SEALS, BARRIERS, AND BAFFLES OF THE NORTH MONAGAS OVERTHRUST GIANT FIELDS, EASTERN VENEZUELA: IMPLICATIONS FOR MULTI-SCALE COMPARTMENTATION OF CLASTIC RESERVOIRS

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The distal deformation front of the northern Monagas overthrust belt in the Eastern Venezuelan basin is the site for multiple hydrocarbon-yielding structures, including the giant Furrial, Carito and Santa Bárbara fields. These fields are the subject of ongoing research on the potential for faults and intra-formational heterogeneity to partially or completely isolate clastic reservoir compartments. The fundamental concept being tested is that structural and stratigraphic heterogeneity act at multiple, predictable scales, as seals, barriers, or baffles for fluid flow.

The first giant discovery in the overthrust belt was the El Furrial field in 1986. The reservoir interval occurs in rocks of Late Cretaceous (Campanian) to Early Miocene age. Over 9000 MM barrels of recoverable reserves of medium to light oil have been documented in adjacent structures, and new opportunities are being explored both in deeper targets and in lateral field extensions. The initial discoveries are now considered mature reservoirs. Pressure maintenance and secondary recovery efforts include water and gas injection, and studies are underway for WAG (combined water and gas) and nitrogen injection.

A multidisciplinary team has recently completed the sub-regional structural, stratigraphic, and sedimentologic interpretation of the three adjacent giant fields, from the integration of 980 Km^2 of 3D seismic, 430 wells, and 60 cores. Additional studies currently underway include geomechanical and diagenetic models, integration of geochemical data, and a preliminary appraisal with dynamic fluid and pressure information.

These efforts constitute the static model for a multi-scale compartment/seal three-dimensional reservoir decision platform. The elements of this multi-scale approach are summarized in Table 1. Regional *megacompartments* are confined by basin-scale seals associated with the tectono-sedimentary evolution of the basin, and by large faults. *Macrocompartments* are defined by field-scale seals and barriers, including faults, and stratigraphic surfaces. *Sedimentologic compartments* are the result of intra-reservoir heterogeneity.

Basin-scale seals

The El Furrial overthrust formed as a result of progressive compressional deformation from Early to Late Miocene, due to the oblique collision of the Caribbean allochton with continental crust of the South American plate. The deformation involved Cretaceous clastics and carbonates, and Paleocene to Early Miocene clastics.

A pre-tectonic marine shale deposited in the Early Miocene, acted as the top seal for an early pulse of hydrocarbons into a growing mega-anticlinal structure. A later syn-tectonic phase resulted in sedimentation of a thicker shaly section above. This shaly interval acted as the decollement level for the propagation of the thrust sheet. The resultant structure shows south-verging fault-bend fold geometry, sealed above, below and in the front by thick marine shales. Lateral sealing is presumed to occur against the lateral ramps of the thrust sheet. During the Late Miocene, the structure was modified by thrust events that resulted in loading of the western sector by Cretaceous rocks.

Field-scale seals and barriers

Structural saddles and normal faults segment the three giant anticlines in the 50- x 15-Km study area. Younger thrust faults create blocks that effectively divide the fields into large, partially isolated structural compartments. The sealing capacity of these faults is currently being evaluated using the FAPS™ software, and the results will be used as a calibration dataset for faults in areas with few wells. Dynamic fluid and pressure data is being analyzed to test communication between the structures, and across large normal faults.

A full-scale sequence stratigraphic and depositional system model was developed in order to understand and better predict controls on seals, barriers, and reservoir quality (Figure 1). Ten unconformity-bounded sequences of 3^{rd} to 4^{th}-order, record the transition from passive margin sedimentation to a regime of increasing accommodation due to greater tectonic subsidence ahead of the deformation front. Field-scale stratigraphic seals in the El Furrial field seem to be associated with major flooding events that locally separate the reservoir interval into several pressure compartments. Deteriorating seal effectiveness appears to occur in the direction where flooding events become shallower and thinner (in the Carito and Santa Bárbara fields). A relatively uniform pressure trend in this area seems to indicate that some vertical communication occurred initially and during the early stages of reservoir development.

