Marine and Petroleum Geology 28 (2011) 149–176

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Structural controls on Quaternary deepwater sedimentation, mud diapirism, and hydrocarbon distribution within the actively evolving Columbus foreland basin, eastern offshore Trinidad

Emilio Garciacaro [a,1], Alejandro Escalona [b,*], Paul Mann [a], Lesli Wood [c], Lorena Moscardelli [c], Sean Sullivan [c]

[a] University of Texas Institute for Geophysics, Jackson School of Geosciences, J.J. Pickle Research Campus, 10100 Burnet Road, Bldg. 196 [R2200], Austin, TX 78758-4445, USA
[b] University of Stavanger, Department of Petroleum Engineering, 4036 Stavanger, Norway
[c] University of Texas Bureau of Economic Geology, Jackson School of Geosciences, J.J. Pickle Research Campus, 10100 Burnet Road, Bldg. 130 [E0600], Austin, TX 78758-4445, USA

ARTICLE INFO

Article history:
Received 6 November 2008
Received in revised form
15 April 2010
Accepted 17 May 2010
Available online 25 May 2010

Keywords:
Caribbean
Hydrocarbons
Trinidad
Orinoco delta
3D seismic survey
Submarine slides
Mass-transport complexes
Sequence stratigraphy

ABSTRACT

Eastward migration of the Caribbean plate relative to the South American plate has caused lithospheric loading along the northern margin of South America, which is recorded by an 1100-km-long foreland basin which is oldest in the west (Maracaibo basin, 65–55 Ma) and youngest in the east (Columbus basin, eastern offshore Trinidad, 15–0 Ma). The Orinoco River has been the primary source of sediment for the basin since early Miocene. We have integrated approximately 775 km of deep-penetration 2D seismic lines acquired in the area of eastern offshore Trinidad as part of the 2004 "Broadband Ocean-Land Investigations of Venezuela and the Antilles arc Region" (BOLIVAR) project, 8000 km^2 of shallow industry 3D seismic data, and published industry well data from offshore eastern Trinidad. Active mud diapirism in the Columbus basin is widespread and is related to overthrusting and tectono-sedimentary loading of upper Miocene-lower Pliocene age mud. Analysis of the shallow 3D seismic data reveals the presence of extensive gravity-flow depositional elements on the Columbus basin slope and the deepwater area. These stacked gravity-flow deposits are characterized by mass-transport deposits at the base, turbidite frontal-splay deposits, leveed-channel deposits, and capped by fine-grained condensed-section deposits. Exploration targets in the deepwater area are located towards the center of the Columbus basin, where northeast-trending fault-propagation folds are important Plio-Pleistocene trap-forming elements. Deep basin wells drilled in recent years have proven that turbidites were transported into the deepwater Columbus basin during the Plio-Pleistocene. Analysis of these well results suggests that a deeper oil charge is present within the deepwater Columbus basin area. The primary uncertainty for this variable hydrocarbon system is whether fault or diapiric pathways connect or divert the petroleum charge at depth with shallower reservoir rocks.

1. Introduction

Trinidad and Tobago is the 18th largest supplier of oil and liquid natural gas (LNG) to the United States. In 2004, Trinidad and Tobago provided more than 17.8 million barrels of oil equivalent and more than 400 billion cubic feet of gas to the United States (United States Energy Information Administration, 2010). In the eastern offshore Trinidad area, the majority of gas production occurs along the continental shelf, southeast of the island of Trinidad in the Columbus basin (Leonard, 1983; Wood, 2000) (Fig. 1). During the last decade, the deepwater region of eastern offshore Trinidad has become the focus of increased exploration driven by the need to increase reserves to justify the expansion of the LNG processing and shipping facilities in Trinidad and to maintain the currently high levels of LNG exports to the United States and Venezuela (Wood and Roberts, 2001).

