Reservoir Characterization Research Laboratory

Research Plans for 2014

Outcrop and Subsurface Characterization of Carbonate Reservoirs for Improved Recovery of Remaining Hydrocarbons

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EXECUTIVE SUMMARY

The Reservoir Characterization Research Laboratory (RCRL) for carbonate studies is an industrial research consortium run by the Bureau of Economic Geology (BEG) and the Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin (UT). RCRL’s 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 environment and recovery factors.

FUNDING

We invite you to participate in the continuation of the RCRL Carbonate Reservoirs Research Program for 2014. A list of recent sponsors is presented in Table 1. In 2014 the annual RCRL Industrial Associates contribution to the program will continue to be $55,000 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 can offer a 2-year (2014 and 2015) rate of $50,000 per year. The agreement would be such that an MOA would be signed agreeing to a 2-year commitment, and payment would be due at the beginning of each year.

RCRL PROGRAM

The RCRL program has run continuously since 1987, maintaining strong company sponsorship each year (Table 1). Sponsors are currently interested in a range of domestic and international carbonate reservoirs, ranging in age from Ordovician to Tertiary. This enrollment, supplemented by other grants, supports between six and nine professional staff members and varying numbers of graduate student research assistants, as well as excellent computer, editing, and graphics services.
**Principal Staff**

Dr. Charles Kerans, Geology Professor, Principal Investigator  
Dr. Robert Loucks, Senior Research Scientist, Principal Investigator  
Mr. F. Jerry Lucia, Senior Research Scientist, Geological Engineer  
Dr. Xavier Janson, Research Scientist, Geologist  
Dr. Christopher Zahm, Research Associate, Geologist  
Dr. Harry Rowe, Research Scientist, Isotope Geochemist  
Mr. Josh Lambert, Research Technician  
Ms. Stephaine Lane, Project Coordinator  

**Associate Staff**

Dr. Gregory Frébourg, Research Associate, Geologist  
Dr. Ned Frost, Research Associate, Geologist  
Dr. Steve Ruppel, Senior Research Scientist, Geologist  
Dr. Hongliu Zeng, Research Scientist, Geophysicist  

Staff members have had extensive industry experience or have worked closely with industry, and they are well aware of the challenges and questions facing development geoscientists and engineers. We are also proud of our graduate students (Appendix A) associated with RCRL, who have included several award-winning students, many of who are now working in industry.

Table 1. 2013 RCRL Sponsors

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AREAS OF INTEREST

Three primary research focus areas compose the RCRL research program: (1) characterization of carbonate-outcrop analogs, (2) characterization of carbonate subsurface reservoirs, and (3) seismic and geomodeling of both subsurface and outcrop analogs. Our research focus areas, themes, and topics that have been developed out of our experience and feedback from our sponsorship are summarized in Figure 1. The research themes are composed of linked and overlapping areas of interest. For each topic, we have listed one or two RCRL members as the primary contact for a topic; however, questions can be addressed to any member of the group.

Figure 1. The RCRL Research Program, primary research leaders and integration of overlapping themes.
We are an integrated program that incorporates established and new research methodologies. Our research is on select datasets, both outcrop and subsurface, that address specific application to subsurface challenges. Our basic approach is to work from rocks to flow modeling, within the context of continuing to develop basic principles and techniques that can be applied to exploration and production of hydrocarbons. We emphasize quantifying what we observe so that our research is (1) applicable to modeling reservoirs and (2) valuable in providing predictive relationships and conceptual tools for reservoir characterization.

**INFORMATION TRANSFER**

**General**

Our industrial sponsors receive research results at annual review meetings, in short courses, during mentoring activities, in publications and DVD’s, and on our continually updated, members-only RCRL website database (http://www.beg.utexas.edu/rcrl/members/). This online searchable database allows us to protect your investment in our collective research and makes previously presented material easy to locate and download from anywhere in the world. Each company has a unique identification logon and password, which are renewed each year of sponsorship. This database includes previous, annotated presentations, maps, core photos, porosity and permeability data, digital-outcrop reservoir models, core descriptions, and field guides from past and current RCRL field trips.

**Workshops and Field Seminar**

In addition to an annual review meeting and associated field trips, we also conduct carbonate reservoir characterization short courses and field workshops for sponsor companies during the year. We will be offering a paleokarst seminar in the spring of 2014 that will be a combined classroom, core workshop, and fieldwork seminar, and we will review carbonate and evaporite paleokarst reservoir development. The seminar will consist of lectures, core-work problems, seismic exercises, and field trips to Lower Ordovician carbonate paleokarst and Lower Cretaceous evaporite paleokarst, as well as visits to several modern cave systems. A more detailed program of the workshop will be made available early in 2014.