Diagenetic processes also have a field-wide sealing effect, since the distribution of quartz cement appears to be structurally controlled. Porosity values deteriorate toward the flanks of the structures, and therefore may place lower limits on reservoir rock quality. Further studies will help refine and predict these limits. Isolated reservoir compartments may occur when rock volumes are sealed in three-dimensions by a combination of these diagenetic limits, by regional flooding events, and by younger thrust faults.

Intra-reservoir seals, barriers and baffles

The sequence framework forms the basis for a hierarchical characterization of intra-reservoir lithologies associated with key stratigraphic surfaces, which include the following groups: (1) shallow marine shales, and glauconite-rich shaly zones associated with condensed sections; (2) prodelta, delta front, interdistributary, subtidal, and coastal lagoon shales and siltstones; (3) laterally-extensive paleosols, and floodplain shales and siltstones; and (4) carbonate-cemented horizons associated with marine-flooding events, and intensively bioturbated zones. The distribution of these surfaces is adequately predicted within the TST and HST, and by their proximity to major flooding events, and to sequence boundaries.

Group 1 lithologies have the greatest potential for intra-reservoir seals, whereas those of groups 2, 3, and 4 may act as barriers or baffles to fluid flow. Their impact on reservoir performance may occur fieldwide, in the interwell realm, or near the borehole, and therefore can be predicted at different stages of field development. Future studies on these lithologies include mercury-injection capillary and geomechanical analyses, to evaluate seal capacity and integrity. In addition to these lithologies, grain-size controlled quartz cementation may further enhance the effects of intra-reservoir barriers and baffles.

Unusual seals and deep opportunities

The lowest producing zone of the El Furrial field is commonly placed at a tar-mat layer of more than 15 Km of lateral extension and 200-400 feet in thickness, at subsea depths of -14700 and -15550 feet (Mengual et al., 2002). Geochemical studies performed on this layer show that it is composed of heavy and extra heavy crude, and of up to 25% of asphaltene in the bitumen extracts, thus following the definition of Wilhelms and Larter (1994).

This thick layer is now being considered a major regional seal, since patches of light and medium gravity oil have been found in few wells that penetrate below it. It is assumed that lighter hydrocarbons cannot pass through the tar-plugged pores, and may therefore be trapped below it.

A deeper hydrocarbon opportunity is being evaluated below the known giant fields, at depths between -16,000 and -20,000 feet. The exploratory concept involves clastic and carbonate targets, below a thick source-rock / seal interval that has only been drilled in the alochtonous block north of the deformation front. The actual thickness and lithology of the seal is uncertain, but estimates indicate between 700 and 1500 feet of platform carbonates (mudstones and pakcstones), marine shales and sandstones. Seal integrity is being evaluated since it is expected that fracturing may have occurred in the later stages of structural development.

Future work

Plans for additional work include evaluating the sealing capacity of different lithologies, and their potential for fracturing. The results will be tested with known reservoir parameters, to obtain a calibration dataset that may be used in other structurally complex areas. A similar approach will be followed for the analysis of different fault types using fault seal modeling software. Diagenetic modeling will be performed in order to establish possible controls on quartz cementation by early hydrocarbon emplacement.

References

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Wilhelms, A, and Larter, S.R., 1994, Origin of Tar Mats in Petroleum Reservoirs. Part I: Introduction and Case Studies: *Marine and Petroleum Geology*, 11, 418-441.

