Reef and Forereef Slope Reservoir Analog Models

Evan K. Franseen, Robert H. Goldstein, student

STATUS: Ongoing research; Several projects complete or in progress
TIMING: 2-4 years
FUNDING: Seeking sponsors; software donated by Schlumberger

Purpose
We have been studying exceptional 3-D exposures of Miocene reef systems in a variety of basin settings in southeastern Spain for over two decades, and this work includes quantitative data on the controls for development of the reef systems (Franseen et al., 1998). These data include quantification of relative sea-level history, including rates of rises and falls, accumulation rates, and aggradation and progradation rates for reef systems. An important control on reef development and progradation is paleotopography. Reef systems in this setting include fringing reefs that flank steep sided basement highs that feature aggradation, progradation, and downstepping over 1 km, and reef systems that developed on gently-sloping substrates that feature aggradation, progradation and downstepping for over 2 km.

Our future work focuses on development of detailed 3-D understanding of stratal geometries, facies distribution, and fluid flow in the studied intervals through integration of field, and laboratory data (including porosity/permeability data) for construction of 3-D cellular reservoir analog models to aid in exploitation of subsurface equivalents, such as those in the Indo-Pacific.

Project Description
Miocene carbonate reef systems are exceptionally exposed in outcrops of southeastern Spain, in the Las Negras area. Our studies on these exposures show most developed as complexes that fringed basement highs. Fringing reef complex strata in the Las Negras area superbly display the close association of carbonate fringing reef development and volcaniclastic deposition. The volcaniclastic sandstone and conglomerate wedges exposed in the area are interpreted as marine portions of fan delta lobes that developed marginal to the eroding volcanic islands. Reef and forereef strata are characterized by local preservation of in-place Porites framestone, reef talus of mostly slumped Porites framestone reef blocks deposited on high-angle, foreslopes, and downlapping foreslope strata consisting of coarse-grained carbonates, fine-grained carbonates or volcaniclastic sandstones/conglomerates.

Reef strata display aggradational to progradational to downstepping geometries that closely tracked the relative changes in sea-level. Autochthonous accumulation of reef strata and development of forereef slopes created steep constructional paleotopography. The early formation of this topography created the slopes on which the youngest reef cycles could step downward during the later period of falling relative sea level. Most phases of reef development are characterized by massive to faintly bedded reef core (1-5 m thick) that grades laterally to talus and forereef slopes with steep (25-35°) cliniforms. The early reefs appear to have prograded (200 - 300 m) with minor aggradation (about 5 m), and the aggradational and largely progradational geometry existed through much of reef development.
development. Later stage reef deposition is characterized by downstepping progradation with successive reef strata formed in topographically lower positions, on the forereef slopes of previous reef cycles, as a result of falling relative sea level. The latest stage of reef development is characterized by clinoforms with steep proximal dips (25 - 30°) that flatten abruptly basinward. This feature is a result of basinward thinning and draping of the flatter topography in basinward locations. These later clinoforms have reef core to distal slope relief of 50 - 90 m over a distance of 300 - 700 m. All stages of reef development reveal abundant reefal material that was transported to foreslopes by mechanisms not necessarily related to sea-level falls. These include turbidity currents, debris flows, and rock falls. It is likely that the apparent rapid production and progradation of the reef itself was a major contributor (self erosion) of reef talus clasts and reefal debris to the foreslopes.

The area adjacent to Las Negras developed one of the more extensive reef platforms in the area (La Rellana platform) that shows various vertical and lateral stages of development over relatively gentle basement paleotopography for approximately 2 kilometers towards the Agua Amarga basin. The La Rellana platform developed in an important drainage divide location for the region that was created by the volcanic substrate. A 2-D cross section exposes the divide and reveals steep basement slope (and resultant steep progradational geometries) dipping towards the Las Negras area to the south, and gentler, more laterally extensive volcanic basement paleotopography (and resultant more extensive and gentler progradational geometries) towards the Agua Amarga basin to the northeast (Figure 2). Therefore, this 2-D La Rellana platform cross section provides an opportunity to determine the role of different paleoslope morphology, and slope dip and direction on evolution of the same platform, as well as providing an opportunity to compare facies, geometries, and sequence development in an extensive platform developed over a gentle substrate paleoslope with equivalent deposits in the Las Negras area that were developed adjacent to steeper sloping substrates. Development of the sequence stratigraphy and depositional controls on the La Rellana platform are the focus of a current graduate student project (summer 2010) by R. Sweeny (project included in this prospectus).

