Paper ID: 2012062

Characteristics of Miocene deep-water reservoirs and its implications on hydrocarbon exploration in the Lower Magdalena basin, Colombia

S. K. Ghosh[1], M. Di Luca[2], V. Azuaje[2] & J. Arminio[2], J. Betancourt[2]

1Geo-Strat Consulting, Mississauga, Ontario, Canada,
2Pacific Rubiales, Bogota, Colombia

Presenting author, E-mail: *skg2007@gmail.com*

Abstract

This paper establishes the regional stratigraphic-sedimentological framework of low permeability gas and condensate sands in the Lower Miocene Porquero Fm., Lower Magdalena Basin, Colombia. The study aimed to support the ongoing exploration projects and refine stratigraphic architecture and reservoir quality models of producing horizons. Additionally, a methodology was established for the integration of the stratigraphic framework with a seismic inversion model.

Introduction

The Guama study area is part of the Plato sub-basin, framed by the Romeral and Santa Marta-Bucaramanga faults on the W and E respectively, and the Andean Central Cordillera range of Colombia on the south. Previous works in the area include Reyes Harker et al. (2000), Flinch (2003), Arminio et al. (2011) and Bernal et al., (2011).

The principal objective of this study is to characterize the Lower Miocene deep-water siliciclastic sequence in the Guama sector of the Lower Magdalena basin, in relation to its tectono-stratigraphic framework, sedimentary facies, depositional environment, reservoir quality, and integration of well data into a three-dimensional model derived from seismic inversion processes. The Guama area hosts a sizable gas and condensate reserve in the Lower Miocene channel-fill and related strata down-dip of paleocanyons associated with the proto-Magdalena delta.

Methodology

Detailed sedimentological study of 17 wells was undertaken in and around the Guama area, duly calibrated with seismic, and biostratigraphic data. Analysis of cores from 3 wells (P-1, C-1 & K-1) supplemented the study for a better understanding of the facies, and its influence on reservoir quality. 9 cross-sections were elaborated to constrain the facies variation of the basin-fill. Special attention was given to the analysis of vertical log motif of the wells in order to differentiate various deep-water subenvironments. Dip meter data also proved useful in interpreting paleotransport directions.

Tectono-stratigraphic framework

Case et al (1984) considered the Lower Magdalena Valley (LMV) basin, along with its two sub-basins (Plato & San Jorge) as “successor” basins. Later Flinch (2003) and Bernal et al. (2011) interpreted the LMV as a back-arc basin with a thick Oligocene-Pliocene sedimentary fill. Arminio et al. (2011) proposed the LMV as a transtensional collapse basin. It is characterized by several horsts and grabens resulting from the transtensional effects of the collision of the Caribbean plate with the northwest corner of the South American continent (Fig.1). Fig. 2 is a generalized stratigraphic column of the area, showing the correlation between 3D seismic and exploratory wells, highlighting the intraformational discontinuities A, B, C & D identified seismically. Additionally, another important intra-Lower Miocene unconformity has been seismically identified regionally, coinciding with the base of a paleocanyon. The present paper deals with the nature of the fill down-dip of this paleocanyon and its implication on hydrocarbon exploration and exploitation. None of the wells in the Guama area traversed the paleocanyon base, though other wells beyond, did reach the erosional base.

Anatomy of the paleocanyon-related basin fill

The main Lower Miocene paleocanyon shows a marked S/SE-N/NW orientation. The erosional base of the paleodepression is continuous regionally across intermediate highs separating several smaller scoured depressions. The feeder paleocanyon, up dip and south/southeast of the Guama area, is approximately 20km long, and 5-7 km wide, based on seismic data. In the vicinity of the Guama wells (C-1, K-1, L-1, M-1 and P-1) the paleocanyon loses its identity as the canyon walls disappear in the broadened slope/ basinal environment. In a sequence stratigraphic context, the paleocanyon-fill is located within a deep-water TST assemblage. A possible origin could be gravitational collapse of a muddy shelf margin, as a result of rapid sedimentation and slope failure, related to a major geological event such as a high magnitude earthquake or some other episodic event. This resulted in deposition of dominantly shaly/silty deposits and other MTD deposits including slumps and slides. Several disperse and isolated mud-prone turbidite channels, associated over bank, and scarce frontal lobe deposits developed within this milieu. These channels host productive sands in the basin.