**Sponsor Interactions with RCRL Staff**

RCRL makes a concerted effort to interact with sponsors during the year through company-specific discussions and short-term projects to help transfer research results into their exploration and production workflow. Over the last several years, RCRL researchers have visited numerous U.S. domestic and international companies.
Charlie Kerans worked with several companies this year, visiting Pioneer Natural Resources in December of 2012 with Chris and Laura Zahm to review geologic and engineering data from Lower Cretaceous Word field and surrounding areas to assess the potential for research at Word field. In January of 2013 Kerans spent 2 weeks with Aramco and BRGM staff examining Jurassic exposures of the Tuwaiq Escarpment. In February Kerans worked closely with Steve Bachtel of Chevron to organize the Turks and Caicos modern carbonates course, which was also attended by Shawn Fullmer of ExxonMobil. During this trip, Chris Zahm, Steve Bachtel, and Charlie Kerans helped to design a UAV overflight of the West Caicos Pleistocene exposures that formed the basis of this year’s facies- and fracture-mapping project. Meetings were held on three occasions with ExxonMobil geologists to review outcrop analog work on the Cutoff/Avalon project, as well as results of the ongoing Word field characterization for which ExxonMobil had provided core and log data. In June, Kerans also visited Statoil’s offices in Austin and PetroChina’s research facility in Hangzhou to present workshops on carbonate stratigraphy and reservoir characterization. Discussions are currently being held with Statoil on a variety of future projects, as well as with KinderMorgan and OXY USA on future projects at Yates and along the NW Shelf of the Permian Basin. Chris Zahm visited KinderMorgan in Midland to gain a better understanding of fracture development and potentially related mud-circulation issues for SACROC field. This interaction has led to a 2014 project on SACROC that includes fracture and rock property characterization with potential for geomodel development. Xavier Janson did 10 days of fieldwork in the Permo-Triassic carbonates of the Sichuan Basin, examining Upper Permian reef and lower Triassic oolitic shoal complexes as part of a 3-year research collaboration with PetroChina. Bob Loucks interacted with several companies, including (1) EnergyCorp, on reservoir quality of the Upper Cretaceous Buda in south Texas, by reviewing cores and thin sections; (2) Pioneer, relative to the pore network in the Lower Cretaceous Stuart City Trend; (3) PetroChina, where he presented several talks on carbonate and evaporite paleokarst; (4) PetroChina, where he completed description of several cores from the Sichuan Basin, Upper Permian reef and lower Triassic section; and (5) OXY, on reservoir quality in the West Texas Clear Fork Formation.

Charlie Kerans, Bob Loucks, Xavier Janson, and Chris Zahm, along with RCRL Program Coordinator Stephaine Lane, visited Calgary August 4–6 to conduct an RCRL workshop on paleokarst systems that focused on the Devonian Grosmont (estimated 400-billion-barrel resource of 7-API bitumen). A total of 25 participants from 11 companies were involved in the 3-day workshop that featured presentations on karst outcrop and subsurface analogs and highlighted reservoir characterization of large-pore carbonates. The second day featured cores from the Grosmont that spanned the Lower and Upper Grosmont through the Nisku and Upper Ireton Formations. Future collaborative research on the Grosmont, including a detailed subsurface characterization study with the RCRL group and sponsor companies, will be conducted in upcoming years.
If your company has an interest in developing a cooperative project with members of the RCRL staff, we would like to hear from you. These cooperative projects, in which RCRL and company staff learn together through hands-on data analysis of real production data and issues, are essential to maintenance of the real-world relevance of our group. In addition, access to data that can be worked on, as well as presented, is imperative.

**RCRL Graduate Student Mentoring and Thesis Supervision**

RCRL has produced a significant number of graduates with advanced degrees in carbonates who are now working in industry. Charlie Kerans, a professor in the Department of Geological Sciences, Jackson School of Geosciences, holds the Robert K. Goldhammer Chair in Carbonate Geology. He teaches both undergraduate and graduate carbonates courses. Xavier Janson, Jerry Lucia, Chris Zahm, Steve Ruppel, Harry Rowe, Greg Frebourg, and Bob Loucks all teach or have taught courses in the Jackson School, and several are on the Graduate Studies Committee. Students obtain comprehensive training in carbonates working on RCRL projects and interacting with RCRL professional staff. Each student presents his or her work at the annual review meeting, which is an opportunity for sponsors to get to know students and consider them for possible future employment. A list of recent and active students is presented in Appendix A.

