TECHNOLOGY CONNECTIONS
PETROLEUM TECHNOLOGY TRANSFER COUNCIL

SMACKOVER MICROBIAL REEF DETECTION AND CHARACTERIZATION

BOTTOM LINE

Improved detection and characterization of microbial reefs will facilitate oil and gas development in the Eastern Gulf Region.

KEY WORDS:
Smackover Formation
Jurassic Reefs
Microbial Reefs
Thrombolite
Appleton Field

PROBLEM ADDRESSED

Application of sequence stratigraphic concepts to microbial reef development provides a framework to interpret the distribution of reservoir rock in Upper Jurassic microbial reefs and to serve as a model for thrombolite reef plays elsewhere. Stratigraphic evidence and forward modeling indicate that Upper Jurassic reefs tended to develop between the point of greatest rise in sea level and the highest position of sea level on hard substrates with low sedimentation rates and moderate hydrodynamic energy. Sequence stratigraphic analysis should, therefore, be useful to predict setting and timing of the thickest potential reef reservoir facies.

TECHNOLOGY OVERVIEW

Sequence Stratigraphic Controls on the Development of Microbial Fabrics. Integration of sequence stratigraphic concepts with fabric and growth form classification of Smackover microbial buildups aids in understanding the distribution of reservoir quality in the updip basement ridge play of southwest Alabama. Microbial growth forms and fabrics, early diagenetic processes, and resulting reservoir quality are all ultimately controlled by the rate of relative sea-level change, position of sea level with respect to exposed Paleozoic basement, and position in an inner ramp setting.

Depositional Characteristics of Smackover Microbialites. Five types of microbial buildups have been recognized. Millimeter to centimeter scale layered thrombolite depositional fabric characterizes Type I buildups. Reticulate and "chaotic" thrombolites comprise Type II buildups. Thrombolite is an organic carbonate composed of micritic to peloidal crusts that exhibits a clotted mm- to cm-scale fabric. In the updip basement ridge play, layered and reticulate thrombolite buildups (Types I and II) grew directly on low and high relief Paleozoic basement and formed in response to late transgressive systems tract (TST) catch-up conditions when sedimentation rates were low and water energies were moderate to high. Type III buildups are characterized by dendroid thrombolites. Type III buildups typically overlie Type I and II buildups on low relief basement structures, but are absent from high relief structures. Dendritic (Type III) thrombolites grew in early highstand systems tract (HST) keep-up conditions when sedimentation rates were slightly elevated and water energy was low on the tops of low-relief basement structures. Type IV microbialite is composed of isolated stromatolitic crusts that acted as binders to Type V oncoidal packstone/grainstone that grew on soft to firm substrates in high-energy conditions. Both isolated crusts (Type IV) and oncoid (Type V) microbialite are found in upper Smackover shoal, lagoon and tidal flat facies.

Classification of microbial types is significant to hydrocarbon exploration and production in southwest Alabama. Types I, II, and III buildups are the best fabrics for productive reservoirs. Of these, Type III buildups are the highest quality reservoir rocks.

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SPEAKERS:

Dr. William C. Parcell, Department of Geology
Wichita State University

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Dolomitized reticulate and dendritic fabrics result in well-connected intercrystalline and vuggy porosity. In contrast, Type IV and V microbialite are poor reservoir rocks because fine intercrystalline pores are often poorly connected.

Three main depositional criteria allow Smackover microbialite bioherms to be economically viable reservoirs:

- Exposure of hard substrates (Paleozoic basement) during decreasing rates of sea-level rise-this correlates to the time of development of largest microbial buildups.
- Thrombolite fabrics—primary fabric of the thrombolites was preferentially altered to highly porous and permeable textures.
- Thrombolite bioherms located in an inner ramp setting—this environment is prone to early dolomitization and meteoric leaching, which enhances permeability by opening pore throats.

Using Outcrop Analogs to Model Smackover Microbial Reefs. Because Smackover strata are not exposed at the surface in the Gulf Coast, determination of the geometries and extent of the thrombolitic buildups is difficult. Outcrop observation of thrombolite characteristics provides critical information about microbialite origin, composition, geometries, areal extent, lateral and vertical facies changes, and growth morphologies. Use of Upper Jurassic microbial reef outcrops in Europe greatly facilitates the design of hydrocarbon development strategies for delineating Smackover microbial reef geometries and extent.

In Portugal microbial reefs consist primarily of thrombolitic buildups more than 100 ft thick. These buildups are associated with sediment starvation surfaces and hardgrounds and occur in early highstand systems tract (HST) deposits.

Outcrop studies indicate that water depth was not a critical factor in development of thrombolites. The composition of Smackover microbialites compares favorably with those from Portugal. The outcropping Portuguese thrombolites required a very low sedimentation rate, a hard substrate for colonization and a rising sea level. A layered to dendroid succession of growth morphologies is common in the European thrombolites as well as the Smackover microbial buildups.

Smackover microbial reef geometries (elongate with an areal extent of 1.3 mi^2) also compare favorably to the Portuguese buildups (elongate with an areal extent of 2.7 mi^2). Vertical facies changes in the Portuguese and Smackover thrombolites are similar. Both are underlain by fine-grained transgressive deposits and both are overlain by higher-energy deposits. Lateral facies to the Portuguese buildups include marls and carbonate muds. Therefore, lateral facies to the Smackover reefs should be expected to be carbonate mudstones.

