Conjugate Basins, Tectonics and Hydrocarbons (CBTH) – Phase V

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/nsm/earth-atmospheric/people/faculty/paul-mann/

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/

Rationale for Project Name Change and Scope of Work for CBTH Phase V

The CBTH Project, or "Caribbean Basins, Tectonics and Hydrocarbons Project" began with the financial support of a consortium of oil companies on September 1, 2005 and has operated continuously for the past 12 years within four, three-year phases identified as I (2005-8), II (2008-11), III (2011-14), and IV (2014-17). This proposal requests funds to continue the consortium for Phase V that would begin on September 1, 2017, and extend for a three-year period to August 31, 2020. While this proposed phase is numbered "V" and consecutively with the other numbered phases, the full title of the project will change from the previous title of "Caribbean Basins, Tectonics and Hydrocarbons (CBTH) Project" to the new title of "Conjugate Basins, Tectonics and Hydrocarbons (CBTH) Project".

As explained during the 2016 year-end meeting for sponsors held on September 30, 2016 and at the annual luncheon for sponsors held during the AAPG-ACE meeting in Houston on April 3, 2017, the reason for the name change is the geographic expansion of the CBTH study area to areas outside of the Caribbean basin that include: the conjugate margins of the Gulf of Mexico, the conjugate margins of the Central, Equatorial, and South Atlantic Oceans, and the conjugate margins of the Mozambique basin of East Africa (Fig. 1). The outline of the expanded study area includes much of the former supercontinent Pangea that rifted apart beginning in the Triassic and Jurassic (Fig 1, inset). For this reason, widely spaced areas in the study area share similar tectonic phases: Triassic-Jurassic rifting followed by Cretaceous-Cenozoic passive margin formation.

This project will continue to study the Caribbean basin and its hydrocarbon potential using the large amount of data compiled over the past 12 years as well as any new data sets that are presently available. The theme for CBTH Phase V will widen into the topic of rifted-passive conjugate margins. The two main reasons for this name change and expansion of the geographic focus of the CBTH project include: 1) our intensive studies of the Caribbean basins since the beginning of the project in 2005 have used all the offshore 2D seismic data sets that are currently available in the Caribbean region; and 2) the rate of major oil and gas discoveries is far greater in the Gulf of Mexico, South Atlantic and East African margins than in the much smaller and more tectonically-complex Caribbean region.

This change in geographic focus has been transitional over the past four years as the UH group began projects in the new, expanded study area in Year Three of Phase III (2013). These studies outside the original Caribbean study area are now coming to fruition with our first completed UH MS thesis from the Gulf of Mexico in 2014 (Ismael, 2014) and two UH PhD dissertations from South Atlantic conjugate margins in June 2017 (Reuber, May 2017; Loureiro, August 2017). All of these results are displayed in the new atlas for three-year Phase IV that will be distributed to sponsors at the year-end meeting held on September 30, 2017, at the University of Houston.

Goals and Scope of Work for CBTH Phase V

The goals and scope of the proposed three-year Conjugate Basins, Tectonics, and Hydrocarbons (CBTH)Project - Phase V (September 2017 – August 2020) 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 - IV. As with previous phases, the central goal of CBTH Phase V 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 including the Suriname, French Guiana, northern Brazil, and its conjugate margin in equatorial and northwest Africa (Figure 1).

Within this central goal, we will work on key well-known hydrocarbon-rich and frontier exploration areas within the expanded CBTH study area that now includes the Caribbean, GOM, and Central-Equatorial-South Atlantic margins (Fig. 1). CBTH Phase V will build on previous mapping work by Mann and Escalona together with graduate and undergraduate students at both institutions as part of CBTH since 2005, as well as previous and ongoing work by others in the region.

As in Phase IV, the work will focus on local to regional mapping, understanding of the petroleum systems, detailed and quantitative plate tectonic reconstructions including observational tests of the in situ versus exotic Caribbean plate models, analogue modeling, flexural and basin modelling, and investigations of both GOM and Atlantic margins to test ideas of upper plate-lower plate margins versus more symmetrical, “mirror-styles” of rifted, conjugate margins. We describe these methods in greater detail as they have been applied to specific areas of the expanded CBTH study area.

Project Management of Personnel for CBTH Phase IV at UH and UiS

As with the previous phases of this study (2005-2017), CBTH Phase V will continue the scientific and educational collaboration between research groups at two separate universities: The University of Houston (Paul Mann, co-PI) and the University of Stavanger, Norway (Alejandro Escalona, co-PI). Mann - a professor at the University of Houston (UH) - will continue to supervise BS, MS and PhD level students and manage GIS and student support staff at UH. UH will act as the main base for the CBTH Phase V project with at total of 23 researchers, graduate students, and undergraduate students supported by CBTH in the spring of 2017. Escalona, a professor the University of Stavanger (UiS), supervises BS, MS, and PhD students along with GIS and student support staff at UiS.