**RESEARCH PROGRAM FOR 2014**

**INTRODUCTION**

A hallmark of the RCRL research program is its unique combination of recognizing subsurface characterization challenges that can be improved by the use of well-defined outcrop analogs and a breadth of subsurface characterization experience that is brought to bear on problems important to sponsors of the program. The RCRL brand has been developed by combining three focus areas: (1) carbonate outcrop reservoir analogs, (2) integrated subsurface carbonate reservoir characterization, and (3) geomodeling and geologically realistic modeling of seismic, matrix pores, karst, and fractures. In the 27 years of RCRL research on carbonate systems, technical methods have been developed that populate the sequence stratigraphic framework with reservoir-flow properties so as to improve hydrocarbon recovery. Yet many challenges still exist within carbonate reservoirs, especially in the area of integration of nonmatrix pore systems (e.g., fractures and karst), pore-network-related diagenesis (e.g., micropores/tight carbonate reservoirs), and the realistic three-dimensional variability of lithofacies distribution. We think that the research challenges that remain have the best chance of being solved when they are incorporated into the overarching stratigraphic architecture that provides the fundamental framework of the reservoir characterization process.
Within the primary focus of RCRL, six thematic areas encompass the expertise of the consortium: (1) remote-sensing characterization (e.g., lidar and ground-penetrating radar), (2) geologic framework development (e.g., stratigraphic and structural architecture and mechanical stratigraphy), (3) nonmatrix pore characterization (e.g., fractures and karst cavities and vugs), (4) tight carbonate reservoirs (pore types in these varied reservoirs), (5) reservoir characterization (e.g., identification and distribution of relevant properties important to enhanced hydrocarbon recovery), and (6) analog-based synthetic seismic and geomodeling of facies, fractures, and karst.

For 2014, we are focusing research on six main themes: (1) reservoir architecture and structural style of carbonate shelf-to-basin transitions, (2) fault-related fractures within sequence stratigraphic frameworks, (3) evaporite paleokarst systems, (4) Tertiary carbonate systems, (5) tight carbonate reservoirs (including micropore-dominated reservoirs), and (6) mechanical and acoustic characterization of carbonate rocks. We will also integrate isotopes and geochemistry into our research projects as Dr. Harry Rowe develops new research approaches using these techniques in chemostratigraphy and paleodepositional interpretations.

The RCRL research projects were selected using the following criteria: (1) topics that specifically address hydrocarbon recovery issues important to our sponsors, (2) multiple levels of integration within our themes, (3) maximization of the abilities and experience of our research group, and (4) the potential to make the greatest impact on fundamental understanding of the carbonate reservoir system.

RESERVOIR ARCHITECTURE AND STRUCTURAL STYLE OF CARBONATE SHELF-TO-BASIN TRANSITIONS

The dynamics of platform-to-slope transitions (including characteristics and width of key facies tracts, density of syndepositional and later reactivated fractures, scale of margin collapse, development of growth faulting and fracturing vs. extensive collapse, timing and drivers for collapse and debris-flow megabreccia generation, and associated changes in permeability pathways) are critical to an understanding of production in fractured steep-rimming microbial systems. Field applications of this analog work include Tengiz, Kashagan, Korolev, and Karachaganak. Similar large-scale collapse is observed in the Cretaceous of the Gulf of Mexico margin, such as along the margins of the Golden Lane platform and Stuart City margin. Three datasets will receive attention this coming year for an in-depth understanding of steep microbial rim-to-slope settings: (1) Tansill-age Capitan exposures in the Rattlesnake-Walnut area of the Guadalupe Mountains, (2) Leonardian- to Capitan-age exposures of the Glass Mountains area in West Texas, and (3) Cretaceous Word field shelf and shelf-margin settings in the subsurface of south Texas.
Integrated Stratigraphic/Structural Framework of the Guadalupe Mountains

The Guadalupe Mountains remain a key laboratory for our research and training in the stratigraphy and structural attributes of steep-rimmed platforms. Study of the interaction of a prograding, steep-rimmed platform (Capitan system) and its genetically linked syndepositional faults and fractures remains a high priority for 2014. During 2013 we extended our fault-fracture mapping to northern Rattlesnake and Slaughter Canyons, and we were able to demonstrate significant syndepositional fault movement. Modeling showed that strike-extensive grabens and subsidiary faults were localized by differential compaction over immediately preceding margins and could have displacements of as much as 18 m. Mapping in 2014 will push the syndepositional structural framework south toward McKittrick Canyon. Focus on fractures systems will form part of Mathisen’s thesis, and diagenetic patterns will be incorporated into Simon’s dissertation.

Platform-to-Basin Architecture of Lower Permian Carbonates in the Glass Mountains

The Glass Mountains have long been a classic exposure of Permian stratigraphy in the southern Delaware Basin. Owing to limited access, no modern (post-80’s) work has been completed on the outcrops that expose the entire section from folded Ordovician through Wolfcampian to nearly undeformed Lower Permian (Leonardian) to Upper Permian (Castile Formation and younger equivalent units). Glass Mountain outcrops are located in the south part of the Delaware Basin, just in front of the terminal thrust of the Marathon orogenic belt near the Hovey Channel. They are therefore critical to an understanding of the regional paleogeography and the stratigraphic evolution of the south part of the Permian Basin in general. Our long-term goals are to establish a robust sequence tectono-stratigraphic framework in the southern Delaware Basin and compare it with the well-established framework of the Hueco, Sierra Diablo, and Guadalupe Mountains. Because of the paleogeographic and tectonic setting, these outcrops also provide a unique opportunity to gain an understanding of the development of carbonate platforms, as well as slope and basins in an active compressional tectonic setting.

