Reservoir Characterization Research Laboratory

Research Plans for 2013

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

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Cover Photo

Mississippian Madison Formation as exposed in the Bighorn Canyon National Recreation Area in Montana. The upper strata have within this exposure have been subjected to widespread evaporite karst development and may be an analog reservoir type for heavy oil deposits within the Canadian Grosmont Formation.
Reservoir Characterization Research Laboratory Research Plans for 2013

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Reservoir Characterization Research Laboratory

Research Plans for 2013

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

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 2013. A list of recent sponsors is presented in Table 1. In 2013 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 (2013 and 2014) 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.
The RCRL program has run continuously since 1987 and has produced numerous external publications, as well as BEG publications, on carbonate reservoir characterization, sequence stratigraphy, petrophysics, geostatistics, and petroleum engineering, 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. Logan Pennington, Lidar Research Specialist
- 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
- Ms. Laura Zahm, Research Scientist Associate, 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 student students associated with RCRL, who have included several award-winning students, many of who are now working in industry.
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, similar to those of subsurface characterization, 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.

Table 1. 2012 RCRL Sponsors

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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 field seminar in the spring of 2013. This course will use the unique Lower through Upper Cretaceous carbonate outcrops in southwest Texas to illustrate both exploration and reservoir-scale stratigraphic architecture. This field trip will visit a suite of outcrops that highlight different depositional setting, facies, and reservoir types. Formation will include the Edwards, Del Rio, Buda, Eagle Ford, and Austin Chalk. Data examined will include outcrops, cores, and subsurface analog data. This course will contain both field lectures and hands-on field exercises such as measuring sections, mapping, cycle variability, and stratal geometries, combined with evening discussions/lectures. This trip is ideal for geologists and engineers who actively work with subsurface data. The participants will gain substantial insight about the systems they are studying through working on these RCRL-researched outcrops. This trip is tentatively planned for the third week of April 2013.

We will also be offering a combined classroom, core workshop and fieldwork seminar in 2013. It 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. We will send a more detailed program of workshop early in 2013.
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 visited numerous US domestic and international companies. During 2012 Chris Zahm visited Husky Oil in Calgary to examine core and discuss modeling of Grosmont heavy oil system with an integrated team of Husky geoscientists and engineers. Several companies within RCRL now have working or operating interests within the Grosmont and a trip to Calgary is being planned for early 2013 to meet with RCRL member companies. During this visit we will discuss ways to utilize RCRL strengths of outcrop characterization, stratigraphic and structural framework development and karst processes in a way that provides meaningful concepts for development of the Grosmont reservoirs. Chris also visited Shell in Houston to discuss fracture modeling and to present work on evaporite paleokarst as it relates to the Grosmont. From this visit, a follow-up field trip examined outcrop analogs of fault damage zones in the Hill Country. Bob Loucks interacted with several companies including: (1) discussions on Upper Cretaceous reservoirs with Devon, (2) fieldtrip and core workshop with ConocoPhillips on carbonate karst reservoirs, (3) core workshop with Oxy on the North Cowden Grayburg field, (4) a review of seismic recognition of reef complexes for BHP (along with Xavier Janson), and (5) several presentations to management of PetroChina on various carbonate topics. Jerry Lucia did several special projects for KinderMorgan on thief zones in the Sacroc field. Charlie Kerans, Laura Zahm and Chris Zahm visited ExxonMobil and Pioneer Natural Resources to initiate a cooperative project on the Lower Cretaceous Word Field along the Stuart City in south Texas. Kerans and Greg Hurd also worked with ExxonMobil to begin work on the Permian Bone Springs play in West Texas using outcrop data from the Western Escarpment of the Guadalupes and adjacent subsurface well data. Work on Jurassic outcrop analogs has begun with Aramco, and will continue in 2013. Xavier Janson is leading the RCRL effort in a 3-year project with the research arm of the China National Petroleum Company (CNPC-RIPED) to help them build outcrop-based models that can be integrated into their reservoir characterization projects. The Permo-Triassic outcrop in the Sichuan Basin in China will be the research outcrop area. Within the agreement of this project, RCRL held a two week outcrop-modeling workshop here in Austin that was attended by 6 CNPC personnel and participated in a week long initial field campaign in the Sichuan Basin. Additional field work and data collection, as well as analysis of subsurface data are planned for 2013. As part of the expanding effort on Tertiary carbonate reservoir systems, Xavier Janson and Bob Loucks conducted a 2-day core workshop on the Oligo-Miocene of the Philippines for BHP. In addition, RCRL researchers visited several other companies for one-on-one interaction and review of our research goals and their applicability to each company’s specific assets and issues.

