CARIBBEAN BASINS, TECTONICS AND HYDROCARBONS - PHASE IV

Submitted
by:
Dr. Paul Mann,
Professor, Co-principal investigator CBTH project
Department of Earth and Atmospheric Sciences
312 Science and Research, Bldg. 1
University of Houston
Houston, TX 77204-5007
Telephone: 512-809-2843
Email: *pmann@uh.edu*
Web: http://www.uh.edu/search/directory/index.php?cmd=search&uid=E-pmann@uh.edu

and

Dr. Alejandro Escalona, Professor, Co-principal investigator CBTH project
Department of Petroleum Engineering, University of Stavanger
N-4036 Stavanger, Norway
Phone: 47-51-832259
Email: *alejandro.escalona@uis.no*
Web: http://www.ux.uis.no/escalona/

Project Website:
http://cbth.uh.edu/

Scope of Work for CBTH-Phase IV

The goal of the proposed three-year Caribbean Basins, Tectonics, and Hydrocarbons – Phase IV (CBTH) project (September 2014 – August 2017) at the University of Houston and the University of Stavanger in Norway is to continue and expand upon the research activities and focus of the Caribbean Basins, Tectonics, and Hydrocarbons (CBTH) project, Phases I through III. The main goal of CBTH Phase IV will be to continue to provide our industry sponsors with a fully integrated, web-based, digital surface and subsurface synthesis of a hydrocarbon-rich, study area that includes on- and offshore areas of the circum-Caribbean, the Gulf of Mexico region, the Caribbean region, the equatorial Atlantic area of Suriname, French Guiana, northern Brazil, and the Andean foreland basins (Figure 1). We will work on key well-known hydrocarbon-rich and frontier exploration areas within this region that include: on- and offshore Colombia, Venezuela, Trinidad and Tobago, the Leeward Antilles, the Barbados accretionary prism, the offshore Gulf of Mexico, the offshore Nicaraguan Rise, the Yucatan basin, the Greater Antilles area, and the Bahamas platform. CBTH Phase IV will build on previous mapping work by Mann and Escalona together with graduate and undergraduate students at both institutions as part of CBTH over the past nine years, as well as previous and ongoing work by others in the region. As in Phase III, the work will focus on local to regional mapping, understanding of the petroleum systems, detailed plate tectonic reconstructions and paleogeography, analogue modeling, and flexural and basin modelling, and a geographic expansion of the project into equatorial West Africa in order to achieve a more complete understanding of the conjugate margins of northeastern South America and West Africa (Figure 2). These countries and their maritime zones of interest of West Africa include the countries of Benin, Togo, Ghana, Ivory Coast, Sierra Leone, Liberia, Guinea, Guinea-Bissau, Gambia, Senegal, and Mauritania (Fig. 2).

Project Management of CBTH Phase IV

As for the previous CBTH Phases of this study (2005-2014), CBTH Phase IV will be a scientific and educational collaboration between research groups at two separate universities: The University of Houston (P. Mann, co-PI) and the University of Stavanger, Norway (A. Escalona, co-PI). P. Mann, a professor at the University of Houston, will continue to supervise BS, MS and PhD level students and manage GIS and student support staff. UH will act as the main base for the CBTH Phase IV project with several new students entering the program in August 2014 and plans to hire one full-time GIS support person and one fulltime seismic support person. A. Escalona, a professor at the University of Stavanger, is a co-PI who together with Lisa Bingham (Associate Professor) and Nestor Cardozo (Associate Professor) at the University of Stavanger, supervise 3 MS students and 2 research assistants. Due to the proximity of UH to most CBTH sponsors in Houston, Mann and the UH group will host the annual CBTH year-end meeting in early September of each year of the project (next yearend meeting scheduled for Friday, September 12, 2014, at Cemo Hall, UH campus). As with CBTH Phases I-III, the Norway group will use funds from CBTH Phase IV sponsors to employ scientists, post-doctoral researchers, graduate students, and undergraduate students to accomplish the goals of the proposed study. We

also use sponsor funds to collaborate with key experts including Dr. Ian Norton (UTIG researcher, specialist on PaleoGIS-based plate reconstructions), Prof. Willy Fjeldskaar (UiS, specialist in basin modeling), Dr. Carlos Zuluaga (professor from the National University of Colombia, who will spend a one-year sabbatical with the CBTH group at UH starting in the fall of 2014), and Dr. Karen Leever (researcher at Potsdam GFZ who specializes in structural analogue modeling). Information on all current researchers involved with both the UH and UiS groups are summarized on the CBTH website: http://cbth.uh.edu/proj_res.php

Data Sources and Products for CBTH Phase IV

As with the previous CBTH project phases, CBTH Phase IV data sources include 2D seismic data, well data, outcrop data, previous publications on the region, and original seismic and well data provided with permission by the sponsoring companies or government agencies. As we have done over the past 9 years of the study, CBTH Phase IV will continue to respect the conditions placed on the use of donated data either by the research staff or by graduate and postdoctoral researchers employed by the project.