Our main research goals are to

- Understand and unravel the combined tectonic and eustatic influence on the stratigraphic architecture of the Lower Permian mixed carbonate-siliciclastic system.
- Evaluate the influence of a northward-migrating thrust front on the carbonate-platform architecture.
- Characterize the controls of platform development, margin geometry and trajectory, and the nature of the slope system for delivery of deepwater sediments to the basin.
- Expand our models of carbonate slopes by including examples of carbonate-slope architecture in an active tectonic setting.
- Explain the regional paleogeography and its control of Capitanian reef development.
Integrated Reservoir Characterization of Lower Cretaceous Word Field, Stuart City Margin

Word field is the largest cumulative producing gas reservoir of the Stuart City Trend and is important in that virtually all storage in the reservoir is assignable to micropore systems. In addition to this pervasive micropore network, a dominant NE-SW shelf-parallel fault/fracture trend is seen as a connecting pathway for gas production. Position of the producing field within the uppermost Edwards and possibly the Georgetown (uppermost Albian) section presents an excellent opportunity to develop models for “Faulted Margin” reservoirs. RCRL initiated a reservoir characterization study of Word in 2012 using six conventional cores already at BEG, wireline logs, and regional 2D seismic data. An additional 16 cores have been lent to the study by ExxonMobil, and 6 of the 16 have now been described. In 2014 we will continue to gain access to the Halletsville 3D and will work to complete detailed logging of the EM cores from Word. We have begun to develop a high-frequency sequence stratigraphic framework using these closely spaced core data. Important results will include a better understanding of controls on the distribution of microporosity, whether they are facies related or purely diagenetically controlled. Also, relative contributions of micropore networks and fracture networks will be examined largely through evaluation of production data and updated fault mapping.

On a subregional scale, RCRL, in conjunction with industry partners, plans to investigate the effect of the end-Edwards/Georgetown drowning phase and resultant palimpsest paleotopography on Cenomanian depositional patterns.

West Caicos—Laboratory for Modeling Embryonic Fracture Systems on Steep-Rimmed Margins and Strandplain Grainstone Depositional Patterns

West Caicos is a grainstone-dominated island on the west margin of the Caicos Platform. The superb exposures of foreshore-upper shoreface and reefal facies along the west shoreline of the island were the focus of this year’s UAV-assisted mapping project. Next year, we hope to expand the study to the remainder of the western shoreline, a limited amount of offshore exploration, and a digital image and DEM capture of the entire island that would allow high-resolution mapping and modeling of island evolution, fracture and karst systems, and active hydrology. Material will also be collected for age dating to address questions concerning the absolute age of different unconformity-bound units.

This year’s results allowed recognition of a suite of 15 facies within the reef complexes and foreshore-upper shoreface deposits. We are currently mapping these facies digitally using high-resolution UAV-created DEM and photography, which will allow for quantification of facies dimensions, absolute water-depth ranges of facies, and relationship between facies and early-formed fracture systems. We also intend to further document the unique storm-generated boulder ridges both on West Caicos in the Pleistocene and near Water Cay in the Holocene.
EVAPORITE PALEOKARST SYSTEMS

Through our research relative to karstification of both carbonates and evaporites, we recognize that they form important reservoirs in their own right or modify other reservoirs (e.g., Lower Ordovician throughout the world, Siluro-Devonian and Permian in West Texas, Lower Cretaceous in Mexico and the Western Florida Shelf, Mississippian in the western U.S., Permian in Kazakhstan, etc.). Important features and concepts relative to an understanding of ancient systems include (1) controls on cavern dimensions and resulting products, (2) system and passage morphology, (3) early breakdown/collapse and associated fractures, (4) differentiating far-field stress fractures from cavern-stress-related fractures, (5) sediment-fill types and origins, (6) origin and description of pore networks, (7) rejuvenation of caves (composite cave systems), (8) comparing karst expressions regionally, and (9) integrating results into reservoir-flow modeling.

Evaporite Paleokarst Characterization and Associated Fracture Development, Cretaceous Kirschberg, Junction, Texas

We are completing a detailed investigation of evaporite paleokarst in a series of roadcuts (over 80 miles) near Junction, Texas, in the Lower Cretaceous Edwards Group. This area is an excellent analog for an evaporite karst system that did not have a superficial sediment source to fill caverns. As a result, the cavern had little internal sediment fill to support the ceiling. Extensive cavern collapse occurred with associated brecciation and extensive suprastratal deformation, including development of open shear fractures and faults. This study has developed the concept that older fracture-system stress patterns control the fracture patterns of much younger suprastratal fracture development. Alternatively, the evaporite horizon may be acting as a strain-partitioning horizon, decoupling the overburden rock and associated deformation from underlying strata. We will continue to test these hypotheses and compare this case history to other systems.

