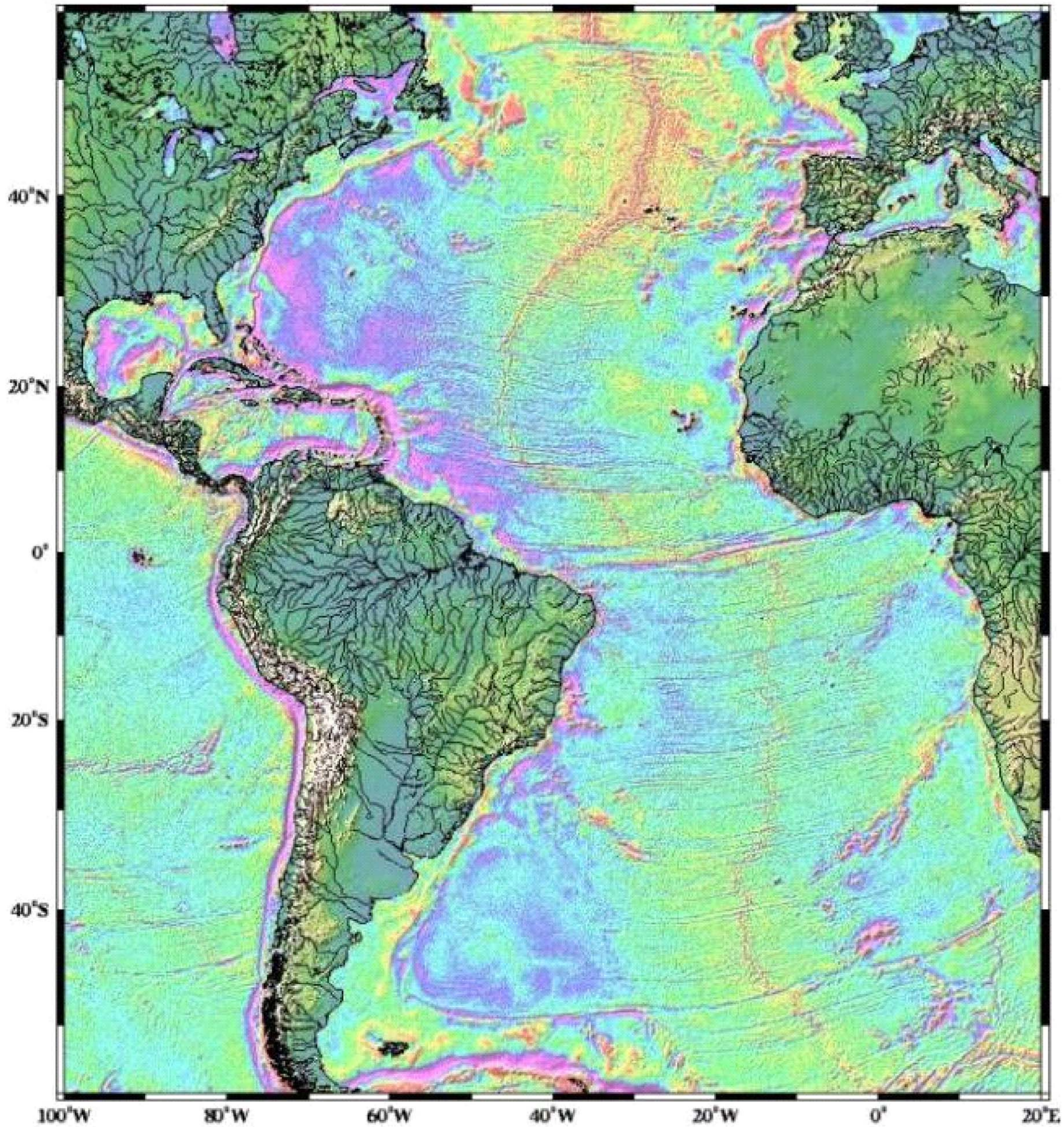


34th Annual GCSSEPM Foundation Perkins-Rosen Research Conference
December 13—16, 2015, Houston, Texas

Petroleum Systems in "Rift" Basins

Editors: Paul J. Post, James L. Coleman, Jr., Norman C. Rosen, David E. Brown, Tina Roberts-Ashby, Peter Kahn, and Mark Rowan

Program and Abstracts

EXCELLENCE • EDUCATION • RESEARCH • 1981

GCS SEPM FOUNDATION

Petroleum Systems in “Rift” Basins

34th Annual Gulf Coast Section SEPM Foundation
Perkins-Rosen Research Conference

2015

Program and Abstracts

OMNI Houston Westside
Houston, Texas
December 13–16, 2015

Edited by

Paul J. Post
James L. Coleman, Jr.
Norman C. Rosen
David E. Brown
Tina Roberts-Ashby
Peter Kahn
Mark Rowan

Published December 2015

The cost of this conference has been subsidized by generous grants from
Hess Corporation, Nexen, and BP.

Foreword

The 34th GCSSEPM Foundation Bob F. Perkins Research Conference on Petroleum Systems in "Rift" Basins grew out of a joint effort by the U. S. Geological Survey (USGS) and the Bureau of Ocean Energy Management (BOEM) to bring together knowledgeable geologists, geophysicists, and resource managers from federal and state agencies at a series of workshops to examine the oil and natural gas resource potential of the Mesozoic synrift basins in the Atlantic coastal states and the adjacent offshore areas. These workshops were convened in preparation for a proposed Outer Continental Shelf (OCS) lease sale scheduled for 2011 in the Mid-Atlantic planning area, focused on the OCS area offshore Virginia that was announced as part of the BOEM 2007–2012 Five-Year Leasing Plan in February, 2006 (BOEM, 2006). The area of the draft proposed program initially included the previously identified Norfolk Mesozoic rift basin, which was later removed at the request of the governor of Virginia to create a 50-mile shore buffer from future exploration activities (BOEM, 2008, 2010).

The Atlantic OCS planning areas have not been the focus of seismic acquisition since 1988, or drilling since 1984 (BOEM, 2012). Consequently, at the time of the announcement in 2006, very few of the federal or state geoscientists and resource managers working the onshore, adjacent state waters, or Atlantic OCS had personal experience in the processes necessary to address the scientific requirements for successful oil and gas exploration in these frontier areas. In addition, in the 24 years since the last US Atlantic OCS drilling, new exploration activity in the offshore Atlantic margin basins of Africa and South America had resulted in amazingly prolific oil and gas discoveries—potential analogs that were factored into new Atlantic OCS petroleum resource assessments (Post *et al.*, 2012; BOEM, 2012, 2014).

Consequently, beginning in 2008, the USGS sponsored three regional workshops to review the known geological concepts and available data of the sedimentary basins in the Atlantic coastal states and adjacent offshore areas. The first two workshops (May, 2008 and March, 2009) were hosted by the Virginia Department of Mines, Minerals, and Energy at their offices in Charlottesville, VA, and addressed the energy resource potential of the Mid-Atlantic (NC, VA, MD, and DE) and South Atlantic (VA, NC, SC, and FL), respectively (Lassetter, 2009). The third workshop (October, 2010) was hosted by the New Jersey Geological Survey at their offices in Trenton, NJ, and addressed the energy resource potential of the North Atlantic area (DE, PA, NJ, CT, MA, and ME). The USGS used the results from these meetings and the contacts established to begin its oil and natural gas resource assessment of the Mesozoic synrift basins of the Atlantic coastal states and state waters completed in late 2011 (Milici *et al.*, 2012; Coleman *et al.*, 2015, this volume).

In progressively reviewing the current data on petroleum systems in rift settings, we recognized that extensional and transtensional "rift" and overlying/related sag basins have been targeted by petroleum explorationists for nearly 200 years. These basins are "disproportionately rich," containing ~30% of all "giant" (>500 MMBOE) fields (Mann *et al.*, 2003), but frustrating and confounding to explorationists and developers because each is a unique geological entity; yet all are variations on a common theme (Lambiase, 1994).

Successful "rift" and overlying/related sag basin analogs are notoriously unreliable as analogs. Basins having apparently identical petroleum system elements and processes as productive basins often are unproductive. Obviously, this is neither a structural "problem" to be worked out, nor a sequence stratigraphic or paleoclimatological issue, and it apparently is not as simple as "just a timing 'thing'."

As each of these basins is drilled and examined, explorationists and developers continue to be confounded. In some of these basins, discoveries have been made early in the first exploration cycle, while decades pass before discoveries are made in other, very similar, often connected, on-trend basins, if they occur at all. Furthermore, advances in exploration, drilling, completion, and development concepts and technology have resulted in previously nonproductive basins being reexamined.

One decision coming out of these workshops was to convene a special session at an upcoming professional society venue to review with a larger and technically diverse audience the recent results of USGS and BOEM resource assessments of rift basins in the context of historic and ongoing exploration and production in other rift basins. As a result for this conference, 33 authors have combined to write 39 papers that have resulted in 36 oral presentations on the petroleum systems and their settings in rift basins around the world. These include examinations of very old (Cambrian) to very young (Miocene-Holocene) rift systems in addition to the world-class oil and gas accumulations in the presalt Mesozoic synrift basins of the South Atlantic.

We believe that a systematic petroleum systems comparative analysis approach will help identify a key combination of elements and processes that result in an effective and exploitable petroleum system in these basins and settings. This approach may help uncover both new discoveries in currently nonproductive basins and trends that can be developed with the insights from this conference and new technologies.

Special thanks are extended to Bill Bosworth, Harry Doust, David Houseknecht, Christopher Jackson, Peter Kahn, Webster Mohriak, Michal Nemčok, Mark Rowan, and Gabor Tari, who formed the program committee. Without their help providing and soliciting papers and presentations, we would never have come close to realizing the fulfilment of our vision for this conference, its volume and program. Tina Roberts-Ashby contributed substantially with her reviews of the many submitted papers from USGS staff. We also thank Dr. Norman Rosen for his continued dedication and service to the GCSSEPM Foundation Perkins Research Conferences and to the profession as a whole. In closing, we also thank our corporate sponsors who generously supported our conference.

James L. Coleman, Jr. (U.S. Geological Survey)
Paul J. Post (U. S. Bureau of Ocean Energy Management)
David E. Brown (Canada-Nova Scotia Offshore Petroleum Board)

References

BOEM, 2006, Draft proposed program Outer Continental Shelf oil and gas leasing program 2007-2012 (also available at http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Five-Year-Program/DPP2007-2012-pdf.aspx) Viewed 9/23/2015.

BOEM, 2008, Virginia lease sale 220 information, (also available at http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Regional-Leasing/Gulf-of-Mexico-Region/Lease-Sales/220/Virginia-Lease-Sale-220-Information.aspx). Viewed 9/23/2015.

BOEM, 2010, Preliminary revised program Outer Continental Shelf oil and gas leasing program 2007-2012 (also available at https://www.doi.gov/whatwedo/energy/ocs/upload/PRP2007-2012.pdf). Viewed 9/23/2015.

BOEM, 2012, Assessment of undiscovered technically recoverable oil and gas resources of the Atlantic outer continental shelf 2011 as of January 1, 2009: BOEM Technical Report 2012-016, 40 p. (also available at http://www.boem.gov/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Resource_Evaluation/Resource_Assessment/BOEM-2012-016%5B1%5D.pdf. Viewed 9/26/2015.

BOEM, 2014, Assessment of undiscovered technically recoverable oil and gas resources of the Atlantic outer continental shelf, 2014 update: BOEM Fact Sheet RED-2014-01, 3 p. (also available at http://www.boem.gov/Assessment-of-Oil-and-Gas-Resources-2014-Update/). Viewed 9/262015.

Coleman, J. L., Jr., Milici, R. C., and Post, P. J., 2015 (this volume), Assessment of the oil and natural Gas potential of the east coast Mesozoic synrift basins, onshore and state waters of the United States.

Lambiase, J. J., editor, 1994, Hydrocarbon habitat in rift basins: Geological Society (London) Special Publication 80, 371 p.

Lassetter, W. L., compiler, 2009, Proceedings of the 2009 southeastern U.S. Mesozoic basins energy resources workshop, March 19-20, 2009, Charlottesville, Virginia: Virginia Department of Mines, Minerals and Energy Division of Geology and Minerals Resources Open File Report 09-03, various pages (also available at https://www.dmme.virginia.gov/commercedocs/OFR_09_03.pdf). Viewed 9/2615.

Mann, P., L. Gahagan, and M. B. Gordon, 2003, Tectonic setting of the world's giant oil and gas fields: American Association of Petroleum Geologists Memoir 78, p. 15-105.

Milici, R.C., J.L. Coleman, E.L. Rowan, T.A. Cook, R.R. Charpentier, M.A. Kirschbaum, T.R. Klett, R.M. Pollastro, and C.J. Schenk, 2012, Assessment of undiscovered oil and gas resources of the east coast Mesozoic basins of the Piedmont, Blue Ridge thrust belt, Atlantic Coastal Plain, and New England Provinces, 2011, U.S. Geological Survey Fact Sheet 2012-3075, 2 p. (Also available at http://pubs.usgs.gov/fs/2012/3075/) Viewed 9/23/15.

Post P.J., E.T. Elliott, R.J. Klazynski, E.S. Klocek, T.M. Decort, T.J. Riches, Jr., and K. Li, 2012, US central Atlantic: new plays and petroleum prospectivity, in W.U. Mohriak, A. Danforth, P.J. Post, D.E. Brown, G.C. Tari, M. Nemčok, and S.T. Sinha, eds., Conjugate Divergent Margins, Geological Society, London, Special Publications 369, p. 323-336, First published online February 29, 2012, http://dx.doi.org/10.1144/SP369.2, 369.

Tribute to Norm Rosen

With the completion of the 2015 GCSSEPM Foundation Research Conference, Dr. Norman Rosen will be retiring as the Foundation's executive director. Norm stepped in to guide the annual conference in 1999, when Bob Perkins, the founder and initial executive director of the Foundation, died unexpectedly in April of that year. For those of you who remember 1999, that was a year of price and profit challenges in the petroleum industry, not that dissimilar from what is going on in mid-2015. The concerted efforts of Norm and Tucker Hentz resulted in a December GCSSEPM Foundation Research Conference, appropriately named the Bob F. Perkins Research Conference. The event carried that name until 2015, when the GCSSEPM Foundation executive council and trustees voted to rename the current and future meetings the GCSSEPM Foundation Perkins-Rosen Research Conference.