The CBTH Phase IV study will integrate the results of our own seismic interpretation and well correlations over the entire region to produce structural, isopach, and paleogeographic maps, which we will make available to our sponsors in digital format. These data will be integrated with our large GIS database and literature compilation to produce regional and more detailed geologic models and will serve as a basis for modeling and visualization of critical hydrocarbon basins in the area. Proposed work for CBTH Phase IV (2014-2017) will continue to focus on the understanding of the regional geology and basin-forming mechanisms of the study area and will also address improved characterization of the many petroleum systems in the study area (e.g. source, reservoir, trap, etc.). In addition, we will continue to update and expand our database compilation in the key exploration areas of Suriname, French Guyana, the northern equatorial margin of Brazil and its conjugate margin in equatorial West Africa, the Andean foreland areas of southern Colombia and Ecuador, and in the Mexican sector of the Gulf of Mexico (Figures 1, 2). The level of detail for these studies will largely depend on the amount of new data we can access for the project. Our practice is not to accept new graduate students into the project until we have verified that they have obtained access and permission for a dataset.

Deliverables for CBTH Phase IV

The focus areas and deliverables for each year of the project will be discussed during each annual meeting with sponsors and will be subject to changes depending on the availability of new data. Deliverables provided to sponsors by the CBTH Phase IV Project will include: (1) an integrated and user-friendly GIS database which is updated regularly and accessible through our secure website; (2) plate tectonic and paleogeographic models built in PaleoGIS and also updated as new data is accessed; (3) a series of structural and stratigraphic maps of key seismic surfaces in the region; (4) our original interpretations of seismic data and well data; (5) modeling

results using the most complete compilations of available data; (6) all student and researcher poster and oral presentations from international meetings including the AAPG annual meeting held in the US (mainly presentations by the UH group) and the EAGE meeting in Europe (mainly presentations by the UiS group); and (7) access by sponsors to the secure, online CBTH-Phase I-IV database where all project information can be downloaded. In addition to these web-based products, we will continue to provide sponsors with an annual atlas in the third and final year of each phase and FTP delivery of the annual deliverables. Our year-end meeting in September of each year of the project will involve oral presentations by members of the UH and UiS groups. We use an 80-person-capacity meeting room and welcome as many company representatives as you would like to send to the yearend meeting. In addition to the yearend meeting, we organize a 1.5 hour luncheon at each annual meeting of AAPG. This is a good opportunity for sponsors to meet with the CBTH group and learn more about our presentations at this meeting.

Special Projects to be delivered for CBTH Phase IV

Our work is largely driven by the data that is made available to us through the efforts, generosity, and specific exploration priorities of our sponsors. Given our discussions with sponsors at our last year-end meeting in September of 2013, we will work on the following thematic studies in the coming year (pending availability of data from sponsors, companies, or governmental agencies):

1. Improved understanding of the continent-ocean boundary between equatorial northeastern South America and West Africa. The PhD project of Kyle Reuber (in progress, to be completed in early 2015) is applying backstripping and isostatic analysis for both the Brazilian and west African equatorial margins to better delineate the continent-ocean boundary that has remained controversial in many areas including those with very thick deltas such as the Amazon and Niger (Fig. 2). We would like to use this project as a way to identify key areas for future, more detailed studies using seismic and well data obtained from the oil industry. Kyle Reuber is a part-time employee at ION in Houston and through this connection has accessed data for the Demerara Rise that is being incorporated into his PhD study. Kyle will also be co-convening the annual Africa meeting of the Houston Geological Society to be held in Houston on September 9-10, 2014 (the same week as our yearend meeting on Friday, September, 12, 2014). Three other CBTH students will be presenting at this meeting.