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, where RCRL and company staff learn together through hands-on data analysis of real production data and issues, are
essential to maintain the real-world relevance of our group. In addition, access to data that can be worked on, and presented, is imperative.

**RCRL Graduate Student Mentoring and Thesis Supervision**

RCRL has produced a significant number of graduates with advanced degrees in carbonates that 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, and Bob Loucks all teach or have taught courses in the Jackson School, and several of them are on the Graduate Studies Committee. The students obtain comprehensive training in carbonates working on RCRL projects and interacting with RCRL professional staff. Each of the students 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 2013**

**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 wide 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 25 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), 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, five 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) reservoir characterization (e.g., identification and distribution of relevant properties important to enhanced hydrocarbon recovery), and (5) analog-based synthetic seismic and geomodeling of facies, fractures, and karst.

For 2013, we are focusing research efforts 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 have also added expertise in isotopes and geochemistry with the addition of Dr. Harry Rove to our group. We will apply his expertise to chemostratigraphy and paleodepositional settings.

The RCRL research projects were selected using the following criteria: (1) topics that specifically address hydrocarbon recovery issues important to our sponsors, (2) have multiple levels of integration within our themes, (3) maximize the abilities and experience of our research group, and (4) have 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

Understanding 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 for understanding production in fractured steep-rimming microbial systems. Field applications for 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 to gain 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.
Airborne Lidar-Assisted Regional 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. The ability to study the interaction of a prograding steep-rimmed platform (Capitan system) and its genetically linked syndepositional faults and fractures remains a high priority for 2013. During 2012 our mapping and modeling showed that strike-extensive grabens and subsidiary faults were localized by differential compaction over immediately preceding margins and could have displacements up to 18 m. In 2012 we mapped the Yates (G24-26) and Tansill (G27-28) between Rattlesnake and Walnut Canyons, a distance of 11 miles and approximately 1 km of vertical section and 4 high-frequency sequences. The Cave Graben fault system was the main through-going structural element, but similar features occur at both younger and older margins, as well as independently across the platform. Mapping in 2013 will push these sequences and structures south towards McKittrick Canyon as well as north of Walnut Canyon around the shelf-margin salient to Dark Canyon, attempting to determine patterns and timing of sequence development, syndepositional fault character, and associated diagenesis.

Platform to Basin architecture of the Early Permian carbonates in the Glass Mountains.

In 2013, we will start investigating the Permian outcrop in the Glass Mountains. These outcrops are time-equivalent of the rock exposed in the Guadalupe Mountains and Diablo Mountains that were studied in previous years by the RCRL group. The interest in the Glass Mountains is both at the regional scale and the reservoir scale. We hope to complete our regional understanding of the Permian carbonate system by adding this southern location to the dataset. The Glass Mountains are located in the southern part of the Delaware basin close to the Marathon orogenic thrust front. As a result, the Earliest Permian (Wolfcampian) is strongly influenced by the waning tectonic activity associated with the orogeny. Similarly, the overall shape of the basin and its connection to the open ocean, as well as the cessation of carbonate production in the basin, are still unsettled questions. In addition, there are excellent, almost continuous exposures of platform to basin transition of the Leonardian strata that can be mapped and reconstructed in detail. This part of the study will focus on relating the architecture of the Leonardian platform interior and margin to the basinal deposits of the Bone Spring Formation, which is currently a key exploration target in the basin. In addition, an excellent exposure of the Capitan margin could be investigated (if granted access) and compared with its time equivalent margin in the Guadalupe Mountains.
Integrated Reservoir Characterization of Lower Cretaceous Word Field, Stuart City Margin