The numbers of of UH supported students have fluctuated in Phase IV, Year 3 (2016-17) with four PhDs graduating in 2017 (Reuber, Carvajal, Loureiro, Blanco), , two new PhD students arriving in August of 2017 to begin studies of the western Gulf of Mexico margin (A. Gomez) and the Namibian margin of west Africa (Kenning), and two PhDs graduating in 2018 (S. Gomez, Torrado). For the first year of Phase V in 2017-18, Mann will supervise a total of 9 PhD students and 1 MS student in 2017-18, who will work on various CBTH-funded projects in our expanded study area (boxes in Figure 1 indicate the various student projects discussed in detail below). Mann and GIS specialist and PhD student, Nawaz Bugti, also manage between 7-8 undergraduate workers who contribute towards our GIS database and conduct senior research projects that are part of their BS degrees in either geology or geophysics at UH.

A. Escalona, together with Lisa Bingham (Associate Professor and GIS expert) at UiS, will supervise students and 2 research assistants.

Due to the proximity of UH to most of the CBTH sponsors in Houston, Mann and the UH group will host the annual, one-day, CBTH year-end meeting in September of each year of the project (next year-end meeting scheduled for Friday, September 29, 2017, at Cemo Hall, UH campus). During this meeting, all researchers will summarize progress for the year in a series of talks and future plans will be discussed for the coming year.

CBTH funds are used to sponsor researchers from the CBTH region to work either at UH or UiS. Mann is currently hosting Dr. Marvin Bacquero from Venezuela for the summer of 2017 to conduct detrital zircon dating using UH lab facilities from key areas of the Venezuelan and the offshore Venezuela islands. Dr. Bacquero is also working with our group in compiling radiometric, thermochronlogic and other information from the Caribbean and northern South America in addition to preparing publications on the results of his most recent detrital zircon results. 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 V 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 12 years of the study, CBTH Phase V 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 V 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 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 V (2017-2020) will continue to focus on understanding the regional geology and basin-forming mechanisms of the study area and will also address improved characterization and modeling of the many petroleum systems in the study area (e.g. source, reservoir, trap, seals, etc.). In addition, we will continue to update and expand our database compilation in the key exploration areas that are described in detail below and shown on Figure 1. The level of detail for these local 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 V

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 V 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 GPlates and posted with documented data sources such as wells, radiometric dates, etc.; (3) a series of structural and stratigraphic maps of key seismic surfaces in the region formatted for our 3-year atlas delivery; (4) our original interpretations of seismic data and well data; (5) basin modeling results using the most complete compilations of available data; (6) 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 Phases I-IV database where all project information can be downloaded in a targeted and more efficient year-by-year manner. 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 held at UH 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 at the University of Houston and welcome as many company representatives as you would like to send to the year-end meeting. In addition to the year-end meeting, we organize a luncheon at each annual meeting of AAPG-ACE. This annual luncheon is a good opportunity for sponsors to meet with the CBTH group and learn more about our presentations at the meeting, which is the primary conference to present at for most CBTH researchers at UH. We also conduct office visits during the course of the year with the UH-based group visiting those sponsors in Houston and the UiS-based group visiting those sponsors in Europe.

Completed and In-Progress Special Projects to be delivered for the CBTH Phase IV atlas in September 2017 and during CBTH Phase V

Our work is largely observationally-driven by 2D well and offshore 2D seismic data made available to us through the efforts, generosity, and specific exploration priorities of our sponsors. We also are increasingly making use of potential field data from publicly-available gravity and magnetic datasets for understanding crustal types, regional basinal structure, and continent-ocean boundaries. We are also focused more on basin modeling using the basin framework constraints we establish from potential fields and interpretation of 2D seismic and well data. Given our discussions with sponsors at our last year-end meeting in September 2017, we will work on the following thematic studies for Phase V (for all of the areas listed below we have accessed or are in the process of accessing data from sponsors, companies, or governmental agencies):

1) GIS-based research, models, and products. CBTH Phase V 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. To facilitate the viewing and access to our GIS database, we have developed the GeoMapper tool on our CBTH website that allows sponsors to view our data without a detailed knowledge of GIS. In addition to PaleoGIS and GPlates reconstructions, paleogeographic data will be provided to sponsors in geodatabase format.

