Journal of Mining and Earth Sciences Vol. 58, Issue 6 (2017) 53-59

Journal of Mining and Earth Sciences

Website: http://tapchi.humg.edu.vn

Gas hydrate-related BSR and associated amplitude anomalies: A case study in Douala basin, west Africa

Anh Ngoc Le *

Faculty of Oil and Gas, Hanoi University of Mining and Geology, Vietnam

ARTICLE INFO

Article history:
Received 12 Sept. 2017
Accepted 15 Nov. 2017
Available online 29 Dec 2017

Keywords:
Amplitude anomalies
BSR pull-up
Bright spot

ABSTRACT

Analysis of 3D seismic data in the area of 1500 km² offshore Cameroon reveals a large area of BSR occurrence, c. 350 km² in water depths ranging from 940 m - 1750 m. The BSR is associated with the amplitude anomalies which are bright spots above the BSR and pull-up BSR. The areas of bright spots have been mapped in three zones, from zone 1 to zone 3, with the area of 60 km², 8 km² and 84 km², respectively. The appearance of bright spots in the blanking zone is supposed to be caused by the development of porous sandstone of channel-fan complex in those areas, from Pliocene to Pleistocene. The porous sandstone layers will store more free gas thus have higher concentration of gas hydrate compared to the surrounding areas. Due to the higher concentration of gas hydrate, the Vp of seismic velocity will increase incredibly, creating the bright spots in the blanking zones. The pull-up BSR phenomena is observed within the pipe and beneath the pockmark depression proved for the local positive heat flow anomaly in the study area. There are number of pipes and pockmarks observed in the study area possibly suggesting for the slightly rise the thermal gradient of the study area.

1. Introduction

Bottom Simulating Reflections (BSRs) arise from seismic reflectors that cross-cut sedimentary strata and are generally related to geological processes or fluid migration occurring after deposition of the sediments (Berndt, et al., 2004). They are controlled by the temperature and pressure within the shallow subsurface (Kvenvolden and Barnard 1983). The bottom simulating reflections 'simulate' the sea bed surface by following the sea floor topography as they essentially delimit a temperature (isotherm) and pressure threshold which are mainly controlled by depth of burial. Isotherms commonly are well documented parallel to the sea bottom (Dillon, et al., 1994).

The Bottom Simulating Reflection (BSR) has been known as a direct indicator of gas hydrate occurrence, which is caused by the presence of free gas (acoustic impedance decrease) at the base of the Gas Hydrate Stability Zone (GHSZ) (Badley 1985). Methane hydrates are formed at appropriate temperature and pressure conditions when water is saturated with natural gas (99% methane) and freezes to form the cubic clathrate