The Neogene evolution of the hydrocarbon-rich Columbus basin lies in a diffuse and complex zone of interaction between the Caribbean and the South American plates that formed by progressive, oblique west-to-east collision of the Caribbean arc with the northern South American passive margin (Erlich and Barrett, 1992; Pindell et al., 1998; Babb and Mann, 1999; Di Croce et al., 1999;

* Corresponding author.
E-mail addresses: emga@statoil.com (E. Garciacaro), alejandro.escalona@uis.no (A. Escalona), paulm@ig.utexas.edu (P. Mann), lesli.wood@beg.utexas.edu (L. Wood), lorena.moscardelli@beg.utexas.edu (L. Moscardelli), sullivansmi@mail.utexas.edu (S. Sullivan).
[1] Present address: Statoil, Gulf of Mexico LLC, Building 4, 8th floor, 2101 Citywest Blvd., Houston TX 77042, USA.

0264-8172/$ – see front matter
doi:10.1016/j.marpetgeo.2010.05.007

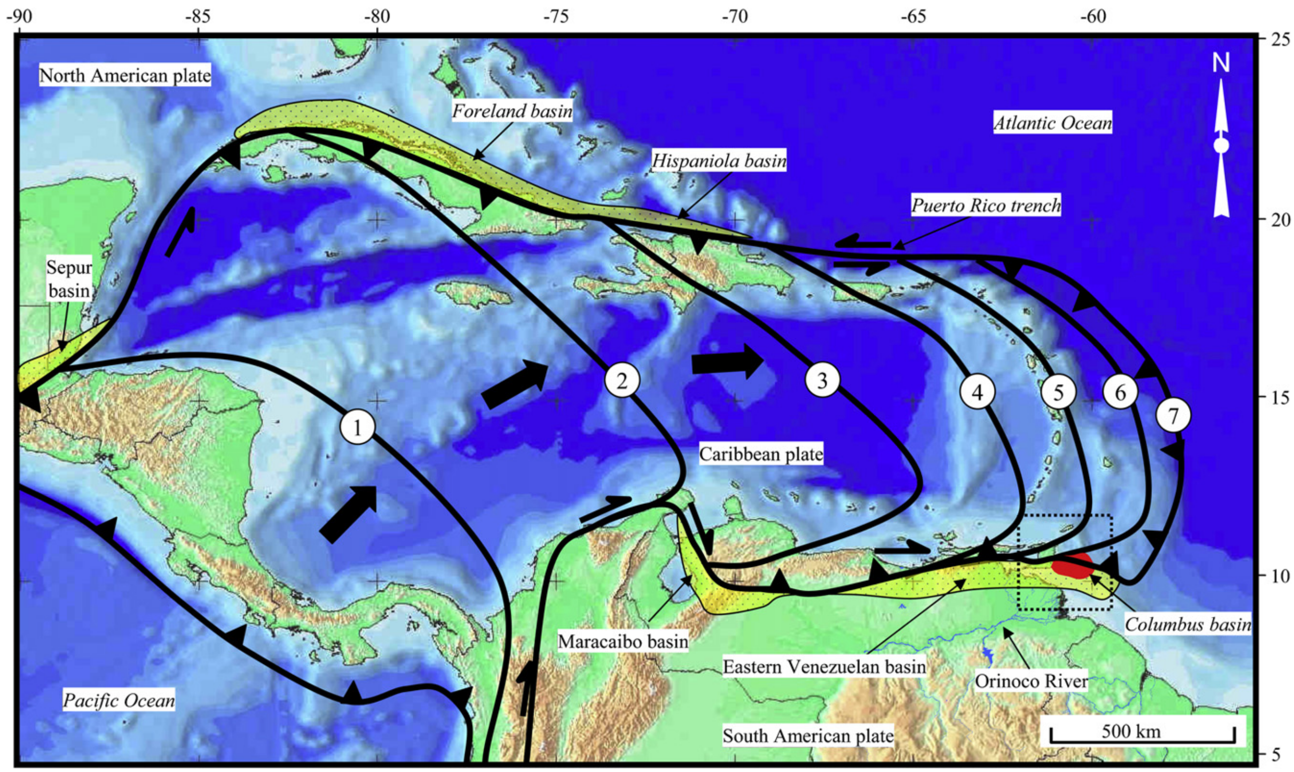

Fig. 1. Plate reconstruction of the Caribbean plate relative to North and South America showing successive positions of the leading edge of the Caribbean plate based on ages of foreland basins (yellow) deposited on the North and South American plates: 1 = Late Cretaceous (~80 Ma); 2 = Paleocene (~60 Ma); 3 = middle Eocene (~44 Ma); 4 = Oligocene (~30 Ma); 5 = middle Miocene (~14 Ma); 6 = Pliocene (~5 Ma); 7 = Recent. The Columbus foreland basin in the southeastern Caribbean near Trinidad is highlighted in red. Dashed square represents area shown in Fig. 2.(For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Garciacaro et al., 2010) (Fig. 1). Regional transpression along the plate boundary zone, produced by the obliquely colliding and overriding Caribbean arc, caused lithospheric loading and flexure of the northern continental margin of the South American plate forming an elongate, east-west-trending foreland basin (Fig. 1). The age of this foreland basin area tracks the diachronous collision of the Caribbean arc with the oldest foreland basin deposits of Eocene age in the Maracaibo basin of western Venezuela (Eocene of the Maracaibo basin) (Escalona and Mann, 2010) and progressively younger foreland basin deposits in eastern Venezuela and Trinidad (Wood, 2000; Garciacaro et al., 2010) (Fig. 1). The Orinoco River has been the primary source of sediment for the foreland basins in eastern Venezuela and the Trinidad area since the early Miocene (Diaz de Gamero, 1996). Following a period of folding and thrusting that culminated in the middle Miocene, a period of protracted transpression and right-lateral strike-slip faulting affected the area up to the present-day (Weber et al., 2001, 2010; Soto, 2007; Soto et al., 2007; Soto et al., 2010).

