Petroleum Systems in "*Rift*" Basins

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The following abstracts have been received and accepted for our conference. Please check our Web site periodically for the most up-to-date listing and information.

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

Ahmad, Mirza Naseer
Lambiase, Joseph J.
Do, Toan Manh
Tran, Oanh Thi
Chulalongkorn University Petroleum Geoscience Program
Department of Geology,
The Faculty of Science
Chulalongkorn University
254 Phyathai Rd., Patumwan,
Bangkok 10330 Thailand
e-mail: naseerrb3@yahoo.com

Abstract

Many of the important Gulf of Thailand reservoirs are fluvial sandstones within the early to late Miocene succession. 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 Songkhla Basin, in the SW Gulf of Thailand, was investigated by integrating seismic geomorphology, well logs and biostratigraphic data.

The Oligocene to early Miocene depocenter was controlled by syn-rift faulting and was adjacent to large, basin-bounding faults. Oligocene lacustrine sediments are overlain by an early Miocene fluvial succession with sinuous, 0.2 - 2.0 km wide NW-SE channel belts in the basin center. Channel belts became straighter and narrower (0.65 km) and changed orientation to NE-SW 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 indicates at least one period of marine influence in the middle Miocene, with the incursion coming from the northeast and suggesting extensive marine deposition. Wide (1.9 km), NW-SE sinuous channels again dominate in the post-rift succession that comprises the top middle Miocene through the Pleistocene.

The general temporal variations indicate that tectonics was the main control on channel distribution, morphology and orientation and that relative sea level played a secondary role until at least the very latest Miocene. However, short-lived marine incursions and episodic faulting were important locally.

Nigeria's Frontier Basins - Unrealized Rift System Hydrocarbon Potentials

Bako, M. D.
Umaru, A. F. M.
Nigeria National Petroleum Corporation,
Napims, FES, Ikoyi
Lagos, Nigeria

Adegoke, O. S.
c/o Mosunmolu Ltd.
The Oceanview Place
4th Floor
Alpha Beach Road,
Lekki Peninsula,
P.O. Box 8066
Marina, Lagos, Nigeria
e-mail: OLU.ADEGOKE@MOSUNMOLULTD.COM

Abstract

Nigeria is 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 between the Pan African (750-550 Ma) to Holocene period. 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 (WAS) of the West and Central African Rift Systems (WCARS).

The Chad Basin, the largest, is an intracratonic rift basin with an area of 2,335,000 sq. km that covers Chad, Niger, Cameroun Republics and the northeastern part of Nigeria. Only about 10% of the Chad Basin lies within Nigeria (Fig. 1). It is a two-stage rift basin comparable to the petroliferous south Chad Basins (Doba, Doseo) with (a) a Lower Bima early rift stage generated by EW gravity faults (Albo-Aptian) 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 basin, only the Wadi-1 and Kinasar-1 wells recorded non-commercial gas accumulations. Three possible petroleum systems have been muted. The petroleum systems of this and other Nigeria Frontier basins are discussed. Suggestions are made for the unsuccessful search for hydrocarbons in these basins.

A Systematic Approach to Analogue Comparison to Identify Potential New Exploration Opportunities

Beglinger, Suzanne E.
Statoil
Svanholmen 8
Stavanger, Norway NO-4035
e-mail: sbeg@statoil.com

Abstract

Although every basin in the world is unique, they can still be classified according to their structural genesis and evolutionary history. This classification is 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, we can compile a dataset of potential analogues. This dataset will allow us to identify the key combination of elements and processes that result in an effective exploitable petroleum system, and assist in the evaluation of exploration opportunities in un- and under-explored rift basins.

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, and areal field distribution maps.

I will introduce you to the world of analogue comparison of basins, megasequences and petroleum system elements, and discuss how to apply the different tools to identify potential new exploration opportunities in the South Atlantic, like in the Gabon Coastal- and Almada-Camamu basins.

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

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

Drummond, Michael
Fronterra Geosciences
Balgownie Centre
Campus 3, Aberdeen Innovation Park
Balgownie Drive
Aberdeen
AB22 8GW
UK

Abrams, Michael
Apache Corporation
2000 Post Oak Boulevard
Suite 100
Houston, Texas 77056

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 syn-rift 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 syn-rift fill. These Middle Jurassic strata were deposited in predominantly fluvial (overbank marshes) to estuarine environments. TOC content generally varies from ~1-3% in the shale intervals. The crude oils derived from these are generally waxy and with a wide range of API gravities. Thin coal seams are also commonly present and contribute mostly gas. The deeper stratigraphic position of the Western Desert source rocks results in different exploration strategies than those applied to the lacustrine model. For example, the Jurassic source rocks are capable of sourcing oils to pre-rift reservoirs even along basin axes due to simple proximity of source and reservoir. Also, the Jurassic source rocks are mature in some areas where the Early Cretaceous main subsidence phase strata would not be. The fluvial-estuarine source rock model offers an additional exploration strategy in continental rift systems.

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

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

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

Abstract

The Demerara Plateau is located 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 side which rifted from the Demerara during 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 the Atlantic transform faults and its eastern edge by extensional deformation during rifting. Jurassic evolution of the Demerara Plateau is not addressed and the platform itself is commonly interpreted as a continental block (Greentroyd *et al*., 2008, Krauspenhar *et al*., 2014) left behind by the South Atlantic rifting. Significant deformation beneath a dated Albian unconformity on the plateau was noted by some authors (Maillard *et al*., 2010) and interpreted as acoustic basement ridges by others (Basile *et al*., 2013). The question of the nature of the deformation observed on the Demerara Plateau and the amount of shortening underneath the Albian unconformity were not addressed and thought to be a part of an older Demerara history not important to the understanding of the rifting of South Atlantic.

Opening of the South and Central Atlantic is still debated. Current models of Atlantic Ocean opening have unexplained gaps, overlaps and overall misfits, including large amounts of internal deformation in South America for which there is no geologic evidence. We suggest that the Demerara deformation underneath the Albian unconformity may hold the key to some unanswered questions of South Atlantic opening.

Interpretation of seismic and potential field data on the Demerara Plateau, and plate tectonic and structural reconstructions, suggests significant compressional deformation of the southern edge of Guinea Plateau and north–northeast edge of the Demerara Plateau during the Early Cretaceous. Shortening of 20–50 km is topped by an Albian unconformity observed on seismic, which according to our modeling has removed up to 6 km of sediments from the Demerara Plateau. Accounting for this deformation in plate models of South Atlantic opening allows for reconstructions that do not require large amounts of internal deformation of South America.