Table 1: Simplified multi-scale compartmentation scheme

TYPE	MEGACOMPARTMENTS		MACROCOMPARTMENTS	SEDIMENTOLOGIC COMPARTMENTS
	I	II		
DEFINITION	REGIONAL / PLAY	STRUCTURAL	COMBINED STRUCTURAL AND STRATIGRAPHIC	GENETIC UNITS FACIES ASSOCIATIONS
AREA ANDTHICKNESS	10^3 Km^2 10^3 feet	10^2 Km^2 10^2 – 10^3 feet	10^2 Km^2 10^2 feet	10^2 Km^2 10´s of feet
VERTICAL SEALS	MARINE SHALES ABOVE AND BELOW	MARINE SHALES ABOVE	MAJOR FLOODING EVENTS AND REGIONAL SEQUENCE BOUNDARIES	MINOR FLOODING EVENTS, PALEOSOLS
LATERAL SEALS	LATERAL RAMPS	SEALING FAULTS	SEALING / PARTIALLY SEALING FAULTS	UNCONFORMITIES FACIES CHANGES
INTERNAL HETEROGENEITY	TAR-MATS UNCONFORM.	THRUST FAULTS	MINOR FAULTS DEPOSITIONAL SYSTEMS	CLINOFORMS CEMENTED HORIZONS
IMPACT	DEEP AND SHALLOW OPPORT.	FIELD EXTENSIONS	PRIMARY AND SECONDARY RECOVERY	IMPROVE RECOVERY FACTOR

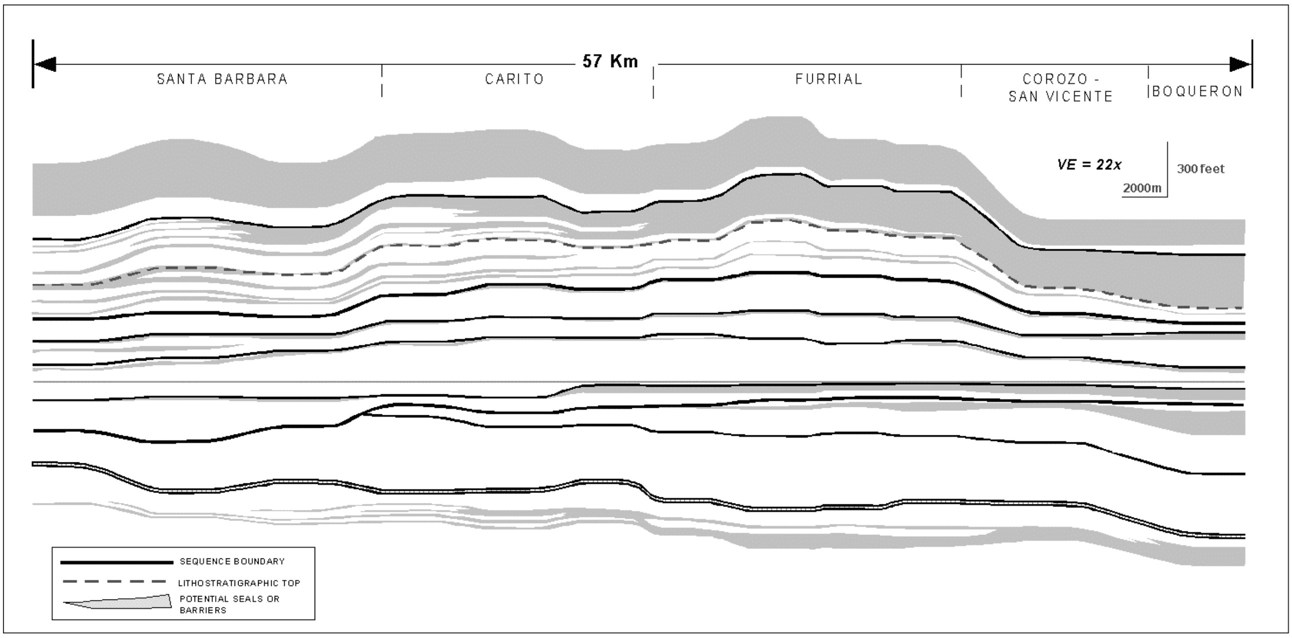

Figure 1: Stratigraphic section across the giant structures, showing the field-scale distribution of potential stratigraphic seals and barriers, based on the sequence model.