GIS expertise at UH is provided by Nawaz Bugti and Jeff Storms while GIS

expertise at UiS is provided by Dr. Lisa Bingham, who is a professor in in the area of GIS applications to petroleum exploration. During Year 3, Phase IV at UH, we supported as many as 9 undergrads supported to georeference critical maps, age dates, thermochronology, heat flow, faults, natural hydrocarbon seeps, seismic lines, regional cross sections, wells, burial plots and other types of information relative to hydrocarbon exploration that were derived from more than 15,000 published articles, reports, internet pages, unpublished theses, and other data sources that cover the vast CBTH area shown in Figure 1. We then use these data points to populate plate models in PaleoGIS or GPlates. With support from this pool of experts, CBTH Phase V will continue to provide novel and useful GIS-based research and projects along with assisting sponsors in data management as needed.

2) Improved, quantitative plate tectonic model for the Caribbean-Gulf of Mexico region. During Phase IV we continued to refine the exotic Caribbean plate model by Escalona and Norton (2010) whose development was supported by CBTH funds and was delivered to sponsors in 2014. This plate model serves as the main template for the paleogeographic maps and for sponsors to visualize a regional framework which we will continue refining during Phase V. With the large number of CBTH projects in the Caribbean, we have been able to modify the original Escalona and Norton (2010) model during CBTH Phases III and IV based on newly discovered intraplate and plate boundary faults including whose structure and timing has been described in its modified form in the completed UH PhD dissertations and publications in review by Ott (2015), Sanchez (2017), and Carvajal (2017). Gomez (paper submitted, 2017; PhD expected May 2018) is using potential fields and deeply-penetrating seismic data to make important new observations on the structure of the Lesser Antilles Arc and Barbados accretionary prism, which is a key area for understanding the paleo-position and subduction polarity of the early Cretaceous Great Arc of the Caribbean. Lin (revised paper in review, PhD expected August 2018) used potential fields data combined with grids of 2D seismic reflection lines from the southeastern GOM to reveal for the first time the Jurassic spreading ridge and its flanking areas of Jurassic oceanic crust.

Building on the widely-accepted Pacific-derived origin of the Caribbean plate, we have expanded the reconstructions and paleogeographic maps to include detailed observations from the Chortis block of Honduras and the Nicaraguan Rise (Sanchez et al., 2015), the Lower Nicaraguan Rise and the Colombian basin (Carvajal, 2017), and the Upper Nicaraguan Rise including the Jamaica area (Ott, 2015). We have also integrated into our Caribbean plate model several hundred kilometers of Eocene to recent subduction of the Caribbean plate beneath the Caribbean margin of Colombia based on a completed PhD dissertation by Rocio Bernal and based on an MS thesis by Orietta Mata. We have also explored stratigraphic implications of this subduction system in a published paper by Vargas and Mann (2013) and several CBTH papers by Bernal (2015, a, b, c) in AAPG Memoir 108 (2015) that was co-edited by C. Bartolini (Repsol) and Paul Mann.

3) Tomographic studies of subducted slabs of the Caribbean with implications for the in situ vs exotic tectonic origin of the Caribbean plate. In fall 2016, the UH Department of Earth and Atmospheric Sciences hired US National Academy of Science member and renowned structural geologist Dr. John Suppe and assistant professor Dr. Jonny Wu, who

started the University of Houston Center for Tectonics and Tomography. This group is presently creating an updated tomographic model for the Caribbean that will allow greater resolution of subducted slabs during Phase V of the CBTH study. We are working with this group on restoration of the Lesser Antilles, Nazca, Cocos, and Atlantic slabs and the constraints these slabs place upon the in situ vs. exotic tectonic origin of the Caribbean plate. Mann, Suppe, Wu, and Vargas are co-convening a special session on Caribbean and Andean tomography for the fall AGU meeting in New Orleans, December, 2018, that will show results based on ongoing collaborations between the CBTH and Suppe groups.

4) Regional structural and thickness maps of the circum-Caribbean, GOM, and selected areas of the South Atlantic region. Previous regional maps in the circum-Caribbean region include Case and Holcombe (1980), Letouzey (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. We have compiled the top basement and overlying key surfaces across most of the Caribbean and GOM and will provide these to sponsors for our year-end meeting in September 2017, both in a hard-copy atlas format and as GIS files. Due to the vastness of the Central and South Atlantic margins in the expanded CBTH study area (Fig. 1), we will only include a few key areas of compiled tectonosequences that we have worked to date including: the Amazon cone of Brazil, the Santos basin and Sao Paulo plateau of Brazil, offshore Senegal and Guinea-Bissau and the Guinea plateau.