In 1999, Norm picked up the leadership baton and, in the 16 years that followed, he guided a variety of editors and technical committees down the pathway of maintaining a high quality, technically relevant, and topically informative program of oral and poster presentations, and the timely publication of the proceedings volume to coincide with the meeting or a few months afterwards. Norm shepherded the transition from a bound, hardcopy volume to a CD/DVD-ROM compilation, which allowed for significant additions of large-format illustrations and data tables. Norm also led the Gulf Coast Section in the establishment of a website for which he was presented with a Distinguished Service Award in 1997. His continued contributions to the section resulted in his Honorary Membership Award in 2004.

We see Norm's smiling face at each research conference, but we do not see the behind-the-scenes meetings he has with Gail Bergan at Bergan *et al.*, Inc., who prepares the abstract booklet for conference attendees and the high-quality CD/DVD-ROMs that contain the published manuscripts from the presenters, as well as our GCSSEPM Web site. He also works with the GCSSEPM membership, officers, trustees, and Gail to produce a regular newsletter three times a year.

Norm reestablished funding for student research in Gulf Coast-related topics (the Ed Picou Fellowship Grant; http://www.gcssepm.org/scholarships/picou_grant.htm) and recognition for contributions in sedimentary geology with an emphasis on the Gulf of Mexico basin (the Doris M. Curtis Medal; http://www.gcssepm.org/about/curtis_medal.htm). In 1994, when Paul Weimer suggested participation by international experts in fields of interest to Gulf Coast geoscientists, Bob Perkins was supportive. Norm has continued this legacy and today the Foundation's research conference has an international following and reputation for displaying and discussing new and innovative science from all aspects of geology, especially those that relate directly to the Gulf of Mexico.

Born in Cleveland, Ohio, in 1941, Norm was the third son of a pharmacist father and a bright, self-taught linguist mother. By the time he started high school, he was already helping other people, as a track manager and a stagehand in the drama club. Also active in the Boy Scouts, he attended a career conference about geology at what is now Case Western Reserve University. The professor made geology sound so bad as a profession that it made Norm curious as to what he was hiding, and showed how early Norm displayed the inquisitive nature that has served many of us so well in our careers. He ultimately decided that geology was something he wanted to learn about and pursue, which he did by leaving Cleveland and enrolling at The Ohio State University in Columbus.

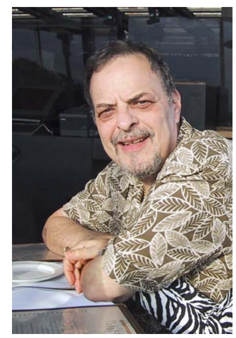
Norm received his B.Sc. in 1963 and his M.Sc. in 1964 from The Ohio State University. While there, he met and married the love of his life, Rashel, in 1964. They moved south to Louisiana and together pursued doctorates, receiving their PhDs from the Louisiana State University in 1967 (Rashel) and 1968 (Norm). As an "experienced and kind uncle" for the LSU geology graduate students, Norm organized and led study groups. In this *ex officio* position, Norm was always there to help with difficult problems and adjudicate conflicts. These "people skills and leadership traits" came naturally to Norm and has served him well throughout his professional life.

Upon graduation, he accepted a position as a geologist and editor at the Geological Survey of Iran, at that time a mission with the United Nations. And thus began the professional career of one of the best editors to which our science has ever been exposed. Norm joined Texaco in New Orleans in 1969 as an exploration geologist to develop a petrographic laboratory. During the next five years, he examined cuttings and cores from Miocene to Paleozoic strata, sat wells from the Louisiana swamps to the Florida Panhandle, taught a carbonate course, led a delta field trip, developed prospects, and performed regional studies.

In 1974, he went to work for Deminex Iran Oil Company as Chief Geologist. He spent the next four years leading their exploration team in Iran. The team discovered Jufeyr, a seismically defined structure in southwest Iran, near the Iraqi border with in-place reserves estimated at 2.1 billion barrels of relatively heavy oil, one-fourth of which is estimated to be recoverable.

Returning to the U.S. in 1978, Norm was hired by Tenneco for its Frontier Projects Group. Tenneco had an aggressive exploration program during this time, and Norm worked the U.S. Atlantic Margin from the Georges Bank basin on the north to the Bahamas on the south, the Appalachians, and the Michigan basin. In 1981, he joined Robertson Research (U.S.) as vice president. He moved to Sohio (now BP) in 1983. He worked on eastern Gulf of Mexico lease sales, served as Division Geologist, and guided regional studies. Becoming a consultant in 1992, Norm worked with, and for, multiple companies. He organized and prepared regional studies in Colombia, Poland, South Louisiana, South Texas, and the offshore Gulf of Mexico.

Norm first volunteered with the GCSSEPM as assistant editor for its transactions volume in 1982. He later served as editor for the 1991 and 1993 transactions; and in 1991 wrote the first set of guidelines for transaction articles. Also in 1991, Norm served as Poster Chairman for the GCSSEPM Research Foundation Symposium on Coastal Processes. In 1992, he was program co-chair for the GCSSEPM Foundation research conference on *Mesozoic and Early Cenozoic Development of the Gulf of Mexico and Caribbean Region: A Context for Hydrocarbon Exploration*. In 1998, he served as co-chair for the GCSSEPM Session *Gulf of Mexico Basin: Sequences and Hydrocarbons* at the GCAGS. In 1995, Norm designed and set up the Gulf Coast Section/Foundation Web site and served as Web master until 2000. In 1998, he was elected treasurer of the Section and served in that position until early 1999.



Since 1999, Norm has been the final editor and arbitrator for all papers published as part of the GCSSEPM Bob F. Perkins Research Conference proceedings, and all of us who have submitted manuscripts have benefitted from his editing, which has made many of us appear to be much better writers than we are. He has helped make the Foundation financially viable, reestablished a fellowship program, worked with other groups to jointly sponsor meetings, and done much of the gritty behind-the-scenes "elf work," without which the GCSSEPM conferences could not only be successful, but held.

Without Norm's dedication, efforts, and persistence, what are now known as the GCSSEPM Foundation Perkins-Rosen Research conferences, which have benefited so many of us personally and professionally, would have ceased.

Norm, we all thank you.

James L. Coleman
Paul J. Post
David E. Brown

with significant contributions from

Rashel N. Rosen,
Paul Weimer,
Harry H. Roberts,
Edward B. Picou, Jr.,
and John M. Armentrout

Petroleum Systems in "Rift" Basins

34th Annual Gulf Coast Section SEPM Foundation Perkins-Rosen Research Conference

2015

Sunday, December 13

4:00–6:00 p.m. Registration and refreshments (by Texas Ballroom: Most activities, including all talks and poster sessions, will take place in the Texas Ballroom. Registration will be by the Ballroom entrance.)

Monday, December 14

7:00 a.m. **Continuous registration (coffee will be available)**
7:45 a.m. Welcome remarks, Tony D'Agostino (Chairman of the Board of Trustees, GCSSEPM Foundation)
8:00 a.m. Introduction to the Conference, James Coleman (Conference Co-Convenor)

Session 1: Eastern United States Late Triassic–Early Jurassic Rift Basins

8:15 a.m. Introduction: Paul J. Post, James L. Coleman, Jr., Session Co-Chairs

Session 2: Continuation of Eastern North American Mesozoic, Paleozoic, and Proterozoic Rifts

Session 3: Continuation of Eastern North American Rifts and Global Rift Systems

Tuesday, December 15

7:15 a.m. **Continuous registration (coffee will be available)**

Session 4: Rift Petroleum Systems and Evolution

8:00 a.m. Introduction: Harry Doust and Suzanne E. Beglinger, Session Co-Chairs

9:35—9:55 a.m. Coffee Break

Session 5: Transform and Transtensional Rift Systems–1

10:00 a.m. Introduction: Michal Nemčok and Donald Gautier, Session Co-Chairs

12:15—1:25 p.m.Lunch

Session 6: Transform and Transtensional Rift Systems–2

1:25 p.m. Introduction: William Bosworth and Olu S. Adegoke, Session Co-Chairs

2:30 p.m. *Jurassic and Cretaceous Tectonic Evolution of the Demerara Plateau—Implications for South Atlantic Opening* ...23
Casey, Katya; Krueger, Ana; and Norton, Ian

3:00 p.m. Coffee Break

Session 7: Other African Rifts

3:25 p.m. Introduction: William Bosworth and Olu S. Adegoke, Session Co-Chairs

3:30 p.m. *Jurassic Rift Initiation Source Rock in the Western Desert, Egypt—Relevance to Exploration in other Continental Rift Systems* ...24
Bosworth, William; Abrams, Michael; Drummond, Michael; and Thompson, Melissa

4:00 p.m. *Nigeria's Frontier Basins—Unrealized Rift System Hydrocarbon Potential* ...25
Adegoke, O. S.; Ladipo, K. O.; Bako, M. D.; and Umaru, A. F. M.

4:30 p.m. *Searching High and Low: Correlating Shallow (Drift Phase) and Deep (Rift Phase) Structural Trends with Surface and Subsurface Geochemistry in the Niger Delta, West Africa* ...26
Dickson, William; and Schiefelbein, Craig

5:15—8:00 p.m. Refreshments and poster sessions (meet the authors). Remove posters at 8:00 p.m.

Wednesday, December 16

7:30 a.m. Continuous registration (coffee will be available)

Session 8: Arctic Rift Basins

8:00 a.m. Introduction: David Houseknecht and Brian Horn, Session Co-Chairs

8:05 a.m. *Late Jurassic–Early Cretaceous Inversion of Rift Structures, and Linkage of Petroleum System Elements across Postrift Unconformity, U.S. Chukchi Shelf, Arctic Alaska* ...27
Houseknecht, David W.; and Connors, Christopher D.

8:35 a.m. *Petroleum Systems of Frontier Siberian Arctic Basins* ...28
Horn, Brian W.; Granath, James W.; McDonough, K. J.; and Sterne, Edward J.

9:05 a.m. *Mississippian–Mesozoic Evolution of the Dinkum Graben System, Central and Eastern Beaufort Shelf of Alaska* ...29
Houseknecht, David W.; and Connors, Christopher D.

9:35 a.m. Coffee Break

Session 9: South Atlantic Rift Basins–1

Session 10: South Atlantic Rift Basins–2

Other Included Papers

As a result of changes in corporate policies, the authors of the following accepted papers were not granted permission to attend the conference. The papers are included in our Proceedings.

Posters Only

Standby Presentations

Because of the number of authors who have not been able to attend the conference, we have arranged for possible replacement talks. Abstracts of these potential presentations are listed below and included in our Proceedings.

GCSSEPM Foundation

Contributors to the GCSSEPM Foundation

Sponsorship Categories

Please accept an invitation from the GCSSEPM Section and Foundation to support Geological and Geophysical Staff and Graduate Student Education in Advanced Applications of Geological Research to Practical Problems of Exploration, Production, and Development Geology.

The GCSSEPM Foundation is *not* part of the SEPM Foundation. In order to keep our conferences priced at a low level and to provide funding for university staff projects and graduate scholarships, we must have industry support. The GCSSEPM Foundation provides several categories of sponsorship. In addition, you may specify, if you wish, that your donation be applied to Staff support, Graduate support, or support of our Conferences. Please take a moment and review our sponsor categories for 2015, as well as our current and past sponsors. In addition, we ask that you visit our sponsors' Web sites by clicking on their logo or name. Thank you for your support.

Corporate Sponsorships

Diamond
($15,000 or more)

Platinum
($10,000 to $14,999)

Gold
($6,000 to $9,999)

Silver
($4,000 to $5,999)

Bronze
($2,000 to $3,999)

Patron
($1000 to $1,999)

Individuals & Sole Proprietorships

Diamond
($3,000 or more)

Platinum
($2,000 to $2,999)

Gold
($1,000 to $1,999)

Silver
($500 to $999)

Bronze
($300 to $499)

Patron
($100 to $299)

Sponsor Acknowledgment

For 2015, all sponsors will be prominently acknowledged on a special page inserted in the 2015 and 2016 Program & Abstracts volume, and with placards strategically placed in the registration area of the conference.

Corporate level Diamond sponsors will be acknowledged by having their logo placed in the front matter of the Program & Abstracts volume and are eligible for a free half-page ad in the Section newsletter.

Corporate level Platinum sponsors will be acknowledged by having their logo placed in the front matter of the Program & Abstracts volume and are eligible for a free quarter-page ad in the Section newsletter.

All contributions used for scholarships and/or grants will be given with acknowledgment of source. In addition to the recognition provided to our sponsors in GCSSEPM publications, we proudly provide a link to our sponsors' Web sites. Just click on their logo or name to visit respective GCSSEPM sponsors.

The GCSSEPM Foundation is a 501(c)(3) exempt organization. Contributions to the organization are tax deductible as charitable gifts and contributions. For additional information about making a donation as a sponsor or patron, please contact Dr. Norman C. Rosen, Executive Director, GCSSEPM Foundation, 611 Calle Paula, Solana Beach, CA 92075. Telephone (832) 492-1763, or e-mail at gcssepm1@gcssepm.org.

2015 Sponsors

Sponsorship Category	Corporations	Individuals and Sole Proprietorships
Platinum		Michael Styzen
Gold		Michael J. Nault
Silver	HESS CORPORATION	Tim Bennett Richard Fillon Ed Picou
Bronze	nexen A CNOOC LIMITED COMPANY bp	

2013–2014 Sponsors

Sponsorship Category	Corporations	Individuals and Sole Proprietorships
Diamond	ion → Charged to innovate. Driven to solve.™	
Platinum	HESS CORPORATION	Michael Styzen
Gold		Michael J. Nault (Applied Biostratigraphix) J. Carl Fiduk
Silver	Chevron Human Energy®	Richard Fillon
Bronze	HALLIBURTON Schlumberger	Barbara Radovich

Credits

Design and Digital Publishing by

Bergan et al., inc.

Rockport, Texas
www.bergan.com

Cover Image

The cover image chosen for this year's conference is Figure 1 from Fainstein and Mohriak, which contrasts the regional morphologies of the north and south Atlantic oceans. The North Atlantic is marked by massive volcanism, while the South Atlantic morphology and marginal basins have different features such as autochthonous salt and a prebasalt stratigraphy.

Mesozoic Rift Basins of the U.S. Central Atlantic Offshore: Comparisons with Onshore Basins, Analysis, and Potential Petroleum Prospectivity

Post, Paul J.
Bureau of Ocean Energy Management
1201 Elmwood Park Blvd.
New Orleans, Louisiana 70123
e-mail: paul.post@boem.gov

Coleman, James L., Jr.
U.S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214

Abstract

Limited exploratory drilling based on relatively sparse seismic data has occurred since at least 1890 in onshore Late Triassic–Early Jurassic rift basins of the eastern United States (U.S.). Although rich source rocks and thermally generated hydrocarbons have been documented, commercial petroleum accumulations have not been found. Consequently, in 2012 the U.S. Geological Survey (USGS) assessed these basins as having potentially modest volumes of primarily continuous (unconventional) resources.