COMPUTER MODELING OF CARBONATE FACIES

Predicting Facies Distribution Using Fuzzy Logic. A new computer model was developed at the University of Alabama to predict depositional facies distribution and productivity rates on a 3D carbonate platform using continuous set theory (fuzzy logic), which accepts complex linguistic data with large uncertainties. A great advantage of the new "fuzzy logic" model over deterministic models is that it accepts parameters that are difficult to define. The new model integrates water depth with such complex variables as water energy, circulation, climate, and distance from siliclastic input to produce depositional facies including sabkha, tidal flat, reef, shoal, and subtidal.

The program was written in C/C++ and is designed to run in a Windows interface. The program dynamically calculates productivity and depositional facies at shallow water depths by integrating variables including water depth, water energy, depositional slope, distance from shoreline, and distance from submarine relief. Integration of these variables makes the model much more complex and geologically realistic than models developed using deterministic methods. The model should eventually be useful both to academic circles and to the hydrocarbon industry as a predictive tool for reservoir distribution.

Interpreting Upper Jurassic Reef Through Geologic and Computer Modeling. The Late Jurassic was one of the major periods of reef development in the geological record. Based on field examinations it remains unclear whether the development of these reefs is due solely to local environmental conditions or can be attributed to regional and global-scale factors, such as relative sea level or climate change. In order to examine this problem, a fuzzy logic-based computer model (FUZZYREEF) was developed that simulates the response of the carbonate system to many variables at local, regional, and global scales.

Forward modeling of reef development and facies distribution using the computer program FUZZYREEF generated stratigraphic thickness and facies distributions that matched observed geometries. Simulations for data from Alabama (subsurface) and French (outcrop) sections indicate that background sedimentation rates, substrate conditions, and hydrodynamic energy were the principal local physical factors controlling the development of reefs. Initiation of reef development requires hard substrates during times of low background sedimentation rates and moderate hydrodynamic energy.

The rate of relative sea level rise is critical to the development of reefs because the rate of sea level rise strongly controls the background sedimentation rate. With rapid rises in sea level, background sedimentation rate drops off quickly and takes longer to recover. It is during the extended recovery period that reefs have a window of opportunity to develop. The largest reefs tend to develop after rapid rises in sea level between deposition of the latest transgressive systems tract and early highstand systems tract. Reefs continue to grow until the carbonate system begins to prograde during deposition of the late highstand systems tract when the background sedimentation rate is very high.

APPLETON FIELD CASE STUDY

Recent efforts by the University of Alabama and the New Mexico Bureau of Mines and Mineral Resources have sought to explain the occurrence of reservoir-grade rock (6 percent or greater porosity and 0.1 mD or greater permeability) on the crest of the Appleton structure, Escambia Co., Alabama. The objective of the research was to assist the unit operator to improve oil production from Appleton Field, which is approaching abandonment. The field produces from microbial reef boundstones and shoal grainstones and packstones of the Upper Jurassic Smackover Formation located on a northwest-southeast trending paleotopographic ridge comprised of local paleohighs.

Differences in production within the field are related to variation in the size of individual reservoir compartments associated with the eastern and western paleohighs. Greater production from the eastern paleohigh is related to greater relief, which places more reef reservoir above the oil-water contact. Production from the western paleohigh is limited by the lower relief of the structure, which places much of the reservoir below the oil-water contact and the fact that wells draining the structure are located on the flanks rather than the crest of the feature.

For these reasons, it was recommended that a sidetrack well to the McMillan 2-14 be drilled to improve oil recovery. The integrated model predicted that the proposed sidetrack well would gain structural elevation, would encounter porous and permeable Smackover reef boundstone reservoir on the crest and would be oil productive. If the sidetrack well was not drilled, attic oil would remain undrained in the field.

The model predicted 61 ft of porous Smackover at a depth of 12,680 ft. The sidetrack well penetrated 69 ft of porous Smackover near the crest of the western paleohigh at a depth of 12,707 ft. The well tested 136 BOPD. Therefore, it is believed that the integrated model has excellent potential as a technique for designing effective development strategies of fields with porous Smackover over the crest of paleohighs.

For information on PTTC s Eastern Gulf Region and its activities contact:

Ernest A. Mancini, Professor of Geology,
University of Alabama, Box 870338, 202 Bevill Building, Tuscaloosa, Alabama 35487
Phone 205-348-4319, Fax 205-348-0818, Email emancini@wgs.geo.ua.edu

CONNECTIONS:

Dr. William C. Parcell
Department of Geology
Wichita State University
1845 Fairmount
Wichita, Kansas 67260-0027
Phone: 316-978-3140   Fax: 316-978-3431
Email: William.parcel@wichita.edu

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Petroleum Technology Transfer Council, 2916 West T. C. Jester, Suite 103, Houston, TX 77018
toll-free 1-888-THE-PTTC; fax 713-688-0935; e-mail hq@pttc.org; web www.pttc.org