We are in the process of collecting ground-penetrating radar data in several areas adjacent to the roadcuts to define the evaporite paleokarst architecture in 3D detail. The 3D data are needed to derive orientation of the collapse-related features so that a clearer 3D mechanical model might be developed. Whether the collapse produces linear or circular patterns is important to understand because these patterns will partly define the controls on fractures in the damaged zone.

Collaborative Research Project for Karst and Fracture Characterization and Modeling of the Pelican Lake Property in the Devonian Grosmont

Complex deformation related to evaporite removal in the Grosmont of the Upper Ireton creates significant reservoir heterogeneity. However, billions of barrels of low-API bitumen is present in
the Grosmont, making characterization valuable. The RCRL group will be working with Cenovus Energy to both characterize the karst and fracture distribution and develop subsurface reservoir models that are based on well and core data, as well as 3D seismic volumes over the Pelican Lake asset. It will probably be a multiyear study. Research results, including modeling strategy and work flow, will be shared with the RCRL group during annual meetings.

**Geomodeling of Karst-Collapse Systems**

Karst-collapse systems have distinct reservoir elements that are extremely heterogeneous, with matrix, fractures, and touching and nontouching vuggy pores. We will construct geomodels that capture these variations within the Cretaceous Kirschberg (greater Junction area) and Mississippian Madison Formations (Bighorn Canyon Recreation area). The geomodels constructed for the karst-collapse systems will include distribution of essential reservoir elements, including matrix and karst-collapse breccias, along with dissolution-enhanced fractures, fracture fills, and deformation-related discrete fractures. We expect nonunique geomodel solutions, but we hope to highlight key elements to reservoir-flow behavior, including pore-volume distribution and recovery and sweep efficiency.

**TERTIARY CARBONATE SYSTEMS**

The RCRL has worked on cores from several southeast Asia reservoirs. The cores, which are from isolated platforms, cover depositional settings ranging from platform interior, to reef-rim, to deeper-water slope systems of Oligocene to Miocene age. One focus of the research in Tertiary carbonates is to improve depositional models that will cover a wide spectrum of Oligo-Miocene platforms. In 2014, a particular focus will be on improving our understanding of carbonate deposition and stratigraphic architecture in extension-tectonic settings and carbonate deposition and stratigraphic architecture of platforms deposited over highly irregular topography.

**Miocene Carbonate Platform in the Mut and Adana Basins, South Turkey**

Next year we will investigate new outcrops and initiate an outcrop study in the Adana Basin in SW Turkey to study the response of the Lower to Mid-Miocene carbonate platform to extension tectonic. The Adana Basin is a rapidly subsiding basin of the Neogene, with a small (1–4 km wide) platform developing on the crest of normal fault blocks. In addition, we will revisit the classic exposure of the Mut Basin to acquire lidar and Gigapan and ultimately build an updated 3D geocellular model of these exceptionally exposed attached and isolated platforms.
Lower Miocene Isolated Platforms in the Java Sea, Indonesia

As part of Reynaldy Fifariz’s Ph.D. research, and in collaboration with Professor Benjamin Sapiie of ITB Bandung, we have gained access to a regional dataset of 2D seismic and cores and are in the process of getting permission to work on several 3D seismic datasets over the East Java Sea area. The goal of the study will be to provide a regional architecture and detailed depositional and reservoir model of the various Oligo-Miocene isolated carbonate platforms that grew on a complex horst-and-graben system reactivated by later inversion. These platforms have several reservoir intervals of different ages and present numerous styles of carbonate systems ranging from a mixed carbonate-siliciclastic, clay-rich shelf system to small aggrading coralgal pinnacle reefs.

TIGHT CARBONATE RESERVOIRS

Origin and Petrophysics of Tight Limestone Reservoirs

We see gas production from “tight” carbonate reservoirs as a significant unconventional resource, with important examples including the Lower Cretaceous Stuart City Trend and Sligo Trend in south Texas or many of the Middle East Lower Cretaceous reservoirs. We are now searching for other gas fields that produce from low-permeability limestones to determine whether micropores are major contributors to production. Candidates include the Georgetown, Buda, and Austin Chalk units in Texas and the Niobrara in Colorado. An important part of this study is the investigating and cataloging of micropore/microrhombic calcite reservoirs worldwide. In this project, we want to define the types, origins, temporal and spatial distribution, and petrophysical properties of micropore/microrhombic calcite.