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 in central Connecticut and Massachusetts, is the northernmost 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, modern oil and gas wells have not been drilled there 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 they 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 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 one percent to 21 percent, with a mean of five percent. Permeability is equally low, except around joints, fractures, and faults. Seals are likely to be intra-formational shales and tight igneous bodies. Maturation, generation, and expulsion likely occurred during the late syn-rift period (Early Jurassic) accentuated by an increase in local geothermal gradient, igneous intrusions, and hydrothermal fluid circulation. Migration pathways were likely along syn- and post-rift faults and fracture zones. Resources, if present, are probably unconventional (continuous) accumulations.

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

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

Milici, Robert C.
U.S. Geological Survey
12201 Sunrise Valley Drive
MS 956
Reston, VA 20192-0002

Post, Paul J.
Bureau of Ocean Energy Management
1201 Elmwood Park Blvd.
New Orleans, LA 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 continental shelf. Using a petroleum systems based methodology, the U. S. Geological Survey examined 13 onshore Mesozoic rift basins and estimated a mean undiscovered natural gas resource of 3.86 trillion cubic feet of gas and a mean undiscovered natural gas liquids resource of 135 million barrels 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 not assessed due to insufficient data.

Individual composite total petroleum systems are 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 tight 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) and one or more episodes of water washing 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.

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, Georgian 30214
e-mail: jlcoleman@usgs.gov

Pratt, T. L.
U.S. Geological Survey
12201 Sunrise Valley Drive
MS 905
Reston, VA 20192-0002

Abstract

The Reelfoot Rift is one segment of a late Proterozoic(?) early Paleozoic intracontinental rift complex in the south-central United States. The rift complex is situated beneath Mesozoic-Cenozoic strata of the Mississippi Embayment of southeastern Missouri, northeastern Arkansas, and western Tennessee and Kentucky. The stratigraphic section consists primarily of syn-rift Cambrian and Ordovician strata, capped by a post-rift sag succession of Late Ordovician to Cenozoic age. Potential syn-rift source rocks have been identified in the Cambrian Elvins Shale. Thermal maturity 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 eight of 21 exploratory wells have reported petroleum shows, mainly gas shows with some asphalt or solid hydrocarbon residue. Regional seismic profiling shows the presence of a large inversion structure (Blytheville Arch), which is cored by structurally thickened Elvins Shale. 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.

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, Georgian 30214
e-mail: **jlcoleman@usgs.gov**

ten Brink, Uri S.
U.S. Geological Survey
Woods Hole Science Center
Quissett Campus, 384 Woods Hole Rd.
Woods Hole, MA 02543-1598

Abstract

Numerous basins of varying lengths and depths exist along the Dead Sea fault zone, a large continental transform plate boundary, since its inception in the Mid-Miocene. The modern day left-lateral fault zone has accumulated 105-110 km of left-lateral offset. The deepest basin along the fault zone, the Lake Lisan or Dead Sea basin, reaches depths of 7.5-8.5 km, and shows evidence of hydrocarbons. The basins are compartmentalized by normal faulting associated with rapid basin subsidence and, where present, domal uplift accompanying syn-rift 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 Maastrichtian Cretaceous Ghareb Formation (and equivalents) with a total organic content measurement of 8 to 18 percent. Lesser potential source rocks may also be found in the Pleistocene, Turonian Cretaceous, Oxfordian-Callovian Jurassic, and Ladinian-Carnian Triassic. 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, sub-salt traps may exist. Unconventional source rock reservoir potential has not been tested.

Rifting Along the South Atlantic Margins and Some General Principles for Exploration in Rifts on Continental Margins

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

Abstract

The main rifting phase in the South Atlantic occurred in a 5-10 M yr period during the Barremian to Aptian with subsidence creating deep lakes where high quality source rocks developed that generated the many giant oil fields discovered in Angola and Brazil over the last thirty years.

Axial drainage with fine clastic deposition predominated in these early rifts, but once the uplifted footwall blocks began to erode, large alluvial fans poured into the grabens. These alluvial fans can contain large basement boulders (2-3 m diameter) and reach up to 3 km in thickness. They scatter seismic energy and the top of the fan is often mis-picked as the top of the intact crystalline basement, because there is no seismic reflectivity present below the top of the fan. Even when the fans are drilled they can be mistaken for intact basement, as the basement clasts are large and there is little matrix. The alluvial fans hide underlying fault terraces with high quality pre- and syn-rift lacustrine turbidite sandstone reservoirs which were fed axially along the deep hangingwall grabens. These 'hidden reservoirs' host significant oil reserves on both sides of the Atlantic (e.g. Rio do Bu Field in the Reconcavo, and M'Boundi in Congo) and more oil can be expected in this play. We will show several undrilled examples of from the West African margin.

Denudation of large amounts of footwall crests removes a crustal load and causes the adjacent basin to be uplifted by 1 km or more. This is due to the crust acting as a cantilevered beam. This may in turn give rise to an unconformity, even in the middle of the half-graben. The unloading of footwalls and the rebound effect produces an unconformity, which is at the top of the syn-rift sequence. Many authors refer to this as the 'break-up' unconformity which supposedly correlates with the onset of sea-floor spreading. However, there is no known physical explanation why the onset of spreading should lead to a basinwide unconformity, and the 'break-up' unconformity I suggest that is better described as an 'end-rift' unconformity.

Where basement weaknesses (shear zones) intersect the graben at high angles and are sub-parallel to the rift opening direction then important through-going transfer faults can develop. The transfer faults can separate rift segments of opposing polarity, but instead of broad relay arches, complex transtensional and transpressional flower structures are developed along the hard-linked transfers. Large oil fields can preferentially develop along these zones where the high angle transfer faults provide oil migration and sediment pathways across the rift (e.g. Mata-Catu Fault in the Reconcavo Basin). Similar hard-linked transfer faults occur in the Kwanza and Gabon Basin where the orientation of basement weaknesses are parallel to the rift opening directions.

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
DIGs (Dickson Int'l Geosciences)
1206 Provident Oaks Lane
Houston, TX 77077
e-mail: billd@digsgeo.com

Schiefelbein, Craig F.
Geochemical Solutions International
11419 Canyon Trail Dr.
Houston, TX 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 sub-surface seismic detail and well control; and by the regional structural interpreter in a crustal view from potential field data. We combine these shallow, middle 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 tectono-structural and geochemical interpretation (Dickson & Schiefelbein, 2011) of a transform/passive margin without the complications of salt-related deformation. Gravity data provided primary control for tectono-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 (SGE) 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 SGE results. This published and non-exclusive material facilitated the correlation between basement features and shallower drift-phase intra-sedimentary structuring with inferred hydrocarbon leakage pathways terminating at the surface.