*Corresponding author
E-mail: lengocanh@humg.edu.vn

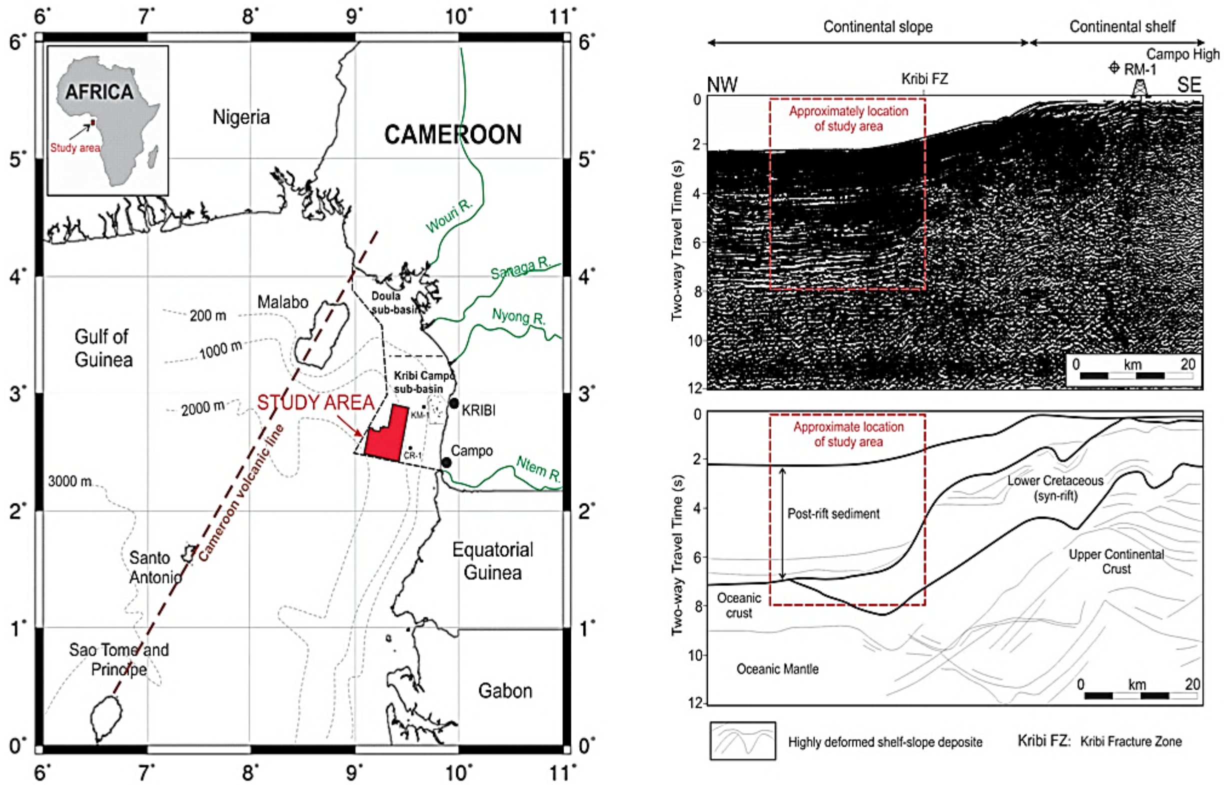

Figure 1. Bathymetry map (right) of the continental slope on the Cameroon margin. It shows the location of the study area, the two wells that have been drilled within the basin (Pauken 1992), and the location of the fracture zone system (Meyers, et al., 1996a). Seismic line and line drawing (left) illustrating a regional line across the study area from the continental shelf to slope. The paleotopographic high is composed of syn-rift sequences overlying continental crust, adapted from Meyers, et al., (1996a) and Rosendahl and Groschel-Becker (1999).

structure ($CH_4.7H_2O$) in which gas molecules are trapped in the voids within the crystal lattice (Sloan 1998). The existence of hydrate reduces the rock permeability considerably, creating layers that act as a seal trapping free gas within the more permeable hydrate free sediments below (Dillon, et al., 1994). The thickness of the GHSZ is mainly determined by water depth (as it controls ambient pressure) and geothermal gradient, and as a general rule, the greater the water depth the thicker the potential gas hydrate-bearing interval (Kvenvolden and Barnard 1983). The BSR therefore simulates the seafloor and increases in depth as a function of water depth with local modulations caused by variations in geotherm, presence of fluid advection, sediment physical and thermal properties, and recent erosional events (Hornbach, et al., 2008). Gas hydrate-related BSRs have been documented along both passive and active margins where water depths exceed 300 m (Kvenvolden, et al., 1993, Cunningham and Lindholm 2000).

Gas hydrate-related BSRs can be recognised based on five key criteria: (1) A change in seismic reflection polarity (opposite to the sea floor reflection); (2) Presence of a reflection cross-cutting primary stratal reflections. However, when the angle of cross-cutting is small, the polarity of the cross-cutting event is difficult to determine due to the superimposition of reflections (Berndt, et al., 2004, Calvès, et al., 2008); (3) Location at specific depth range and temperature (1 - 12 MPa, < 300°K); (4) Changes in seismic character, with common amplitude blanking/reduction above the BSR compared with the reflection amplitudes below; (5) Presence of bright seismic anomalies caused by the presence of free gas below the BSR.