Macro sequential and Paleoenvironmental Variation

Fig 3 shows a symmetrical motif of paleoenvironmental evolution in the Lower Magdalena basin. The lower half, spanning from Oligocene to top of Lower Miocene, reflects a progressive deepening, reaching down to slope and basinal depth, coincident with a well-defined Lower Miocene regional MFS. The upper half encompassing the Middle Miocene to Plio-Pleistocene interval reflects a gradual shallowing of the basin with a basin-fill progressively coarser upward.
Dipmeter data helped define sediment provenance and paleo-transport directions. A low to very low dip angle, suggests the dip amount and orientation is syn-sedimentary, not significantly affected by later tectonic deformation. Both the Guama sector wells, as well as the ones outside the area, indicate a predominant paleocurrent vector toward the N, NW and W.

Conceptual Facies Model

Deep-water sedimentation is a product of complex processes; chaotic (slumps, slides, debris flows or MTD), current-related processes, and hemipelagic/pelagic sedimentation were important in the Plato-sub basin. Moreover, evidence of oceanic bottom current structures (contourites) is present in drill cores. In a mud-prone environment such as here, the lobe or frontal-splay sandy facies will be poorly developed and the channel sands are likely to be argillaceous and/or silty. Range of channel facies thickness in the Guama sector wells is 30-150' (10-50m). This data, when compared with the width-depth cross-plots of channels (Weimer & Slatt, 2007) suggests a likely average width of the Lower Miocene channels of about one kilometer or less. Both areally and vertically these channels were few and isolated, encased in thick extra-channel and basinal muddy sediments.
A Gross Depositional Environment (GDE) map was constructed using physical, chemical and biostratigraphic criteria for the Lower Miocene interval. The map shows three broad facies belts from E/SE to W/NW: 1) Shallow marine shelf, 2) Shelf-slope transition, and 3) Slope area and beyond. The first two belts lie to the east and south, partly outside of the Guama sector, whereas the deep-water facies is conspicuous in the Guama area wells (Fig 4). The dip meter data described earlier corroborates the areal distribution of the 3 facies belts indicating a progressively deepening paleoenvironment from E to W. The channels interpreted in the wells, show an S/SE to N/NW trend in seismic images. Thus, seismic and well data are concordant and mutually supportive.

Facies analysis

Detailed vertical log motif analysis (Gamma Ray) and cores from 4 wells offer vital evidence regarding the various depositional facies that make up the Lower Miocene interval in the study area. The turbidite subfacies identified are: channels, levee-crevasse splay, scarcely developed frontal-splays, and shaly basin plains, away from the channel axis areas. Presence of matrix-supported conglomerates has been documented only in well L-1. Additionally, some sizable packages of MTD deposits have been identified seismically in some adjacent areas. The channel facies unit (as in P-1) is filled with thin silty sandstones and associated siltstones/claystones, suggesting episodic pulses of channel filling.

Evidence of oceanic bottom current structures (contourites) has been documented in cores of 2 wells in the area (well P-1 and C-1). Cores from well P-1, shows interlamination of very thin, wavy to streaky sand laminae/beds alternating with dark shales. Sharp upper and lower contacts of sand beds are noteworthy (Fig. 5).

A common feature of all Guama wells is the wide presence of thin to very thin sands associated with even finer siltstones and mudstones. These sands could have originated in distal channels, levees, and crevasse-splays, and also as reworked contourite beds of oceanic bottom current origin.
Another unusual aspect of the channel-fills is the presence of thin intercalations of lime mudstone within the stacked sandy/silty assemblages, best observed in well M-1. The cyclic alternations of sands and thin limestone beds could be the product of episodic current-driven sedimentation. An oscillating sediment transport regime would have triggered siliciclastic sedimentation when currents were active or relatively strong. The periods of short-lived still-stands meant absence of clastic input, and in situ deposition of thin deep-water lime mudstones.

Reservoir Quality Analysis

Table 1 summarizes the sedimentary facies in relation to reservoir quality in 4 Guama wells based on log and core data. All the wells are currently producing gas and condensates. Diagenetic events such as physical compaction, silica overgrowth, calcite, and clay mineral cements partially occluded primary porosity. XRD analysis identified authigenic clay minerals chlorite, kaolinite and illite-smectite. The silty and highly mud-prone nature of the Lower Miocene sands may explain the high content of clay mineral cements and resultant low natural permeability. However, subordinate dissolution of labile grains somewhat improved the porosity. Average porosity varies between 10-20% and permeability is always less than 10mD. Because of the very low permeable nature of the reservoir, fracturing is required to extract hydrocarbons from the reservoir.