Petroleum Systems of the West African Equatorial (Transform) Margin

Dickson, William
DIGs (Dickson Int'l Geosciences)
1206 Provident Oaks Lane
Houston, TX 77077
e-mail: billd@digsgeo.com

Schiefelbein, Craig F.
Geochemical Solutions International
11419 Canyon Trail Dr.
Houston, TX 77066

Odegard, Mark E.
Grizzly Geosciences Inc.
PO Box 1371
5078 US Hwy. 287 N
Suite 13
Ennis, Montana 59729

Zumberge, John E.
GeoMark Research, Houston
9748 Whithorn Drive
Houston, Texas 77095

Abstract

Our petroleum systems interpretation followed two lines of evidence, considering both tectono-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 non-exclusive oils studies of the conjugate margins of Africa and South America, plus considerable published material.

The non-exclusive 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 Margin (WATM). 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 pre-rift to early syn-rift) source rocks to the NE Brazil margin and b) locally narrowed the width of the optimal marine (well-known Mid to Late Cretaceous post-rift) WATM source kitchens. Burial of the latter, offshore Ivory Coast and Ghana, aggravated the risk of late charge from light (condensate and gas) hydrocarbons.

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

Abstract

Most sedimentary basins originate in a period of extensional faulting or rifting, mainly in 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, perhaps later, foreland cycles. This presentation provides a summary overview of some of the different structural, sedimentary and evolutionary characteristics of rift cycles that relate to petroleum system and play development.

While not all rift basins are petroliferous, many types represent important oil and gas provinces. In such provinces the characteristic sedimentary and tectonic responses to the evolution of rift cycles make it possible to make the jump from basin cycle to petroleum system development. By definition petroleum systems are dependent on the presence of characteristic active source rocks, together with reservoir and seal rocks, traps and fields and we can recognize patterns of recurring types of petroleum systems, which we may call synrift petroleum system types, or PSTs.

In this discussion I will review a number of synrift PSTs and their characteristics in a number of important rift basin types, distinguished as follows:

Continental rifts developed in tropical climates,
Continental to marine rifts developed in tropical environments,
Continental rifts developed in temperate climates,
Continental to marine rifts developed in arid climates,
Deeper marine rifts on continental platforms and margins,
Relatively shallow marine rifts on continental platforms.

The importance of climate is emphasized.

Regional Investigations Along the Rifted Margins of the South Atlantic: Development of Rifted Salt Basins and of Transform Margins Without Salt, Their Relationship with Oceanic Fracture Zones and Volcanism

Fainstein, Roberto
Cairn India Ltd.
India, Gurgaon, Haryana 122002
e-mail: rfain@gmail.com

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

Abstract

The rifted continental margins off East Brazil and West Africa contains morphological distinct areas that are related to the history of their rift separation episodes of East Brazil and West Africa. By and large the major petroleum producing basins on both conjugate margins of the South Atlantic are the rifted salt basins these all mostly produce from post-salt Tertiary turbidites and from cluster trends of pre-salt carbonate reservoirs in deep-water, all reservoirs sourced by Lower Cretaceous syn-rift lacustrine strata. By contrast the equatorial conjugate margins consist of basins without salt these are transform margins shaped by large offset equatorial fracture zones.

There are two types of South Atlantic margins: a) the transform margins where the large fracture zones intersect the continental conjugate margins are where the transverse structural lineaments are predominant except for features where the pre-existing or newly formed structures are not along the transform directions, and b) the salt basins conjugate margins, these are petroleum provinces associated with salt tectonics predominantly autochthonous salt. The very high petroleum yield of slat basins is explained by adequate maturation and timing of hydrocarbons migration, through salt windows, into post-salt turbidite reservoirs that range from the early Cretaceous to Miocene. In the pre-salt syn-rift source and carbonate reservoirs are capped by massive salt. On basins with no salt, however, these still exhibit bright spots associated with deep-water amalgamated channels or pinch-outs.

All deep-water basins are shaped either by salt or shale tectonism and related to episodic volcanism. In the southernmost Atlantic volcanism dominate the conjugate margins. Leaking through the Agulhas fracture and oceanic hot-spots spread over large areas in deep-water.

Rifting and Petroleum in the Los Angeles Basin

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

Abstract

The Los Angeles basin has 68 named oil fields; some of them exhibit extreme petroleum concentration. For example, at Santa Fe Springs a productive area of less than 1500 acres originally contained between 2 and 2.6 billion barrels of oil. Its primary structures were established during Miocene rifting that began with basaltic volcanism at about 17.4 Ma. Initial extension was followed by crustal detachment and > 90° of clockwise tectonic rotation of the transverse ranges, including the Santa Monica Mountains, which form the northern margin of the basin. In the wake of tectonic rotation, the nascent basin was more or less open to the nutrient-rich waters of the eastern Pacific but shielded from sediment influx. As a result, organic-carbon-rich sediments accumulated widely between 13.5 and about 8 Ma.

The dominant feature of the basin is the Central Syncline, a mysterious north-northwest trending trough within which the organic-rich Miocene sediments were buried to the oil window and beyond beneath thick submarine fan deposits. Petroleum is still being actively generated; gas lost through leaky seals accounts for the profound preference of oil over gas. Slope-channel and basin-floor fan sandstones also provide the principal reservoir rocks. Although many trapping structures were established during rifting, most have been modified and commonly reversed during the compression of the past 5 million years.

L.A. is now intensely urbanized. Most fields have low recovery efficiencies and billions of barrels of recoverable oil remain in the ground.

Seismic Volcanostratigraphy in the Basaltic Complexes on the Rifted Margin of Pelotas Basin, Southeast Brazil

Gordon, Andres Cesar
El Paso Oleo e Gas do Brazil & Universidade do Estado do Rio de Janeiro,
Avenida Pasteur 154 CEP 22290-240, Rio de Janeiro, Brazil
Universidade do Estado do Rio de Janeiro,
Rua Sao Francisco Xavier, 524 –CEP 20559-900 Rio de Janeiro, Brazil
e-mail: Andres.Gordon@epenergy.com or acgordon@ymail.com

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

Abstract

The syn-rift and break-up stages of the Pelotas Basin in Southeast Brazil are characterized by scarce siliciclastic deposits and a copious volcanism in the form of sea ward dipping reflectors (SDRs). Using high quality seismic profiles integrated with gravity, magnetics and exploratory boreholes, a volcanostratigraphy analysis has been undertaken to understand the geological processes observed during the rifting and break-up stages of the continental margin. Ten volcanic units were identified and mapped from the extended continental to the transitional and oceanic crusts. The magmatic cycle initiated in an early syn-rift age with alkaline/high TiO_2 basalts (125 Ma), followed by a series of voluminous tholeiitic/high TiO_2 SDR wedges during the late syn-rift and break-up stages. The break-up process was completed with flat-lying late syn-rift/early post-rift volcanic deposits of tholeiitic/low TiO_2 basalts (118 Ma). During the Late Cretaceous and Early Tertiary the magmatic activity continued only in the oceanic crust forming volcanic cones and seamounts.