The Word Field is the largest cumulative producing gas reservoir of the Stuart City Trend, with 600 BCF produced to date. After viewing results of studies by Lowell Waite and others at Pioneer Natural Resources and Ryan Phelps PhD work (RCRL 2011), we determined that Word had important characteristics of a fault-modified margin reservoir and fit within the larger "Faulted Margins" theme. RCRL initiated a reservoir characterization study of Word in 2012 with 6 conventional cores already at BEG, wireline logs, and regional 2D seismic data. An additional 16 cores have been loaned to the study by ExxonMobil, making this by far the best rock dataset of any area along the Stuart City margin. Other data that we are pursuing are modern log suites, the original CGG Halletsville 3D survey, and detailed per-well production data. Goals of the 2013 study are improved characterization of facies, faults, and the relative role of fractures, macropores, and micropores in reservoir performance.

Upper Cretaceous Austin Chalk Regional Study

The Austin Chalk is an integral part of the unconventional hydrocarbon system in the Texas portion of the Gulf of Mexico and is also genetically and temporally linked to the prolific oil-rich Eagle Ford system. In order to better understand the evolution and demise of the Gulf of Mexico carbonate platform succession, the RCRL plans to take a multi-pronged approach to the study of the Austin Chalk. Depositional patterns of the Austin Chalk will be reviewed using existing and new data (measured sections, core descriptions, wireline logs) along a proximal to distal transect looking for changes in facies, oxidation and productivity trends, and organic richness. Significant work is ongoing in southwest Texas and we plan to leverage against that experience while working the eastern outcrop belt and available core data.

This stratigraphic framework will be coupled with collection of basic data on cores of the Austin Chalk including XRF mineralogy, UCS (unconfined compressive strength), spectral gamma, minipermeameter, and velocity profiles. Petrology, petrography, and SEM analysis to understand 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 relationship to production trends will ultimately tie the stratigraphic and structural framework, along with petrophysical data and reservoir productivity together to arrive at a more complete understanding of production trends and fairways within this Late Cretaceous system.
Mixed Siliciclastic-Carbonate Systems Synthesis

Last year we presented our results on humid, clay-rich mixed carbonate siliciclastic system. This year we will initiate a synthesis of mixed system based on in-house datasets and literature review. The goal of this synthesis will be to (1) better understand the range of facies, facies belt arrangement, stratigraphic architecture, and tectonic and climate forcing on mixed system, and (2) provide semiquantitative data compilation on facies type frequency, reservoir quality, geobody dimensions, and shelf/platform morphology for a wide-range of mixed systems.

**FRACTURES WITHIN A CARBONATE SEQUENCE STRATIGRAPHIC FRAMEWORK**

Carbonate sequence stratigraphy provides a framework that enables an improved predictive fracture distribution in outcrop exposures and subsurface reservoirs. Characterization of relative bed thickness, lithofacies, rock strength, and other rock properties will be linked to the larger sequence stratigraphic architecture, providing additional information about the distribution of fracture-prone facies.