2. Objectives of this paper

The main objective of this paper is to integrate the structural results from Garciacaro et al. (2010) with sedimentary and basinal interpretations derived from the same combined multi-channel 2D and 3D seismic reflection and well dataset. The methodology includes:

- Use the previous 2D and 3D seismic interpretations of this same dataset used by Brami et al. (2000), Sullivan (2005); Sullivan et al. (2005), Moscardelli et al. (2006); Moscardelli (2007), and Moscardelli and Wood (2008) as a starting point to define the main seismic facies present in the Quaternary section of the deepwater Columbus basin. The lack of publicly available well data from the deepwater Columbus basin means that all of our interpretation of sedimentary environments needs to be inferred from seismic facies and interpreted from seismic reflection data.
- Use the deeply - penetrating 2D multi-channel seismic lines collected by the BOLIVAR study in 2004 to better constrain the deeper structure beneath the deepwater Columbus basin. These data can be compared directly to arbitrary lines taken from the 3D megamerged dataset from the Columbus basin.
- Using this knowledge of the deeper structure, explain the structural controls on the seismic facies, seafloor morphology, distribution of shallow faults and mud diapirs observed in the shallower 3D dataset from the deepwater Columbus basin.
- Using structure and isochron maps of the five main Pleistocene sequences in the deepwater Columbus basin, show how structural and eustatic sea level effects have jointly influenced the temporal evolution of deepwater deposits in the 8000 km^2 area of the 3D megamerged survey.
- Using all of the above structural and sedimentary information, provide an evaluation of the Columbus basin deepwater hydrocarbon potential. In particular, can the same strategies that have been successfully used for the shelf section of the Columbus basin over the past decade be applied to the deepwater area (Wood, 2000; Wood and Roberts, 2001)? If not, is the deepwater part of the Columbus basin sufficiently different in structure and stratigraphy to require an entirely new exploration approach?

3. Data and methodology

This paper interprets the regional BOLIVAR 2004 2D seismic reflection survey from offshore eastern Trinidad, along with