The Pelotas volcanism is part of the western branch of the South Atlantic LIPs. A comparison between the Brazilian and the Southwest African branches in Pelotas, Luderitz and Walvis Basins offshore Namibia is discussed. The SDRs province in the Pelotas Basin is almost geographically in contact with the Paraná Basin continental flood basalts near the coastline. This fact makes the Pelotas Basin a key place to understand the relationships between the tectono-magmatic events that preceded and continued during the Gondwana break-up, resulting in the development of rifts basins and the formation of the South Atlantic Ocean.

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 at the 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
e-mail: mnemcok@egi.utah.edu

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 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 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, with the onshore rift-border faults in Argentina 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 Gulf of Aden–Red Sea 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 syn-rift sedimentation. Episodic marine incursions resulted in accumulation of massive layers of evaporites, which 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 crust spreading, with allochthonous salt flows advancing towards the axial trough and covering the volcanic basement.

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
Kentucky Geological Survey
336 Mining and Mineral Resources Building
University of Kentucky
Lexington, KY 40506-0107
e-mail: jhickman@uky.edu

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 were 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 were 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 and Conasauga section.

Petroleum Systems of Frontier Siberian Arctic Basins

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

Granath, James W.
Consulting Structural Geologist
Denver, CO

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

Sterne, Edward J.
Independent Consultant
Littleton, CO

Abstract

Sparse data has 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.

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

Houseknecht, David. W.
U.S. Geological Survey
12201 Sunrise Valley Drive
Reston, VA 20192-0002
e-mail: dhouse@usgs.gov

Connors, Christopher D.
Dept. of Geology
Rm 217 Science Addition
Washington and Lee University
116 N. Main St.
Lexington, VA 24450

Abstract

The focus of ongoing exploration on the U.S. Chukchi Shelf is a petroleum system whose geologic evolution spans: (1) Late Paleozoic deposition of up to 6 km or more of syn-rift strata in Hanna Trough half grabens; (2) Triassic through Early Jurassic deposition of up to 3 km or more of syn-sag strata above the relict rift axis; (3) Late Jurassic (Oxfordian) through Early Cretaceous (Hauterivian) deposition of up to 1.5 km of strata during initial inversion of the Hanna Trough; and (4) Cretaceous through Tertiary deposition of up to 6 km or more of foreland basin strata related to the Chukotkan and Brookian orogenies. Key elements of the petroleum system include source rock deposition during the sag phase, reservoir rock (sandstone) deposition and initial combination trap development during the inversion phase, and petroleum generation and additional trap development during the foreland-basin phase.

Interpretation of 2-D seismic and sparse well data indicate the presence of a series of en-echelon, north-south oriented monoclinal fold limbs, which display up to 1 km of structural relief and are located above rift-phase normal faults. We interpret these as inversion structures generated during contractional re-activation of rift-phase normal faults. Oxfordian–Hauterivian strata display growth geometry across the inversion structures and develop east-dipping clinoforms off structure to the east. A basal sequence-bounding unconformity truncates rift- and sag-phase strata, including the main source-rock succession, and the Oxfordian–Hauterivian sequence includes reservoir-quality sandstone in low-accommodation, structurally high positions, both on the inversion structures and on relict horsts.

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

Krueger, Ana
Sr. Staff Structural Geologist
Murphy Exploration & Production Company
9805 Katy Freeway
Suite G-200
Houston, Texas 77024
e-mail: acaguiar@earthlink.net

Murphy, Mike
Burke, Kevin
University of Houston
Department of Earth and Atmospheric Sciences
312 Science & Research
Building 1, Rm. 312
Houston, Texas 77204-5007

Darros de Matos, Renato M.
PPSA
Brazil

Abstract

Basement faults form and grow during rifting, but their geometry gets locked in place at the time that the emplacement of oceanic crust begins. Therefore the geometry of the basement provides a snapshot in time of the end of rifting. At 125 Ma Oceanic crust was being formed in the South Atlantic and in the North Atlantic, but not in the Equatorial Atlantic. Because the created shear zone between was a true plate boundary linking spreading centers in the North Atlantic to spreading Centers in the South Atlantic it can be described as a Transform boundary. During Aptian time (125 Ma to 110 Ma) intra-continental pull-apart basins formed and grew. Along the transform boundary transpressive folds also developed locally. Oceanic crust started to form during Albian time (110 Ma to 97Ma) and with continued slip transform fault contacts North and South of the Romanche Transform evolved from Continental/Continental to Continental/Oceanic and finally Oceanic/Oceanic.

In Oblique margins, like the Brazilian Equatorial margin, the regional strike of the COTZ (Continental Oceanic transition zone) is not normal to the direction of spreading and to the fracture zones. The COTZ forms an oblique angle with the fracture zones and angles between COTZ and the fracture zones vary among different segments of the margin. But the angle between the fracture zone and the mid-ocean ridge is always 90 degrees and that difference is accommodated by segmentation at the mid-Oceanic ridge. Oblique rifts have a strong strike-slip component expressed primarily during the early rift stages and start as a complex pattern of pull-apart basins along strike-slip fault systems that eventually coalesce into through going systems (Umhoefer et al., 2002). Strike-slip components during rifting in the Central Atlantic have been described in from the onshore basins of northeast Brazil (Magnavita, 1992, Darros de Mattos, 1999, Destro et al., 2003 and Burke et al. 2003 Fig.19, who interpreted the results of Neves 1988), in the South American margin between Northeast Brazil and the Guinean coast of Africa (Greenroyd *et al*., 2008), and in the counterpart Guinean coast of Africa (Antobreh *et al*., 2009).

We identified four segments on the basis of basement structures: 1- Fault strike direction and 2- Fault strike length in the Brazilian Equatorial margin. Those segments are associated to with individual strike-slip basins at early rifting stages. Individual segments correspond to impart different degrees of

obliquity to the margin. From the Barreirinhas to Amapá basins the margin is oblique to the main motion direction between the continents with a decrease in obliquity from south to north. It has been demonstrated by many authors that because faults nucleate at random heterogeneities and grow by tip propagation. In more moderate oblique rifts it faults can grow by linkage, but as obliquity increases an upper limit is reached causing fault length to be inversely proportional to obliquity. That relationship is observed in the basement fault geometries of the Brazilian Equatorial margin with a correlation in the basement faults between obliquity and strike length. In the most oblique rifted segments of the Barreirinhas and Pará-Maranhão fault strike lengths range from 5 to 50 km. Offshore Amapá where the rift was less oblique, basement faults strike lengths can be as long as 180 km.