5) Improved quantitative plate tectonic model for the Gulf of Mexico region and potential field studies of its crustal structure. Our group has made significant contributions to the understanding of the GOM plate evolution and stratigraphic history since our initial efforts in 2013. Completed efforts include an MS study by Murad Ismael (2014) using deeply-penetrating Dynamic seismic reflection data from the eastern GOM and a published paper by Luan Nguyen and Mann (2016) using new satellite gravity released to the public by Sandwell et al. (2014). Nguyen and Mann are currently completing a 3D gravity modeling study of the entire GOM basin that includes a new crustal thickness map showing variations in crustal thickness across the thinned continental area and the area of oceanic crust in the deep GOM. This study also used gravity inversion to derive a thickness map for both the US and Mexican Jurassic salt bodies. These results are featured in our Phase IV atlas and will be summarized at our year-end meeting in September 2017. Gravity studies that will continue into Phase V include a regional study of the eastern GOM and Florida by PhD student Pin Lin who has focused on both the oceanic area, the continent-ocean boundary and continental crust underlying the Florida platform.

6) Use of regional compilations of detrital zircon, radiometric ages, thermochronologic, heat flow, oil and gas seep, and other types of data to validate plate models for the Gulf of Mexico, Caribbean, and Atlantic. During Phase IV, we have employed undergrads and grads at both UH and UiS to a variety of databases from the published literature, unpublished theses and other types of reports. 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. For the atlas for Phase IV, we are compiling the data points on present-day and reconstructed map views. For example, Marie Kouassi in her recently completed UH undergraduate thesis compiled and georeferenced into our GIS database 10,370 detrital zircon U/Pb ages from southern North America, the GOM, and the Caribbean to statistically test previously-proposed, late Paleozoic plate reconstructions, including those from CBTH. For northern South America, our group has published two studies on tracking the eastward motion of the Great Arc and Barbados accretionary prism that indirectly supports the exotic model for Caribbean plate origin (Xie et al., 2010, 2014). The project is currently supporting Dr. Marvin Bacquero's dating of detrital zircons from Venezuela and the Venezuelan islands to continue testing these earlier plate and tectonostratigraphic models. We will present his preliminary results at the year-end meeting and continue these efforts for Phase V.

7) Improved sequence stratigraphic framework for the Gulf of Mexico including implications for potential source rocks, reservoir rocks, and areas of maturity. By fall 2017 and the start of CBTH Phase V, we will have student projects in all major sectors of the the US and Mexican GOM all using 2D seismic data and wells to improve mapping of the stratigraphic framework that began with the MS study of Ismael (2014). For Phase V, Pin Lin will be focusing on mapping the Jurassic-recent tectonosequences overlying oceanic crust and thinned continental crust to better understand the timing of deposition relative to continental stretching followed by oceanic spreading in the southeastern GOM. In the northwestern GOM, Nawaz Bugti has mapped the Port Isabel area for his PhD study using an extensive grid of 2D data and has used these data to constrain a model of radial convergent gliding into this complexly, deformed corner area of the northwestern GOM. During Phase V he will be creating a basin model for this area in order to better understand why this is one of the largest areas of the GOM that lacks hydrocarbon production. Andrew Steier is presently working on a MS study of the northern Yucatan Peninsula and its rifted conjugate margin in the northeastern GOM, and in particular how the region of late Jurassic Norphlet aeolian dunes was separated by rifting during the formation of the US and Mexican conjugate margins of the GOM. For his study, he is building on the plate opening model developed by Nguyen and Mann (2016) and the 3D gravity inversion work by Nguyen and Mann in progress. We have a new PhD student starting in fall 2017, Ali Gomez, who will work on the western Gulf of Mexico and eastern Mexico margin.

8) Potential fields studies of the crustal structure and crustal types for the Nicaraguan Rise, Colombian basin, and Venezuelan basin including implications for the in situ vs. exotic origin of the Caribbean plate. Regional mapping and correlation is key to understanding the plate evolution of this vast, underexplored submarine carbonate bank of the northern Caribbean Sea, 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 1970's 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). Progress is recorded by three now-complete PhD studies by Bryan Ott (2015), Javier Sanchez (2015), and Luis Carlos Carvajal (2017). All three students completed gravity models to constrain basement structure and regional subsurface maps that encompass the various sectors of the Nicaraguan Rise. We then used these maps to constrain our PaleoGIS plate reconstructions for the area.

9) Improved sequence stratigraphic framework for the Nicaraguan Rise, Colombian basin, and Venezuelan basin including implications for potential source rocks, reservoir rocks, and areas of maturity. All three PhD students completed detailed mapping which have integrated into a top basement surface and key horizon maps for the area. Mann is currently editing a special issue of AAPG Bulletin which will be the published form of the three thesis studies. This synthesis study of the Nicaraguan Rise and understanding the impact of these data on Caribbean plate models will continue into Phase V.

10) Potential fields studies of the crustal structure and crustal types for the area of the Lesser Antilles, Trinidad, and the Barbados accretionary prism including implications for the in situ vs. exotic origin of the Caribbean plate. Shenelle Gomez has completed a gravity study of the southern part of the Tobago-Barbados ridge that is currently being explored for hydrocarbons (revised paper submitted to Interpretation). Her subsequent efforts will move from defining the basinal structure to mapping the tectonostratigraphic sequences in the overlying basins and accretionary prism using extensive grids of 2D seismic data made available for her study.

