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SEDIMENTARY RESPONSE TO SALT RELATED TECTONICS AND ITS HAZARDS IN A HYDROCARBON FIELD, KWANZA BASIN, ANGOLA

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Abstract

The presence of extensive Aptian salt basin underlying the south Atlantic passive margin has in so many ways influenced the pattern of tectonics and its sedimentary response during the Cretaceous. Aptian salt in the Kwanza Basin was deposited in two sub-basins separated by a margin-parallel chain of platforms on which salt is either small or absent. Salt withdrawal and dissolution during the mid-Cretaceous led to the formation of a series of north-south trending salt ridges and associated depo-centres that provided, and controlled the accommodation space for the deposition of marine sediments. The post-salt marine deposition was controlled by the subsidence of sediment packages into synforms between salt walls initiated by extension of the underlying Aptian salt. Thermal subsidence was locally enhanced by halokinesis in the vicinity of the salt horizon, creating sediment down-building which led to the initiation of prominent salt domes. These thick salt-bearing successions in the basin form sealing hydrocarbon traps with abnormally high fluid pressures (AHFP). Forecasting of AHFP in evaporates is difficult due to the absence of transition zones in salts. Such poor pressure forecast and risk evaluation in an oil field can result in well kicks and subsequent blow-outs. Better seismic imaging and interpretation of the subsurface reduces the risk of possible blow-out hazard in such hydrocarbon field.

Keywords*: Salt-related tectonics; sedimentary response; abnormal fluid pressure; blow-out*

1. Introduction

The Kwanza Basin (south Atlantic passive margin) is characterized by predominantly Cretaceous sedimentary section with both pre-salt lacustrine and post-salt marine sediments. A thick section of Aptian salt divides the lacustrine section from the overlying marine section. The good seismic image of the Kwanza Basin allows a completely chaotic and bumpy horizon to be displayed. Careful seismic interpretation revealed a series of salt ridges and their associated depo-centres that provided the accommodation space for marine sediments. The basin is more than 300 km wide, from the onshore exposures of the Precambrian Congo craton to the Angola abyssal plain [1].

This paper focuses on the sedimentary response to the Aptian salt- related tectonics in the Kwanza Basin (Fig. 1) and the abnormally high fluid pressure associated with thick salt sequences that form sealing complexes in many oil regions. A better understanding of these salt related seals in a basin helps to reduce the risk of well-bore kicks and eventual blow-outs in the oil field.

2. Regional geological settings

The Kwanza Basin was formed during the Early Cretaceous opening of the South Atlantic Ocean [1-3]. The basin's fill started with a continental regime in the early Cretaceous (Neocomian) and ended in Tertiary with the marine regime (Fig. 2).

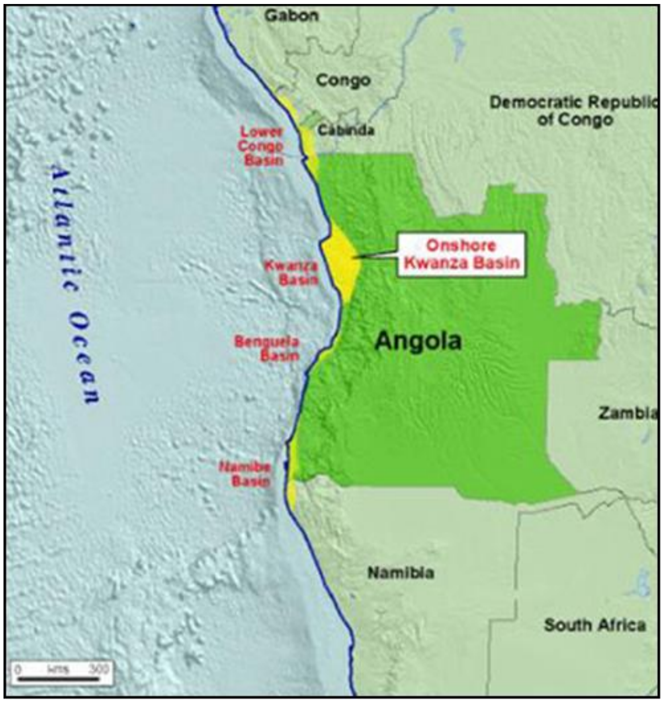

Fig.1. Map of Africa showing the location of Kwanza Basin in the south Atlantic passive margin [11]

Early Cretaceous time witnessed the splitting of the huge continent named Pangea, which gave rise to two continents known as South America and Africa. This break up process corresponds to the rifting phase. Huc [4] stated that this separation was initiated by the thinning and dislocation of mainly granitic crust. The crustal thinning was caused by the local uprise of partially melted igneous rocks from underlying asthenosphere. The resulting rifts were then occupied by large lakes such as the East Lakes of the East African Rift, and thick lacustrine sediments were deposited in those lakes.

The next process was an ocean opening in which the asthenospheric magma began to be emplaced at the mid-oceanic ridge, where basaltic oceanic magma was generated to make up the floor of the ocean that is being formed [5].