In this study, BSR have been widely observed with many of the above characteristics of BSR previously defined in the literature. However, some additional features have been recorded, including high amplitude reflections observed above the BSR, in the 'blanking' zone. This paper utilizes a high quality 3D seismic dataset to document the nature of a newly discovered BSR in a deepwater slope area offshore southern Cameroon and its associated high amplitue anomalies including bright sports in the 'blanking' zone and BSR pull-up phenomena.

2. Geological setting

The study is part of Kribi campo sub-basin, in the nothern most of a series divergent, salt basin along the West African continental margin. While most of the basins have well data and seismic control, allowing a good understanding of their basin development, history and petroleum system, the Kribi-Campo sub-basin remains largely unexplored.

The study area covers an area of 1500 km^2, between 2^{o}20' N to 3^{o}00' N latitude, 9^{o}00 E to 9^{o}50' E longitude, and is located on the continental slope of the Kribi-Campo sub-basin (Figure 1). Modern day sea bed gradient is c.3.4^o in the upper slope and c. 0.7^o on the lower slope. It lies within a water depth ranging from 600 m to 2000 m. The Kribi-Campo sub-basin is the northernmost of a series of salt basins on the West Africa margin (Figure 2). It is bounded to the east by Precambrian basement outcrops that occur close to the shoreline, the southern margin is limited by the Kribi Fracture Zone (KFZ), which separates the Kribi-Campo sub-basin from the Equatorial Guinea Rio-Muni basin (Figure 1). The northwest limit of the basin is bounded by another facture zone, and a further c. 100 km to the northwest is the Cameroon Volcanic Line (CVL), a NE - SW trending feature that extends onshore. The basin extends south offshore, across a shallow shelf into the deep water area of Equatorial Guinea (Figure 1).

The basin was initially a rift branch of the proto-Atlantic, which includes the Rio-Muni, North Gabon (West Africa), and Sergipe-Angolas (Brazil) (De Matos 1992, Davison 1999) During the aterpassive margin phase, the basin experienced several additional regional tectonic events resulting in inversion and folding in the Santonian, and gravity sliding during Early/Mid/Late Tertiary time. These events are marked by major unconformities including the Albian-Aptian break up unconformity (115 Ma), middle Cretaceous (Santonian - ~ 85 Ma), late Cretaceous (K/T boundary - ~ 70 Ma) and mid-Oligocene (~ 30 Ma), mid-Miocene (~ 15 Ma) and late Tertiary event (~ 5.3 Ma) (Turner 1995, Lawrence, Munday et al., 2002).

Figure 2. Map of the South Atlantic salt province (Davison 2007).

3. Dataset and methodology

The data used for this study comprises a high-resolution 3D seismic dataset, covering an area of 1500 km^2 (Figure 1). It includes c. 1581 inlines and 2051 crosslines with a line spacing of 25 m, and a record time of 6.6 s TWT.

The seismic data is zero-phase, and displayed in this study such as red, yellow or orange corresponds to positive polarity and light blue to negative polarity. The interpretation of the seismic data has primarily used the

Schlumberger™ Petrel software. Interpretation has been carried out using a manually picked fine interpretation grid; followed by auto-tracking where there is a good quality surface

4. Bottom Simulating Reflection (BSR)

Widespread BSR covers an area of 350 km^2 within a water depth range from 940 m to 1750 m. The BSR occurs at a depth below the seafloor that ranges from 104 m - 250 m, crossing the two slopes (Figure 3 & 4). The BSR is characrterized as (i) cross-cut the primary strata reflection and sub-parallel to the seabed; (ii) increase in depth with increasing water depth; (iii) blanking or reduction of seismic amplitude above the reflector; (iv) the reflector has reversed polarity to the seafloor and variable amplitude (High amplitude in the Low gradient slope and low amplitude in the High gradient slope); (v) pulled-up where fluid pipe go through it (Figure 3a).