Development of Microporous Reservoirs through the Stabilization of Mg-Calcite Sediments

We have made significant progress in understanding and documenting the transformation of original Mg-calcite allochems, such as foraminifera, Lithocodium, and red algae, to low-Mg calcite and associated micropores. We have data on over 20 reservoirs that show micropore development from the stabilization of Mg calcite, and the ages of these reservoirs range from Pennsylvanian through Miocene. A major conclusion from these observations that we are leaning toward is that microrhombic calcite formation may simply be the normal stabilization product of Mg-calcite. No specific diagenetic pathway or fluid is necessary, only a diagenetic environmental disequilibrium change. Micropores result where equilibrium occurs within the grain between dissolution and reprecipitation. When calcium carbonate is added to the grain, cementation occludes pores. When calcium carbonate leaves the grain, moldic pores develop. This conclusion addresses the varied and contradicting conclusions suggested for the formation
of microrhombic calcite and associated micropores. Along with finding more worldwide examples of micropore-dominated reservoirs, further research of younger samples (Recent and Pleistocene) of carbonates undergoing diagenesis needs to be conducted. Also, laboratory experiments of Modern, high-Mg-calcite grains need to be pursued to see whether we can convert Modern, Mg-calcite grains into microrhombic calcite.

Origin of Micropores in Coccolith-Rich Muds (Chalks)

In the past year we have begun investigating the occurrence of micropores in chalks and how they evolve with burial. They are deposited with high porosities, and they lose much of this porosity by mechanical compaction. Diagenesis associated with burial (time, temperature, and pressure) consists of calcite overgrowths on coccolith plates, and fragments reduce porosity further. We have started on a sample set of carbonated muds (some argillaceous) from outcrops west of Del Rio, Texas. These include Upper Cretaceous Buda, Eagle Ford, and Austin Chalk units. We are now analyzing subsurface datasets from the Buda, Eagle Ford, Austin, and Annona/Ozan chalks in the GOM, as well as the Niobrara Chalk in Colorado. We plan to collect more petrophysical data on these chalks and relate reservoir quality to grain size and sorting.

Origin of Micropores in Carbonate Mud

The origin of micropores continues to be a principal research interest. Our approach is to collect information concerning the changes in microfabrics in grains and in carbonate mud beginning with deposition and tracing changes that occur through the geologic column. Many porous and permeable carbonate reservoirs produce from mud-dominated fabrics, as noted in numerous Middle Eastern reservoirs. Several ideas have been presented to explain the origin of these reservoirs, including compaction, transformation and cementation of an aragonitic and Mg-calcite lime mud, and burial dissolution. Our previous studies of mud-dominated fabrics suggest that conversion of a minicmicrite aragonitic and HMC lime mud to a microspar fabric is a simple dissolution and reprecipitation process. This early diagenetic process creates the basic microporous fabric to be modified by burial diagenesis. We hypothesize that only occlusion of the intercrystalline pore space by compaction and cementation follows. We will continue to search for and develop information on the origin of microfabrics and micropores in lime mud and grains by collecting data from Modern, Miocene, Cretaceous, and Pennsylvanian carbonates.

Petrophysics of Microporous Limestone Reservoirs

A major research direction in the understanding of carbonate reservoirs is the origin and petrophysics of limestones that have significant volumes of micropores. Our current interest is in cemented grainstones and mud-lean, grain-dominated packstones with microporous grains. Our previous research has found an excellent correlation between median pore-throat size and
permeability. The relationship between permeability and crystal size, however, has not been as robust as expected. This year we plan to gather data from Word field sufficient to formulate a meaningful relationship between the crystalline fabric containing intragrain micropores, porosity, and permeability for cemented grain-dominated fabrics. In addition, Word field has significant microporous mud-dominated fabrics that will provide a basis for examining the relationship between intragrain micropores in cement.

Upper Cretaceous Buda and Austin Chalks Regional Study

The Buda and Austin Chalks are an integral part of the unconventional hydrocarbon system in the Texas part of the Gulf of Mexico and are also genetically and temporally linked to the prolific oil-rich Eagle Ford system. To gain a better understanding of the evolution and demise of these Gulf of Mexico drowned-carbonate platform successions, the RCRL, with cooperation of the BEG STARR Program, has undertaken a multipronged approach to the study of the Buda and Austin Chalks. Depositional patterns of these chalks will be reviewed using existing and new data (measured sections, core descriptions, wireline logs) along a proximal to distal transect so that changes in facies, oxidation, and productivity trends can be looked for, along with organic richness. Significant work is ongoing in southwest Texas, and we plan to leverage against that experience while working with the eastern outcrop belt and available core data.