2. Suriname, French Guiana, Trinidad, and Eastern Venezuela. We will pursue collaborations with the Suriname and French Guiana energy ministries and universities in order to improve our database and access more subsurface data including the study of the UH PhD student Kyle Reuber on the Demerara Rise using ION span data. Because some of our sponsors are actively exploring along this margin, we would hope to gain access to subsurface data in the deep basin and the southeastern part of the shelf. Basin modeling would be conducted using available subsurface data combined with reconstruction of major tectonic and eustatic events that have

affected the margin. We published an important new synthesis paper on the petroleum geology of the Guyana margin using well and reflection data that is being widely used by exploration companies along this margin (Yang and Escalona, 2011ab; Escalona and Yang, 2013). We will also incorporate the new results provided by Tricia Alvarez who will graduate from The University of Texas at Austin, December 2014. The main goal is to improve our regional structural and stratigraphic knowledge on this frontier margin of northeastern South America along with its conjugate in West Africa. We also will include the results of Karilys Castillo, who is completing her study of the Orinoco delta area of easternmost Venezuela using data made available from PDVSA. In addition, we are in discussion with data providers for data from Barbados that will fill an important gap in a known petroleum-producing area of the Barbados accretionary prism.

3. Study of the northern Brazilian margin and its conjugate margin in West Africa. We have developed a close working relationship with Spectrum, who is also one of our sponsors. Spectrum has been generous in providing us data from the Brazilian margin that we have used in one project (Reuber, PhD in progress) along with developing future studies that involve both northern Brazil and the equatorial margin of west Africa (Loureiro, PhD in progress, Dowla, PhD in progress, who are both starting at UH in the fall of 2014). Our goal is to provide the sponsors with a regional framework for both of the conjugate margins of the Cretaceous transtensional margin formed during the opening of the equatorial and central Atlantic Ocean that is now blanketed by passive margins that contain many possible petroleum systems. This Atlantic equatorial margin is the last remaining frontier area of Brazil's Atlantic margin. Our experience and completed studies in Trinidad and Guyana will allow us to attempt regional stratigraphic comparisons for this source-rock-rich coast of northeastern South America. We also are refining the plate opening and strike-slip model for the Mesozoic opening of the area which would act as a framework for all paleogeography data compiled for the area. A critical question is whether the so-called "Mirror Hypothesis" can be used as a predictive model for future exploration for the equatorial basins of northeastern South America and Western Africa (Fig. 2). This is an important topic for Kyle Reuber's PhD study and was recently presented by him at the AAPG meeting in Houston in May 2014 (Reuber et al., 2014). In a related topic we have one undergraduate, Vanessa Alejandro, working on a GIS-based senior thesis for West Africa: "Comparison of rock types in modern watersheds of equatorial West Africa to quality of sandstone reservoirs in offshore basins."

4. Northern Andean foreland basin flexure study. We will continue to expand on a series of projects from Venezuela to Ecuador that will aim to provide the basis for a regional and synoptic study of the Northern Andean foreland basin. Our previous studies have shown that the Northern Andean foreland basin has been tectonically influenced by the Caribbean "Great Arc" collision that we have previously studied in the area of Venezuela and Trinidad and Tobago. From our more recent work on onland basins in Colombia, we are also recognizing that the Andean foreland basins have a more complex evolutionary history that is also strongly influenced by the

interaction of the Andean margin with subducting oceanic plateaus, arcs, young oceanic plates, and thickened oceanic ridges of Pacific origin. During Phase III, we completed two projects focused on the northern (UH – Pachon, MS, 2013) and southern (UiS – Moreno, MS, 2012) Llanos foreland basin of Colombia and have made considerable progress on a third project at UiS on a modeling study of regional flexure by Elisabeth Johansen, whose preliminary results were presented at the CBTH 2013 annual meeting. We also have two projects in progress on the structure of the frontal thrusts of the Llanos basin at both UH and UiS (Mejia at UH and Muñoz-Barrera at UiS). Both projects are making use of 2D and 3D MOVE software for structural restorations of complexly deformed, yet highly productive reservoirs in the foothills area. We are also collaborating with Ecopetrol-ICP to incorporate thermochronological studies of core samples into these studies.

All these oil- and gas-rich basins of the Northern Andean foreland basin once formed part of a large and interconnected Cretaceous seaway that contains world-class source rocks and evolved into a foreland setting during tectonic events of the late Cenozoic. The basins in these regions, particularly in Ecuador, are among the richest hydrocarbon basins in South America, yet they have not placed into the type of regional tectonic framework that we propose for the CBTH Phase IV study. A main focus of the CBTH Phase IV project is to expand our GIS and reference compilations for all these foreland areas, seek opportunities to access subsurface data, and build regional maps of key tectonosequences that will form the basis of the CBTH Phase IV regional framework. We have found that these data-driven types of activities are of great benefit to our sponsors and can be done at relatively modest costs given that our compilation effort is carried out by undergraduate, graduate, and post-doctoral students.