The strength of the BSR is controlled by both the presence of gas hydrate above and free gas below. The existence of free gas below the BSR is considered for the primarily cause of BSR strength. Strong BSR associated with the Pliocene fan - channel complex system is located immediately underneath the BSR, is interpreted to be related to the presence of coarse grain sediment in the channels, which have higher porosity and thus store free gas, creating a high

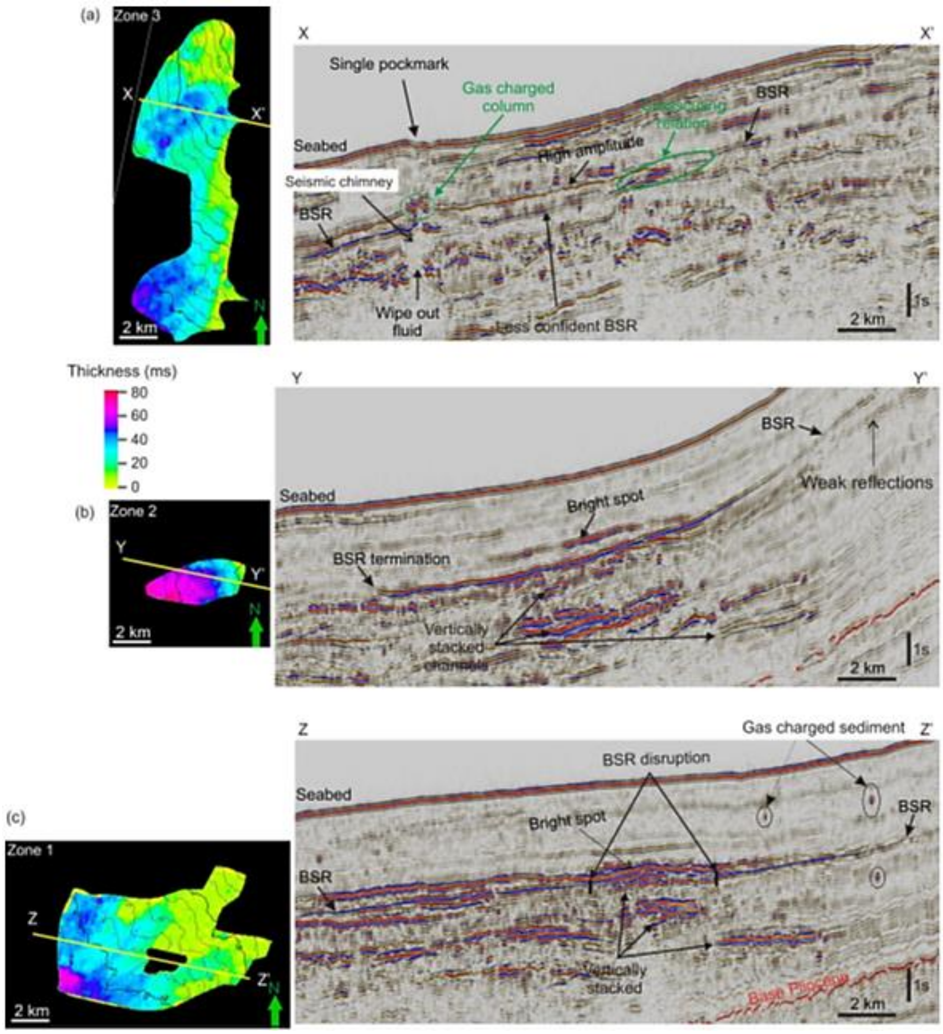

Figure 3. Seismic cross secions and thickness map showing the relationship between the high to bright amplitude reflections and the BSR in the three zones (1 to 3). They are all related with the fan - channel complex system which were highly developed. The high/bright amplitude reflections are c. 0 - 80 ms TWT above the BSR.

velocity contrast above and below the BSR. This results in a strong BSR. In contrast, the weak BSR observed in the High gradient slope is interpreted to be caused by the absence of porosity in the underlying sediment thus reducing the velocity contrast (Figure 4) (Le, et al., 2015).