11) Improved sequence stratigraphic framework for the area of the Lesser Antilles, Trinidad, and the Barbados accretionary prism including implications for potential source rocks, reservoir rocks, and areas of maturity. For Phase V Shenelle Gomez is developing a regional tectonostratigraphic framework for the southeastern Caribbean that will increase understanding of potential sources, reservoirs, and traps in this complex, accretionary prism setting.

12) 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, UH PhD, 2014, Mata, UH MS, 2014), the offshore Sinu-accretionary prism (Sanchez, UH PhD, 2015; Leslie, UH PhD, in progress), and the Llanos foreland basin (Mejia, UH MS, 2015). 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, defining its zone of suturing with

continental South America that respects recent basement dating by Marvin Bacquero and others, its regional structural effects, and the later structures superimposed on the region by the late Miocene to recent Panama collisional event. This later, superimposed Panama event has a profound, regional impact on the subsidence and uplift history of hydrocarbon-bearing basins in the region (Sanchez, UH PhD, 2015; Sanchez and Mann, 2015; and Mata, UH MS, 2014)

13) 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, 2013; Sanchez, et al., 2015; Sanchez and Mann, 2015; Carvajal et al., 2015). 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 CBTH Phase V, 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.

14) Potential field studies of the crustal structure and crustal types for the Atlantic margins including implications for upper plate-lower plate rifting models and plate restorations. We have developed a close working relationship with Spectrum USA, based in Houston, who is also one of our CBTH sponsors. Spectrum has been generous in providing us data from the Brazilian margin that we have used for several PhD studies. 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 several known and suspected petroleum systems. 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. The PhD project of Kyle Reuber completed in 2017 used ION transects to better delineate the main elements of volcanic type rifted margins in Uruguay and its conjugate margin in Namibia. The now-completed PhD study of Patrick Loureiro used gravity modeling to compare the Sao Paulo plateau area of southeastern Brazil with is conjugate in Angola. In northwestern Africa, Beatriz Serrano is starting a PhD study using gravity data and an extensive grid of 2D seismic lines tied to wells in the Senengal-Guinea-Bissau-Guinea Plateau area and on the equatorial Atlantic margin of Brazil. Eric Lunn is using gravity modeling to study upper plate-lower plate relationships across the Romanche fracture zone. A central theme of all of these studies is understanding both the asymmetries of the early continental rifting and the role of massive volcanics (“seaward-dipping reflectors”) in the development of the rifting and passive margin phases.

15) Petroleum geochemistry studies in Jamaica. In Phase V, UiS plans field work in

Jamaica to sample some natural seeps and examine material from cores stored by the Petroleum Corporation of Jamaica. Previous workers have reported that Jamaican oils have affinities with Jurassic sources of the Gulf of Mexico which is not supported of the exotic Caribbean plate model - but this has been attributed by others claiming that the sampling was not done correctly, so further study of the origin of the Jamaican oils is warranted.

Cost of CBTH Phase V

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 V 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 2017. If sponsor payments are not received by August 31, 2017, we will consider these companies "late buy-ins" who will be charged 150% of the annual $60,000 US rate ($90,000).

References Cited

Alvarez, T., 2014, The Southeastern Caribbean Subduction to Strike-Slip Transition one: A Study of The Effects of Lithospheric Structures and Overlying Clastic Basin Evolution and Fill: PhD dissertation, University of Houston, 270 p.

Bernal-Olaya, R. 2014, Tectonostratigraphic evolution of the Sinu accretionary prism and Lower Magdalena forearc basin formed above a shallow-dipping subduction zone, Caribbean margin of Colombia: PhD dissertation, University of Houston, 237 p.

Bernal-Olaya, R., Mann, P., and Escalona, A., 2015a, Cenozoic tectonostratigraphic evolution of the Lower Magdalena Basin, Colombia: An example of an underfilled to overfilled, forearc basin, in C. Bartolini and P. Mann, eds., Petroleum geology and potential of the Colombian Caribbean Margin: AAPG Memoir 108, p. 345–398.

Bernal-Olaya, R., Mann, P., and Vargas, C. A., 2015b, Earthquake tomography, seismic reflection, and gravity evidence for a shallowly-dipping subduction zone beneath the Caribbean margin of Colombia, in C. Bartolini and P. Mann, eds., Petroleum geology and potential of the Colombian Caribbean Margin: AAPG Memoir 108, p. 247–270.