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

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

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. The sediments within the graben were first studied by Wayland (1925) and O'Brien (1939) among other earlier researchers using fossil mammals to describe the exposed succession of the graben to be Plio-Pleistocene. The basic stratigraphic frameworks established by earlier workers have been further modified by the Government geoscientists, and international oil companies operating in the graben with aid of recently acquired data.

This study aims to establish a coherent stratigraphic scheme for the entire graben by undertaking an extensive integral study of surface and subsurface data involving a review of previous work, study of field exposures, seismic, biostratigraphy and petrophysical studies. It also involves radiometric dating of tuff beds from field exposures for precise age dating. The work precisely describes the type and reference sections for various formations, both in exposures, and in the wells drilled in the graben. Lithostratigraphic columns of the different basins in the graben have been developed.

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. Models developed from this study suggest that the platform deposits, which are just a small fraction of the thickness of the basinal succession, represent a highly condensed sequence which only saw deposition at times of lake highstand. At other times, the platform was marked by non-deposition and sediment bypass, characteristic ironstones that are common in the succession often marking significant discontinuity surfaces.

Triassic Taylorsville Basin, Virginia, USA: Comparative Thermal History and Organic Facies Within the pre-Atlantic Newark Supergroup Lacustrine Rift-basin System

Malinconico, MaryAnn L.
Lafayette College
821 Paxinosa Avenue
Easton, PA 18042
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 Tr-J Newark Supergroup basin system that trends north–south from the southern US into maritime Canada and formed within a wide-rift zone between Early Triassic collapse of the Appalachian orogen and Jurassic initiation of Atlantic seafloor spreading. The basin is a half-graben with western border fault, mostly buried under the Cretaceous and younger Atlantic passive-margin coastal plain. It was a target of conventional exploration drilling >25 years ago; there is recent interest in shale gas exploitation. It has been used as an analog for the undrilled offshore Norfolk basin.

Differences in kerogen type, basement and advective heatflow, and stratigraphic/ hydrologic architecture among the Newark Supergroup basins is predictable when paleolatitude/paleoclimate and position within the late Paleozoic Appalachian orogen are considered. For example, the Taylorsville basin, 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. Borehole vitrinite reflectance data, with maturation modeling, shows the Taylorsville basin, along the axis of Appalachian metamorphism/ orogenic collapse, experienced long-term elevated heat flow modified by syn-rift gravity-driven cross-basin fluid flow (40–55˚C/km), compared to the off-axis Newark basin (≤35˚C/km). Post-rift structural inversion resulted in variable (<1 to >3 km) erosion of Taylorsville syn-rift strata. Duration of sedimentation modeling suggests basin syn-rift sedimentation likely ended before the Jurassic, unlike sister basins to the north with extant earliest Jurassic formations.

Namibia; The Hunt Continues in the Land of Giants

Mello, Márcio
Av. Vieira Souto 284, Ipanema
City: Rio de Janeiro
Rio de Janeiro, Brazil 22420-004821
e-mail: MRM1@hrt.com.br

Peres, W
Assmyr, H.

Mohriak, Webster U.
University of the State of Rio de Janeiro – UERJ
Rua São Francisco Xavier 524 - Campus UERJ
Rio de Janeiro, RJ, 20559-900

Abstract

Geological reconstructions in the last two years involving the elements and processes of the petroleum systems across the southern South Atlantic margins of Namibia and Brazil show great similarities, 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, in Namibia, show the presence of, at least, two distinct active petroleum systems; a lower Barremian lacustrine saline and a Barremian, marine restricted characterized by correlation with a world class marine source rock entity. These results suggest that sea incursions occurred earlier in the Namibian coast as observed in their Brazilian counterparts.

The presence of at least three prolific source rock systems in the wells recent drilled in offshore Namibia confirmed a new exploration petroliferous frontier in the southern Namibian coast.

Geology and Hydrocarbon Potential of the Richmond Basin, Virginia

Milici, Robert C.
U.S. Geological Survey
12201 Sunrise Valley Drive
MS 956
Reston, VA 20192-0002
e-mail: rmilici@usgs.gov

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

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 1700's. 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 was assessed by the USGS as one composite total petroleum system, in which the hydrocarbon potential of the source beds (both coal and dark shale) and potential reservoirs were 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 values that range from <1% to 10%, and vitrinite reflectance values that range generally from about 0.3 to 1.1%, which indicates that the submature to supermature 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 and 11 million barrels of natural gas liquids.

Geology and Hydrocarbon Potential of the Taylorsville Basin, Virginia

Milici, Robert C.
U.S. Geological Survey
12201 Sunrise Valley Drive
MS 956
Reston, VA 20192-0002
e-mail: rmilici@usgs.gov

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

Abstract

The Taylorsville basin is a rift basin of Late Triassic to Early Jurassic age in east-central Virginia and adjacent Maryland. The basin was 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 were 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 and 37 million barrels of natural gas liquids.

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.

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 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 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, with the onshore rift-border faults in Argentina 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 Gulf of Aden–Red Sea 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 syn-rift sedimentation. Episodic marine incursions resulted in accumulation of massive layers of evaporites, which 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 crust spreading, with allochthonous salt flows advancing towards the axial trough and covering the volcanic basement.

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
Department of Earth Sciences
Dalhousie University
1459 Oxford Street
PO BOX 15000
Halifax NS B3H 4R2
CANADA
e-mail: webmohr@gmail.com

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 sub-basin 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, 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 with pebble to cobble clasts, with minor mud and conglomeratic facies. These are interpreted to have 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 suggesting 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 MFZ were 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).

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

Paton, Douglas
Norcliffe, J
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

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

Abstract

At a first order our current models of lithospheric extension elegantly describe the processes by which rifting of the continental crust progressively evolves from incipient rifting, through rift climax, lithospheric necking and ocean crust formation into a passive margin basin. However, recent advances in the imaging quality, maximum recording time and line density of industry acquired seismic reflection across passive margins is increasingly challenging the validity of these models. In much of the South Atlantic the transition or sag phase has been well documented but its genesis and indeed geometry is poorly understood. 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.