5. Structure and stratigraphy of the Nicaraguan Rise. Regional mapping and correlation is key to understanding the plate evolution of this vast, underexplored submarine carbonate bank, its underlying tectonic terranes, and how these terranes control the overlying source and reservoir units. We have made much progress in our regional study given that most of the data we are using was collected in the 1970s and has limited depth penetration, especially in submarine carbonate environments. We have supplemented these vintage seismic and well data with a complete compilation of all exploration well logs available in the Honduran and Colombian sectors where possible with data available from modern, deeper penetration seismic surveys. We have also integrated both data and drilling results from the publicly available, high resolution, stratigraphic wells completed by the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Project (ODP). For this study - that is being carried out by three UH PhD students (Bryan Ott, and Javier Sanchez, who presented at the 2014 AAPG meeting, and Luis Carlos Carvajal) - we plan to continue our collaboration with ANH in Colombia and build collaborations with ministries in Honduras and Jamaica. All three students are completing regional subsurface maps that encompass the various sectors of the Nicaraguan Rise and then use these maps to constrain our PaleoGIS plate reconstructions for the area. These PaleoGIS reconstructions can then form the basis of updated paleogeographic maps. We have recently finalized an agreement with

ministers and governmental officials in Jamaica who control extensive areas of the Nicaraguan Rise for their providing Bryan Ott additional data from this area. In addition, Sayyid Suhail, MS at UiS, is working on building the paleogeography from Cretaceous to recent by integrating the new results of Ott and Carvajal, and all previous available information. These results will be integrated with previous paleogeographic maps developed by Escalona and Mann.

6. Mexican and US sectors of the Gulf of Mexico. About half of the Gulf of Mexico falls within Mexican waters which are now a topic of much exploration interest by some of our sponsors (Fig. 1). Our goals in this area include linking the onland geologic history of Mexico with the offshore depositional record on the shelves, slopes, and deep basins of the Mexican sector of the Gulf of Mexico. Mann has completed one study on the Chicontepec basin of the western Gulf in collaboration with Mexico that he presented at a special session on Mexico at the 2014 AAPG meeting. He is also supervising one UH MS student, Luan Nguyen on a magnetic-gravity study of that margin (Nguyen et al., 2013, fall AGU meeting). We have also completed a full length paper based on the MS study of Rodriguez that synthesized all available seismic and well data from the Mexican GOM and submitted it for review. We have one UH MS study in progress on the deep structure of the eastern GOM using deep-penetration seismic data from industry (Murad Hasan, presented at 2014 AAPG meeting). This study integrates new deep-penetration seismic data with PaleoGIS plate reconstructions and our studies of the Mexican GOM. Mann has been invited to present on the petroleum geology of the Gulf of Mexico at a conference being organized by the Mexican Petroleum Institute in August of 2014.

7. Onland basins of Colombia and regional effects of Panama indentor. Colombia experienced the collision of the Great Arc of the Caribbean in the Late Cretaceous and Paleogene and was again subjected by a superimposed collision by the Panama arc “indentor” in ;late Miocene times. Using ANH seismic and well data, we have several projects in Colombia that include a study of all earthquakes and subducted slabs in the region (Vargas and Mann, 2013), the Lower and Middle Magdalena basins (Bernal, completed UH PhD, May, 2014, Mata, UH MS, December 2014), the offshore Sinu-accretionary prism (Sanchez, UH PhD in progress; Leslie, UH PhD, December 2014), and the Llanos foreland basin (Mejia, UH MS, December 2014). Our proposed CBTH Phase IV work for this area includes incorporation of the many recent surficial stratigraphic and structural studies by other groups into our subsurface mapping effort. One main goal of this study is to constrain the presence of the Great Arc in the subsurface of northwestern Colombia, its regional structural effects, and the later structures superimposed on the region by the Miocene Panama collisional event. This later, superimposed Panama event appears to have a major impact on the subsidence and uplift history of hydrocarbon-bearing basins in the region (PhD study of Javier Sanchez and MS study of Orietta Mata)