Partitioned Fracture Development Related to Mixed Carbonate-Evaporite, Sheep Mountain Anticline

Fracture development within the Mississippian Madison at Sheep Mountain Anticline has been shown to be partitioned by the mechanical stratigraphic packages as a result of evaporite dissolution. This important relationship has important implications for fracture development as a fractured reservoir analog for emerging exploration in Khurdistan as well as other mixed Cretaceous systems in the greater Gulf of Mexico-Caribbean region. We will provide a more detailed examination of structural elements that partition fractures at the bed, cycle and third-order sequence scale. We will continue lidar and Gigapan acquisitions along the northern railroad canyon exposure. Sheep Mountain anticline is a world-class exposure due to its ideal reservoir scale. Our ultimate goal is to construct a model that incorporates the matrix, evaporite karst, and fractures within the deformed geometry to better understand the effects of each element on the flow performance within a mechanically-stratified reservoir analog.
Quantifying Bedding Thickness, Facies Proportions and Rock-Strength effects on Fracture Development in Carbonate Systems

The RCRL group has a growing database of rock-strength measurements in carbonates, now requiring a formalized database to capture essential elements about rock properties, facies, pore types, and unconfined compressive strength measurements (UCS). Over the past 4 years, we have developed a database that highlights variations in rock strength and resultant fracture development when subjected to deformation. We think that this research represents a distinct advance in how fractured reservoir models are developed. Linking facies, lithology, pore type, and rock properties to the broader stratigraphic architecture (e.g., vertical mechanical facies associations and comparisons between TST-HST styles) to appropriate fracture-intensity variations will be a differential factor in characterizing carbonate reservoirs.

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, 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 cave dimensions and resulting products, (2) system and passage morphology, (3) early breakdown/collapse and associated fractures, (4) differentiating far-field stress fractures from cave-stress-related fractures, (5) sediment-fill types and origins, (6) origin 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 the development of open shear fractures and faults. This study has developed the concept that the older fracture system stress patterns control the fracture patterns of the much younger suprastratal fracture development. Alternatively, the evaporite horizon may be acting as a strain partitioning horizon, decoupling the overburden rock and the associated
deformation from underlying strata. We will continue to test these hypotheses and compare this to other systems. We want to supplement this study with Lidar and GigaPan data collection.

**Geomodeling and Flow Simulation of Karst-Collapse Systems**

Karst-collapse systems have distinct reservoir elements that are extremely heterogeneous with matrix, fractures, and touching and non-touching 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 the distribution of essential reservoir elements including matrix, karst collapse breccias along with dissolution enhanced fractures, fracture fills, and deformation-related discrete fractures. We expect non-unique geomodel solutions, but we hope to highlight key elements to reservoir-flow behavior, including pore volume distribution along with recovery and sweep efficiency.

**TERTIARY CARBONATE SYSTEMS**

In recent years, the RCRL has worked on a series of cores from several Southeast Asia reservoirs. The cores are from isolated platforms and cover depositional settings ranging from platform interior, reef-rim, to deeper-water slope systems of Oligocene to Miocene age. One focus of the research in Tertiary carbonate is to establish improved depositional models that will cover a wider spectrum of Oligo-Miocene platforms. In particular, we are interested in improving our understanding of: (1) carbonate deposition in oligophotic low- and high-energy environments; (2) carbonate deposition and stratigraphic architecture in an extension-tectonic setting; (3) carbonate deposition and stratigraphic architecture of platforms deposited over highly irregular topography; (4) deep-water carbonates associated with Oligo-Miocene platforms; and (5) pore-networks associated with the different lithofacies and diagenetic pathways. An effort will be made to obtain associated wireline-log suites and seismic data. Major objectives are to develop updated models for linking facies associations and stratigraphic architecture to reservoir-pore-network evolution, with a special emphasis on the abundance of micropore development. Also, several field areas are being considered for outcrop analog research.

**Lower Miocene Isolated Platforms in the Northwest Palawan Area, Philippines**

In 2013, we will compile data that the RCRL acquired from a long, informative core from the reefal margin of an isolated buildup on the Palawan Shelf. The dataset includes: (1) facies and texture description, (2) detailed analysis of the foraminifera, (3) detailed petrographic analysis, (4) minipermeameter measurements, (5) sonic measurements, and (6) UCS measurements. In
2013 we plan to add stable isotope data and detailed x-ray fluorescence (XRF) mineralogy data to the dataset. This dataset will be made available digitally on our RCRL web-site.

