide the most comprehensive model yet for understanding the nature of reservoir development in the basinal unconventional setting as tied to a well-constrained eustatic record on the platforms and atolls.

Stratigraphic Architecture of Reservoirs, Central Basin Platform

RCRL has access to large 3D seismic surveys provided by WesternGeco that cover the northwest corner of the Central Basin Platform (CBP). In this area, major production comes from the San Andres and Grayburg Formations (e.g., Eunice North Monument, Hobb) as well as the Lower Clearfork (e.g., Abo, Drinkard). We are currently focusing on the San Andres–Grayburg interval in the northeast corner of the CBP. We will soon expand our study to deeper intervals, where the seismic integration will allow clearer identification of reservoir architecture and enhanced strategies for enhanced oil recovery (EOR), water disposal, carbon capture and underground storage (CCUS), and hydrogen storage.

Fracture Modeling of Ellenburger Fault Zones in the Midland Basin

The development of fracture models in the Ellenburger Formation represents a crucial endeavor in advancing our understanding of fluid flow and seismicity within subsurface reservoirs. The Ellenburger Formation, known for its complex geological structure, poses challenges and opportunities for research in the realm of hydrocarbon exploration and reservoir characterization. By meticulously constructing fracture models in

combination within reasonable matrix models, we aim to simulate the intricate network of fractures that permeate the formation, considering factors such as fracture density, orientation, and connectivity. These models play a pivotal role in predicting fluid flow behaviors and seismic responses, offering valuable insights into reservoir dynamics. The integration of advanced modeling techniques, coupled with real-world data collected from salt-water disposal (SWD) wells, enhances the accuracy and reliability of these fracture models, providing a sound foundation for optimizing reservoir management strategies and mitigating potential seismic activity risks. As the energy industry continues to evolve, the development of fracture models in formations like the Ellenburger becomes instrumental in ensuring sustainable development of the Midland Basin.

Slope and Basinal Depositional Systems Studies

Late Wolfcampian-Leonardian Mixed Slope Outcrop Analogue Characterization, Sierra Diablo Mountains

This year we plan to continue work on the shelf-to-slope strata transition exposed in the Sierra Diablo Mountains. Our focus will be on the Upper Wolfcampian and Leonardian strata (Wolfcamp B/2nd Bone Spring Formation-equivalent), where complex interfingering of carbonates and siliciclastic slope deposits are well exposed. This outcrop analogue work will shed light on the detailed architecture and stratigraphy of this important producing interval in the subsurface and how some of the complexity seen on the slope might affect the way we understand the basinal deposits further down-dip.

Mississippian Toe-of-Slope to Basinal Deposits in Outcrop and Subsurface Wells, Orogrande Basin

This study will capitalize on previous RCRL studies of the Mississippian strata contained in outcrop exposures in the Sacramento Mountains, Bishop Cap, and Franklins Mountains. Our goal is characterizing the temporal and spatial transition from outer ramp to basinal gravity flows and current deposits to the organic-rich shale that forms the Barnet Fm. The outcome of this study will highlight potential implications of understanding the distribution, alternation and/or mixing of various distal deposits (i.e., gravity flow vs contourites) for potential unconventional development of Mississippian-age organic-rich pelagic deposits in the Permian Basin and other unconventional resources of similar origin.

Large-scale Neogene to recent carbonate slope contourite, NW Shelf of Australia

The late Miocene to recent carbonate slope off the NW Shelf of Australia illustrates a complicated seismic architecture developing downdip of a strongly gullied steep upper to middle slope. This lower slope portion is made of both large-scale (>2 km wide and 100's m deep) s submarine canyons combined with equally large (2-5 km wide by 200-500 m thick) mounded, dip-elongated positive topographic features. Using high-quality 3D seismic dataset enables investigation into the evolution of this complex submarine topography created by the combination of gravity-flow and contour-current processes. The goal of this project is to improve understanding on how the two different depositional mechanisms coexist and interfere through time to create a complex stratigraphic architecture and to provide guidance for recognizing this type of system in other subsurface datasets, including lower-resolution seismic volumes.