8. Basin modeling of selected basins. Previous research in which Escalona has completed and published have shown the importance of basin modeling for understanding the evolution of the petroleum system (Escalona et al., 2011; Yang and Escalona, 2011; Escalona and Yang, 2013b). In particular, basin modeling has shown the importance of temperature variations from

underlying and contrasting tectonic terranes including thinned continental crust, accreted arcs, and basins overlying actively subducting slabs such as in the Trinidad, Leeward Antilles, offshore Venezuela, and northwestern Colombia areas. In the CBTH Phase IV project, we will use basin modeling to evaluate the effects of basin subsidence, deformation, heat flow on source rock maturity, and reservoir rock quality. All models will take advantage of the information we have compiled in our database. 9. PaleoGIS plate reconstructions encompassing a wider area. Building on the widely accepted Pacific-derived origin of the Caribbean plate, we will expand the reconstructions and paleogeographic maps to include from the offshore equatorial basins of northern Brazil to the Andean foreland basins of Colombia and Ecuador and explore tectonic and stratigraphic linkages to the central and south Atlantic opening (Escalona and Norton, PaleoGIS reconstruction and paleogeography paper in prep). We will also develop a full set of plate tectonic animations based on the PaleoGIS database and reconstructions between Jurassic to recent. A particularly labor-intensive effort is to fully integrate the data points in our GIS database with the reconstructed maps in order to verify the plate model. Work by support staff in Norway has been progressing over the past year in this area and is currently being synthesized into the Phase III atlas that will be distributed to sponsors at the yearend meeting in September of 2014. The plate model serves as the main template for the paleogeographic maps and for the sponsors to visualize a regional framework. Because the generation of the plate tectonic model is time consuming, we have scheduled the delivery of the PaleoGIS compatible geodatabase at the end of Year 3 of the CBTH-Phase IV project.

10. Regional structural and thickness maps of the circum-Caribbean region. Previous regional maps in the region include Case and Holcombe (1980), Letouzey et al. (1990), and the USGS regional maps of hydrocarbon potential compiled by French and Schenk (2004). All these previous maps show the main stratigraphic and structural elements of each basin, but do not discriminate between the different tectonosequences. The ultimate goal of CBTH is to develop a 3D earth model by integrating all data generated by CBTH and previous workers. Work by the UiS group in Norway includes developing the methodology necessary to build the 3D earth model in Landmark, which allows us to handle large amounts of data. Preliminary results with regional maps will be presented in the September 2014 annual meeting. This work will continue as as updates are received from various ongoing projects with a model update provided to sponsors at each yearend meeting.

11. GIS-based research, models, and products. CBTH Phase IV will continue to use the power of GIS technology to both deliver information quickly to our sponsors along with simplifying data management especially to any sponsors who may not routinely work with GIS applications. For this effort we have developed the GeoMapper tool on our CBTH website that allows sponsors to view our data without a detailed knowledge of GIS. Papers on GIS applied to petroleum exploration in the CBTH area in Phase III include Bingham et al. (2012) which was one of the most viewed papers in AAPG Bulletin in 2013-14. In addition to PaleoGIS reconstructions, paleogeographic data will be provided to sponsors in geodatabase format. With support from a

fulltime GIS support person to be hired, CBTH Phase IV will continue to provide novel and useful GIS-based research and projects along with assisting sponsors in data management as needed.

12. Cross-section restorations and flexural modeling. Cross-section restorations and flexural modeling in 2D and 3D will be another research topic we will apply to key, hydrocarbon-rich areas in the CBTH-Phase IV study area (Fig. 1). We have three balanced cross section studies using 2D and 3D MOVE in progress: Eastern Colombia (Mejia, UH, MS), offshore Colombia (Sanchez, in progress; Leslie, in progress), Hispaniola (Ambrosius, BS senior thesis in progress), and Puerto Rico-Virgin Islands (Loureiro, MS, August 2014). The main goal of this activity is to quantitatively evaluate the effect of tectonic and sediment loading during convergence and mountain uplift along with rifting effects in extensional settings. Since the CBTH Phase IV study area contains so many examples of deep basins adjacent to high mountains, the linkages between mountain uplift and basin subsidence is a widespread problem in the region. This type of modeling will lead to important predictions about the stratigraphy of the basin and its paleogeography that can in turn be compared to the data we have in our database.

Cost of CBTH Phase IV

The total cost of the three-year CBTH Project Phase IV is $180,000 per sponsor. We will require a three-year financial commitment from all CBTH Phase IV sponsors with a minimum annual fee of $60,000 US due by August 15 of each year starting with year one of the project in September 2014. If sponsor payments are not received by August 31, 2014, we will consider these companies “late buy-ins” who will be charged 150% of the annual $60,000 US rate ($90,000).