**Lower Miocene Isolated Platforms in the Java Sea, Indonesia**
As part of Reynaldy Fifariz’s PhD research, and in collaboration with Professor Benjamin Sapiie of ITB Bandung, we will have access to a regional dataset of core, wireline-log, and seismic (2D and 3D) data 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 mixed carbonate–siliciclastic clay-rich shelf system to small aggrading coralgal pinnacle reefs.

**TOPICAL SUBSURFACE STUDIES**

**Origin and Petrophysics of Tight Carbonate Reservoirs with Emphasis on Microporous Limestone Reservoirs**

We see gas production from “tight” carbonate reservoirs as a significant *unconventional* resource with important examples being 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 and determine whether micropores are major contributors to production. Candidates include the Georgetown and Buda limestones in Texas. 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 process on understanding and documenting the process of 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, we are leaning towards, from these observations is that microrhombic calcite formation may just 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 there is equilibrium within the grain between dissolution and reprecipitation. Where calcium carbonate is added to the grain, cementation occludes pores. Where 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 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 if we can convert modern Mg-calcite grains into microrhombic calcite.

Origin of Micropores in Coccolith-Rich Muds (Chalks)

In the past year we have started to investigate the occurrence of micropores in chalks and how they evolve with burial. They are deposited with very high porosities and 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 the Upper Cretaceous Buda, Eagle Ford, and Austin Chalk units. We will collect data on these formations from cores at various depths in the subsurface to tract burial changes in pores.

Origin of Micropores in Carbonate Mud

Many porous and permeable carbonate reservoirs produce from mud-dominated fabrics, as noted by 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 studies of mud-dominated fabrics from the Pliocene of the Clino core taken on the west slope of the Bahama Platform suggest that the conversion of a minimmicrite 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 only occlusion of the intercrystalline pore space by compaction and cementation follows. We suggest that microporous reservoirs in the Middle East are simply microporous mud-dominated fabrics that are not completely cemented. We want to test these ideas by collecting rock fabric and petrophysical data from ancient mud-dominated microporous reservoirs of Tertiary and Cretaceous age.

*Petrophysics of Microporous Limestone Reservoirs*

A major research direction in understanding carbonate reservoirs is the origin and petrophysics of limestones with significant volumes of micropores. Micropores are very common in limestones and present a major petrophysical problem when present in grainstones. Our current interest is in cemented grainstones with microporous grains. Our research on bimodal grainstones from offshore Brazil and microporous grainstones from the Stuart City Reef in southeast Texas has provided us with an excellent database to work from. Last year we collected additional pore-throat size measurements from MICP data and crystal size measurements from SEM analysis. This data suggest that the size of microrhombic crystals associated with micropores within carbonate grains in cemented grainstones is a major fabric element controlling permeability. This year we intend to gather more information on crystal size and pore-throat size in grainstones where the intergrain pore space is filled with calcite cement. The goal is to develop a meaningful relationship between fabric, porosity, and permeability for cemented grainstones.

*Carbonate Rock Properties and Geomodel Distribution*

*Influence of microporosity on seismic velocity of oomoldic grainstones*

We will continue our detailed investigation of the relationship between acoustic properties and petrographic and petrophysical properties of the Permian oomoldic grainstones. Last year, we demonstrated the important effect of microporosity in the crystalline framework on acoustic properties. This year, we will quantify this effect using MICP and NMR data and try to investigate how this microporosity effect can be detected on wireline logs and upscale to seismic scale.
Spatial distribution of acoustic properties in Cretaceous grainstones

Following up on the spatial analysis of acoustic properties of Permian grainstone, we will start a similar study on Albian grainstone exposed along the Pecos River. In the HST of the Albian high-frequency sequence, there is a continuous exposure of approximately 17 miles of a grainstone complex, which will allow to investigate acoustic properties of this large composite geobody in details at a scale applicable to seismic reservoir characterization and also exploration.