Using these findings and interpretations, what then is the prospectivity of similar age undrilled rift basins in the offshore of the U.S. Central Atlantic? Are there any indications of differences between the offshore and onshore basins in the apparent mode of formation, structural style, amount of inversion, *etc*., documented, or suggested by seismic data in these undrilled offshore basins? What do we know, and what can we speculate regarding petroleum system elements and processes in these unexplored basins?

Seismic data interpretation suggests most offshore rift basins are generally similar to the Late Triassic–Early Jurassic rift basins onshore. The amount of eroded synrift strata predicted by geohistory modeling in the seismically defined Norfolk basin, offshore Virginia, is similar to that of onshore basins. However, seismic data interpretation also shows differences among some of the offshore basins; *e.g.*, a rift system northwest of the Yarmouth arch in the northern Georges Bank basin, offshore New England, appears to have less synrift section eroded than most basins in the U.S. Central Atlantic and contains inversion features that appear seismically similar to productive structures found offshore Indonesia.

Assessment of the Oil and Natural Gas Potential of the East Coast Mesozoic Synrift Basins, Onshore and State Waters of the United States

Coleman, James L., Jr.
U. S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214
e-mail: jlcoleman@usgs.gov

Milici, Robert C.
U. S. Geological Survey
12201 Sunrise Valley Drive, MS 956
Reston, Virginia 20192

Post, Paul J.
U. S. Department of Interior
Bureau of Ocean Energy Management
Office of Resource Evaluation
1201 Elmwood Park
New Orleans, Louisiana 70123

Abstract

Immediately prior to the opening of the Atlantic Ocean in the Mesozoic Era, numerous extensional and transtensional basins developed along the eastern margin of North America from Florida to Canada and from the Appalachian Piedmont eastward to the edge of the present-day continental shelf. Using a petroleum system-based methodology, the U.S. Geological Survey examined 13 onshore Mesozoic synrift basins and estimated a mean undiscovered natural gas resource of 3.86 trillion cubic feet (TCF; 109 billion cubic meters, BCM) of gas and a mean undiscovered natural gas liquids resource of 135 million barrels (MMBNGL; 21.5 million cubic meters, MMCM) in continuous accumulations within five of these basins: the Deep River, Dan River-Danville, Richmond, Taylorsville basins, and the southern part of the Newark Basin. The other eight basins were examined, but not assessed due to insufficient data. An additional 26 basins in the East Coast Mesozoic synrift basins trend were examined here for further insights into the development and evolution of a large, but short-lived set of petroleum systems in Mesozoic synrift basins.

An individual composite total petroleum system is contained within each of the assessed basins. Small amounts of oil and natural gas have been recovered from many of the basins, yet no commercial production has been established. Potential and identified source rocks are present as shale and (or) coal. Potential reservoir rocks are low porosity and permeability sandstones as well as shale, siltstone, coal, and fractured igneous rocks. Examination of data indicates that many of these rift basins have undergone substantial uplift (greater than 4,000 ft, 1200 m), and one or more episodes of water washing have affected oil accumulations. Drilling for conventionally trapped structural and (or) stratigraphic prospects has not been successful. Remaining potential appears to be in continuous (unconventional) gas and natural gas liquid accumulations in a variety of reservoir types.

Geology and Hydrocarbon Potential of the Hartford-Deerfield Basin, Connecticut and Massachusetts

Coleman, James L., Jr.
U.S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214
e-mail: jlcoleman@usgs.gov

Abstract

The Hartford-Deerfield basin, a Late Triassic to Early Jurassic rift basin located in central Connecticut and Massachusetts, is the northernmost basin of the onshore Mesozoic rift basins in the eastern United States. The presence of asphaltic petroleum in outcrops indicates that at least one active petroleum system has existed within the basin. However, to-date oil and gas wells have not been drilled in the basin to test any type of petroleum trap. There are good to excellent quality source rocks (up to 3.8% present day total organic carbon) within the Jurassic East Berlin and Portland formations. While these source rock intervals are fairly extensive and at peak oil to peak gas stages of maturity, individual source rock beds are relatively thin (typically less than 1 m) based solely on outcrop observations. Potential reservoir rocks within the Hartford-Deerfield basin are arkosic conglomerates, pebbly sandstones, and finer grained sandstones, shales, siltstones, and fractured igneous rocks of the Triassic New Haven and Jurassic East Berlin and Portland formations (and possibly other units). Sandstone porosity data from 75 samples range from less than 1% to 21%, with a mean of 5%. Permeability is equally low, except around joints, fractures, and faults. Seals are likely to be unfractured intra-formational shales and tight igneous bodies. Maturation, generation, and expulsion likely occurred during the late synrift period (Early Jurassic) accentuated by an increase in local geothermal gradient, igneous intrusions, and hydrothermal fluid circulation. Migration pathways were likely along syn- and postrift faults and fracture zones. Petroleum resources, if present, are probably unconventional (continuous) accumulations as conventionally accumulated petroleum is likely not present in significant volumes.

Triassic Taylorsville Basin, Virginia, USA: Comparative Thermal History and Organic Facies Within the Early Mesozoic Eastern North American Lacustrine Rift Basin System

Malinconico, MaryAnn Love
Lafayette College
Department of Geology and Environmental Geosciences
Easton, Pennsylvania 18042 USA
e-mail: lovem@lafayette.edu

Abstract

The Late Triassic Taylorsville basin is an onshore continental rift basin along the US Central Atlantic margin. The basin is one member of the early Mesozoic North American rift basin system that trends north–south from the southern US into maritime Canada and has formed within a wide rift zone between Early Triassic collapse of the Appalachian orogen and Jurassic initiation of Atlantic sea floor spreading. The basin, mostly buried under the Cretaceous and younger Atlantic Coastal Plain, is a half-graben having a western border fault. It was a target of conventional exploration drilling >25 years ago, although recent interest is in unconventional gas exploitation.

Difference in kerogen type, basement and advective heat flow, and stratigraphic/hydrologic architecture among the Late Triassic–Early Jurassic rift basins is predictable when paleolatitude, paleoclimate, and position within the late Paleozoic Appalachian orogen are considered. For example, the Taylorsville basin, which formed in a humid equatorial climate, is a gas-prone overfilled-lake-type basin, in contrast to the temperate oil-prone balanced- to underfilled Newark rift-lake basin. Downhole vitrinite reflectance data and maturation modeling show that the Taylorsville basin, along the axis of Appalachian metamorphism/orogenic collapse, experienced long-term elevated heat flow modified by synrift gravity-driven cross-basin fluid flow (40–55°C/km), compared to the off-axis Newark basin (≤35°C/km). Postrift structural inversion resulted in variable (<1 to >3 km) erosion of Taylorville synrift strata. Duration of sedimentation modeling suggests basin synrift sedimentation likely ended before the Jurassic, unlike sister basins to the north with extant earliest Jurassic formations.

Geology and Hydrocarbon Potential of the Richmond Basin, Virginia

Milici, Robert C.
U. S. Geological Survey (retired)
12201 Sunrise Valley Drive, MS 956
Reston, VA 20192
email: rmilici@usgs.gov

Coleman, James L., Jr.
U.S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214
e-mail: jlcoleman@usgs.gov

Abstract

The Richmond basin, a rift basin of Late Triassic to Early Jurassic age in east-central Virginia, produced the first coal mined in the United States in the early 1700s. These Triassic coal beds are thick and gas-rich, and fatal explosions were common during the early history of exploitation. Since 1897, at least 38 confirmed oil, natural gas, and coal tests have been drilled within the basin. Although shows of asphaltic petroleum and natural gas indicate that active petroleum systems existed therein, no economic hydrocarbon accumulations have been discovered to-date.

The Richmond basin has been assessed by the U. S. Geological Survey (USGS) as one composite total petroleum system, in which the hydrocarbon potential of the source beds (both coal and dark shale) and potential reservoirs have been combined into a single continuous tight gas assessment unit within the Chesterfield and Tuckahoe groups (Upper Triassic). Sandstone porosities are generally low (<1 % to 14 %). Thick, dark-colored shales have total organic carbon (TOC) values that range from <1% to 10%, and vitrinite reflectance (%R_o) values that range generally from about 0.3 to 1.1%, which indicates that the submature to super mature shales appear to be the source of the hydrocarbons recovered from some of the boreholes. The stratigraphic combination of these potential source rocks, tight sandstones, and hydrocarbon shows are the basis for the current USGS assessment of the technically recoverable undiscovered hydrocarbon resources of the basin. Mean values for these resources are 211 billion cubic feet of gas (BCFG) and 11 million barrels of natural gas liquids (MMBNGL).

Geology and Hydrocarbon Potential of the Taylorsville Basin, Virginia and Maryland

Milici, Robert C.
U. S. Geological Survey (retired)
12201 Sunrise Valley Drive, MS 956
Reston, VA 20192
email: rmilici@usgs.gov

Coleman, James L., Jr.
U.S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214
e-mail: jlcoleman@usgs.gov

Abstract

The Taylorsville basin is a rift basin of Late Triassic to Early Jurassic age in east-central Virginia and adjacent Maryland. The basin has been a target for oil and gas exploration by Texaco and partners in the 1980s, when six continuous cores were drilled followed by three deeper exploratory wells. Currently, no hydrocarbon production has been established from the basin. Relatively thick sequences of dark-colored shale that may serve both as source rocks and self-sourced reservoirs for hydrocarbons have been encountered near the basin's center. The current USGS assessment concludes that the mean values for undiscovered hydrocarbons in the basin are 1,064 billion cubic feet of gas (BCFG) and 37 million barrels of natural gas liquids (MMBNGL).

The Taylorsville basin contains one composite total petroleum system, in which the hydrocarbon potential of the source beds and potential reservoirs were combined and assessed together as a single continuous gas assessment unit. Potential source rocks within the Taylorsville basin include coals and shales of the Triassic Falling Creek and Port Royal formations. Vitrinite reflectance data indicate that the source rocks range from pre-peak oil to peak gas thermal maturity. Potential reservoir rocks are continuous accumulations in shales, coal beds, and tight sandstones as well as possible conventional accumulations in porous and permeable strata within the Triassic Dowell and King George groups. However, well log based sandstone porosity values are generally low. Potential seals may be present in shale beds or igneous intrusions within the basin or by pore-throat restrictions within the continuous reservoir bodies.

Mesozoic Rift Basins—Onshore North Carolina and South-Central Virginia, U.S.A.—Deep River and Dan River: Danville Total Petroleum Systems and Assessment Units for Continuous Gas Accumulation, and the Cumberland-Marlboro "Basin," North Carolina

Reid, Jeffrey C.
North Carolina Geological Survey
1612 Mail Service Center
Raleigh, North Carolina 27699-1612, USA
e-mail: jeff.reid@ncdenr.gov

Abstract

Two continuous gas assessment units (AU's) are present in the Late Triassic (Norian) onshore rift basins of North Carolina and south-central Virginia. Continuous AU's are the USGS classification/nomenclature for the oil and gas rich resource plays industry has been pursuing and exploiting throughout the continental United States. "Continuous gas assessment units" include tight gas sandstone as well as two resource plays—coal-bed methane and shale gas/oil. The USGS assessed the East Coast Mesozoic rift basins as continuous gas AU's primarily as tight gas AU's because oil and gas have been found (although not produced) from tight (*i.e.,* low porosity and permeability) sandstones, coal beds, and shale beds/intervals. The source rocks are lacustrine shales that were deposited in freshwater lakes that were near the paleo-equator after the onset of Pangea rifting.

These two rift basins, the Deep River basin wholly within North Carolina, and the Dan River-Danville basin, located in north-central North Carolina and south-central Virginia have been assessed numerically as part of the USGS's National Petroleum Resource Assessment (Fig. 1). The name 'Dan River-Danville basin' is used by the U.S. Geological Assessment team for assessment, and the name, 'Dan River basin' is used herein following stratigraphic revision and formal basin naming in 2015 (Olsen *et al.*, 2015). These two rift basins are part of a series of larger continental series rift basins that formed during the Permian to Early Jurassic extension in central Pangea as the supercontinent began to fragment.

These continuous gas-prone AUs each have a single total petroleum system (TPS). The Deep River basin continuous AU has an estimated mean gas content of 1,660 billion cubic feet of gas (BCFG) and an estimated mean of 83 million barrels of natural gas liquids (MMBNGL). Noble gases have been documented from two shut-in wells in the Deep River basin by the North Carolina Geological Survey in a separate study (Reid *et al.*, 2015c). The Dan River-Danville basin continuous AU has an estimated mean gas content 49 BCFG and no natural gas liquids from data available in 2011 assessed by the U.S. Geological Survey (Milici *et al.*, 2012) (Table 1).

The Dan River basin stratigraphy has been clarified by Olsen *et al.* (2015). A continuous 1,477-foot-deep stratigraphic core hole drilled in 2015 by the North Carolina Geological Survey penetrated a 323-ft-thick unconventional lacustrine shale reservoir containing a 3-ft-thick coal having gas shows in the coal and lower siltstone and then drilled through an underlying siliciclastic formation containing previously unknown thin organic strata, to basement at a depth of 1,451.2 ft below the surface.

The Cumberland-Marlboro 'basin,' a large, strike-parallel and seaward negative aeromagnetic anomaly that is buried beneath thin unconsolidated coastal plain sediments, also was drilled and cored (three Rotasonic holes) in 2015 by the North Carolina Geological Survey. Metasedimentary Paleozoic(?) basement rock was recovered; no Triassic strata were present.

Additional information that accompanies this extended abstract is found in Appendices 1-3.

Lacustrine Source Rock Potential in the Middle Triassic–Early Jurassic Chignecto Subbasin, Fundy Basin, Offshore Eastern Canada

Brown, David E.
Canada-Nova Scotia Offshore Petroleum Board
800 TD Centre
1791 Barrington Street
Halifax, Nova Scotia, B4A 3S5, Canada
e-mail: dbrown@cnsopb.ns.ca

Abstract

Over the past decade, discoveries of super-giant, multibillion barrel presalt oil fields in Brazil's offshore basins and related discoveries in its African conjugates highlighted the great importance of synrift/prebreakup fluvial-lacustrine successions to the success and efficiency of their petroleum systems. Improvements in seismic acquisition and processing technologies were keys in imaging the architecture of the underlying rift basins, and interpreting the basin fill and internal depositional facies later confirmed by drilling.