Figure Captions

Figure 1. CBTH-Phase IV proposed study area is shown in the large boxed area. The CBTH-Phase IV area includes the oil-rich areas of the Mexican and US sectors of the Gulf of Mexico, the Caribbean, and northern South America. Numbers on map refer to areas of proposed work described in the text of this proposal: 1 = Trinidad region; 2 = Suriname and French Guyana; 3 = equatorial basins of northern Brazil; 4 = northern Andean foreland basins; 5 = Nicaraguan Rise; 6 = Mexican sector of the Gulf of Mexico; and 7 = onland basins of Colombia.

Figure 2. CBTH-Phase IV proposed study area is shown in the large boxed area. The CBTH-Phase IV area includes the equatorial, conjugate margins of Guyana, Suriname, French Guyana, Brazil along with countries in west Africa (Western Sahara, Mauritania, Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Cote d’Ivoire, Ghana, Togo, Benin, Nigeria, Cameroon, Equatorial Guinea, Gabon, Congo, and Angola. . Numbers on map refer to areas of proposed work described in the text of this proposal: 1 = Suriname and French Guyana; 2 = equatorial basins of northern Brazil; 3 = Mauritania; 4 = various countries of equatorial west Africa.

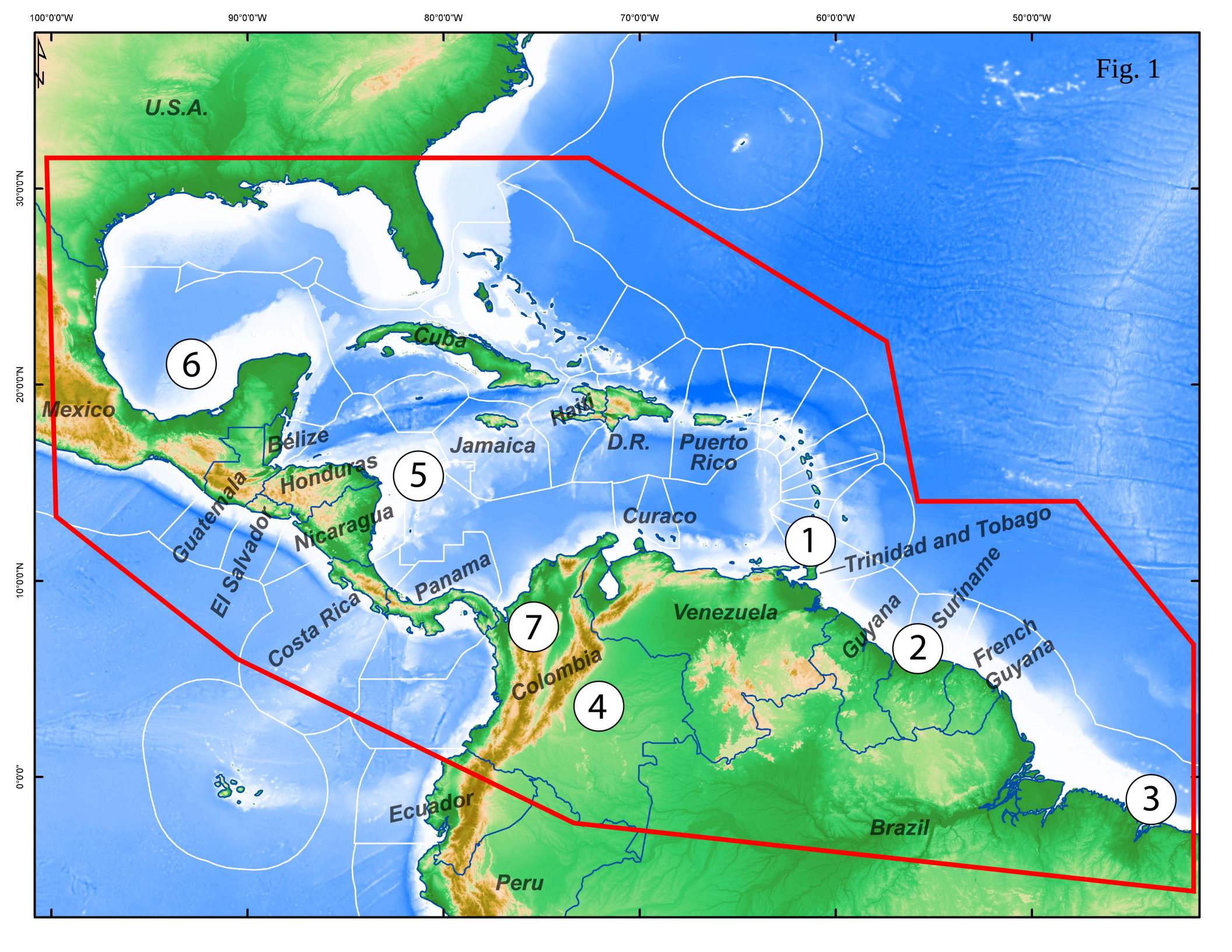
Fig. 1
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Jamaica
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Puerto Rico
Belize
Guatemala
Honduras
El Salvador
Nicaragua
Costa Rica
Panama
Curaco
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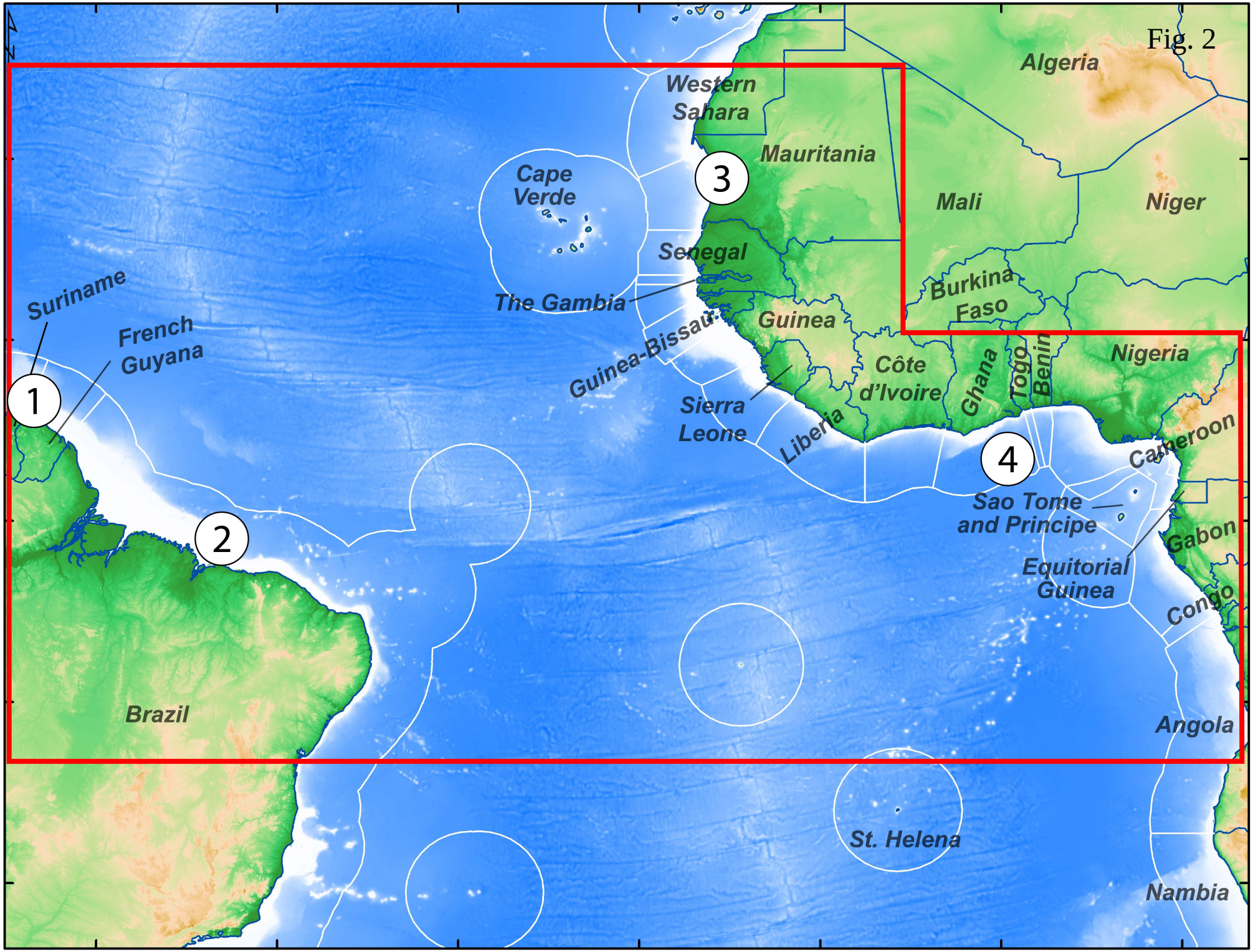
Fig. 2
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Western Sahara
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Mali
Niger
Cape Verde
Senegal
The Gambia
Burkina Faso
Guinea
Guinea-Bissau
Nigeria
Côte d'Ivoire
Ghana
Togo
Benin
Sierra Leone
Liberia
Cameroon
Sao Tome and Principe
Gabon
Equitorial Guinea
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French Guyana
Brazil
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St. Helena
Nambia
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References