5. Amplitude anomalies associated with BSR

5.1. The Bright spots within the GHSZ

Bright spots or high amplitude reflections are observed above the BSR when it crosscuts the other reflectors and the amplitude of the horizon above the BSR increases (Figure 3). Bright spots often appear to be bounded by the BSR on one side; the other side is marked by either an abrupt termination or decrease in amplitude. They have been mapped in three zones (Zone 1 to 3), with the area of 60 km^2, 8 km^2 and 84 km^2, respectively, and appear dominantly in the area that have channel-fan development (Figure 3) see more in (Le, et al., 2015). The bright spots within the Gas Hydrate Stable Zone (GHSZ) are interpreted to be discrete layers of highly concentrated hydrate formed by upward migration of gas (Hornbach et al., 2003). The bright spots are found near the top of the Pliocene fan - channel complex system (Figure 3). This indicates the presence of porous sandstones. The sands are interpreted to pinch out toward the higher slope, resulting in loss of bright spots (Figure 3b and Figure 3c).

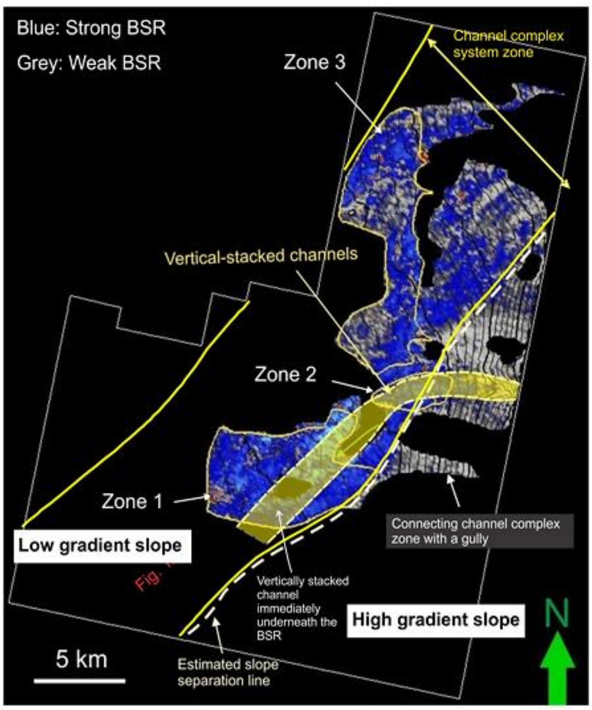

Figure 4. Bright spots have been mapped in three zones from zone 1 to zone 3, with the area of of 60 km^2, 8 km^2 and 84 km^2, respectively, and appear dominantly in the area that have channel-fan development.

5.2. BSR pull-up

The BSR shift upward locally when it is cross-cut by a pipe (Figure 3a). This pull-up phenomena is quite common in the study area where there are lots of pipes and pockmarks have been observed (Le, et al., 2015). The BSR is deflected upward directly beneath the pockmark depressions, suggesting a localized positive heat flow anomaly. Rising local temperature will change the P-T stable condition of gas hydrate and shift the BSR upward.

6. Discussion

6.1. Widespread of BSR in the study area

The BSR is considered to be both a direct hydrocarbon indicator (DHI) and a direct thermal indicator (DTI) (Grauls 2001). It marks the base of the gas hydrate stability zone therefore BSR distribution will give direct constrain for the gas hydrate occurrence. Gas hydrate development along the continental margin is controlled by the presence of sufficient methane in shallow sediments. Widespread occurrence of gas hydrates detected in the study area suggests that a large amount of gas has been generated in the basin.