Middle Triassic to Early Jurassic synrift basins are exposed onshore eastern North America and extend into adjacent offshore areas, including equivalent basins in Northwest Africa. Organic-rich lacustrine successions occur in a number of the U.S. basins and although no commercial discoveries have been made, hydrocarbon shows in outcrops and wells confirm that a working petroleum system exists in virtually every basin.

The basin-fill model for these extensional basins' sedimentary successions defines four tectonostratigraphic (TS) units. In the Fundy-Chignecto rift basin complex, TS I is an unconformity-bounded, early synrift fluvial-eolian sequence of Late Permian age. TS II is a dominantly fluvial (with some lacustrine) sequence believed representative of an underfilled, hydrologically open basin (subsidence < sedimentation). This is followed by either a closed basin or one in hydrological equilibrium (subsidence ≥ sedimentation) dominated by lacustrine (TS III), and later playa / lacustrine (and basal CAMP volcanics) successions (TS IV). The climate sensitive lacustrine facies—especially in TS III—are exquisite recorders of paleoclimate, and with paleomagnetic data refine the determination of the basins' age and paleolatitudinal positions.

Seismic profiles in the Fundy-Chignecto (Canada) and Newark (USA) basin reveal high-amplitude, laterally continuous reflections adjacent to the respective border faults. In the Newark basin, these are calibrated against academic and industry wells revealing a correlation with large scale climatic cycles and lacustrine facies in TS III. In both basins, similar reflections are observed in the undrilled distal portion of TS II fluvial successions and are interpreted as indicating similar lacustrine successions. This architecture departs from the original TS II model (subsidence < sedimentation) by inferring high levels of tectonically driven extension resulting in the basins being closed from their inception (subsidence ≥ sedimentation) thus facilitating lake formation.

During TS II deposition (approximately Late Anisian to Early Carnian), paleomagnetic data positions these basins within the north equatorial humid belt. This is a favorable setting for the evolution of lakes; *i.e.*, elevated precipitation coupled with tectonic extension, and most importantly, under conditions for organic matter creation and preservation. If correct, this interpretation would have a significant impact on the potential for hydrocarbons sourced from Late Triassic lacustrine successions in presalt synrift basins offshore Nova Scotia and Morocco. Importantly, a potential new oil-rich resource play may exist beneath the shallow waters of Chignecto Bay. In the deep water portion of the offshore Scotian basin, presalt synrift basins having similar lacustrine source rock potential may also exist.

Structural Evolution and Petroleum Potential of a Cambrian Intracratonic Rift System—Mississippi Valley Graben, Rough Creek Graben, and Rome Trough of Kentucky, USA

Hickman, John B.
University of Kentucky
228 MMR Bldg., 504 Rose St.
Lexington, Kentucky 40506-0107
e-mail: jhickman@uky.edu

Harris, David C.
University of Kentucky
228 MMR Bldg., 504 Rose St.
Lexington, Kentucky 40506-0107

Abstract

Drilling and geophysical data demonstrate that the Mississippi Valley graben, the Rough Creek graben, and the Rome trough are fault-bounded graben structures filled with as much as 27,000 feet of Cambrian sediments. Data including stratigraphic tops from 1,764 wells, 106 seismic profiles, aeromagnetic and gravity surveys, and mapped surface geology at a 1:24,000 scale have been used to study seven stratigraphic packages resolvable in both wells and seismic profiles across parts of Kentucky, Ohio, Indiana, Illinois, Missouri, and Tennessee. Detailed analyses of the thickness patterns of these stratigraphic packages have been used to interpret the locations and timing of movements along major faults systems in the study area.

Active rifting of the Precambrian crystalline bedrock began by the Early Cambrian, and resulted in thick, sand-rich deposits of the Reelfoot Arkose in the Mississippi Valley graben and Rough Creek graben, and the Rome Formation in the Rome trough. Subsidence continued in these grabens during the Middle to Late Cambrian, leading to an alternating succession of shales and carbonates being deposited (Eau Claire Formation of the Illinois basin and Conasauga Group of the Appalachian basin) on top of the coarse clastic Reelfoot Arkose and Rome Formation. Although the tectonic extension that formed these features ended by the Late Cambrian, fault zone reactivation during the Taconic, Acadian, and Alleghenian Orogenies altered fault block orientations and produced areas of basin inversion, creating the possibility of numerous deep structural traps for hydrocarbons sourced by the Cambrian shales of the Eau Claire Formation and Conasauga Group.

Examination of the Reelfoot Rift Petroleum System, South-Central United States, and the Elements that Remain for Potential Exploration and Development

Coleman, James L., Jr.
U.S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214
e-mail: jlcoleman@usgs.gov

Pratt, Thomas L.
U. S. Geological Survey
12201 Sunrise Valley Drive, MS 905
Reston, VA 20192
e-mail: tpratt@usgs.gov

Abstract

The Reelfoot rift is one segment of a late Proterozoic(?) to early Paleozoic intracontinental rift complex in the south-central United States. The rift complex is situated beneath Mesozoic to Cenozoic strata of the Mississippi embayment of southeastern Missouri, northeastern Arkansas, and western Tennessee and Kentucky. The rift portion of the stratigraphic section consists primarily of synrift Cambrian and Ordovician strata, capped by a postrift sag succession of Late Ordovician to Cenozoic age. Potential synrift source rocks have been identified in the Cambrian Elvins Shale. Thermal maturity of Paleozoic strata within the rift ranges from the oil window to the dry gas window. Petroleum generation in Elvins source rocks likely occurred during the middle to late Paleozoic. Upper Cretaceous sedimentary rocks unconformably overlie various Paleozoic units and define the likely upper boundary of the petroleum system.

No production has been established in the Reelfoot rift. However, at least nine of 22 exploratory wells have reported petroleum shows, mainly gas shows with some asphalt or solid hydrocarbon residue. Regional seismic profiling shows the presence of two large inversion structures (Blytheville arch and Pascola arch). The Blytheville arch is marked by a core of structurally thickened Elvins Shale, whereas the Pascola arch reflects the structural uplift of a portion of the entire rift basin. Structural uplift and faulting within the Reelfoot rift since the late Paleozoic appear to have disrupted older conventional hydrocarbon traps and likely spilled any potential conventional petroleum accumulations. The remaining potential resources within the Reelfoot rift are likely shale gas accumulations within the Elvins Shale; however, reservoir continuity and porosity as well as pervasive faulting appear to be significant future challenges for explorers and drillers.

Regional Rift Structure of the Western Black Sea Basin: Map-View Kinematics

Tari, Gabor
Fallah, Mohammad
Kosi, Walter
OMV Exploration and Production GmbH
Trabrennstrasse 6-8
Vienna, 1020, Austria
e-mail: gabor.tari@omv.com

Schleder, Zsolt
Turi, Valentin
Krezsek, Csaba
Petrom
Petrom City, Strada Coralilor 22
Bucharest, Romania

Abstract

The geological understanding of the opening of the Western Black Sea Basin appears to be quite far from being reasonably resolved. The main faults used in the existing map-view reconstruction schemes are either very poorly defined (West Black Sea fault) or simply nonexistent as interpreted earlier (West Crimean fault) and therefore they need be redefined or replaced by other structural elements.

Various kinematic elements and facies boundaries on the conjugate margins of the Western Black Sea (*i.e.*, the Bulgarian, Romanian and Ukrainian margin in the northwest versus the Turkish margin in the southeast) appear to be a key in constraining the opening geometry of the basin. The along-strike changes in the synrift structural pattern of the Bulgarian-Romanian margin, reflecting contrasting crustal rheologies inherited from prerift deformational phases, do appear to have their counterparts in the offshore part of the conjugate Turkish margin including the Pontides. A correlation of regional 2D reflection seismic and well data, and the critical review of the relevant onshore geology did provide some preliminary corresponding tie-points to constrain the kinematics of the basin opening.

If the European margin is fixed in a kinematic reconstruction, the clockwise opening of the rift basin occurred along northwest–southeast trending transform faults around an Euler rotation pole positioned to the southwest of the present Black Sea. The rotational element in the opening of the Western Black Sea Basin, as opposed to the dominantly translational kinematics used in some of the existing kinematic models, is also supported by the broadly triangular shape of oceanic crust imaged in the basin center.

Regional Structure of the Western Black Sea Basin: Constraints from Cross-Section Balancing

Schleder, Zsolt
Krezsek, Csaba
Turi, Valentin
Petrom
Bucharest, Romania

Tari, Gabor
Kosi, Walter
Fallah, Mohammad
OMV
Vienna, Austria

Abstract

A regional, long-offset 2D reflection seismic grid that images the basin to a depth of ~30–40 km has been studied across the entire Western Black Sea Basin (WBSB). Mapping the structure and the stratigraphy of the basin on these transects provides valuable insights into the basin dynamics. An approximately 50–150 km wide zone (Turkish margin and Ukrainian sector, respectively) that roughly agrees with the present-day shallow shelf area corresponds to unstretched continental crust having a thickness of 35 km. Normal faults detach at a depth of about 15–20 km, marking the brittle-ductile transition zone. Some of the rift-related normal faults can be shown to be a re-activation of the older structural grain. Basinward, there is a distinct segment of the margin consisting of stretched continental crust and the interpreted Moho reflection located at about 20 km. The width of this zone is fairly uniform in the Bulgarian-Romanian-Ukrainian sector (80–110 km) but is much less on the Turkish side (30 km). In the central part of the basin, we interpret two distinct basement types.

In the East, between the Ukraine and Turkey, there is a transparent 7 km thick seismic facies interpreted to consist of oceanic crust. The zone occupied by this crust has a broadly triangular shape. The center of the basin in the Bulgaria-Turkish sector shows a strikingly different seismic facies: rotated fault blocks, fault planes, magmatic intrusions, and large paleo-volcanoes representing extremely stretched continental crust, very much akin to that described in other passive margins (*i.e.*, offshore Iberia). Assuming plane strain deformation and constant crustal area on the 2D lines during and after the rifting, we calculate approximately 250 km of extension in the eastern part of the WBSB, and progressively smaller values to the west; *i.e.*, ~110 km at the westernmost seismic line. High extension values also correlate well with the position of the oceanic crust. This systematic variation in stretching values and crustal types is best explained by assuming clockwise rotation of Turkey away from the conjugate margins on the northwest.

Sedimentologic Characterization of Postrift Depositional Systems (Tithonian to Albian) from DSDP Leg 41, Site 370 and DSDP Leg 50, Site 416, Deep Water Offshore Morocco

Zarra, Larry
Chevron North America Exploration and Production Company
1500 Louisiana Street
Houston, Texas 77002
e-mail: lzarra@chevron.com

Barrie, Gemma M.
Oppert, Shauna K.
Chevron Energy Technology Company
1500 Louisiana Street
Houston, Texas 77002

Abstract

Predicting potential sandstone reservoir character of deep-water sedimentation units in the postrift subsurface section of the Morocco Atlantic coast is problematic as there are only a few deep wells in the area. Two key control points for uppermost Jurassic to Lower Cretaceous deposition in this area are the Deep Sea Drilling Project (DSDP) Leg 41, Site 370 (1975), and DSDP Leg 50 Site 416 (1976) cores. Sites 370 and 416 are located approximately 150 kilometers from the coast of Morocco, and are in 4,200 m of water, at the base of the continental slope. Sedimentologic characterization of cored strata in the 1978 and 1980 DSDP volumes is generalized, and only a few restricted intervals are described in detail.

This study presents results from a new lithologic description of 440 meters of conventional core from Sites 370 and 416. Strata range from Tithonian to Albian in age. Claystone and siltstone are the dominant lithofacies and comprise 91% of the cores. The cores also contain 6.8% sandstone, 1.7% fine-textured carbonate, and 0.6% carbonate grainstone. The focus here is on the sandstone and grainstone.

Sandstone beds are either Bouma turbidites (26.4%) or contourites (73.6%). Sandstone turbidite beds range from centimeter to several decimeters thick, and are not preferentially distributed within the Mesozoic section. Contourite beds are ≤4 cm. Carbonate grainstones occur in Valanginian to Aptian strata. They were deposited as calciturbidites, and contain platform derived carbonate grains. The presence of numerous turbidite beds (>200) distributed throughout the Tithonian to Albian strata suggests the repeated occurrence of throughgoing turbidite fairways on the Morocco Atlantic slope.

Rift Basin Evolution and Petroleum System Development

Doust, Harry
Visiting Professor
Department of Earth Science
University of Utrecht
Willem C. Van Unnik Building
Heidelberglaan 2
P.O. Box 80.115
3508 TC Utrecht, Netherlands
e-mail: harrydoust@hotmail.com

Extended Abstract

Most sedimentary basins originate in a period of extensional faulting or rifting, mainly as a response to crustal and lithosphere extension. We can talk of the period of active rifting as the rift cycle in basin development, since many basins evolve further through periods of thermal relaxation into unfaulted postrift sag or subsidence cycles that form passive margins, failed rifts, or foreland cycles (Fig. 1). This presentation provides a summary overview of some of the different structural, sedimentary, and evolutionary characteristics of rift cycles and relates these to petroleum system and play development.

The structure and orientation of rifts depend on a number of geodynamic factors – the lithosphere (or prerift) structure, rheology and geometry, the rate and amount of extension, the location and magnitude of thermal perturbations, and the nature of the stress (orthogonal or transpressional) being perhaps the most important. The main rift geometries (Fig. 2) comprise asymmetric half-grabens, in which the faulting is concentrated on one flank of the basin; symmetrical grabens, in which faulting is distributed equally on either side of the rift; or where rift segments form chains offset by high blocks (distributed grabens).

In rift cycles, it is often possible to recognize three divisions or stages (Fig. 3): (A) a rift initiation stage, during which extensional faulting commences, often along a host of minor faults, producing local topographic depressions usually filled with coarse-grained erosion products; (B) a rift climax stage, during which faulting, fault-linkage, and fault-block rotation are most active, often resulting in the creation of significant topography and deep marine or (in the case of continental rifts) lake conditions; and (C) a rift waning stage, during which the rate of extension decreases until it finally stops.