Regional Stratigraphy Studies

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Icehouse Mixed System Model Refinement - Missourian-Virgilian Beeman-Holder Formation HWY 81 and Surrounds

The magnificent outcrop of mixed siliciclastic-carbonate sequences exposed along New Mexico Hwy 81 have long served as a classic examples of icehouse carbonate systems, models of complex reef mound geometries, and as mixed siliciclastic-carbonate cycles driven by high-amplitude, high-frequency sea-level oscillations. The general stratigraphic architecture of the Beeman-Holder interval is well established by previous studies, but we continue to visit and map localized areas of the outcrop to improve our understanding of the complex interplay of siliciclastic and carbonate elements across this important time period and to leverage our ability to capture the high-resolution images of the exposures with detailed on-the-ground observations. In 2024 we will work to consolidate data across the La Luz anticline and surrounds to elevate our understanding of the Late Pennsylvanian of this area to a point where we can fully link the high-frequency sequence development and detailed mixed system facies architecture. The results of this project will be a new digital VR outcrop model as well as a new high-resolution sequence framework tied to essential outcrop exposures allowing those who visit both virtually and in person to gain the most from these exceptional outcrops. Patterns of reciprocal sedimentation, how carbonates develop around siliciclastic depositional elements such as deltaic lobes, and how siliciclastic sediments move around, through and over carbonate topographic relief, will be highlighted. Though possible to understand conceptually, the ability to visualize complex relationships in 3D will enhance the utility of these outcrops.

Cretaceous (Albian) Shelf- to Intrashelf-Basin Exposures, Facies Patterns, and Structure/Fracture Models, Sanderson Area, SW Texas

We are exploring areas of southwest Texas along the Rio Grande, where exceptional outcrop exposures along the canyon walls of the Rio Grande, within Big Bend National Park, and in other canyons. These outcrops provide seismic-scale views of the subtle intrashelf basin framework including large coral-rudist reef complexes and prograding grainstone ramp margins of multiple sequences. Integration of digital technology and detailed section measuring and facies mapping along with structural analysis will build on the work being conducted by RCRL along the Pecos River Canyon and associated road-cut exposures.

Regional Austin Chalk Synthesis

A nannofossil analysis of the GOM-wide Austin Chalk is in progress where the major goal is to develop a chronostratigraphic framework which will allow the regional lithofacies distribution to be developed. This chronostratigraphic framework will guide the correlation of our numerous core descriptions along the trend to define a regional framework of lithofacies distribution and associated reservoirs and source rocks. This will be the first GOM regional chronostratigraphic framework investigation of the Austin Chalk and adjacent formations.

Upper Jurassic Smackover Core-Based Geological Synthesis from South Texas to Florida

The Smackover Formation is a well know hydrocarbon reservoir along the northern GOM. It has been studied for many years and selected areas are well understood. The RCRL investigation is looking at the Smackover regional geology to define variations in lithofacies, lithofacies stacking pattern, mineralogy, and reservoir characteristics. The concepts developed can be used for further hydrocarbon exploration and lithium

exploration, such as in northeast Texas. Selected long cores from along the Smackover trend are characterized as to their reservoir characteristics and overall reservoir quality.

Integrated Structure, Stratigraphy, Fractures and Karst Studies

Survey of Regional Permian Basin Ellenburger Karsted Reservoirs Based on Integration of Seismic and Core Data

The Lower Ordovician Ellenburger carbonate continues to be a hydrocarbon target as well as a prospect for waste-water injection and carbon-dioxide storage. A regional survey of Ellenburger karsted reservoirs (joint project between RCRL and STARR Programs) is being conducted using seismic datasets and cores to define the distribution, heterogeneity, and reservoir characteristics of the Ellenburger section. Analysis of the seismic data allows the identification of karst-related seismic attributes that can be used to recognize highly karsted areas where enhanced reservoir quality may be present. Associated core-based reservoir characterization will substantiate depositional lithofacies and karst-related diagenetic reservoir pore systems. This will be the largest seismic-based regional study of Ellenburger karsting to date.

Geomechanical Modeling of Pennsylvanian-Wolfcampian Structures for Improved Understanding of Syntectonic Sedimentation of the Orogrande and Permian Basins

Unraveling the complex geological history of Texas during the Paleozoic, especially the Atokan-Wolfcampian period, we will develop geomechanical models to enhance our understanding of fault timing and uplift mechanisms associated with times of significant sedimentation proximal to these active tectonic elements. Integration of geomechanical-derived fault attributes into models provides for a more realistic representation of the conditions at the time of sedimentation and contributes to a deeper understanding of fault timing, uplift mechanisms, sedimentation and overall geologic evolution of the Delaware Basin and the Central Basin Platform.