Gas may be derived from in-situ biogenic gas or from the thermogenic alteration of organic matters. In general, biogenic gas are produced at the depth of less than 600 m, about the depth of Pliocene in this study area. However, the evidence of long scale pipe rooting from the deeper sequence that is Miocene in age and terminated in Pleistocene indicates thermal gas are generated at depth c. 1100 m and trapped in the mid Miocene fan lobe system (Le, et al., 2015). This suggests that thermogenic gas may also present in the Pliocene/Pleistocene interval and turned into gas hydrate at specific temperature and pressure.

6.2. Bright amplitude anomalies associated with the channel - fan system in the Low gradient slope

High to bright amplitude reflection has been widespread observed above the BSR, in the blanking zone. They only can be mapped in the location of channel- fan complex (Figure 4). The occurrence of channel-fan complex with high amplitude reflections is interpreted to be porous sandstone. Those porous sandstone may have higher capacity to store more upward migration gas. The gas bearing sandstone will turn into gas hydrate with higher concentration of gas hydrate compare with the surrounding sediment. Higher concentration of hydrate will result in higher Vp velocity, such as with 30% of hydrate saturation, Vp velocity will be 2245 m/s (Ojha and Sain 2007), creating the bright spots above the BSR.

The bright spots in the study are observed in three zones which are also coincidence with the area of channel-fan complex developed from Pliocene to Pleistocene which supports for the the above explanation of the bright spots occurrence.

6.3. BSR pull up anomalies

Pull up of the BSR is mostly observed associated with single pockmarks (Figure 3a). BSR pull-up phenomenon can be produced by a number of processes. The seismic velocity pull up indicates local high velocity anomalies BSR and plumbing system directly above the reflector affected, producing apparent highs. This would be produced by a reduction in porosity, such as by carbonate cemented sandstones or a high concentration of gas hydrate above the BSR, both of which would result in high velocities (Hornbach, et al., 2003, Gay, et al., 2007). However, BSR elevation could be related to local variations of the thermal condition due to the fluid movement (focused fluids) upwards (Gay, et al., 2007). Advection of heat through focused fluid flow causes local higher temperatures as a result; the BSR is stable bellow 25^{o}C at shallower depths.

7. Conclusions

Widespread BSR has been mapped in the study area, covering an area of at least 350 km^2, in the water depth from 940 m to 1750 m. The occrence of BSR indicates large amount of gas has been generated and turned into gas hydrate at appropriate temperature and pressure.

The bright spots above the BSR in the blanking zone has been observed and mapped in three zone with the area of 60 km^2, 8 km^2 and 84 km^2. They are associated with the area that developed the channel-fan complex and is interpreted to be porous channel sand can be trapped more free gas to create a higher concentration of gas hydrate layers, result in the bright spots abundance. Another amplitude anomalies is also detected as pull-up BSR. The BSR is deflected upward directly beneath the pockmark depressions and within the pipe, suggesting for the local positive heat flow anomaly in the study area.

Acknowledgements

This work has been done as part of the PhD project funded by Vietnam government and the Manchester University. Many thanks to the Sterling Energy for the high quality data set and all of the sponsorships.

References

Badley, M. E., 1985. Practical seismic interpretation. *International Human Resources*, Boston. 266 pp.

Berndt, C., Bünz, S., Clayton, T., Mienert, J., and Saunders, M., 2004. Seismic character of bottom simulating reflectors: examples from the mid-Norwegian margin. *Marine and Petroleum Geology* 21 (6)(6): 723-733.

Calvès, G., Huuse, M., Schwab, A., and Clift, P., 2008. Three-dimensional seismic analysis of high-amplitude anomalies in the shallow subsurface of the Northern Indus Fan: Sedimentary and/or fluid origin. *Journal of Geophysical Research* 113(B11): B11103.

Cunningham, R. and Lindholm, R. M., 2000. Seismic evidence for widespread gas hydrate formation, offshore West Africa. *AAPG Memoir* 73, 93-105.