Scaling up acoustic and mechanical properties of carbonate rocks

The RCRL has a collection of tools to acquire mechanical and acoustic data from outcrop or core. Acoustic properties of carbonate rock can be determined on the outcrop, cores surfaces, or core plugs using a variety of sonic, ultrasonic measurement, or resonance testing. A previous study of Permian grainstones has demonstrated the validity and consistency of these in-situ unconfined measurements. Similarly, unconfined compressive stress (UCS) can be reliably estimated using a rebound hammer on outcrop, core surfaces, or core plugs. Previous RCRL studies have shown the value of analyzing those measurements at the facies level within a sequence stratigraphic framework. These in-situ measurements can be made at a spacing scale ranging from centimeters to decimeters providing an excellent opportunity to investigate improved methods to upscale the highly variable properties at the small scale (e.g., cm to m) to a scale relevant to similar measurement made in subsurface such as well-log scale (cm) or seismic scale (decameter).

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

A concerted effort to develop the linkages between isotopic and elemental chemistry of carbonate and mixed carbonate/siliciclastic reservoirs is underway, and will shortly encompass work on many Cretaceous units from the Austin Chalk, Eagle Ford/Boquillas, Buda, Salmon Peak, Stuart City, and Pearsall strata in Texas, Sunniland Formation in Florida, and Miocene-age strata from Indonesia and Philippines. Two portable x-ray fluorescence units, a microbeam x-ray fluorescence unit, and a rapid-analysis x-ray diffractometer have been acquired by the BEG in order to develop geochemical, micro-geochemical, and mineralogical datasets, respectively, for the above mentioned reservoirs. Over the coming year, a stable isotope laboratory devoted to the analysis of \(^{13}C/^{18}O\) of carbonates and \(^{13}C/^{15}N\) of rock organics will be built at the BEG. It is anticipated that the geochemical datasets will be utilized for chemostratigraphic control, but also to arrive at a deeper understanding of depositional and post-depositional conditions. Harry Rowe will focus on developing geochemically-based models that complement ongoing work and help to expand the understanding of paleoceanographic setting and diagenetic conditions.
history. An additional goal is the development of reference material suites that will better underpin the elemental analysis of evaporite paleokarst and redox-sensitive metals in diagenetic carbonates.

**LiDAR-Orthogrammetry Fusion and Drone Acquisition**

This project will continue ongoing research of carbonate outcrops via remote sensing. Benefits to the RCRL group and our associates are the creation of a high-quality virtual outcrop experience. It is our vision to provide very high quality visualization of many of our outcrops on your workstation to aid in accurate interpretation of subsurface data.

An RCRL priority that will be pushed by Logan Pennington is LiDAR-Orthogrammetry Fusion where high-resolution ground-based LiDAR and GigaPan images are merged into a common dataset. We will be refining the workflow of this process in 2013, emphasizing synchronous acquisition of LiDAR and GigaPan photographs. These key datasets must be taken from exactly the same position and 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 2012 we began exploring application of high-resolution orthographic acquisition using aerial drones. Both basic ortho-rectified 2D images and advanced 3D orthogrammetry using photo interpretation software to create a 3D image from the photographs. The two drone acquisition methods are available: (1) fixed wing drones that are presently being evaluated, and (2) hexacopter drones that are currently in use through a separate contractor. Through more integration, experience, and research, LiDAR and orthogrammetry will continue to improve as a cutting-edge approach to carbonate outcrop research.

**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 to better understand and describe the 3D carbonate reservoir system. We have a multi-faceted 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 to develop the “best practice” approach to integrated reservoir characterization.
2013, 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).

**APPENDIX A: RECENT AND ACTIVE RCRL STUDENTS**

**Students in Progress**

**Rebekah Simon**, Ph.D. candidate (expected completion, May, 2016) C. Kerans and C. Zahm, co-supervisors, committee undeclared

Title of Thesis: Not yet selected

Research objective: General understanding of the role of syndepositional fractures and faults in controlling early and late diagenesis of platform margins.