We investigate the evolution of the transition phase through an integrated approach of reflection interpretation, structural and stratigraphic analysis, backstripping, and gravity modelling. In addition, we use plate and kinematic modelling to reconstruct the two margins in their proper paleogeographic position. This approach highlights that the transition phase is much more complex than previously considered and does not simply form a wide, narrow basin but instead has more variability in its thickness and distribution. Not only does this constrain possible source rock distribution better, it also provides insight into the possible formation of salt basins elsewhere in the Atlantic margin. In addition, we show that the transition phase evolution is intimately linked to the late syn-rift and volcanic stages of margin evolution and that an understanding the lithospheric stretching prior to break-up influences the nature of the transition phase. We conclude that although the transition phase is enigmatic, by considering its evolution within an integrated geodynamic context can we understand not only its spatial distribution and evolution better but also the processes involved as continental lithosphere evolves into the oceanic lithosphere.

Comparative Analysis of Magmatic Margins: Implications for Rifting and Hydrocarbon Exploration

Pindell, James
Tectonic Analysis
Chestnut House, Burton Park,
Duncton
West Sussex, UK
GU28 0LH
e-mail: jim@tectonicanalysis.com

Paton, Douglas
McDermott, Kenneth
Graham, Rod
Bellingham, Paul
Horn, Brian
ION Geophysical
1st Floor, Integra House
Vicarage Road
Egham
Surrey, UK
TW20 9JZ

Abstract

Research on magma-rich continental margins has lagged behind the collective investigation into magma-poor ones. We have therefore undertaken an examination of many of the world's margins to characterize and interpret the processes involved with magmatic margin formation, comparing those processes with models for low-magma margins. We observe a continuous spectrum of magma volume from magma-poor to magma-rich margins, implying that magmatism plays a modifying rather than a primary role in the basic rift process. With increasing magmatism, margins preferentially show (1) landward dipping, lower angle basement faults with apparent large offset and block rotation (2) magmatic infilling of syn-rift accommodation space such that volcanic basement is a misnomer with respect to rifting, and (3) broader and more regular volcanic basal marine onlap surfaces (i.e., tops of seaward dipping reflector packages, SDRs).

We infer: (1) transient elevation of the brittle-ductile transition, leading to landward dipping faults and detachments in both future margins, (2) higher rift-related early heat flow, increasing the potential/risk of early maturation depending on syn- and early post-rift sedimentation rate, and (3) basinward magmatic evacuation from the intrusive cores of Icelandic-type magma source areas as a mechanism for (a) production of steep dips in SDR arrays, and (b) rapid deepening of margins when magmatic volume wanes. In addition, we examine the commonly accepted cause-and-effect relationship between fast rifting and magmatic margin development, pointing out that several magmatic margins formed either very slowly or on sites of pre-existing mantle plumes. Finally, we highlight the thermal implications of the magmatic spectrum seen at margins and relate them to petroleum systems in general.

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, LA 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.). While rich source rocks and thermally generated hydrocarbons have been documented, commercial petroleum accumulations were not found. Consequently, in 2012 the U.S. Geological Survey (USGS) assessed these basins as having relatively 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.

Triassic Rift / Lacustrine Continuous Gas Assessment Units (AU): North Carolina and Virginia, USA

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

Abstract

Two continuous gas-prone assessment units (AUs) are present in two Late Triassic (Norian) onshore rift basins of North Carolina and south-central Virginia. Continuous AUs are the USGS classification/nomenclature for the oil and gas-rich resource plays industry has pursued and exploited throughout the continental United States. The source rocks are lacustrine shales deposited in freshwater lakes located near the paleo-equator after the onset of Pangea rifting. These rift basins are part of a series of somewhat larger continental rift basins that formed during the Permian to Early Jurassic extension in central Pangea as the supercontinent began to fragment.

The Deep River basin is wholly within North Carolina; the Dan River basin is located in north-central North Carolina and south-central Virginia. Both basins were assessed numerically as part of the USGS's National Petroleum Resource Assessment. Both AUs are total petroleum systems (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). Helium content is about 0.218-0.223% in two shut-in wells in the Deep River basin. The Dan River basin continuous AU has an estimated mean gas content (BCFG) of 49 and no natural gas liquids from data available in 2011 assessed by the U.S. Geological Survey (Milici and others, 2012).

The continental rift / lacustrine basins provide a natural laboratory for resource assessment; the North Carolina Geological Survey (NCGS) built an extensive integrated database to better understand these rift / lacustrine basins. The database includes: organic and inorganic geochemical data, drill core and cuttings, 2-D seismic lines constrained by surface geologic mapping and drill holes with extensive geophysical logs, SEM/FIB, whole rock mineralogy, porosity and permeability analyses using high pressure mercury infusion, and extensive rock mechanics data.

The NCGS is the custodian of cores and cuttings and geophysical well logs that are available for examination at its Raleigh, N.C. repository. The 2011-2012 state budget bill directed the NCGS to evaluate statewide hydrocarbon energy potential.

A new draft rule set, including administrative procedures, has been written by the N.C. Energy and Mining Commission.

Giant Conjugate-Margin Salt Basins: Subsidence, Evaporites, and the Ocean-Continent Transition, USA

Rowan, Mark G.
Rowan Consulting, Inc.
850 8th Street
Boulder, Colorado 80302;
email: mgrowan@frii.com

Abstract

Giant conjugate-margin salt basins are 1000-2500 km long and 170-800 km wide and were originally up to 5 km or more thick. They were deposited late in the rift history as contiguous sequences that were separated by oceanic spreading. Seismic data from the Gulf of Mexico and South Atlantic show similar features: 1) the base salt is largely unfaulted but has significant structural relief in the most distal areas, where both outer troughs and outer highs may exist; 2) the 'sag' sequence underlying salt in central domains is mostly absent beneath the distal, irregular base salt; and 4) sag depocenters in some cases progressively young basinward.

These observations lead to a simplified model. As continental crust is thinned, extension shifts basinward and is recorded by synrift growth strata. Eventually, further extension occurs by distal exhumation of lithospheric mantle and/or lower continental crust, matched by subsidence in slightly more proximal areas, with both processes also progressively shifting basinward. The subsidence is generated by thermal cooling, with or without distal faulting during exhumation and enhanced by loading subsidence during deposition, and provides the accommodation for the sag sequence. The topographic relief of the exhumed material plus any volcanoes is gradually onlapped and infilled by the distal portions of the sag sequence, including the salt at its top, although there may locally be salt-free islands. Breakthrough of asthenospheric mantle leads to oceanic spreading, separating the exhumed material and its cover into two typically asymmetric ocean-continent transition zones.