In 2024 research will be on parsing focus on the influence of tectonic events in the northern Delaware Basin and the Pedernal Uplift of the Orogrande system. Leveraging previous research efforts, we will develop models to better understand the kinematic evolution of these two systems. We strive to construct comprehensive models that capture the regional variations in fault timing and uplift, thereby providing a more holistic understanding of the sedimentary and tectonic evolution during this critical geological epoch. This effort will contribute to the precision of interpretations, especially sedimentation, during key intervals and provide practical applications to the development of Wolfcampian deposition within the basins.

Cretaceous (Albian-Santonian) Fault-Related Fracture Diagenesis Age Dating to Delineate the Influence of Compressional Tectonics in the Texas Foreland

Studying the age of fault-related fractures in Texas provides a unique and valuable insight into the geologic history, petroleum systems, and reservoir characterization of the region often described as unaffected by the

Laramide orogeny (30-60 Ma). The fractures within this area hold the key to understanding the formation and evolution of fractures that are crucial for determining the permeability and porosity of the reservoir rocks, influencing fluid flow and hydrocarbon migration. Using U-Pb dating to constrain the timing of fracture cementation, we will constrain the age of various diagenetic events and provide a chronological framework which aids in discerning the relationship between fracture development and regional geological events, such as tectonic and changes in fluid composition. The integration of U-Pb dating with studies of fracture diagenesis offers a more comprehensive understanding of the dynamic geological history of the Cretaceous rocks in Texas, crucial for reservoir characterization and resource assessment in the oil and gas industry.

Virtual Reality Outcrop Models, Virtual Field Trips, and Digital Analogues

Digital outcrop models (DOMs) play a crucial role in enhancing the understanding of stratigraphic, structural and non-matrix elements that are common to the carbonate reservoir environment. Geoscientists can utilize DOMs to simulate different geological scenarios, improving their ability to interpret subsurface conditions and make informed decisions regarding exploration and production strategies. The value of digital outcrop models lies in their ability to bridge the gap between field observations and application to reservoir development scenarios.

The RCRL team will continue our efforts to develop and optimize virtual reality field trips, digital outcrop models, and other analogue models for our sponsors. Our plan is to make key areas available as digital models (OBJ or LAS files), interpreted 3D models (VRGS), and Virtual Reality sessions (Craytive Technologies BaselineZ, VRGS, RCRL VR, and other environments), and to begin to catalogue video and VR field trips. Some or all of these data types will be made available in the following areas:

- Complete: Lawyer Canyon, Algerita Escarpment - San Andres reservoir analog
- Coming in 2024: Last Chance Canyon - San Andres-Grayburg stratigraphic architecture
- Coming in 2024: Dry Canyon – Pennsylvanian stratigraphy, reservoir architecture
- Coming in 2024: Pecos River Analogs – Albian stratigraphy, sedimentology, fault zones

Our goal is to continue to generate 3D virtual-reality fieldtrips, integrating digital outcrop models with geological interpretations, core descriptions, subsurface models, and documentary materials from RCRL's database of key analogues.

Sponsor Activities in 2024

2024 Spring Core Work Session: A core workshop highlighting cores from key integrated datasets will be featured, illustrating various carbonate reservoir age, style, and setting to be determined. This workshop will contain 2 days of basic training on carbonate systems and facies descriptions followed by additional days of timely and relevant cores from current RCRL research initiatives.

Tentative 2024 Fall Field Field Trip: The current field trip plan is to visit spectacular exposures of Mississippian and Pennsylvanian depositional systems in the Franklin and Sacramento Mountains of New Mexico. Recent research on these areas has illustrated fundamental relationships in syntectonic deformation and mixed

carbonate-clastic deposition. Our intent is to highlight the importance of peak icehouse climatic conditions on deposition and interweave this dynamic deposition with an evolving syntectonic story of the Ancestral Rocky Mountains. Stops will include:

- Dog Canyon: highlight the Mississippian stratigraphic architecture present in the canyon and establish the relevant framework of the Mississippian-Pennsylvanian stratigraphic architecture.
- Bishop Cap, Dog Canyon and exposures south: view exposures of deep-water Mississippian mixed contourites- turbidites
- Alamo Canyon: Highlight depositional system exposed and view syntectonic structures and the potential impact on post-deposition fracture development
- Dry and Beeman Canyons: Virgilian lateral and temporal mixing of carbonate and siliciclastic during peak Icehouse conditions.
- Fresnal fault, La Luz anticline, and Bursum Fm: superb exposures of field-scale, syntectonic deposition and deformation of Pennsylvanian-Wolfcampian deposits