**Reynaldy Fifariz**, Ph.D. candidate (expected completion, May, 2016) – Co-supervisors, X. Janson and C. Kerans, committee, undeclared

Title of Thesis: Regional Stratigraphic Architecture and Depositional Model of Miocene Carbonate, East Java, Indonesia

Research Objectives: Integrating core, well log, seismic and outcrop analogues to propose a regional architecture of a faulted carbonate platforms of the East Java area, Indonesia

**Maren Mathisen**, M. Sc. Candidate (expected completion, May 2014), Co-supervisors C. Zahm and C. Kerans, committee undeclared

Title of thesis: Structural evolution along a strike change in the Capitan shelf margin, Guadalupe Mountains, SE New Mexico

Research objectives: Characterize the fault and fracture system between Walnut Canyon and Dark Canyon to understand structural processes along a change in strike of the Capitan shelf margin.

Title of thesis: Multi-scale fault analysis of Laramide-aged oblique-slip faults relating to pre-existing structures, SW Texas

Research objectives: Map and document fracture development at multiple scales in outcrop and in the subsurface to better understand the influence of pre-existing faults on subsequent fracture development

Gregory Hurd, PhD. Candidate (expected completion, May 2015), Co-supervisors—C. Kerans and X. Janson, committee – P. Flemings, D. Mohrig, T. Simo

Title of thesis: Not yet selected

Research objective: Interpreting and modeling processes of deposition and deformation on carbonate slopes

Alex Parker, M.Sc. candidate (expected completion, May, 2013)—Supervisor, C. Kerans; Committee—C. Olairu and W. Fisher

Title of Thesis: Outcrop characterization of Ooid Grainstones in the Grayburg Formation, Guadalupe Mountains, New Mexico

Research objectives: Obtain a high-resolution geospatial and paleocurrent understanding of the Grayburg’s ooid geobodies preserved in outcrop to assist in the development of analogous subsurface ooid grainstone reservoirs

Sam Hiebert, M.Sc. candidate (expected completion, May, 2013), Supervisor —C. Kerans; Committee—Steve Ruppel and W. Fisher


Research Objectives: Develop high resolution cyclostratigraphic and chemostratigraphic framework for Middle Permian Grayburg Formation that can be used to resolve long-standing differences in shelf-to-basin correlations of San Andres-Grayburg-Queen strata in the Guadalupe Mountains
Stephanie Wood, M.Sc. candidate (expected completion, August 2013), Co-supervisors - R. Loucks and S. Ruppel; Committee—C. Kerans and J. Sprinkle

Title of thesis: Lithofacies, Stratal Architecture, and Sequence Stratigraphy of the Pennsylvanian Marble Falls Formation in central Texas

Research objective: Through the analysis of a number of complete cored sections, the stratal architecture of the Marble Falls Formation from shelf to basin will be developed. The variety of carbonate and siliciclastic lithofacies will be described and their origin will be investigated. The understanding of the relationships between these lithofacies will be used to develop a regional sequence stratigraphic framework.

Graduation in December 2012

Nathan Jones, M.Sc. candidate (Dec., 2012), Integrated Lidar and Outcrop Study of Syndepositional Faults and Fractures in the Capitan Formation, Guadalupe Mountains, New Mexico, U.S.A. Co-supervisors —C. Zahm and C. Kerans; Committee—R. Steel


Recently Graduated


Rachel Aisner, M.Sc. 2010, Supervisor—C. Kerans; Committee—R. Steel, R. Loucks

Charles Harman, M.Sc. 2010, Quantified Facies Distribution and Sequence Geometry of the Yates Formation, Slaughter Canyon, New Mexico: Supervisor—C. Kerans; Committee—N. Frost and D. Mohrig


APPENDIX B: RECENT RCRL PUBLICATIONS

In Press


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


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


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