The reservoir analog model project will utilize field data already or currently being collected for the Las Negras and La Rellana areas. That and additional data to be collected, including additional detailed section measuring and facies mapping, and collection of porosity and permeability data, will be integrated to build a 3-D cellular model for each area (Las Negras, La Rellana).

**Deliverables**

Deliverables for the project include maps, stratigraphic sections, cross sections, copies of theses, copies of presentations, quantitative data that have been completed to date, and those that are currently being studied. Detailed measured stratigraphic sections, tracing on photomosaics, and Lidar data with appropriate overlays of photos, facies, sequences and porosity/permeability distribution. Beyond these data, the project includes routine and special quantitative core analyses on representative samples from each major lithofacies, to characterize the complete range of petrophysical properties and to identify lithofacies-petrophysical relationships, storage, and flow units. Helium porosity, grain density, and air permeability will be measured on not less than 500 samples. These data will be integrated with stratigraphy to generate synthetic seismograms, which will help future explorationists
identify similar systems. Finally, a 3-D model of each reservoir analog system (Las Negras, La Rellana) in Petrel™, which will allow future developers the ability to compare reservoirs of similar character and will provide volumetric data.

References

Figure 1: Fringing reef complex (DS3; blue) in Las Negras area. Scale is in m.
Figure 2: Oblique aerial photographs showing La Rellana platform study site and relationship to adjacent areas.
Grainy Heterozoan Carbonate Reservoir Models

Evan K. Franseen, Robert H. Goldstein, Rachel Dvoretsky, Anya Hess, and Peter Dillet

STATUS: Ongoing research; Several projects complete or in process
TIMING: Completed and ongoing results available; future projects upon funding
FUNDING: Seeking sponsors

Purpose
Heterozoan carbonates, formed in cool-water or below the photic zone, are abundant in modern subtropical to temperate open shelves around the world, and heterozoan systems may be a better analog for many Paleozoic carbonates than warm-water carbonates (James 1997). Much work has been done on the oil and gas reservoir properties of shallow-water tropical carbonates, but from a comparative standpoint, much remains to be understood about reservoir properties of heterozoan carbonates. We have been studying exceptional 3D exposures of Miocene-Pliocene heterozoan carbonate systems in a variety of basin settings in southeastern Spain for over two decades, and this work has resulted in a better understanding of the depositional controls on these systems. Our recent and ongoing work is focusing on development of detailed 3D understanding of stratal geometries, facies distribution, and fluid flow through integration of field, laboratory (including porosity/permeability data) for construction of 3D cellular reservoir analog models to aid in exploitation of grainy heterozoans.

Project Description
Miocene-Pliocene heterozoan carbonate systems are exceptionally exposed in outcrops of southeastern Spain. Our studies on these exposures show heterozoan systems that developed in: 1) a high-energy, shallow-water ramp setting (Agua Amarga Basin) that developed on gently sloping basement paleotopography; 2) a deep-water setting (Las Negras area) dominated by transport over highly variable and steep basement paleotopography; 3) a shaved-shelf system (Carboneras Basin) dominated by lowstand deposition in an area of variable basement paleotopography; 4) a shallow-water, accommodation-limited setting (Agua Amarga Basin) dominated by deposition during transgression over a wave-planation surface.

The status of our progress in understanding the depositional controls and developing reservoir analog models for each of these systems is as follows:

1) High-energy, shallow-water ramp setting (Figure 1) - Sequence stratigraphy and 3-D reservoir model completed (Franseen et al., 2005; Dvoretsky et al., 2009). Major controls on the system are relative sea-level changes interacting with gentle substrate slope and focus of currents. The deposits filled a significant portion of a broad trough-like basin area and resulted in an overall wedge-shaped geometry and a gently inclined ramp-like surface. Thickest accumulations are proximal to areas focusing currents (providing nutrients).