Discussions

Our study established the stratigraphic-sedimentologic framework of a mud-rich, relatively distal deep-water environment for the Lower Miocene gas and condensate reservoirs in the Guama area of Lower Magdalena Valley basin. In such a milieu, expected sand-rich lobe or frontal-splay deposits are not well developed. Having formed under general transgressive conditions, the sand abundance reported from other LST-related global analogs is absent here. This condition probably was exacerbated by a mud-rich sedimentary input during the whole Miocene.

The producing fine to very fine, silty sands of channel and overbank origin are affected by high clay content (authigenic or otherwise) and the resultant low to very low natural permeability. Fracturing of the hydrocarbon-bearing intervals improves the overall drainage performance of the tight sand reservoirs.

References

1. J.F. Arminio, F. Yoris, L. Porras, E. Garcia, M. De Luca, “Petroleum Geology of Colombia – Lower Magdalena Valley”, In ANH (Editor F. Cediel), 10, 202p, 2011
2. O.Bernal, P. Mann and C. Vargas, “Lower Magdalena Basin, Colombia: A Forearc Basin Formed Above a Zone of Active, Shallow Subduction” Student Poster Session, AAPG – ACE, Houston, April, 2011
3. M. Di Luca, T. Salinas, J. Arminio, G. Alvarez, P. Alvarez, F. Bolivar, W. Marin, “Seismic Inversion and AVO Analysis Applied to Predictive-modeling Gas-condensate Sands for Exploration and Early Production in Lower Magdalena Basin, Colombia”, The Leading Edge, Special Section, Latin America, 936-943, 2014
4. J. Case, T. Holcombe and R. Martin, “Map of Geological Provinces in the Caribbean Region”, Bull. GSA, 162, 1-30.
5. J. Flinch, 2003, “Structural Evolution of the Sinu-Lower Magdalena Area (Northern Colombia)”, Memoir AAPG 79, 776-796, 2003
6. A. Reyes Harker, B. Montenegro, C. Posada, “Evolucion Tectono-estratigrafico del Valle Inferior de Magdalena, Colombia”, Simposio Bolivariano VII, Tectonics Section, Caracas, Venezuela, 2000
7. P. Weimer and R. M. Slatt, 2007, “Introduction to Petroleum Geology of Deep-water Settings, (AAPG/Data pages Discovery Series)”, CD-ROM, 214p, 2007

Figures

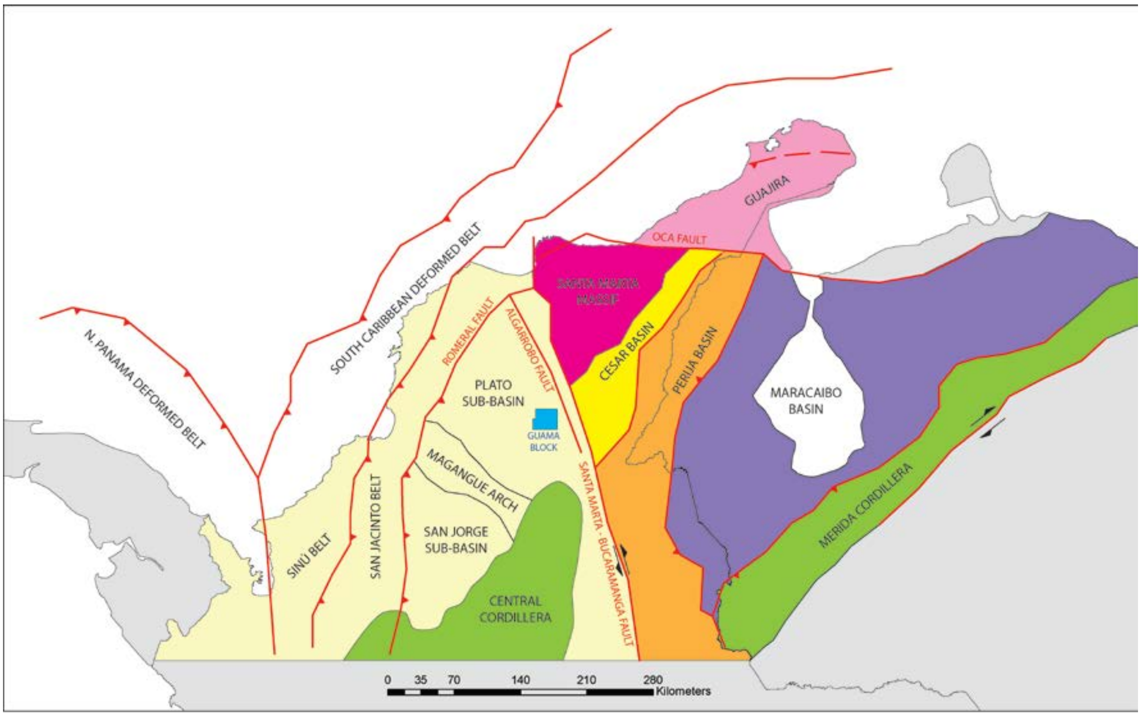


Figure 1. Tectonic Provinces of the Caribbean & NW Part of South America (based on Case et al, 1984 & Reyes Harker et al., 2000)