Systematic Analog Comparison to Identify Potential New Exploration Opportunities in the Gabon Coastal Basin—4 Years Later

Beglinger, Suzanne E.
Statoil
Forusbeen 50
Forus, Norway
e-mail: sbeg@statoil.com

Abstract

In 2012, Beglinger *et al*. (2012a, b, and c) published a series of papers in which they systematically made analogous comparisons between the West African and Brazilian South Atlantic salt basins in order to identify new exploration opportunities. They believed that although every basin in the world is unique, they can still be classified according to their structural genesis and evolutionary history. This classification was based on breaking basins down into their tectonostratigraphic basin cycles or megasequences. By defining their characteristics with respect to the development of source, reservoir, and seal rocks, a data set of potential analogs can be compiled. This data set allowed for the identification of key combinations of elements and processes that resulted in an effective exploitable petroleum system, and assist in the evaluation of exploration opportunities in un- and under-explored basins (Beglinger *et al*., 2012a, b, and c).

Several tools can be used in such an analysis: the trajectory plot, tectonostratigraphies, the petroleum system flow diagram, events charts, creaming curves, field size distribution diagrams (Beglinger *et al*., 2012a, b, and c), and areal field distribution maps.

In this paper, the most recent exploration results in the Gabon Coastal basin will be reviewed in light of the framework that was established for the basin by Beglinger *et al*. (2012a, b).

The Enigma of the "Transition" Phase: How Rift Basins Evolve to Passive Margins

Paton, Doug
Norcliffe, J.
Basin Structure Group
Institute of Applied Geosciences
School of Earth & Environment
University of Leeds
Leeds, UK
e-mail: d.a.paton@leeds.ac.uk

Hodgson, N.
Spectrum ASA
Dukes Court
Woking, UK

Markwick, P.
GETECH
Kitson House
Elmet Lane
Leeds, UK

Introduction

At a first order, current models of lithospheric extension describe the processes by which rifting of the continental crust progressively evolves from rift initiation, through lithospheric necking and ocean crust formation, into a passive margin basin; *e.g.*, Lavier and Manatschal (2006), Pernon-Pinvidic *et al*., (2013). However, recent advances in the imaging quality, maximum recording time, and line density of industry-acquired seismic reflection data across passive margins is increasingly challenging the validity of these models. Many of these recent models are focused on magma-poor systems (*e.g.*, Lavier and Manatschal, 2006), and it is only more recently that the existing models of volcanic margin (*e.g.*, Mutter *et al*. 1982; White *et al*., 1987) have started to incorporate the observations from these recent data; *e.g.*, Franke (2013), Pindell and Graham (2014).

In this study, we consider the evolution of a margin from the end of the rift stage to the initiation of a passive margin. In much of the southern South Atlantic this episode is documented as the transition phase (Jungslager, 1999); however, its genesis and indeed geometry is poorly understood primarily because of a limitation of data. In this study, we use recently acquired data from the Orange Basin of Southern Africa and the Uruguay margin to consider the geometric evolution of this enigmatic phase.

Lower Crust Ductility Patterns Associated with Transform Margins

Henk, Andreas
Institut für Angewandte Geowissenschaften
Technische Universität Darmstadt
Schnittspahnstraße 9
D-64287 Darmstadt
Germany
e-mail: henk@geo.tu-darmstadt.de

Nemčok, Michal
Energy and Geoscience Institute
University of Utah
423 Wakara Way, Suite 300
Salt Lake City, Utah 84108, USA
and
Energy and Geoscience Laboratory at Geological Institute of Slovak Academy of Sciences
Dúbravská cesta 9
SK-840 05 Bratislava, Slovakia

Abstract

Coupled thermal-kinematic finite-element modeling done in 3D is used to study spatial and temporal distribution patterns of the lower crustal viscosity at transform margins during their continent-ocean transform development and passive margin stages. Modelled scenarios combine different pre-rift thermal regimes and lower crustal rheologies. The outcome indicates that substantial parts of the lower crust have the potential to flow at geologically appreciable strain rates. This discovery can lead to our better understanding of lateral variations in uplift/subsidence, upper and lower crustal thicknesses, and Moho depth. Modeled low viscosity zones having effective viscosities below 1018 Pa s make up ductility distributions, which vary spatially and temporally during the entire margin evolution. Thermal history-related ductility patterns can be divided into three categories, including: (1) reduced lower crustal viscosities controlled by continental rifting and break-up in extensional and pull-apart terrains near transforms; (2) reduced lower crustal viscosities along the transform caused be the migrating ridge and oceanic crust; and (3) the background reduced viscosity resulting from the equilibrium temperature field. Superposition of these ductility patterns and the complex interaction of the underlying perturbations of the temperature field result in differences in the potential for lower crustal flow both in space and time. Our modeling results provide templates for the understanding of lower crustal flow at transform margins in general. They await follow-up studies focused on comparing their results with data on thermal regime, maturation history, and uplift/subsidence patterns.

Los Angeles Basin: A Tectonically Complex Rift with Exceptionally Rich Petroleum Concentrations

Gautier, Donald
DonGautier L.L.C.
3954 Nelson Court
Palo Alto, California 94306
e-mail: gautier.donald@gmail.com

Abstract

The Los Angeles basin is a Neogene rift containing a nearly ideal petroleum system. Highly organic-rich strata accumulated slowly during tectonic rotation, followed by rapid subsidence and burial beneath thick successions of submarine fan deposits and nonmarine sediments. Late Miocene and Pliocene slope-channel and basin-floor fan sandstones are the main reservoirs. Most petroleum accumulations have been found in faulted anticlines that are associated with the principal structures of the basin and that have been greatly enhanced and modified by transpressional tectonics during the past 6 million years. The basin's 68 named oil fields probably originally contained more than 40 billion barrels of oil in place. In spite of many years of production, large volumes of technically recoverable petroleum remain in undiscovered accumulations, as additional recoverable oil in existing fields, and possibly in source-rock system reservoirs. Additional large-scale development is problematic, however, owing to the complexities of oil production within a modern megacity.

Is the Black Sea Really a Back-Arc Basin?

Tari, Gabor
OMV Exploration and Production GmbH
Trabrennstrasse 6-8
Vienna, 1020, Austria
e-mail: gabor.tari@omv.com

Abstract

The Black Sea is traditionally thought to be a back-arc basin with active rifting beginning in the middle Cretaceous. As to the magmatic arc associated with the southern margin of the0 basin, however, there are many open-ended questions regarding the nature, age of the arc, and even the polarity of subduction associated with the arc. Also, many models attempt to explain the formation of the Black Sea Basin in terms of geodynamic models of modern back-arc basin formation, in which extension is driven by slab roll-back.

The age of rifting in the Western Black Sea (WBS) basin is still an unresolved issue. Whereas some suggested an Early to middle Cretaceous age (*i.e.*, Barremian to Cenomanian) for the opening, others prefer a younger, Late Cretaceous age for the rifting, such as Turonian to Santonian, or Cenomanian to Santonian. Yet others recently described an unusually long rifting phase from the Barremian to the Santonian.

The stratigraphic record of rifting on the conjugate margins of the WBS basin is markedly different. On the Turkish side, in the Pontides, a significant part of the synrift strata is missing either by erosion or by nondeposition. This is attributed to either uplift/erosion on a rift-shoulder, or to uplift/erosion due to collision to the south of the Central Pontides during Cenomanian–Coniacian times. On the conjugate Bulgarian, Romanian, and Ukrainian margin, the stratigraphic record of the Black Sea rifting is much more complete, indicating separate extensional periods for the Aptian–Albian, Cenomanian–Coniacian, and the Santonian–Campanian.

The opening of the WBS Basin can be explained by asymmetric rifting at the southern margin of the European plate without invoking back-arc extension, at least for the first, wide-rift style phase of rifting during the Aptian–Albian. The subsequent Turonian–Coniacian narrow-rift style phase of rifting of the WBS basin may have been driven by subduction roll-back associated with the Pontides. Therefore only the extensional phase during the Cenomanian/Turonian to Coniacian(?) could be considered as a synrift opening period for a truly back-arc basin. The subsequent prolonged postrift subsidence is punctuated by arc volcanism along the southern margin of the WBS basin during the Campanian.

Geology and Hydrocarbon Potential of the Dead Sea Rift Basins of Israel and Jordan

Coleman, James L., Jr.
U.S. Geological Survey
130 Wesley Forest Drive
Fayetteville, Georgia 30214
e-mail: jlcoleman@usgs.gov

ten Brink, Uri S.
U. S. Geological Survey
384 Woods Hole Road, Crawford Building
Woods Hole, Massachusetts 02543

Abstract

Following its middle Miocene inception, numerous basins of varying lengths and depths developed along the Dead Sea fault zone, a large continental transform plate boundary. The modern day left-lateral fault zone has an accumulated left-lateral offset of 105 to 110 km (65 to 68 mi). The deepest basin along the fault zone, the Lake Lisan or Dead Sea basin, reaches depths of 7.5 to 8.5 km (24,500 ft to 28,000 ft), and shows evidence of hydrocarbons. The basins are compartmentalized by normal faulting associated with rapid basin subsidence and, where present, domal uplift accompanying synrift salt withdrawal.

The stratigraphy of the fault zone is composed of a thick pre-wrench interval of early Tertiary to Precambrian strata overlain by a syn-wrench section of Miocene to Recent sediments. The main potential source rock is the pre-wrench Cretaceous Maastrichtian Ghareb Formation (and equivalents), which has a total organic carbon (TOC) content measurement of 8 to 18%. Lesser potential source rocks may also be found in the Pleistocene, Cretaceous (Turonian), Jurassic (Oxfordian–Callovian), and Triassic (Ladinian–Carnian).

Geochemical analyses indicate that the source of all oils, asphalts, and tars recovered in the Lake Lisan basin is the Ghareb Formation. Geothermal gradients along the Dead Sea fault zone vary from basin to basin. Syn-wrench potential reservoir rocks are highly porous and permeable, whereas pre-wrench strata commonly exhibit lower porosity and permeability. Biogenic gas has been produced from Pleistocene reservoirs. Potential sealing intervals may be present in Neogene evaporites and tight lacustrine limestones and shales. Simple structural traps are not evident; however, subsalt traps may exist. Unconventional source rock reservoir potential has not been tested.

Petroleum Systems Asymmetry Across the South Atlantic Equatorial Margins

Dickson, William
Dickson International Geosciences Inc. (DIGs)
Houston, Texas 77077
e-mail: billd@digsgeo.com

Schiefelbein, Craig
Geochemical Solutions International (GSI)
Houston, Texas 77066

Odegard, Mark
Grizzly Geosciences Inc (GrizGeo)
Ennis, Montana 59729

Zumberge, John
Geomark Research Ltd
Houston, Texas 77095

Abstract

Our petroleum systems interpretation followed two lines of evidence, considering both tectonic-structural evolution and hydrocarbon geochemistry. Our structural mapping was based on compilations of geophysical data and a review of both published literature and oil company public presentations. Geochemically, we accessed regional nonexclusive oils studies of the conjugate margins of Africa and South America, plus considerable published material.

The nonexclusive oils data was refined, with multiple passes, to a group of 286 oils, of which 48 were key to our understanding of the West African Transform (WAT) Margin. Although multiple lacustrine-sourced oil families are seen around the South Atlantic margins, a rich, oil-prone lacustrine source would be a surprise offshore Ivory Coast and Ghana. There is minor evidence of mixed source, possibly lacustrine stringers within an alluvial to marine setting, but the predominant source is marine Cretaceous (Cenomanian–Turonian and possibly Albian).

Opening asymmetry of the Equatorial Margin (A) biased the location of lacustrine (early to mid-Cretaceous prerift to early synrift) source rocks to the northeast Brazil margin and (B) locally narrowed the width of the optimal marine (well known mid to Late Cretaceous postrift) WAT margin source kitchens. Burial of the latter, offshore Ivory Coast and Ghana, aggravated the risk of late charge of light (condensate and gas) hydrocarbons.

Transform Margin Rift Architecture: An Example from the Brazilian Equatorial Margin

Krueger, Ana
e-mail: acaguiar@earthlink.net

Casey, Katya
Murphy Oil Corp
Houston, Texas

Burke, Kevin
Murphy, Mike
University of Houston
Houston, Texas

de Matos, Renato Darros
PPSA
Brazil

Abstract

The Equatorial Atlantic evolved from a transform margin to an oblique-passive margin from the early rifting to early drifting stages. The entire Equatorial region of the South Atlantic behaved as a global-scale accomodation zone linking the evolving Central and Southern Atlantic ocean basins. Lithospheric keels and the roots of thick, stable Proterozoic cratons worked as an anchor, preventing and postponing the continental rupture. The transition, from a continental transform margin to an oblique- passive margin, lasted approximatelly 10 m.y. Once oceanic lithosphere started to be created at the main transtensional segments, large offset transform faults developed. Remarkable differences are observed between adjacent basins. Deformation partitioning ocurred at the equatorial margin due to the coaxiality of the progressive deformation. Diachronous deformation occurred as a function of the degree of obliquity of each basin at a specific time. Individual segments of the margin are associated with individual strike-slip basins at early rifting stages and have different amounts of obliquity with a decrease in obliquity from south to north. Because, basement faults form and develop during rifting their geometry gets locked at the time of first emplacement of oceanic crust. Therefore, the geometry of the basement and basement faults can be used to reconstruct the geometries of the original strike-slip basins prior to oceanic spreading.

Jurassic and Cretaceous Tectonic Evolution of the Demerara Plateau—Implications for South Atlantic Opening

Casey, Katya
Murphy Oil Exploration and Production Corporation Inc.
9805 Katy Fwy, Suite G-200
Houston, Texas 77024
e-mail: Katya_casey@murphyoilcorp.com

Krueger, Ana
e-mail: acaguiar@earthlink.net

Norton, Ian
University of Texas Institute for Geophysics
Jackson School of Geosciences
J.J. Pickle Research Campus, Bldg. 196
10200 Burnet Road (R2200)
Austin, Texas 78758-4445

Abstract

The Demerara Plateau is located on the northeast South America continental margin between 5° and 10° North, marking the northwest corner of the equatorial segment of the Atlantic Ocean. It is conjugate to the Guinea Plateau on the African margin, which rifted from the Demerara during the Early Cretaceous opening of the Central Atlantic. Published studies of the Demerara Plateau are focused on its Cretaceous history, when the northern edge of the platform was formed by trans-tensional deformation along Atlantic transform faults, and its eastern edge by extensional deformation during rifting. The platform itself is commonly interpreted as a continental block left behind following South Atlantic rifting. Seismic data across the plateau reveal significant compressional deformation beneath an Albian unconformity. We suggest that this deformation is the result of early opening of the South Atlantic, with a rotation pole located close to the present-day Amazon delta. Allowing for this compression in plate reconstructions of the South Atlantic results in restorations which do not require large amounts of intra-continental deformation in South America, and, consequently, in a relatively simple plate model for the South Atlantic.