Davison, I., 1999. Tectonics and hydrocarbon distribution along the Brazilian South Atlantic margin. *Geological Society London Special Publications* 153(1): 133.

Davison, I., 2007. Geology and tectonics of the

South Atlantic Brazilian salt basins. *Deformation of the Continental Crust: The Legacy of Mike Coward*. 345-359.

De Matos, R. M. D., 1992. The northeast Brazilian rift system. *Tectonics* 11, No. 4(4): 766-791.

Dillon, W. P., Lee, M. W., and Coleman, D. F., 1994. Identification of marine hydrates in situ and their distribution off the Atlantic Coast of the United States. *Natural Gas Hydrates* 715(1 Natural Gas Hydrates): 364-380.

Gay, A., Lopez, M., Berndt, C., and Seranne, M., 2007. Geological controls on focused fluid flow associated with seafloor seeps in the Lower Congo Basin. *Marine Geology* 244 (1-4)(1-4): 68-92.

Grauls, D., 2001. Gas hydrates: importance and applications in petroleum exploration. *Marine and Petroleum Geology* 18 (4)(4): 519-523.

Hornbach, M. J., Holbrook, W. S., Gorman, A. R., Hackwith, K. L., Lizarralde, D., and Pecher, I., 2003. Direct seismic detection of methane hydrate on the Blake Ridge. *Geophysics* 68(1): 92-100.

Hornbach, M. J., Saffer, D. M., Holbrook, W. S., Van Avendonk, H. J. A., and Gorman, A. R., 2008. Three-dimensional seismic imaging of the Blake Ridge methane hydrate province: Evidence for large, concentrated zones of gas hydrate and morphologically driven advection. *Journal of Geophysical Research* 113(B7): B07101, 07115pp.

Kvenvolden, K. A. and Barnard, L. A., 1983. Hydrates of natural gas in continental margins. Studies in Continental Margin Geology, *AAPG Memoir* 43, 6353-5940.

Kvenvolden, K. A., Ginsburg, G. D., and Soloviev, V. A., 1993. Worldwide distribution of subaquatic gas hydrates. *Geo-Marine Letters* 13(1): 32-40.

Lawrence, S. R., Munday, S., and Bray, R., 2002. Regional geology and geophysics of the eastern Gulf of Guinea (Niger Delta to Rio Muni). *The Leading Edge* 21: 1112.

Le, A. N., Huuse, M., Redfern, J., Gawthorpe, R. L., and Irving, D., 2015. Seismic characterization of a Bottom Simulating Reflection (BSR) and plumbing system of the Cameroon margin, offshore West Africa. *Marine and Petroleum Geology* 68: 629-647.

Meyers, J. B., Rosendahl, B. R., and Austin, J. A., 1996a. Deep-penetrating MCS images of the South Gabon Basin: Implications for rift tectonics and post-breakup salt remobilization. *Basin Research* 8(1): 65-84.

Ojha, M. and Sain, K., 2007. Seismic velocities and quantification of gas-hydrates from AVA modeling in the western continental margin of India. *Marine Geophysical Researches* 28(2): 101-107.

Pauken, R. J., 1992. Sanaga sub field, offshore Cameroon, West Africa. Gian oil and gas field of the decade 1978-1988,. M. J. Halbouty. Mobil exploration ventures Co Texas, *AAPG Memories* 54: 217-230.

Rosendahl, B. R. and Groschel-Becker, H., 1999. Deep seismic structure of the continental margin in the Gulf of Guinea: a summary report. *Geological Society*, London, Special Publications 153: 75-83.

Sloan, E. D., 1998. Clathrate hydrates of natural gases. 2nd ed., CRC Press, Boca Raton, Fla.

Turner, J. P., 1995. Gravity-Driven Structures And Rift Basin Evolution - Rio-Muni Basin, Offshore Equatorial West-Africa. *AAPG Bulletin-American Association of Petroleum Geologists* 79(8): 1138-1158.