Bernal-Olaya, R. 2014, Evolution of a forearc basin in a flat-slab subduction setting, Lower Magdalena basin, Colombia: PhD dissertation, University of Houston.

Bingham, L., R. Zurita-Milla, and A. Escalona, 2012, Geographic information system–based fuzzy-logic analysis for petroleum exploration with a case study of northern South America: AAPG Bulletin, v. 96 no. 11.

Case, J.E., and T.L. Holcombe, 1980. Geologic-Tectonic Map of the Caribbean Region: USGS Misc. Investigation Series Map 1-1100, scale 1:2 500 000.

Escalona, A., and P. Mann, 2011, Tectonics, basin subsidence mechanisms, and paleogeography of the Caribbean-South American plate boundary zone: Marine and Petroleum Geology, v. 28, p. 8-39.

Escalona, A. and W. Yang, 2013, Impact of low-angle subduction in petroleum systems along the Leeward Antilles island arc emergent gas trend, northern South America: First Break., v. 31, p. 55-65.

French, C.D., and Schenk, C.J., 2004, Map showing geology, oil and gas fields, and geologic provinces of the Caribbean region: U.S. Geological Survey Open-File Report 97-470-K, 1 CD-ROM. [on-line] available at: http://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470K/

Hasan, M. and P. Mann, 2014, Stages of Jurassic Rifting, Magmatism, and Salt Deposition in the Eastern Gulf of Mexico Inferred from a Grid of Deep-Penetration Seismic Reflection Data Tied to Wells, AAPG Annual Conference and Exhibition, Houston, Texas.

Letouzey, J., 1990, Faulting Reactivation, Inversion and Fold-Thrust Belt Petroleum and Tectonics Mobile Belts, p. 101-128

Moreno, C., 2012, Evolution of the southern Llanos basin, Colombia: MSc thesis, University of Stavanger, Stavanger, 88 p.

Nguyen, L., P. Mann, D. Bird, 2013, Location of deeply buried, offshore Mesozoic transform fault along the western margin of the Gulf of Mexico inferred from gravity and magnetic data, AGU Annual Conference, San Francisco, California.

Ott, B., P. Mann, M. Saunders, 2014, Island Arcs, Misplaced Continents, and a Large Igneous Province: Challenges for Petroleum Prospecting in the Western Caribbean, AAPG Annual Conference and Exhibition, Houston, Texas.

Ott, B. and P. Mann, 2014, Structural and Gravity Transects of the Colon Mountains-Nicaraguan Rise Orogenic Belt of Honduras and Offshore Nicaragua/Jamaica, AAPG Annual Conference and Exhibition, Houston, Texas.

Pachon, L., 2013, Stratigraphic and tectonic history of the Putumayo foreland basin, Colombia: MSc thesis, University of Houston, 153 p.

Reuber, K., P. Mann, M. Saunders, 2014, Are along-strike alternations of symmetrical and Non-symmetrical South Atlantic conjugate margins controlled by volcanic vs. non-volcanic rifting process?, AAPG Annual Conference and Exhibition, Houston, Texas.

Sanchez, J. and P. Mann, 2014, Regional Transect Across the Western Caribbean: Structural Styles and Plate Reconstructions of Late Cretaceous to Cenozoic Tectonic Events, AAPG Annual Conference and Exhibition, Houston, Texas.

Vargas, C., and Mann, P., 2013, Tearing and Breaking Off of Subducted Slabs as the Result of Collision of the Panama Arc-Indenter with Northwestern South America: Bulletin of the Seismological Society of America, Vol. 103, No. 3., p. 2025-2046, June, 2013, doi: 10.1785/0120120328

Yang, W., and A. Escalona, 2011a, Tectonostratigraphic evolution of the Guyana Basin: AAPG Bulletin, v. 95, p. 1339-1369.

Yang, W., and Escalona, A., 2011b, Basin modeling and source rock evaluation in the Guyana basin, First Break, v. 29, p. 59-69.