Jurassic Rift Initiation Source Rock in the Western Desert, Egypt—Relevance to Exploration in other Continental Rift Systems

Bosworth, William
Apache Egypt Companies
11 Street 281, New Maadi
Cairo, Egypt
e-mail: bill.bosworth@apacheegypt.com

Abrams, Michael
Apache Corporation
2000 Post Oak Blvd, Suite 100
Houston, Texas 77056-4497

Drummond, Michael
Task Fronterra Geoscience
Campus 2, Aberdeen Innovation Park,
Balgownie Drive
Aberdeen, UK AB22 8GU

Thompson, Melissa
Quadrant Energy Pty Ltd
Perth, Western Australia 6000
Australia

Abstract

Sedimentologic and hydrocarbon systems modeling of continental rift systems often incorporate deposition of organic-rich source rocks in deep, long-lived lacustrine settings as a central premise. A corollary of these models is that the lakes in which organic material can be produced and preserved form during the main phase of synrift extension and associated subsidence; *i.e.*, during the middle of the rifting history. The deep-lake model has been very successful as an exploration tool but does not describe the relationships observed in all hydrocarbon producing continental rifts. In the Mesozoic basins of the Western Desert of Egypt, the most important and regionally extensive source rock occurs at the base of the synrift fill. These Middle Jurassic Khatatba Formation strata were deposited in broad fluvial flood plains with overbank swamps and small lakes transitional to estuarine or lagoonal environments. Total organic carbon content generally varies from ~1–3% in the shale intervals. The crude oils derived from these shales have variable wax content and a wide range of API gravities. Thin to locally thick coal seams are also commonly present and contribute mostly gas. Production tests of over 8000 barrels per day have been recorded from reservoirs sourced by these Khatatba oils. The deeper stratigraphic position and different lithologic facies of the Western Desert source rocks results in different exploration strategies than those applied to the lacustrine model. The Jurassic source rocks: (1) were deposited over very broad areas and not just along main basin depocenters; (2) were capable of sourcing oils to high-quality prerift Paleozoic reservoirs due to simple proximity of source and reservoir; and (3) are thermally mature in some areas where the Early Cretaceous main subsidence phase strata are not. The fluvial-estuarine source rock model offers an additional exploration strategy in continental rift systems.

Nigeria's Frontier Basins—Unrealized Rift System Hydrocarbon Potential

Adegoke, O. S.
c/o Mosunmolu Ltd.
The Oceanview Place
3th Floor
Alpha Beach Road
Lekki Península
P.O. Box 8066
Marina, Lagos, Nigeria
e-mail: OLU.ADEGOKE@MOSUNMOLULTD.COM

Ladipo, K. O.
Block 8, House 35 Friends Colony Estate,
Agungi, Lekki-Epe Expressway, Lagos, Nigeria
e-mail: kennyladipo@aol.com

Bako, M. D.
Umaru, A. F. M.
Nigeria National Petroleum Corporation
NAPIMS, FES, Ikoyi
Lagos, Nigeria
e-mail: mazadu.bako@nnpcgroup.com

Abstract

Nigeria's under explored and poorly understood frontier basins include the Nigeria, Chad, Bida, Dahomey, Sokoto, and Benue basins. They have their origins in the multi-phased rift systems that were formed during the breakup of Gondwanaland in Early Cretaceous time. The rifting is widely attributed to the stretching and subsidence of the African crustal blocks accompanied by reactivated plate movements in the early Tertiary. These basins are part of the West African Rift Subsystem (WARS) of the West and Central African Rift Systems (CARS).

The Chad basin, the largest, is an intracratonic rift basin having an area of 2,335,000 km^2 that covers Chad, Niger, Cameroun Republics, and the northeastern part of Nigeria. Only about 10% of the Chad basin lies within Nigeria. It is a two-stage rift basin comparable with the petroliferous south Chad basins (Doba, Doseo) by having (A) a Lower Bima early rift stage generated by east–west gravity faults of Albo-Aptian age, followed by an Upper Bima Sag phase (Albian); and (b) an Upper Cretaceous rift phase with deposition of lower Fika source rocks followed by a mild Tertiary sag phase corresponding to the sedimentation of Lower Kerri Kerri and Chad formations. Of the 23 dry wells drilled in the Chad basin, only the Wadi-1 and Kinasar-1 wells recorded non-commercial gas accumulations. Three possible petroleum systems have been mooted. The petroleum systems of this and other Nigeria frontier basins are discussed. Suggestions are made for the successful search for hydrocarbons in these basins.

Searching High and Low: Correlating Shallow (Drift Phase) and Deep (Rift Phase) Structural Trends with Surface and Subsurface Geochemistry in the Niger Delta, West Africa

Dickson, William
Dickson International Geosciences Inc. (DIGs)
Houston, Texas 77077
email: billd@digsgeo.com

Schiefelbein, Craig
Geochemical Solutions International (GSI)
Houston, Texas 77066

Abstract

We began with three views of the same region of the Niger Delta: as seen by the geochemist in the near-surface data; as seen by the prospect mapper in published subsurface seismic detail and well control; and by the regional structural interpreter in a crustal view from potential field data. We combine these shallow, intermediate, and deep views to illuminate the hydrocarbon plumbing system. Specific basement features, including the deep basin framework, were correlated to detailed published interpretations within the objective sedimentary section. We then showed hydrocarbon access to these features via evidence of leakage to surface with piston cores and correlated these results with oils geochemistries.

We built on an earlier tectonic-structural and geochemical interpretation (Dickson and Schiefelbein, 2011) of a transform/passive margin without the complications of salt-related deformation. Gravity data provided primary control for tectonic-structural interpretation, augmented by magnetics, depth, thickness, and published literature to define the deep rift-phase structure. Active hydrocarbon exploration meant that broad coverages of detailed 3D seismic and surface geochemical exploration programs have been acquired and presented in a half-dozen recent cited papers. From a non-exclusive study used here by permission, characteristic oil geochemistry of the Niger Delta was matched to the surface geochemical exploration results. This published and non-exclusive material facilitated the correlation between basement features and shallower drift-phase intrasedimentary structuring with inferred hydrocarbon leakage pathways terminating at the surface.

Late Jurassic–Early Cretaceous Inversion of Rift Structures, and Linkage of Petroleum System Elements across Postrift Unconformity, U.S. Chukchi Shelf, Arctic Alaska

Houseknecht, David W.
U.S. Geological Survey
956 National Center
Reston, Virginia 20192
e-mail: dhouse@usgs.gov

Connors, Christopher D.
Washington and Lee University
Geology Department
Lexington, Virginia 24450-2116

Abstract

Basin evolution of the U.S. Chukchi shelf involved multiple phases, including Late Devonian–Permian rifting, Permian–Early Jurassic sagging, Late Jurassic–Neocomian inversion, and Cretaceous–Cenozoic foreland-basin development. The focus of ongoing exploration is a petroleum system that includes sag-phase source rocks; inversion-phase reservoir rocks; structure spanning the rift, sag, and inversion phases; and hydrocarbon generation during the foreland-basin phase.

Interpretation of 2-D seismic and sparse well data documents the presence, in the south-central part of the shelf, of a series of en-echelon, north-south trending monoclonal fold limbs that display up to 1+ km (3,300 ft) of structural relief. These folds, which are located above the tips of rift-phase normal faults, are interpreted as inversion structures formed by maximum compressive stress oriented obliquely to the strike of rift-phase normal faults. Erosional relief on a Jurassic unconformity, growth strata in the overlying Upper Jurassic to Neocomian strata, and east-dipping clinoforms in a high accommodation depocenter east of the inversion structures indicate profound structural influence on sedimentation.

Oil-prone source rocks, reservoir-quality sandstone, migration pathways, and structural closure are linked intimately across the Jurassic unconformity, which reflects inversion. Thus, all these key petroleum systems elements were in place when Triassic source rocks entered the oil generation window during Cretaceous–Cenozoic stratigraphic burial.

Petroleum Systems of Frontier Siberian Arctic Basins

Horn, Brian W.
ION Geophysical
2105 City West Blvd, Suite 900
Houston, Texas 77042
e-mail: brian.horn@iongeo.com

Granath, James W.
Consulting Structural Geologist
Denver, Colorado

McDonough, K. J.
KJM Consulting, LLC
68 Nova Circle
Pine, Colorado 80470

Sterne, Edward J.
Independent Consultant
Littleton, Colorado

Abstract

Sparse data have hindered efforts to characterize the general geology and petroleum systems in the Siberian Arctic in and east of the Laptev Sea, a region whose potential has often been discounted. Recent acquisition and interpretation of 13,000+ line-km of new long offset, long record reflection data in the North Chukchi, East Siberian, and Laptev Seas has clarified the geometry and inter-relationships of several basins in this enormous 3 x 106 km^2 area devoid of wells. The 16 sec (PSTM) and 40 km (PSDM) data image a number of attractive late Mesozoic and Cenozoic extensional basins superimposed on older Phanerozoic fold belts that lie below acoustic basement. These basins all relate in various ways to the opening of the Arctic Ocean, and many contain 7.5 to 10 km of sedimentary fill and, up to 20 km in the case of the North Chukchi Basin. A variety of stratigraphic fill styles related to their underlying tectonics can be observed. For example, late-stage (postrift) architecture in the North Chukchi Basin shows Tertiary deltaic sequences traversing over 400 km northward overlying Late Cretaceous rift-fill sediments which contain potential source rocks. . In contrast, the Laptev Sea exhibits successions related to a passive margin subsidence history, with low-angle sedimentary systems tracts including well-developed ancient shelf margins and lowstand systems, all cut by intra-continental extensional structures on trend with the active Gakkel Ridge spreading center. Slightly older sediment fill occupies rifts under the East Siberian Sea. The observed potential petroleum systems in this region offer source, reservoir and seal lithologies and hydrocarbon migration geometries to access shelf margin, lowstand depositional systems in addition to the potential within the Neogene rifts.

Mississippian–Mesozoic Evolution of the Dinkum Graben System, Central and Eastern Beaufort Shelf of Alaska

Houseknecht, David W.
U.S. Geological Survey
e-mail: dhouse@usgs.gov

Connors, Christopher D.
Washington and Lee University
e-mail: connorsc@wlu.edu

Abstract

The Dinkum graben system beneath the central to eastern Beaufort shelf of Arctic Alaska comprises a complex of grabens and horsts that records multiple phases of extension and contraction spanning the Mississippian through Early Cretaceous (Neocomian). The graben system extends from about 150°W eastward for more than 200 km, approximately parallel to the Alaska Beaufort Sea coast. The eastern extent of the graben system (east of about 145.5°W) is masked by deep burial beneath Cenozoic strata and by complex Cenozoic structures. The graben system developed above regional basement that includes the pre-Mississippian Franklinian sequence, interpreted as Late Proterozoic–Devonian strata deformed and metamorphosed during the Ellesmerian orogeny. Franklinian rocks display in seismic data a range of variably dipping structural and metamorphic fabrics described in a companion abstract (Connors and Houseknecht).

Previously published interpretations of the Dinkum graben suggest two phases of extension related to rift opening of the Amerasia basin, a Jurassic phase characterized by generally south-dipping normal faults and an Early Cretaceous phase characterized by generally north-dipping normal faults. However, our interpretation of 2D seismic data, tied to well control near the coast and potential fields data across the Beaufort shelf, documents a geologic history commencing with Mississippian extension accommodated by both north- and south-dipping normal faults detached along the variably dipping basement fabrics. Growth strata indicate that pulses of extension in the graben system occurred during the Mississippian, Late Triassic–Early Jurassic, and Neocomian. Further, certain faults accommodate Mid–Late Jurassic growth strata that grade from positive to negative growth along strike, suggesting inversion of older structures, perhaps by stresses oblique to older fault planes. This polyphase deformational history is reflected in a complex graben system that accommodates Mississippian–Neocomian strata at least 5 km thick in places.

The newly recognized presence of pre-Jurassic strata in the Dinkum graben system has significant implications regarding petroleum systems. Upper Triassic growth strata likely include oil-prone source rocks in the Shublik Formation, corroborated along the southern margin of the graben by oil accumulations (*e.g.*, Northstar) with implausible migration pathways from sources to the south, and by chemistry that suggests a Triassic source rock containing more detrital components and less carbonate than typical Shublik of the North Slope. Considering the timing of extensional pulses discussed above, the presence of Lower Jurassic and Neocomian source rocks also is likely. Although all these source rocks likely are thermally overmature in deeper parts of the graben, shallower parts of the graben, horsts within the graben, and southern and northern margins of the graben may be in the oil window, and may have been charged from the graben.

Seismic Volcano-Stratigraphy in the Basaltic Complexes on the Rifted Margin of Pelotas Basin, Southeast Brazil

Gordon, Andres Cesar
Universidade do Estado de Rio de Janeiro
Rua São Francisco Xavier, 524, Maracanã
Rio de Janeiro, 22059-900, Brazil
e-mail: acgordon@ymail.com

Mohriak, Webster U.
Universidade do Estado de Rio de Janeiro
Rua São Francisco Xavier, 524, Maracanã
Rio de Janeiro, 22059-900, Brazil

Abstract

The synrift and breakup stages of the Pelotas basin in southeast Brazil are characterized by scarce siliciclastic deposits and widespread volcanism in the form of seaward-dipping reflectors (SDRs). Using high-quality seismic reflection and refraction profiles integrated with gravity, magnetics, and exploratory boreholes, a volcanostratigraphic analysis has been undertaken to understand the geological processes observed during the rifting and breakup stages of this segment of the South Atlantic continental margin. Ten volcanic units have been identified and mapped within the extended continental crust and into the transitional and oceanic crusts. The magmatic cycle began during the early synrift stage, with alkaline, high TiO_2 basalts produced at 125 Ma. This was followed by the formation of a series of voluminous tholeiitic, high TiO_2 SDR wedges during the late synrift and breakup stages. The end of the breakup process was marked by flat-lying, late synrift/early postrift, tholeiitic, low TiO_2 basalts at 118 Ma. During the Late Cretaceous and Early Paleogene, the magmatic activity continued only in the oceanic crust, forming igneous intrusions (volcanic cones or seamounts).

A comparison between the Pelotas basin and the Lüderitz and Walvis basins offshore Namibia is discussed by integrating regional geological maps, potential field methods, seismic data, and results of exploratory drilling. The SDR province in the Pelotas basin coincides geographically with the Paraná basin continental flood basalts onshore Brazil, which crop out near the coastline. This makes the Pelotas basin an ideal place to understand the relationships between the tectonic-magmatic events that preceded and continued during the Gondwana breakup, which resulted in the development of continental margin rift basins and the formation of the South Atlantic Ocean.