Bernal-Olaya, R., Sanchez, J., Mann, P., and Murphy, M., 2015c, Along-strike crustal thickness variations of the subducting Caribbean plate produces two distinctive styles of thrusting in the offshore South Caribbean deformed belt, Colombia, in C. Bartolini and P. Mann, eds., Petroleum Geology and Potential of the Colombian Caribbean Margin: AAPG Memoir 108, p. 295–322.

Carvajal, L.C., 2017, Hydrocarbon prospectivity of the Nicaraguan Rise and Colombia basin, Western Caribbean Sea: PhD dissertation, University of Houston, 387 p.

Carvajal, L.C. and Mann, P., 2017, Western Caribbean intraplate deformation, 2: Defining a continuous and active microplate boundary along the San Andres rift and Hess escarpment, in P. Mann, ed., Geologic and geophysical synthesis of the Nicaraguan Rise and western Caribbean: A framework for understanding its petroleum potential: AAPG Bulletin Special Issue, in preparation.

Carvajal-Arenas, L. C., Torrado, L., and Mann, P., 2015, Early and Late Eocene/Oligo-Miocene(!) petroleum system in the Nicaraguan Rise: Insight from basin and 3D petroleum system modeling, in C. Bartolini and P. Mann, eds., Petroleum geology and potential of the Colombian Caribbean Margin: AAPG Memoir 108, p. 615–646.

Case, J. E. and Holcombe, T. L.,1980, Geologic-tectonic map of the Caribbean region US Geological Survey Miscellaneous Investigations Series Map I- 1100, scale 1:2 500 000.

Escalona A., Norton I., 2010, Paleotectonic evolution of the Caribbean, CBTH Annual meeting: Institute for Geophysics, Austin, Texas.

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.

Escalona, A., W. Fjeldskaar, and I. Grunnaleite, 2011, Basin modeling across the emergent Lesser Antilles island arc, southeastern Caribbean: Impact on petroleum systems: First Break, v. 29, p. 23-34.

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 OpenFile Report 97-470-K, 1 sheet, CD-ROM, http://pubs.usgs.gov/of/1997/ofr-97-470/OF97- 470K/

Gomez, S., Mann, P., and Bird, D., 2017, Deep crustal structure and tectonic origin of the Tobago-Barbados ridge, Lesser Antilles arc, submitted to Interpretation.

Ismael, M., 2014, Tectonostratigraphic stages in the Mesozoic opening and subsidence of the Gulf of Mexico basin based on deep-penetration seismic reflection data in the salt-free eastern part of the basin : MS thesis, University of Houston, 103 p.

Loureiro, P., 2017, Early Cretaceous tectonostratigraphic evolution of rift and sag basins of the Campos and Santos basins, southeastern Brazil, using potential fields, seismic reflection, and well data: PhD dissertation, University of Houston, expected August 2017.

Kouassi, M., 2017, Paleozoic and Mesozoic evolution of the central Pangea region prior

to the opening of the Gulf of Mexico: Evidence from compilation of U-Pb detrital zircons ages: BS senior report, University of Houston, 48 p.

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

Mann, P., and Roberson, R., 2017, Historical perspective after one century of petroleum exploration in the western Caribbean and Central America, in P. Mann, ed., Geologic and geophysical synthesis of the Nicaraguan Rise and western Caribbean: A framework for understanding its petroleum potential: AAPG Bulletin Special Issue, in preparation.

Mata, O., 2014, Cenozoic Structure, Stratigraphy, and Paleogeography of the Lower Magdalena Basin, Colombia: MS thesis, University of Houston, 177 p.

Mejia-Hernandez, M.C., 2015, Sequence of folding and thrusting of the Piedemonte oil and gas filed, eastern foothills of the Colombian Cordillera Oriental: constraints from integration of balanced cross sections and thermal maturation data: MSc thesis, University of Houston, 73 p.

Nguyen, L., and Mann, 2016, Gravity and magnetic constraints on the Jurassic opening of the oceanic Gulf of Mexico and the location and tectonic history of the Western Main transform fault along the eastern continental margin of Mexico, Interpretation, v. 4, n. 1, p. SC23-SC33.

Ott, B., 2015, Cretaceous-Cenozoic tectonostratigraphic evolution of the Nicaraguan Rise based on seismic reflection, wells, and potential fields data: PhD dissertation, University of Houston, 262 p.

Ott, B. and Mann, P., 2017, Tectonostratigraphic and petroleum evolution of Jamaica and the offshore Walton basin based on integration of seismic reflection and well data, in P. Mann, ed., Geologic and geophysical synthesis of the Nicaraguan Rise and western Caribbean: A framework for understanding its petroleum potential: AAPG Bulletin Special Issue, in preparation.