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

Schleder, Zsolt
Krezsek, Csaba
Turi, Valentin
OMV Petrom S.A
Petrom City
22, Coralilor Street
Sector 1
013329 Bucuresti
Romania

Tari, Gabor
Kosi, Walter
Fallah, Mohammad
OMV Limited
Trabrennstrasse 6-8
Vienna, 1020
Austria
e-mail: Gabor.Tari@omv.net

Abstract

The past few decades have seen several models proposed for the opening and evolution of the Western Black Sea Basin (WBSB). For various parts of the basin these models made assumptions about the nature of the underlying basement types and were mostly relying on gravity and magnetics data. However, just recently, a regional, long-offset 2D seismic reflection grid was acquired across the entire WBSB and these data image the entire basin down to about 30-40 km depth, for the first time. Mapping the structure and the stratigraphy of the basin on these new seismic transects provided valuable insights into the basin dynamics. About a 50-150 km wide zone that roughly fits with the present day shallow shelf area corresponds to the un-stretched continental crust with a thickness of 35 km. This zone is narrow (50 km) in the Turkish margin and is wide (150 km) in the Ukrainian sector. Normal faults that were active in earlier tectonic phases detach at a depth of about 15-20 km, marking the brittle-ductile transition zone. In the Romanian sector we interpreted a Late Jurassic period of transtension followed by Early Cretaceous extension, both related to reactivated pre-rift basement faults. Basinward, there is a distinct segment of the margin zone with stretched continental crust and a reflection Moho located at about 20 km. The boundary between the unstretched and stretched crust is rather narrow, about 25-30 km wide. In this stretched domain, some of the rift-related normal fault traces are in most cases clearly visible. We interpret multiple phases of normal faulting during rifting similarly to other rift basins. In this zone, the rift-related normal faults have a NE-SW strike. The width of the zone that is underlined by stretched continental is fairly uniform in the Bulgarian-Romanian-Ukrainian sector (80-110 km) and is much less on the Turkish side (30 km). In the central part of the basin we interpreted two distinct basement types. In the East, between Ukraine and Turkey, we observed a transparent, 7 km thick seismic facies unit that we interpret as oceanic crust. The zone occupied by oceanic crust has a broadly triangular shape. The centre of the basin in the Bulgaria-Turkish sector shows a different seismic facies with rotated fault blocks, fault planes and magmatic intrusions and large paleo-volcanoes. We interpret this as extremely stretched continental crust, very much akin to that described in other passive margins (i.e. offshore Iberia). We use simple area balance of the continental crust material on these cross-sections to investigate the amount of stretching and the dynamics of the opening of the WBSB.

A Paleoenvironmental Reconstruction of the Central Lake Albert Rift Basin - Uganda, East Africa from Exploration Well Geochemical Data

Sserubiri, Tonny
Petroleum Exploration Department Uganda/Syracuse University
Petroleum Exploration and Production Department
Plot 21-29 Johnstone Road
Entebbe
Uganda 256
e-mail: t.sserubiri@petroleum.go.ug

Scholz, Christopher
Department of Earth Sciences
204 Heroy Geology Laboratory
Syracuse, NY 13244-1070

Abstract

Detailed and continuous records of past environmental variability are limited, but the tectonic lakes of the East African rift system hold the promise of revealing such changes. In this study, elemental geochemical data from drill cuttings of a 3392m deep well drilled on the shores of Lake Albert-Uganda, East Africa are used to investigate a long-term paleoenvironmental history and stratigraphic evolution of the Lake Albert rift basin-Uganda. The Ngassa-2 well was drilled through loose and coarse sands in the upper section, massive mudstone deposits interbedded with siltstones for middle sedimentary section and a thin conglomerate at the base. Statistical treatment of data in form of 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 TOC and Si (organic and quartz). Results from XRF data and Total Organic Carbon 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 3000 – 3250 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.

Regional, Seismic Data-based Comparison of Syn- and Post-rift Sequences in Salt and Salt-free Basins Offshore Brazil & Angola/Namibia

Strozyk, Frank
Kukla, Peter A.
Back, Stefan
RWTH Aachen University
Energy and Mineral Resources Group
Miner Building
Room: 517d
Wüllnerstr. 2
52062 Aachen Germany
e-mail: peter.kukla@emr.rwth-aachen.de

Abstract

This project focuses on a regional comparison of selected 2D seismic transects (data courtesy of PGS) between large salt and salt-free basins offshore southern Brazil (Espirito Santo Basin, Campos Basin, Santos Basin, Pelotas Basin) and southwest Africa (Kwanza Basin, Benguela Basin, Namibe Basin, Walvis Basin). Based on tectono-stratigraphic analysis and kinematic reconstruction 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 the each margin segment at the time of break-up, (b) the post break-up subsidence history of the respective margin segment, (c) variations in the type, quantity and distribution of margin sediment, (d) the evolution of the large salt basins during sag to post-sag stages, and (e) sea-level changes.

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

Tari, Gabor
Kosi, Walter
Fallah, Mohammad
OMV Limited
Trabrennstrasse 6-8
Vienna, 1020
Austria
e-mail: Gabor.Tari@omv.net

Schleder, Zsolt
Krezsek, Csaba
Turi, Valentin
OMV Petrom S.A
Petrom City
22, Coralilor Street
Sector 1
013329 Bucuresti
Romania

Abstract

The geological understanding of the Black Sea Basin appears quite far from being reasonably resolved. Various kinematic elements on the conjugate margins of the Western Black Sea, i.e. the Bulgarian, Romanian and Ukrainian margin in the NW versus the Turkish margin in the SE, appear to be a key in constraining the opening geometry of the basin. As an example, the pre-rift structural fabric of the Romanian margin, well-known from the nearby onshore, has not been systematically followed into the deepwater part of the basin. In particular, the Capidava-Ovidiu Fault separating the Moesian Platform *sensu lato* from Central Dobrogea is interpreted to dissect the Polshkov High located in the deepwater part of the basin. The Polshkov High is interpreted as a system of exceptionally large syn-rift fault blocks located just basinward from a major breakaway normal fault system. The overall Polshkov High trend has several structural culminations displaying contrasting extension polarity and fault spacing frequency. The along-strike changes in the syn-rift structural pattern of the Bulgarian-Romanian margin, reflecting very different crustal rheologies inherited from various pre-rift deformational phases, do appear to have their counterparts in the offshore part of the conjugate Turkish margin and the Pontides onshore.

A regional correlation of regional 2D reflection seismic and well data, critical review of the relevant onshore geology provided corresponding elements 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 NW-SE trending transform faults around an Euler rotation pole positioned to the SW of the present Black Sea. The more prominent rotational element in the opening of the Western Black Sea basin, as opposed to the existing kinematic models is also supported by the broadly triangular shape of the oceanic crust imaged on recently acquired long-offset (10+ km) reflection seismic data. Contrary to previous models, with a circa 25 counterclockwise rotation of the offshore/onshore Pontides and with an Euler pole close to the SW corner of the Black Sea, we have not found a space problem in the map-view reconstruction of the basin opening.

Is the Black Sea Really a Back-arc Basin?