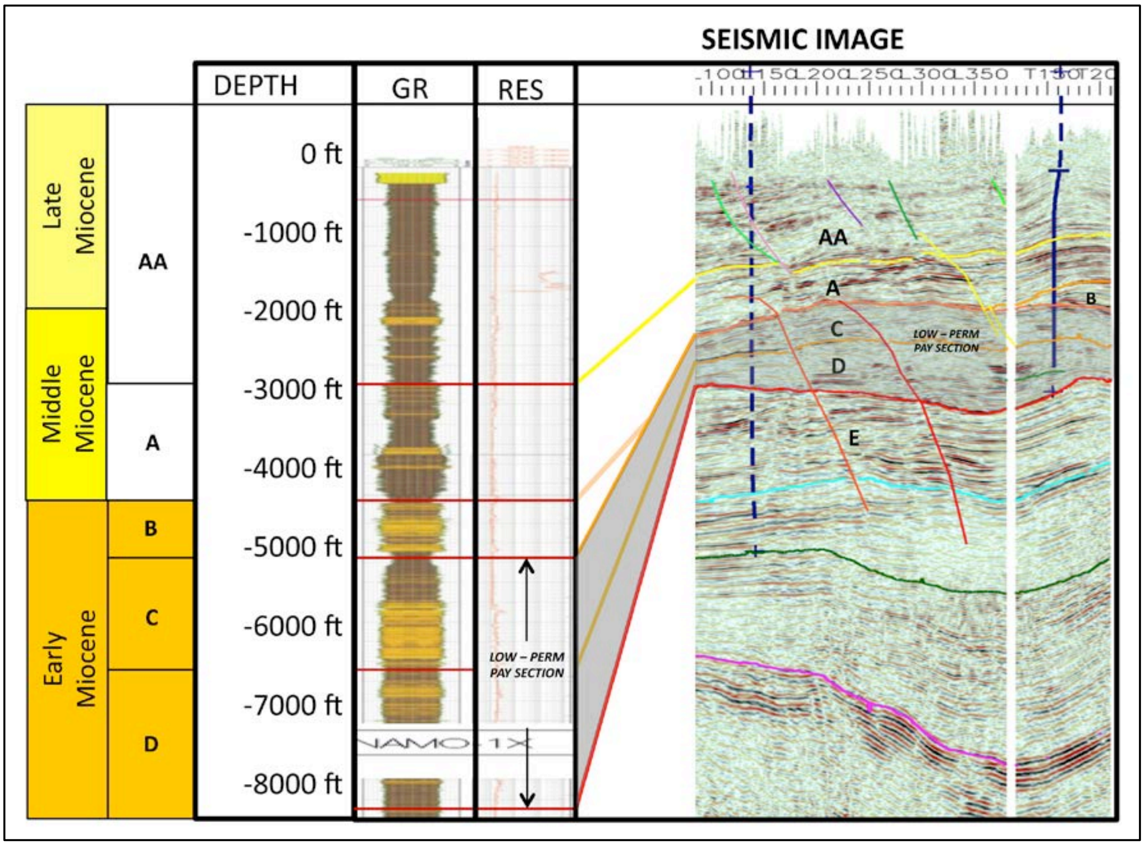


Figure 2. Miocene stratigraphy of the Guama Area, Plato Sub-basin, Lower Magdalena basin (Taken from Di Luca, 2014)