Ott, B., Mann, P., Carvajal, L.C., 2017, Western Caribbean intraplate deformation, 1: Defining a continuous and active microplate boundary near Jamaica and across the Upper Nicaraguan Rise, in P. Mann, ed., Geologic and geophysical synthesis of the Nicaraguan Rise and western Caribbean: A framework for understanding its petroleum potential: AAPG Bulletin Special Issue, in preparation.

Ott, B., Mann, P., Sanchez, J., Carvajal, L.C., 2017, Crustal provinces and tectonic history of the Nicaraguan Rise, Caribbean Sea, based on integration of gravity, refraction, seismic reflection, and well data, in P. Mann, ed., Geologic and geophysical synthesis of the Nicaraguan Rise and western Caribbean: A framework for understanding its petroleum potential: AAPG Bulletin Special

Issue, in preparation.

Sanchez, C.J., 2015, Comparison of Late Cretaceous-Cenozoic deformation and basin formation along the northwestern Caribbean plate boundary on the Honduran borderlands-Nicaraguan Rise and southeastern Caribbean plate boundary in Colombia: PhD dissertation, University of Houston, 229 p.

Sanchez, J. and Mann, P., 2015, Structure and basin analysis of the Cesar-Rancheria basin, northwestern South America: Implications for tectonic events and petroleum systems, in C. Bartolini and P. Mann, eds., Petroleum geology and potential of the Colombian Caribbean Margin: AAPG Memoir 108, p. 431–470.

Sanchez, J., Mann, P., and Emmet, P.A., 2015, Late Cretaceous-Cenozoic tectonic transition from collision to transtension, Honduran Borderlands and Nicaraguan Rise, NW Caribbean Plate boundary, in From: Nemcok, M., Rybar, S., Sinha, S. T., Hermeston, S. A. & Ledvenyiova, L. (eds) Transform Margins: Development, Controls and Petroleum Systems. Geological Society, London Special Publications, 431, Geological Society, London, Special Publications, v. 431, , http://doi.org/10.1144/SP431.3

Reuber, K., 2017, Crustal structure and Mesozoic tectonic evolution of conjugate volcanic passive margins of the south-central and South Atlantic Oceans: PhD dissertation, University of Houston, 207 p.

Sandwell, D. T., Müller, R. D., Smith, W. H. F., Garcia, E. and Francis, R., 2014, New global marine gravity model from Cryo-Sat-2 and jason-1 reveals buried tectonic structure, Science, Vol. 346, 6205, pp. 65-67, doi: 10.1126/science.1258213.

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, v, 103, n. 3., p. 2025-2046, June, 2013, doi: 10.1785/0120120328

Xie, X., P. Mann, and A. Escalona, 2010, Regional provenance study of Eocene clastic sedimentary rocks within the South America-Caribbean plate boundary zone using detrital zircon geochronology: Earth and Planetary Science Letters, v. 291, p. 159-171.

Xiangyang, X. and P. Mann, 2014, U–Pb detrital zircon age patterns of Cenozoic clastic sedimentary rocks in Trinidad and its implications, Sedimentary Geology, v. 307, p. 7-16.