Tari, Gabor
OMV Limited
Trabrennstrasse 6-8
Vienna, 1020
Austria
e-mail: Gabor.Tari@omv.net

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 the basin, however, there are many open-ended questions regarding the presence or absence, age of the arc and even the polarity of subduction associated with the arc. Also, many models attempted 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 Coniacian.

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 syn-rift strata is missing either by erosion or by non-deposition. This could be 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-Turonian and Coniacian-Coniacian.

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. Based on extensive industry seismic data sets in and around the basin, the Ukrainian, Romanian and Bulgarian margins are described as parts of a lower plate continental margin, whereas the conjugate Turkish margin is best understood in terms of an upper plate continental margin. The subsequent Turonian narrow-rift style phase of rifting of the WBS basin might have been driven by subduction roll-back associated with the Pontides. Therefore only the extensional phase during the Turonian to Coniacian(?) could be considered as an opening period for a back-arc basin.

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
Ministry of Energy and Mineral
Plot 21-29 Johnstone Road
Entebbe
Uganda 256
e-mail: w.tumushabe@petroleum.go.ug
tumushabewm@gmail.com

Nicholas, Christopher J.
Trinity College Dublin
College Green
Dublin 2
Ireland

Abstract

The study area is the onshore Ugandan Lake Edward-George basin, Albertine rift, Uganda 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) re-visit 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 less 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 was confirmed that climate and tectonism played a significant role during sedimentation in this basin. It has been found that all scenarios that had been raised in the predictive coupled climatic-tectonic model are present within Lake Edward-George basin. Results from this research however have also show that rift-fill sediments in the south and eastern Lake Edward-George basin (close to the rift shoulders) are majorly dominated by fluvial and alluvial distributary fan complexes and within these fan complexes, could be recognised during the detailed stratigraphic logging to describe the different lacustrine packages were encountered within the basin basin-fill sediments close to the present 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, like as in previous research work within the area, the main challenge was to locate the definite 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 are 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.

Tectonic Evolution of the Lake Edward Basin, Southwestern Uganda and its Implication to for Petroleum Accumulation

Twinomujuni, L.
Department of Geology and Petroleum Studies
Makerere University
P.O. Box 7062
Kampala
Uganda
e-mail: laubens2@yahoo.com

Tumushabe, Wilson M.
Lukaye, Joshua
Sserubiri, Tonny
Petroleum Exploration and Production Department
Ministry of Energy and Mineral development
Plot 21-29 Johnstone Road
Entebbe
Uganda 256

Abstract

The Lake Edward Basin forms the extreme southern part of the Albertine Graben in southwestern Uganda. This graben forms the northern most part of the western arm of the East African Rift System (EARS). This basin has been explored to understand its paleoclimate, tectonics and depositional history and its petroleum potential.

Even with these efforts, its depositional, tectonic history, and petroleum potential is less well understood. Dominion (U) limited carried out seismic studies to ascertain its subsurface geology, and this led to the drilling of Ngaji-1 well in 2010. This well did not encounter any hydrocarbon shows. Even aNo potential source rock was not encountered. However, from surface investigations, there is some evidence for the existence of a source rock somewhere in the basin.

From this study, potential reservoir facies, seal/cap facies and traps were encountered. At this scale of investigations, it is not possible to elucidate the extent of a pre-rift sedimentary basin which appears to host the source rock, or even to ascertain the location of hydrocarbon traps. This could be the subject for further investigations.

Early Post-rift Turbidites From DSDP Leg 50, Site 416A (1976), Deep Water Offshore Morocco: Sedimentologic Characterization and Regional Implications

Zarra, Larry
Oppert, Shauna
Chevron
1500 Louisiana St
20-065
Houston, Texas 77002
e-mail: LZarra@chevron.com

Abstract

Predicting potential sandstone reservoir character of deepwater sedimentation units in the early post-rift subsurface section of the Morocco Atlantic coast is problematic as there are only a few deep wells in the area. One of the key control points for Uppermost Jurassic to Lower Cretaceous section in this area is the Deep Sea Drilling Project (DSDP) Leg 50 Site 416A (1976) core. Site 416 is located approximately 150 kilometers from the coast of Morocco, and is in 4,200 meters of water, at the base of the continental slope. Sedimentologic characterization of these strata in the 1980 DSDP volume is generalized, with only a few very restricted intervals described in detail.

This study presents results from a new lithologic description of 279 meters of conventional core from site 416A. Strata range from Albian to Tithonian age; mostly Hauterivian and older. Claystone and siltstone are the dominant lithofacies and comprise 91.2% of the cores. The cores also contain 6.3% sandstone, 2.3% marl, and 0.2% other lithofacies. Our focus is on the sandstones.

Most sandstone beds are either Bouma turbidites (78%) or contourites (20%). Remaining sandstones include argillaceous (slurry) beds and clast rich (R1) beds. Turbidite beds range from centimeter to several decimeters thick, and are not preferentially restricted within the Mesozoic section. Contourites are ≤4cm. Approximately 5% of the turbidite beds contain platform derived carbonate grains. The presence of numerous (> 500) discrete sandstone beds distributed throughout the uppermost Jurassic and lower Cretaceous indicates continuous or recurring proximity to turbidite fairways.

POSTER ONLY

Tectonic Controls and Timing of Inversion Events of the Late Jurassic Espino Rift of Central Venezuela

Rodriguez, Lourdes
University of Houston
3115 Norfolk St #21312
Houston, Texas TX 77098
e-mail: lourdes.rm10@gmail.com

Abstract

The Espino rift is a 60-100 km-wide, symmetrical, subsurface rift of Jurassic age trending to the northeast beneath central Venezuela and extends 500 km to the southwest into Colombia as the San Fernando rift. The Espino-San Fernando rift has the exact trend as the Tukutu rift of Brazil and Guyana to the southwest; both rifts reflect the breakup of western Pangea into North and South America. The Espino rift is buried by approximately 2800 m of Oligocene to Miocene clastic deposits of the Eastern Venezuelan foreland basin. The deposit is mainly composed, from top to bottom, by green to gray shales, a sequence of sandstones, limestones and shales, and interbedded sandstones and gray shales. Most of the normal faults dip to the northwest.

Seismic data show that the Espino rift experienced two, widely separated periods of tectonic inversion of its bounding, normal faults: a latest Jurassic folding and inversion event that led to a an angular unconformity between the syn-rift section and overlying passive margin and later early Miocene inversion related to collision and strike-slip displacement of the Caribbean plate. The amount of inversion related to this younger event progressively increases from southwest to northeast and culminates in the Anaco thrust, which was of the earliest described inverted normal faults in the literature (Banks and Driver, 1957) reconstructions.