RCRL Database Updates

- Searchable Catalog of RCRL Presentations and Extended Abstracts
- RCRL Core Workshop Database
- Austin Chalk Core Properties Database
- Reservoir Properties Database of Gulf of Mexico Carbonates
- Conversion of Digital Outcrop Catalog to searchable ArcGIS (forthcoming 2024)

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Industrial Sponsors

The RCRL program has functioned continuously since 1987, maintaining strong company sponsorship each year. In 2023, these 18 companies supported our research initiatives:

2023 Financial-Contributor Members

Software and Data Contributors

Fairfield Geotechnologies	**TGS**	**Golder**	**S&P / IHS Markit**	**Velocity Databank**
Ion	**Eliis**	**Halliburton**	**Schlumberger/WesternGeco**	**GeoStar Seismic**
Craytive Technologies	**Cegal**	**VRGeoscience**	**Geophysical Insights**	

Research Group

Principal Staff

Dr. Xavier Janson, Senior Research Scientist, Principal Investigator
Dr. Charles Kerans, Goldhammer Chair of Carbonate Geology
Dr. Robert (Bob) Loucks, Senior Research Scientist
Dr. Christopher Zahm, Research Scientist Associate
Mr. Robin Dommisse, Research Scientist Associate
Mr. Josh Lambert, Research Scientist Associate

Associated Staff

Ms. Kelly Hattori, Research Scientist Associate, Stratigrapher
Dr. Tingwei ("Lucy") Ko, Research Associate, Geochemist
Dr. Hongliu Zeng, Senior Research Scientist, Seismic Analysis
Mr. Evan Sivil, XRF and Isotope Lab Manager
Dr. Sheng Peng, Research, Research Associate
Mr. Jerry Lucia, Retired Emeritus

Carbonate Reservoir Characterization Research Laboratory (RCRL)

RCRL collaborates closely with the Quantitative Clastics Laboratory (QCL) at the Bureau of Economic Geology (BEG) in the characterization of mixed carbonate/siliciclastic slope to deep-water systems in the Permian Basin and in Australia. We also collaborate with BEG's STARR-CCUS consortium on reservoir characterization projects and with the Center for Integrated Seismicity Research (CISR) for improved structural characterization in the Permian Basin.

Graduate Students

RCRL is proud of the research accomplishments of our past and current graduate students. Most of our graduated students are now working in industry research, production, and exploration. Our recent or current students and their research projects include:

Charlie Zheng (Ph.D., Dec 2024) – Origin of Cretaceous Shelf Hypoxia-Anoxia: Oxygen-Poor Oceanic Water Incursion Versus Restriction, DGS and Goldhammer Chair of Geology funding, RCRL contributor

Shawn Fullmer (Ph.D., May 2024)– Quaternary (Mid-Late Pleistocene–-Holocene) Carbonate Geomorphology of the Bahamas-Caicos Archipelago: Carbonate Factory Response to Sea-level and Climate Change. ExxonMobil and DGS-Goldhammer Chair of Geology funding, RCRL contributor

Kyle Fouke (Ph.D., May 2024) – Architecture and climatic record of the Last Interglacial Coral-algal Reef Complexes, Bahamas-Caribbean region. DGS and Goldhammer Chair of Geology funding, RCRL contributor

Evan Sivil (MSc, May 2024) – Stratigraphy and chemostratigraphy of the Eagle Ford section in the Karnes Trough area in South Texas

Colton Hayden (MSc, May 2025) – Stratigraphic architecture of the Smackover Fm. NE Texas and Arkansas, RCRL funded

Taufik Al Amin (MSc, May 2025) – Mechanical properties of carbonate fans (Wolfcamp) and the potential for natural and induced fracture heterogeneity related to differential compaction, DEPS Fellowship

Josh Malone (Ph.D., May 2026) – Pennsylvanian Shelf-to-Basin Architecture, Darwin Basin, Nevada, California, and Permian Basin, TX, RCRL funded and contributor

Invitation

Staff and students of the Reservoir Characterization Research Laboratory cordially invite you and your colleagues to contact the Principal Researchers to join us in these and other important research activities.