Continental Margin Formation and Creation of "Lateral Tectonic Accommodation Space" for Salt Deposition, Campos and Santos Basins, São Paulo Plateau, Brazil

Pindell, James
Tectonic Analysis, Ltd.
Chestnut House
Duncton, West Sussex GU28 0LH UK
and
ION E&P Advisors
Egham, Surrey, UK, and Houston, TX USA

Graham, Rod
ION E&P Advisors
Egham, Surrey, UK, and Houston, TX USA
and
Independent Consultant
Warborough, Oxfordshire UK

Bellingham, Paul
McDermott, Ken
Kaminski, Marek
Horn, Brian W.
ION E&P Advisors
Egham, Surrey, UK, and Houston, TX USA

Paton, Doug
Institute of Geophysics & Tectonics
University of Leeds, Leeds, UK

Abstract

Within the scope of our ongoing seismic reflection interpretations of basement at magmatic continental margins, and in particular those of the South Atlantic, we report on our current views concerning the São Paulo Plateau offshore Brazil, which involves the Campos, Santos, and Pelotas basins. In addition, much can be gleaned by integrating the African conjugate margin, which we also consider to a lesser extent. Our broad-brush view for this segment of South Atlantic rifting is that:

1. A broad zone of mixed magmatic/thinned continental crust formed between opposing "hinge zones" of the two larger plates during an initial period of intracontinental extension, thereby generating the synrift section in numerous grabens and half-grabens;
2. This basinal area of thin, mixed crust began to subside without much further faulting for an interval, thereby generating "sag sections" along both continental margins;
3. Plate divergence was renewed or accelerated and the thin crustal region and sag section broke up in what effectively could be viewed as a second rifting episode, and which created an irregular zone of deeper basement comprising faulted sub-sag crust, exhumed mantle, and magmatic build ups outboard of the respective sag sections; and
4. Plate divergence was finally taken up by more normal styles of seafloor spreading.

Definition of crustal type is hindered in seismic reflection interpretation by whether or not there should be much observable difference in the crustal structure resulting from rifting of a pre-existing oceanic plateau versus rifting of already-thinned continental crust. After all, Iceland is covered by normal faults, and if extension continued as magmatic supply waned, we might expect the resulting surface to have many geometries of rifted continental crust. However, the 080° trending Atlantic fracture zone fabric east of the São Paulo Plateau appears to us to dominate the crustal fabric under the Plateau as well, and thus we strongly suspect spreading-related processes in the development of the Plateau east of the sag section, at azimuths similar to the well-mapped parts of the South Atlantic Ocean.

Within this 3-staged context, outlined as a general overview of "basin zones" and basin opening kinematics, our main objective here is to propose the idea of the generation of "lateral tectonic accommodation space" for salt accumulation in the central South Atlantic. We envision that salt flowed seaward at both conjugate margins as tectonic extension and/or seafloor spreading continued, and that the "lateral accommodation space" created by the extension was

continuously filled with migrating salt while new salt was deposited.

Further, the hypothetical instantaneous salt deflation at the depositional surface as a result of the tectonic extension and salt migration was constantly replaced by the deposition of new salt across the entire basin. This mechanism allows all the salt to be deposited effectively at global sea level, and it entirely avoids poorly supported models, in our view, involving progressive seawater seepage through semi-permeable marine barriers into enormous, deep (>1 km below global sea level), air-filled depressions. While we acknowledge that the basin's depositional surface needn't have remained immediately at global sea level at all times during salt deposition, we present the hypothesis as though it were, simply to provide an end member view that opposes the air-filled hole hypothesis.

Rift Basins in the Red Sea and Gulf of Aden: Analogies with the Southern South Atlantic

Mohriak, Webster U.
UERJ, State University of Rio de Janeiro, DGRG
Rua São Francisco Xavier, 524, Room 4024A
Rio de Janeiro, RJ 20550-018, Brazil
e-mail: webmohr@gmail.com

Abstract

The Red Sea and Gulf of Aden sedimentary basins are developed along the African and Arabian conjugate margins and are characterized by Late Tertiary rifts filled with siliciclastic, carbonate, and thick evaporite successions north of the Bab-el-Mandeb Strait in the Red Sea. Geodynamic models for the development of the Red Sea–Gulf of Aden continental margins include simple shear mechanisms associated with mantle exhumation, as described in the Iberian margin, and pure shear mechanisms, with continental breakup associated with magmatic intrusions and development of organized oceanic crust in some segments of the axial trough. The rifted continental margin in the southern segment of the South Atlantic is characterized by several Mesozoic rifts that extend from onshore to offshore Brazil, Uruguay, and Argentina; the onshore rift-border faults in Argentina are at high angle to the continental margin basins. These rifts and also the Pelotas basin in southern Brazil are essentially devoid of evaporites, which mainly occur northwards of the Florianópolis Fracture Zone. A mantle plume before continental breakup is interpreted to cause the massive volcanic outpouring both in the Red Sea–Gulf of Aden continental margins (Afar plume) as well as in the region between the Pelotas and Santos basins in Brazil (Tristão da Cunha plume). The basalts associated with the continental breakup include seaward-dipping wedges in the transition from continental to oceanic crust, and volcanic eruptions probably formed barriers isolating oceanic basins from an incipient gulf developed on continental crust with synrift sedimentation. Episodic marine incursions resulted in accumulation of thick layers of massive evaporites that were deposited before the development of active oceanic spreading centers. The oceanic ridges split the salt basins initially with localized igneous intrusions and subsequently by organized oceanic crustal spreading, with allochthonous salt flows advancing towards the axial trough and covering the volcanic basement.

Synexhumation Salt Basins: Crustal Thinning, Subsidence, and Accommodation for Salt and Presalt Strata

Rowan, Mark G.
Rowan Consulting, Inc.
850 8th St.
Boulder, Colorado 80302 USA
e-mail: mgrowan@frii.com

Introduction

Divergent margins containing salt may have variable spatial and thickness distribution depending on when in the rifting history the evaporites were deposited (Rowan, 2014; Allen and Beaumont, 2015). Those deposited during early or middle phases (synstretching or synthinning, respectively; see Péron-Pinvidic and Manatschal, 2009, for terminology) typically display significant local thickness variations due to offset of the base salt during ongoing extension. In contrast, those deposited late in the rift history, just before oceanic spreading (synexhumation), have little fault offset over most of their extent and are underlain by prominent sag sequences.

In this extended abstract, I examine several aspects of synexhumation salt basins that remain enigmatic or controversial: the relationships between salt and the crustal architecture in the ocean-continent transition zone, the processes that generate the accommodation for the sag and salt sequences, and depth of the basin in which evaporites are deposited. I first summarize observations primarily from the distal portions of the South Atlantic and Gulf of Mexico conjugate margins, then offer interpretations of the observed features, and finally propose a simplified model that attempts to resolve some of the remaining questions.

Review of Clastic Rift Plays along the Rift Borders of the Central South Atlantic Margins

Davison, Ian
Earthmoves Ltd.
38-42 Upper Park Road
Camberley, Surrey, GU15 2EF, UK
e-mail: i.davison@earthmoves.co.uk

Abstract

The clastic fill of the rifted grabens in the central South Atlantic includes several fields containing over 1 billion barrels of oil in place. The largest fields are mainly hosted by continental fluvial and aeolian sandstones deposited near the base of the rift, before rift topography was fully developed.

Footwall erosion progressively eroded back the main fault scarps, and normal faults propagated through the footwall to create terraces along the rift borders. This increased the potential drainage area on the footwall, so eventually, large alluvial fans developed in the hanging wall along the main rift border faults. The basement clast-supported conglomerates scatter seismic energy; and on seismic data, the top of the fan can appear to be the intact crystalline basement. Even when drilled, the top of the fan can still be mistaken for true basement due to the large size of the clasts. Some important oil fields are hidden below these marginal alluvial fans, within prerift and early rift fluvial and eolian sandstones and in lacustrine turbidite sandstone reservoirs. It is suggested that more fields may be found in West Africa using the model of the sub-fan terrace play.

The large amount of footwall denudation of dense basement rocks can lead to unloading of the adjacent basin, as well as the footwall, when the crust has a finite flexural strength. The resulting uplift and erosion produce an 'End of Rift' unconformity, and it is suggested this process is likely to have caused the so called 'Breakup' unconformity on continental margins, rather than this being due to initiation of ocean spreading.

Regional Investigations and Hydrocarbon Exploration History of the South Atlantic Rifted Continental Margins: Development of the Salt Basins and Transform Margin Basins Without Salt

Fainstein, Roberto
NExT–Network of Excellence in Training–Schlumberger
Rua Alipio de Miranda, 145, Terezopolis, RJ, 25964-040, Brazil
e-mail: rfain39@gmail.com

Mohriak, Webster U.
State University of Rio de Janeiro–UERJ
Rua São Francisco Xavier 524–Campus UERJ
e-mail: webmohr@gmail.com

Abstract

The rifted continental margins off Brazil and West Africa encompass several morphological distinct regions that resulted from the plate separation and subsequent drift of South America and Africa. The main building blocks that controlled the development of the Atlantic-type continental margin basins consist of prerift, synrift, and postrift tectonic stages, and these events determined the basin infill. Oceanic fractures created by transform faults that indent the continental margins form basement highs that ultimately define the tectonic edges of the continental margin basins. These boundaries are involved in the marginal plateaus, marginal banks, and characteristic marginal volcanic ridges.

Major petroleum producing provinces are situated in the rifted margin salt basins and also in the equatorial transform margin basins without salt. In the salt basins, the continental slope and rise are characterized by the development of massive salt walls that delineate minibasins that were in-filled with deep-water sediments. The hydrocarbon production from these deep-water reservoirs are mainly from postsalt Tertiary and Upper Cretaceous turbidite sands, plus added production from the cluster trends of presalt carbonate microbialite reservoirs. These reservoirs are all mainly sourced by Lower Cretaceous synrift lacustrine strata, but Upper Cretaceous source rocks have also been identified in the South Atlantic salt basins. The equatorial conjugate transform margin basins are also characterized by minor salt deposition in some regions (such as the Ceará basin). These basins produce hydrocarbons from combination traps of Tertiary and Upper Cretaceous turbidite reservoirs. All of the deep-water basins are influenced either by salt or shale tectonics and related to episodic volcanism. In the southernmost South Atlantic, volcanism dominates the conjugate margins, as indicated by thick wedges of seaward-dipping reflectors.

There are two main types of South Atlantic continental margins:

A The transform margins shaped by the large offset equatorial fracture zones and in which the transverse structural lineaments are predominant, except for preexisting structuring that is not related to the Cretaceous transform directions. In these basins, where salt is absent, the typical exploratory play includes combination traps with turbidite reservoirs, generally exhibiting remarkable bright-spots amplitudes that reflect the associated deep-water channels and stratigraphic pinch-outs.

B The rifted conjugate margins shaped by salt tectonics, which extend from Sergipe-Alagoas to the Santos basin in Brazil and the corresponding conjugate margin basins from Cameroon to Angola. Here, the typical plays are predominantly associated with autochthonous salt. The salt basins account for most of the South Atlantic's offshore petroleum production. The postsalt and presalt petroleum yields are explained by lacustrine source rock maturation during Tertiary times. Hydrocarbon migration is either into the synrift reservoirs proper or through salt windows into the postrift/postsalt reservoirs of mid-Cretaceous to Miocene. In the presalt plays, the synrift source rock and the carbonate reservoirs in the sag basin are capped either by massive salt or by a thick layered highly mobile evaporite sequence. Future exploration will need to tackle the ultra-deepwater provinces near the continent-ocean boundary, where there are several potential tectonic, structural and stratigraphic targets.

Regional Seismic-Based Comparison of Syn- and Postrift Sequences in Salt and Salt-Free Basins Offshore Brazil and Angola/Namibia, South Atlantic

Strozyk, Frank
Back, Stefan
Kukla, Peter A.
RWTH Aachen University
Energy and Mineral Resources Group
Miner Building
Wüllnerstr. 2
52062 Aachen Germany
e-mail: frank.strozyk@emr.rwth-aachen.de

Abstract

This study focuses on a regional comparison of interpretations from selected 2D seismic transects between large salt and salt-free basins offshore southern Brazil (Espirito Santo basin, Campos basin, Santos basin, and Pelotas basin) and southwest Africa (Kwanza basin, Benguela basin, Namibe basin, and Walvis basin). Based on tectonostratigraphic analysis of megasequences and first-pass geometric reconstructions of synrift settings, including sedimentary decompaction and isostatic correction, it provides a comprehensive basin-to-basin documentation of the key geological parameters controlling asymmetries in basin evolution. The diversity in the tectonic and stratigraphic architecture of the conjugate margin basins reflects variations in the interplay of a number of controlling factors, of which the most important are: (A) the structural configuration of each margin segment at the time of break up; (B) the postbreakup subsidence/ uplift history of the respective margin segment; (C) variations in the type, quantity, and distribution of margin sediment (including salt); (D) the evolution of the large salt basins during sag to postsag stages; and (E) sea-level changes.

Namibia: The Hunt for Oil and Gas Continues in the Land of Giants

Mello, Márcio Rocha
Rio de Janeiro, Brazil 22420-043
e-mail: marciorochamello@gmail.com

Peres, Wagner
Houston, Texas, USA

Mohriak, Webster U.
State University of Rio de Janeiro
Faculty of Geology
Rio de Janeiro, Brazil 22059-900

Abstract

Geological reconstructions in the last two years involving the elements and processes of the petroleum systems across the southern South Atlantic rifted margins of Namibia and Brazil show evidence of great similarities in the geochemical affinity of petroleum systems in the conjugate margin basins, although some differences are present in their structural and stratigraphic framework.

The results of three deep water wells drilled in 2013, in the Walvis and Orange basins, offshore Namibia, showed the presence of at least three prolific active petroleum systems; an early Barremian lacustrine saline, a Barremian marine siliciclastic, and a Cenomanian–Turonian marine anoxic, all of which are characterized by expressive correlations with world-class lacustrine and marine source rock entities. The occurrence of marine anoxic source rocks deposited in Barremian times suggests that sea incursions, in the synrift occurred earlier in the Namibian coast when compared with their Brazilian counterparts where the present of Late Aptian salt is observed (Santos and Campos basins).

The recovery of a marine light oil (41° API), for the first time, offshore Namibia, tested from Barremian turbidite sandstones in the Wingat-1 well in the Walvis basin, together with the penetration of at least three source rock systems intervals in the Wingat-1, Murombe-1, and Moosehead-1 wells, confirmed the oil-charged character of a new underexplored petroliferous basin in the deep water province of Namibia.