This stratigraphic framework will be coupled with collection of basic data on cores of the Buda and Austin Chalks, including XRF mineralogy, UCS (unconfined compressive strength), spectral gamma, minipermeameter, and velocity profiles. Petrology, petrography, and SEM analysis to explain grain and pore types are a fundamental dataset that will be used in combination with the associated data. In conjunction with the BEG-STARR program, 3D seismic analysis of fault and fracture corridors and their relationship to production trends will ultimately tie together stratigraphic and structural frameworks, along with petrophysical data and reservoir productivity, so that a more complete understanding of production trends and fairways within this Upper Cretaceous system can be achieved.

**TOPICAL STUDIES**

Rock-Property Characterization

The primary goal of our rock-property research is to establish a relationship between depositional facies, paragenesis, and elastic properties of various types of carbonates. This long-term work aims at answering the following questions:

- Do facies control elastic properties in carbonate?
- To what extent can we link mechanical properties to facies and thus be predictive?
- What is the distribution and level of heterogeneity of each elastic property within a single facies?
- What controls heterogeneity?
- What are the implications for reservoir characterization?
- Can we confidently invert relevant elastic parameters at the seismic scale?

The RCRL group has a growing database of unconfined rock properties in carbonates from numerous cores and outcrops around the world. The database includes carbonate, unconfined, compressive-strength measurements; ultrasonic velocity; spectral gamma; minipermeability; mineralogy (XRF and XRD); carbonate facies; and pore types. In addition, we will be collecting rock physics and mechanical properties using a new triaxial load frame to collect static and dynamic elastic properties to as much as 140 MPa of both confining and pore pressure and up to a temperature of 150°C. The triaxial test allows accurate measurement of elastic parameters such as yield strength, Young’s modulus, Poisson’s ratio, permeability calculations, and acoustic properties, including shear and compressional velocity. Our approach consists of collecting nondestructive data on a high-resolution vertical scale (0.5 ft or less) and calibrating these results with strategically selected samples that will be measured using the triaxial press. This combination provides a relatively fast way of having a statistically significant, yet well-calibrated number of elastic-properties measurements to help us define the relationship between rock strength and porosity, rock fabric, lithofacies, and pore-throat size and geometry that is critical to producing realistic and predictive subsurface models.

**Integrated Facies, Fracture, and Reservoir Model of SACROC**

The RCRL group has been working on various aspects of SACROC field over the last decade. Next year, we will try to integrate all the different studies that we have performed on this isolated Upper Carboniferous platform into a single reservoir model. Several challenges in the SACROC field make it an ideal, yet challenging, dataset for building a reservoir model. Ultimately, we will try to develop an optimized workflow to integrate facies, mechanical properties, fractures, and reservoir properties from core, log, and seismic data using methods and results of the geomodel being transferred to RCRL sponsors.

**Lidar-Orthogrammetry Fusion and Drone Acquisition**

Lidar-Orthogrammetry Fusion, in which high-resolution, ground-based lidar and Gigapan images are merged into a common dataset, remains an evolving research topic for the RCRL. We will be refining the workflow of this process in 2014, emphasizing synchronous acquisition of lidar and Gigapan photographs. These key datasets must be taken from exactly the same position to capture the same surface area of the specified target. New approaches using Quick Terrain
Modeler software will aid the process of fusing Gigapan high-resolution photography and Optech ILRIS lidar scans. The final product is a highly accurate 3D representation of the outcrop that can be interpreted for input into outcrop reservoir models.

In 2013, we developed a work flow for the acquisition of high-resolution orthographic acquisition using aerial drones. Both orthorectified 2D images and 3D orthogrammetry were used to create 3D models from the photographs. In addition to implementation of the work flow, we demonstrated application of this technology in our research projects. Joint funding from RCRL and the Jackson School equipment fund has led to purchase of our own autonomous hexacopter that will allow us to acquire in-house data of a quality similar to that of the Camera Wings group. This year we will refine the integration of UAV data and photogrammetry in our digital outcrop workflow. Flight altitude, percentage of overlap between photos, camera resolution, shooting angle, and flight plan all influence the final 3D model, and we hope to optimize our methodology.

**Isotopic and Elemental Approaches to Carbonate Stratigraphy, Depositional Settings, and Diagenesis**

A concerted effort to develop the links between isotopic and elemental chemistry of carbonate and mixed carbonate/siliciclastic reservoirs is under way. This work currently encompasses work on many Cretaceous units from the Austin Chalk; Eagle Ford/Boquillas, Buda, Salmon Peak, Stuart City, and Pearsall strata in Texas; the Sunniland Formation in Florida; and the Niobrara in Colorado. Four portable X-ray fluorescence units, a microbeam X-ray fluorescence unit, and a rapid-analysis X-ray diffractometer are the instruments that we use to develop geochemical, microgeochemical, and mineralogical datasets, respectively, for the just-mentioned reservoirs. Over the next 4 months, a stable isotope laboratory devoted to analysis of $\delta^{13}C/\delta^{18}O$ of carbonates and $\delta^{13}C/\delta^{15}N$ of rock organics will be built at the BEG. The geochemical datasets will most likely be utilized not only for chemostratigraphic control, but also to arrive at a deeper understanding of depositional and postdepositional conditions. Harry Rowe will focus on developing geochemically based models that complement ongoing work and help to expand the understanding of paleoenvironmental setting and diagenetic history. An additional goal is development of reference-material suites that will better underpin the elemental analysis of evaporite paleokarst and redox-sensitive metals in diagenetic carbonates. The first reference suite that includes Austin, Buda, Edwards, and Georgetown will be developed.