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

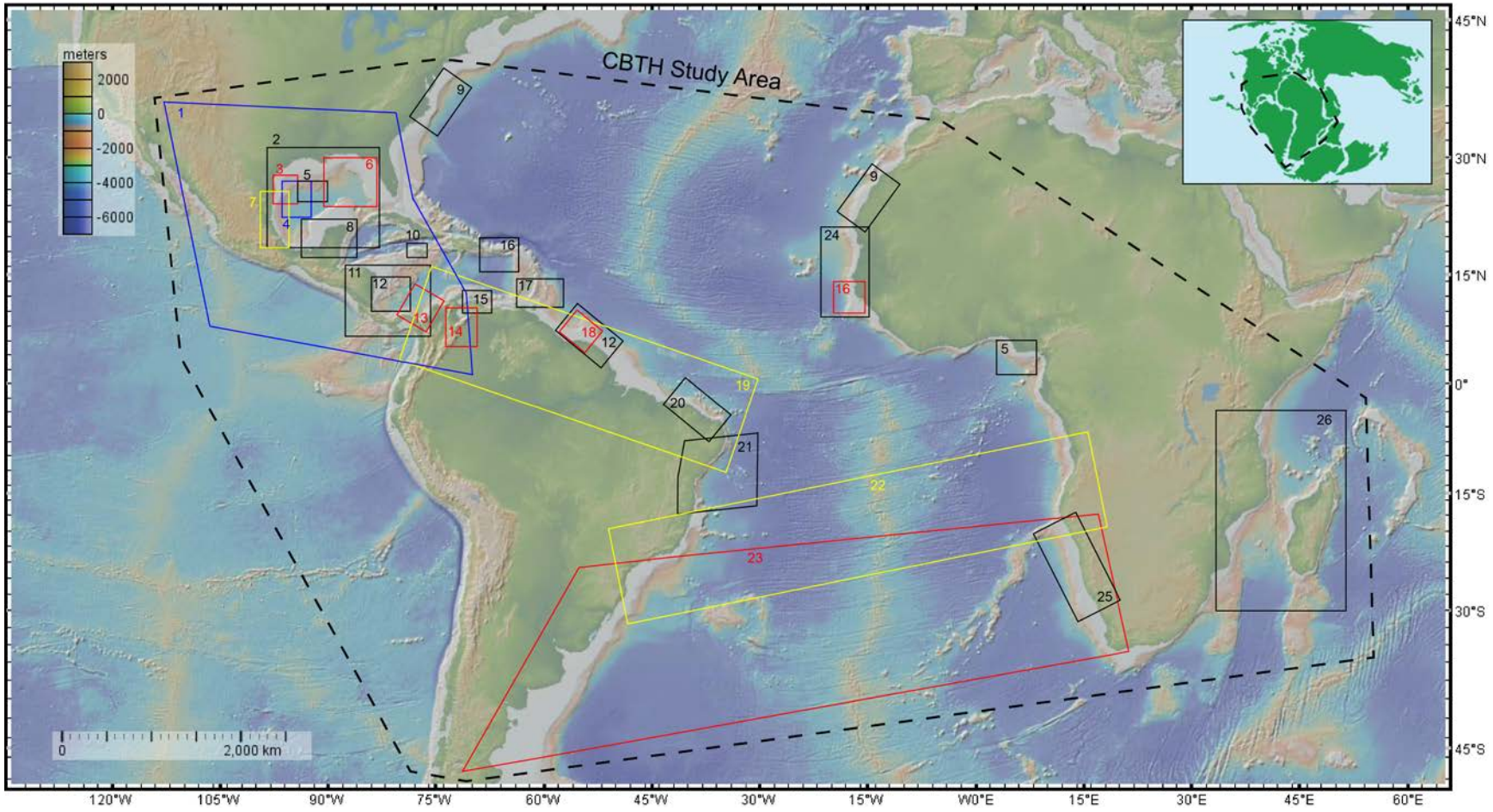
CBTH Study Area
meters
2000
0
-2000
-4000
-6000
0
2,000 km
45°N
30°N
15°N
0°
15°S
30°S
45°S
120°W
105°W
90°W
75°W
60°W
45°W
30°W
15°W
W0°E
15°E
30°E
45°E
60°E

Figure 1. CBTH Phase V proposed study area. Numbers correspond to Phase IV, Year 3 student study areas:

1) M. Kouassi, BS UH, Detrital zircon compilation
2) M. Almatrood, BS UH, GOM well subsidence phases
3) M. Bugti, PhD UH, NW GOM structure, stratigraphy
4) D. Lankford-Bravo, BS UH, Mexican Ridges-Perdido structure
5) R. Ajala, BS UH, Gravity modeling Niger, Mississippi deltas
6) P. Lin, PhD UH, SE GOM basement, structure, stratigraphy
7) A. Gomez, PhD UH, Mexican Ridges-Perdido structure, stratigraphy
8) A. Steier, MS UH, Norphlet reservoirs, N. Yucatan, GOM
9) E. Stibbe, BS UH, Eastern USA-NW Africa conjugate reconstructions
10) A. Escalona, Co-P.I., UiS, Jamaica seeps
11) L.C. Carvajal, PhD, UH, Basin modeling, Colombian basin
12) L. Torrado, PhD, UH, Amazon cone structure, stratigraphy
13) S. Leslie, PhD, UH, Structure, basin modeling, South Caribbean deformed belt
14) A. Escalona, Co-P.I., UiS, Andes flexure modelling
15) J. Blanco, PhD, UH, Structure NW offshore Venezuela
16) S. Martinez, BS, UH, Tectonic geomorphology, Puerto Rico
17) S. Gomez, PhD, UH, Barbados prism structure, stratigraphy
18) O. Zavala, BS, UH, Demerara-NW Africa conjugate reconstructions
19) P. Carr, BS, UH, Compilation of OAE events in well data, NE South America
20) E. Lunn, PhD, UH, Ceara-Barreirinhas basins structure, stratigraphy
21) L. Zhang, BS, UH, Fission track constraints on SE Brazil margin
22) P. Loureiro, PhD UH, Santos-Campos gravity, structure, stratigraphy
23) K. Reuber, PhD, UH, South Atlantic volcanic conjugate margins
24) B. Serrano-Suarez, PhD, NW Africa gravity, structure, stratigraphy
25) J. Kenning, PhD, Namibia stratigraphy, basin modeling
26) M. Copley, BS, Mozambique basin gravity, structure