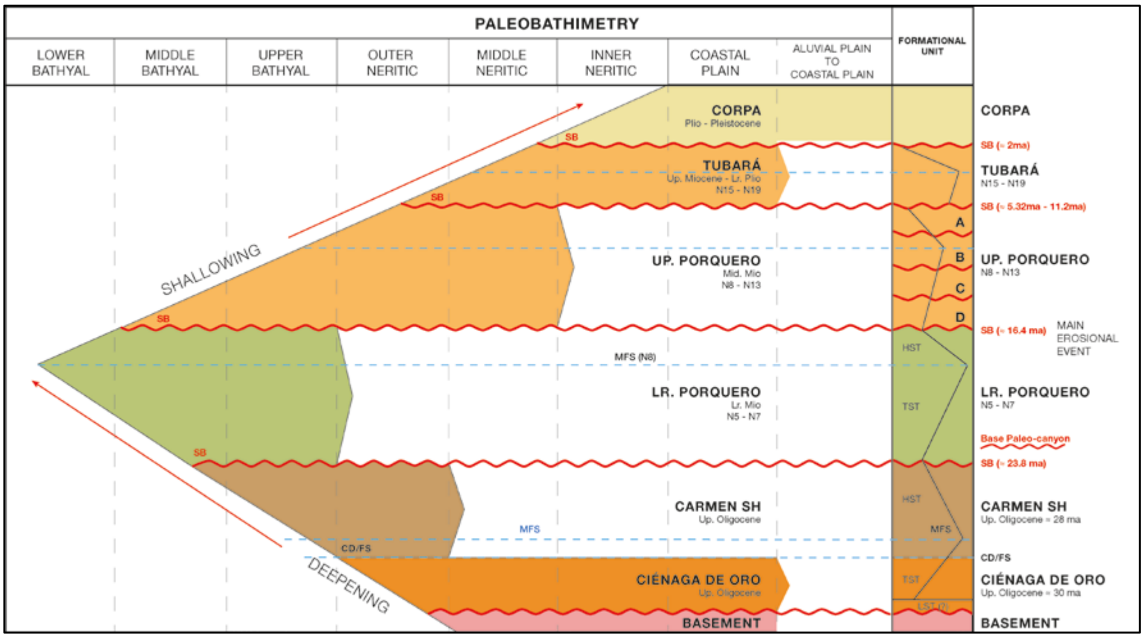
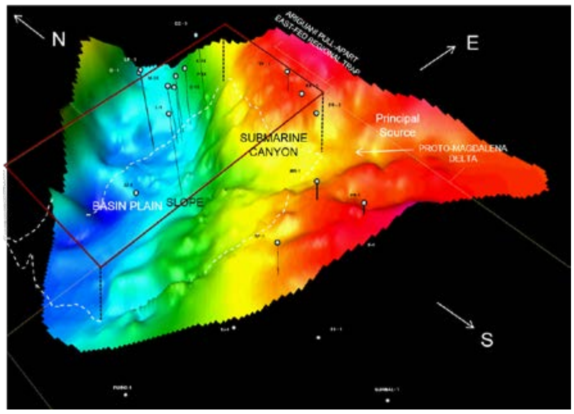


Figure 3. Schematic paleobathimetry & Sequence Evolution, Guama Area, Lower Magdalena basin



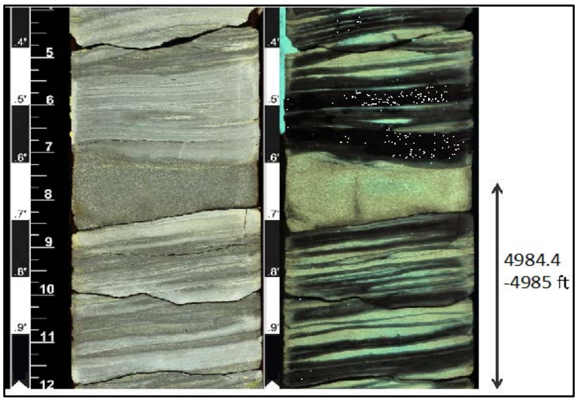


Figure 4 (Left). Miocene submarine canyon, Plato sub-basin –Guama area.
Figure 5. Thin "contourite" sands in Well P-1, Guama area

Table 1: Facies characteristics of producing intervals in Guama wells

Well	Test interval Depth & thickness (ft.)	Results	Facies	Porosity	Remarks
C-1	≈ 6000', 15'	Condensate 55.6^0 API; & Gas	Sandy channels with siltstone interbeds	18-24%	Sand f to v. fine grading to silt; Quartz 90%, calcite cement
L-1	≈ 11000', 10-15'	Condensate 43.4^0 API; & Gas	Thin 10-15' channel sands & associated siltstone of crevasse-splay origin	6-14%	Post-fracture production improved many-fold
M-1	≈ 6500', 10-70'	Condensate 58.9^0 API; & Gas	Channel/crevasse sand; well sorted, silica & calcite cements; carbonaceous laminations	14-18%	Channel facies with very thin micrite interbeds
P-1	≈ 5900', 5'	Condensate 57^0 API; & Gas	F. to vf sand, reg. sorting, Siltstone with org. matter & glauconite	10-12%	Very thin sands; minor coaly matter and pyrite