Using Geochemical Data from Well Samples to Reconstruct Paleoenvironments of the Central Lake Albert Basin, Uganda

Sserubiri, Tonny
Petroleum Exploration and Production
Plot 21-29 Johnstone Road
Entebbe, Uganda
e-mail: t.sserubiri@petroleum.go.ug

Scholz, A. Christopher
Syracuse University
Department of Earth Sciences
204 Heroy Geology Laboratory
Syracuse, NY 13244-1070
e-mail: cascholz@syr.edu

Abstract

Geochemical data from drill cuttings of a 3,392 m deep well drilled on the shores of Lake Albert-Uganda, East Africa were used to investigate a long-term paleoenvironmental history of the Lake Albert rift basin-Uganda. The Ngassa-2 well was drilled through loose and coarse-grained sands in the upper section, massive mudstone deposits interbedded with siltstones in the middle sedimentary section, and a thin conglomerate at the base. Statistical treatment of data by using Principal Component Analysis shows that Fe, Ti and Rb (silicate mineral elements) account for much of the variability in the data, with about 40% of the total variance compared to 20% for total organic carbon (TOC) and Si (organic and quartz). Results from XRF data and TOC are indicative of warm and wet conditions around the late Miocene, later developing into cooler and dryer climatic conditions around the late Pliocene. Anoxic lacustrine conditions in the early Pliocene are documented by a dramatic rise in TOC and coinciding trends with iron for the depth interval 3,000–3,250 m. Lithological observations, seismic data attributes, and down-hole gamma ray logs provide evidence of a basin that transitioned from fluvial to mixed fluvial-lacustrine and subsequently dominantly lacustrine environment before shifting back to fluvial and shallow lacustrine system in the late Pleistocene and Holocene.

Role of Climate and Active Rifting in Sedimentation on the Shore Lake Edward-George Basin, Albertine Graben, Uganda

Tumushabe, Wilson M.

Lukaye, Joshua

Sserubiri, Tonny

Petroleum Exploration and Production Department

Uganda Ministry of Energy and Mineral Development

Plot 21-29 Johnstone Road

Entebbe

Uganda 256

e-mail: w.tumushabe@petroleum.go.ug/

Nicholas, Christopher J.

Trinity College Dublin

Ireland

Abstract

The project area is the onshore Ugandan Lake Edward-George basin, Albertine rift that is located in the northernmost part of the western arm of East African Rift System (EARS). Dominion Petroleum Ltd carried out petroleum exploration in the Lake Edward basin; *i.e.,* field geological mapping, seismic data acquisition, and interpretation, *etc*. This resulted in the drilling of the Ngaji-1 well, the only deep well in the entire area. The major aspects of this research are: (1) to evaluate the sedimentology and stratigraphy of different lithologies in this area using 'lithofacies' or 'lithofacies associations,' (2) revisit the lithostratigraphic framework of this area, and (3) determine how climate and tectonism have influenced sedimentation style, with the major emphasis on further unravelling the petroleum potential of the area. XRF and clay mineralogy (XRD) studies proved to be of little significance in the paleoclimatic interpretations of sediments within the study area, Lake Edward basin and therefore only ICP-MS/OES data has been used in this project.

From field geology and geochemical data (ICP-MS/OES), it is confirmed that climate and tectonism played a significant role during sedimentation in this basin. It has been found that all scenarios raised in the predictive coupled climatic-tectonic model are present within the Lake Edward-George basin. Results from this research however also show that rift-fill sediments in the south and eastern Lake Edward-George basin (close to the rift shoulders) are strongly dominated by fluvial and alluvial distributary fan complexes, and within these fan complexes, could be recognized and described during detailed stratigraphic logging the different lacustrine packages encountered within the basin-fill sediments close to the present-day Lake Edward.

Sediments within the study area were identified and classified into four members: (1) Kabagwe, (2) Rushaya, (3) Kiruruma, and (4) Kisenyi members. However, as in previous research work within the area, the main challenge was to locate the definitive chronostratigraphic markers for these members. It has been further confirmed that sediments in the Lake Edward-George basin represent a petroleum play for hydrocarbon generation and accumulation, in which the necessary elements of a valid petroleum system were identified; *i.e.*, there was excellent or good potential for reservoirs and top seals as well as circumstantial evidence of regionally source rocks, possible seals, traps and hydrocarbon migration pathways.

Developing a Coherent Stratigraphic Scheme of the Albertine Graben, East Africa

Lukaye, Joshua
Sserubiri, Tonny
Tumushabe, Wilson M.
Directorate of Petroleum – Uganda
Plot 21-29 Johnstone Road
Entebbe, Uganda 256
e-mail: j.lukaye@petroleum.go.ug

Worsley, David
PRW Consulting
Saetre, Norway

Abstract

The Albertine graben is one the most petroliferous onshore rifts in Africa. It forms the northernmost termination of the western arm of the East African Rift System. Its surface exposures were first studied by Wayland (1925) and Pickford *et al.* (1993) among others. Pickford *et al.* (1993) especially developed the basic stratigraphic framework of the graben, which was later modified by the Government geoscientists and international oil companies using subsurface data. However, the stratigraphic units have not fully and formally described and have been used informally in different and often confusing ways. The current study therefore aims to solve this challenge by establishing a coherent stratigraphic scheme for the entire graben through an integral study of surface and subsurface data.

The study involves precise description of the type and reference sections for various formations both in exposure and wells and has therefore led to the development of lithostratigraphic columns of different basins in the graben. The approach reveals that the Semliki area, south of Lake Albert, has the most complete sedimentary succession in the graben, spanning the period from middle Miocene (ca 15 Ma) to Recent. It also reveals that platform deposits, which form a small fraction of the thickness of the basinal succession, represent a highly condensed sequence which only saw deposition at times of lake highstand.

Controls on the Stratigraphic Architecture of Fluvial Sandstone Reservoirs, Gulf of Thailand

Ahmad, Mirza Naseer
Lambiase, Joseph J.
Do, Toan Manh
Tran, Oanh Thi

Petroleum Geoscience Program
Chulalongkorn University, Bangkok
Thailand

Abstract

Many of the important Gulf of Thailand reservoirs are fluvial sandstones within the early to late Miocene. The fluvial sandstones vary considerably with respect to channel size, orientation, and sinuosity, making accurate reservoir characterization difficult as many of them are below seismic resolution. The stratigraphic architecture of the Miocene to Pleistocene succession in The Gulf of Thailand has been investigated by integrating seismic geomorphology, well logs, and biostratigraphic data.

The Oligocene to early Miocene depocenter was controlled by synrift faulting and was adjacent to the large basin bounding faults. Oligocene lacustrine sediments are overlain by an early Miocene fluvial succession consisting of sinuous, broad (average width 2 km) northwest–southeast channel belts in the basin center. Channel belts became straighter and narrower (0.65 km) and change orientation to northeast–southwest in the middle Miocene when the main depocenter shifted eastward after the main phase of rifting ceased. Tidal creeks observed on seismic images supports biostratigraphic data that indicate a marine influence in the middle Miocene, the incursion coming from the northeast. Wide (1 km), northwest–southeast sinuous channels again dominate in the post-rift succession that comprises the top middle Miocene through Pleistocene. The general temporal variations indicate that tectonics was the main control on channel morphology until late early Miocene, whereas, in the middle Miocene short-lived marine incursions are present locally.

Noble Gas Isotopes, Major Element Isotopes, and Gas Composition from the Cumnock Formation: Sanford Subbasin, Deep River Basin, Lee County, North Carolina, U.S.A.

Reid, Jeffrey C.
Taylor, Kenneth B.
North Carolina Geological Survey
1612 Mail Service Center
Raleigh, North Carolina 27699-1612
e-mail: jeff.reid@ncdenr.gov

Hunt, Andrew G.
U.S. Geological Survey
Crustal Geophysics and Geochemistry Science Center
Denver, Colorado

Ellis, Geoffrey S.
U.S. Geological Survey
Central Energy Resources Science Center
Denver, Colorado

Patterson, O.F. III
Patterson Exploration Services
Sanford, North Carolina

Abstract

Noble gas isotopes, major element isotopes, and gas composition were obtained from the shut-in Butler #3 (API 32-105-00008) and Simpson #1 (API 32-105-00007) wells, drilled in 1998, and sample gas from the Cumnock Formation of Late Norian age. This is the first gas chemistry compilation of these wells. The wells' gas, sampled in 2009 and in 2014, had a strong "fruity" light petroleum odor, a visible condensate plume when the wells were flowed, and are in the oil and wet gas window. Shutin well pressures were ~900 psi (Butler #3), and ~200 psi (Simpson #1); both had a substantial initial gas flow. Limited data are from the 1982 Dummitt-Palmer #1 CBM well (API 32-105-00002), now plugged and abandoned.

Helium concentrations were ~0.20% to 0.24% from the noble gas analysis, neon ranged from 0.11 to 0.04 ppm, and argon was approximately 33 ppm. The measured noble gas composition contains very low atmospheric contamination with helium isotopes (0.07 R/R_A) clearly defined by a crustal origin, while neon and krypton and are mainly attributed to atmospheric origin ($^{20}Ne/^{22}Ne$ ~9.8, $^{86}Kr/^{84}Kr$ ~0.3). Argon isotopes are mixed between crustal and atmospheric origins with $^{40}Ar/^{36}Ar$ values ~ 418 to 520. The $F^{20}Ne/^{36}Ar$ (~0.9 to 2.6), $F^{84}Kr/^{36}Ar$ (~0.8) and $F^{132}Xe/^{36}Ar$ (0.6-0.7) in the gas show enrichment in the light isotope associated with multi-stage fractionation processes with gas and fluid interaction.

The methane content (range ~58 to 64%) is inverse to the nitrogen content from denitrification of very thin ammonium-bearing units (also rich in oil), and likely from illite in overlying strata.

Airborne Gravity Gradiometer Surveying of Petroleum Systems under Lake Tanganyika, Tanzania

Roberts, Doug
Beach Energy
25 Conyngham Street
Glenside, Australia SA 5065
e-mail: doug.roberts@beachenergy.com.au

Christensen, Asbjorn Norlund
Nordic Geoscience
Melbourne, Australia
e-mail: asbjorn.christensen@nordicgeoscience.com

Chowdhury, Priyanka Roy

Lowe, Sharon J.

Schwartz, David (Presenter)

CGG Multi Physics
10300 Town Park Drive
Houston, Texas 77072
e-mail: david.schwartz@cgg.com

Abstract

Beach Energy has been the sole interest holder and operator of the 7,200 km^2 Lake Tanganyika South block since 2010. The block is located within the western arm of the East African Rift System. The prospectivity of the lake sequence was enhanced by large oil discoveries in the similar geological environment of Lake Albert in Uganda and in the eastern part of the rift in Kenya. The lack of wells drilled in the lake to date make predicting sedimentary sections difficult.

In 2010 Beach Energy commissioned CGG to fly a FALCON Airborne Gravity Gradiometer (AGG) and a high-resolution airborne magnetic (HRAM) survey over the Lake Tanganyika South block in order to map the basin structural framework and the depth to magnetic basement. The FALCON AGG survey facilitated the imaging of the architecture of the rift zone and the interpreted sediment thickness provided an indication of prospective petroleum target areas.

This information was used to plan a subsequent 2D marine seismic survey, which was shot in 2012. The preliminary results from the 2D marine seismic survey has confirmed a rifting structure similar to that encountered further north at Lake Albert in Uganda. A number of targets over tilted fault blocks, low-side rollovers and mounded features, have been identified for follow-up from the seismic sections. Natural oil seeps evident on the surface of Lake Tanganyika, which have been sampled and analyzed by Beach Energy, also indicate that a working petroleum system is present in the sedimentary section of the rift beneath the lake.

Reservoir Characterization and Distribution in Rift and Synrift Basin Fill—Examples from the Triassic Fundy Basin and Orpheus Graben of the Scotian Margin

O'Connor, Darragh

Wach, Grant

Dalhousie University

Halifax, Nova Scotia

Canada

Abstract

Reactivated Paleozoic faults provided accommodation of rift and synrift basin fill in the Triassic Fundy Basin and Orpheus Graben of the Scotian Margin. Age data (Williams, 1985) suggests that the Minas Subbasin opened as early as the Anisian (242–247.2 ma) while the Orpheus Graben opened as early as the Rhaetian (201.3–208.5 ma).

The Minas Fault Zone (MFZ) defines the boundary between the Avalon and Meguma terranes in the Canadian Appalachians and is exposed along mainland Nova Scotia (Murphy *et al.*, 2011). This series of faults mark the northern flank of the Minas subbasin (Fundy basin) and Orpheus graben (Scotian basin), and were reactivated during Mesozoic regional extension. Faults nearest the highlands accommodated the coarsest material (alluvial) while faults toward the basin center accommodated relatively finer grained fluvial, aeolian, and lacustrine sediments (Wade and MacLean, 1990; Leleu *et al.*, 2009).

The Wolfville Formation comprises alluvial facies and generally fines upward into the Blomidon Formation aeolian sediments (Fig. 1), only found along the northern boundary of the basin. Is this facies present due to local deposition within the Minas subbasin in an arid, dry zone or do aeolian sediments persist along all footwalls of eastern North American synrift basins?

The Orpheus graben is an oblique trending Mesozoic extensional basin. At outcrop on the western edge of the basin, facies comprise fine to coarse-grained sandstone containing pebble to cobble clasts and having a minor mud and conglomeratic facies. These are interpreted to have been deposited in an alluvial braided channel complex nearest the mouth of the river system (Tanner and Brown, 1999). To the east, more distal facies representing evaporites, playa lake and marginal marine environments are present in cores of the Eurydice Formation and represent initial opening of the Atlantic Ocean.

Paleoflow indicators suggest axial rivers once existed between the two basins along the MFZ (Tanner and Brown, 1999; Leleu *et al.*, 2009). Could the "Broad Terrane Hypothesis" of Russell (1879) be applicable? Was there a single connected basin which was separated into two subbasins through uplift and erosion of conjoining strata (alluvial deposits along the axial trend of the MFZ)? During basin inversion (Withjack *et al.*, 1995; Withjack *et al.*, 2009; Withjack *et al.*, 1998) sediments deposited along the Minas Fault Zone have been uplifted and eroded. This is most likely the reason for the lack of alluvial facies present along the northern edge (footwall) of the Minas Subbasin.

Facies associations of surface and subsurface synrift sediments are being characterized to discern sediment distribution patterns and sediment provenance (outcrop, thin section) and subsurface (core, cuttings, thin section).

Author Index