**SUMMARY**

RCRL is an integrated carbonate research group whose major mission is to use outcrop and subsurface geological, geophysical, and petrophysical data as the basis for developing new and integrated methodologies for a better understanding and description of the 3D carbonate reservoir system. We have a multifaceted research program that covers (1) carbonate outcrop-
reservoir analogs, (2) integrated subsurface carbonate-reservoir characterization, and (3) geomodeling and geologically realistic modeling of seismic, karst, and fractures. Research members of the RCRL group have had extensive industry experience or have been working closely with industry to solve reservoir characterization problems. We strive to incorporate the latest technology and concepts toward development of the “best practice” approach to integrated reservoir characterization.

In 2014, the annual RCRL Industrial Associates contribution to the program is $55,000 per year. We 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. A 2-year agreement is currently being offered at $50,000 per year for the next 2 years (total of $100,000, with $50,000 due at the beginning of each year).

If you have any questions on any aspect of the RCRL Carbonate Reservoirs Research Program, please contact Charlie Kerans (512-471-4282 or ckerans@jsg.utexas.edu) or Bob Loucks (512-471-0366 or bob.loucks@beg.utexas.edu).
Students in Progress


Reynaldy Fifariz, Ph.D. Candidate (expected completion, May 2016) - Research objectives: Integrating core, well log, seismic, and outcrop analogs to propose a regional architecture of faulted carbonate platforms of the East Java area, Indonesia. Title of thesis: Regional Stratigraphic Architecture and Depositional Model of Miocene Carbonate, East Java, Indonesia; Co-supervisors: X. Janson and C. Kerans; Committee: Ron Steel, Graig Fulthorp, and Ben Sapiie.


Ahmed Hassan, Ph.D. Candidate (expected completion May, 2016) - Research objective: Distribution of intragranular micropores in a low-resistivity pay zone from Lower Cretaceous Thamama Group, Abu Dhabi, United Arab Emirate. Title of thesis: Factors Controlling Dual Porosity Networks in Low-Resistivity Pay Carbonates from Lower Cretaceous Thamama Group, Abu Dhabi, United Arab Emirates; Supervisor: C. Kerans.

Gregory Hurd, Ph.D. Candidate (expected completion, May 2015) - Research objective: Interpreting and modeling processes of deposition and deformation on carbonate slopes. Title of thesis: Not yet selected; Co-supervisors: C. Kerans and X. Janson; Committee: P. Flemings, D. Mohrig, and T. Simo.

Maren Mathisen, M.Sc. Candidate (expected completion, May 2014) - Research objectives: Characterizing the fault and fracture system between Rattlesnake and Slaughter Canyons and integrating with previous work in the Walnut and Dark Canyons toward an understanding of the structural variability along a change in strike of the Capitan shelf margin. Title of thesis: Structural Evolution along a Strike Change in the Capitan Shelf Margin, Guadalupe Mountains, SE New Mexico; Co-supervisors: C. Zahm and C. Kerans; Committee: not yet selected.

Andrea Nolting, Ph.D. Candidate (expected completion, May 2017) - Research objective: Structural controls on shelf margin faulting and failure. Title of thesis: Not yet selected; Co-supervisors: C. Zahm and C. Kerans.
Rebekah Simon, Ph.D. Candidate (expected completion, May 2016) - Research objective: General understanding of the role of syndepositional fractures and faults in controlling early and late diagenesis of platform margins. Title of thesis: Not yet selected; Co-supervisors: C. Kerans and C. Zahm; Committee: not yet selected.

Recently Graduated


APPENDIX B: RECENT RCRL PUBLICATIONS

In Press


Janson, X., and Simo, T., in press, 3D geological characterization of Carboniferous carbonate mounds: Sedimentology.


2013


2012


2011


Janson, X., Eberli, G. P., Lomando, A. J., and Bonnaffé, F., 2011, Seismic characterization of large-scale platform-margin collapse along the Zhujiang carbonate platform (Miocene) of the South China Sea, based on Miocene outcrop analogs from Mut Basin, Turkey: SEPM (Society for Sedimentary Geology) Special Publication No. 95, p. 79-98.


2010


2009