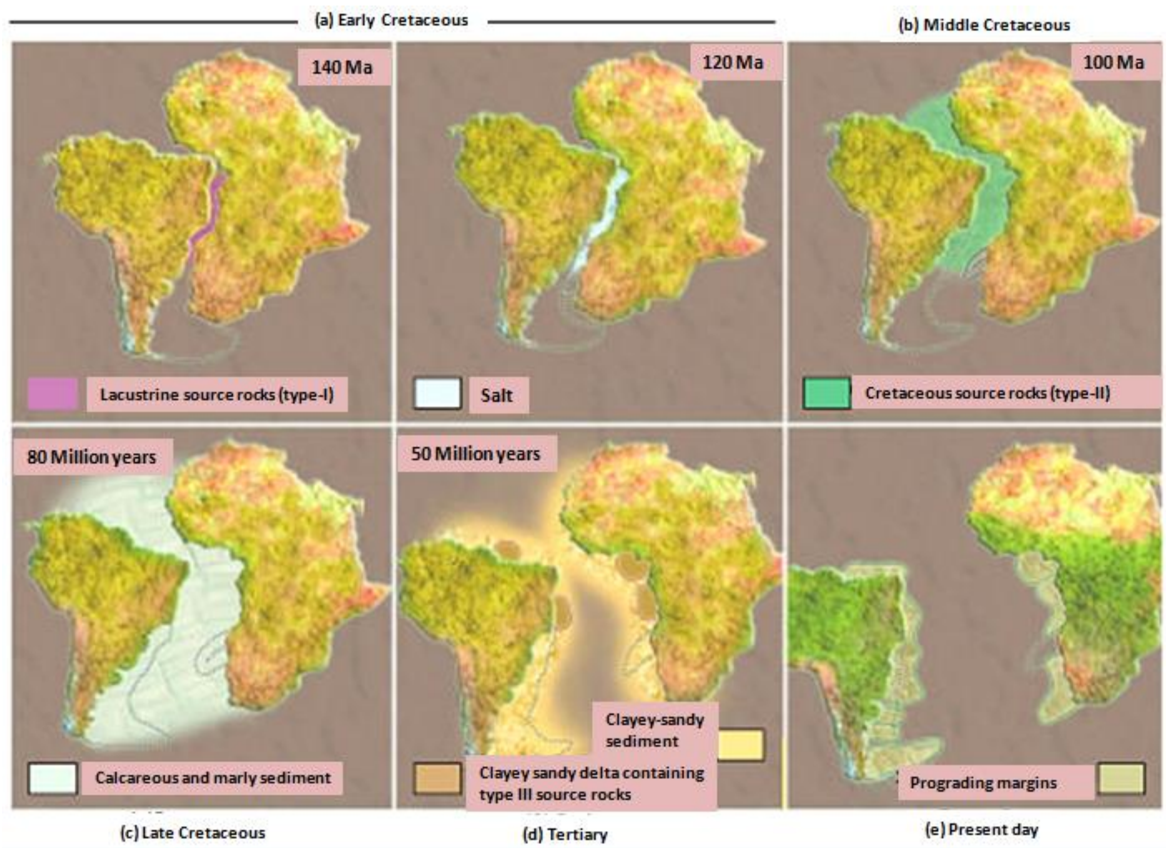

Fig.2.a-e. Schematic evolution of coastal basin in areas around south Atlantic passive *margin (modified from [4])*

This is the drift phase. As the ocean basin continues to open, the oldest oceanic crust, close to the continental margins, become progressively colder with increasing density which led to warping under the effect of their weight. During the opening process, in Aptian, the pathway gave way to oceanic basin of irregular depth and moderate width. The basin underwent periodic isolation from the ocean circulation which then started evaporation process resulting in the accumulation of large quantities of salt. These salt layers covered the pre-salt lacustrine sediments. The confinement of the differ-rent sub-basins at that time led to the regional deposition of organic rich sediments. The ope-ning of the ocean still continued in the late Cretaceous. So the ocean became ventilated, thus interrupting the conditions favourable for the accumulation of organic rich source rocks [5]. In the Tertiary, thick layers of terrigenous sediments were accumulated as deltas, to fill the available space produced by the down warping of the margin.

3. Methodology

The study of the "chaotic bump" seismic volume involves the review of the geological settings of the Kwanza Basin from some related published studies. The 3-D seismic volume (Vertical range: - 594 ms to -2488 ms) was then loaded on Petrel software for 3D geological interpretation (Fig.3). It is a methodology-based approach, which specifically involves data management, seismic data viewing and structural interpretation. These specific actions were achieved using the imaging and interpretations of terminations and horizons, faults, facies, geobodies (salt, channels, mud diapirs) etc. The top and bottom horizons of the volume were picked and gridded to observe the topographic lows and highs. Then, the seismic volume was realized and most of the attributes (chaos, variance with smoothing, phase shift, RMS amplitude, instantaneous frequency, local structural dip and rendered volume) and surface picks were done on a cropped volume with a vertical range of -756 ms to -1424 ms. An analogue basin with similar sedimentary response to salt-related tectonics was used to analyze and interpret the data from Kwanza Basin. The seismic reflections are dull and discontinuous (chaotic) in some places, thereby making it difficult to pick the horizons as continuous reflectors. As a result, horizon misties were encountered which necessitated the imposition of geologic interpretations on the seismic using manual tracking method.

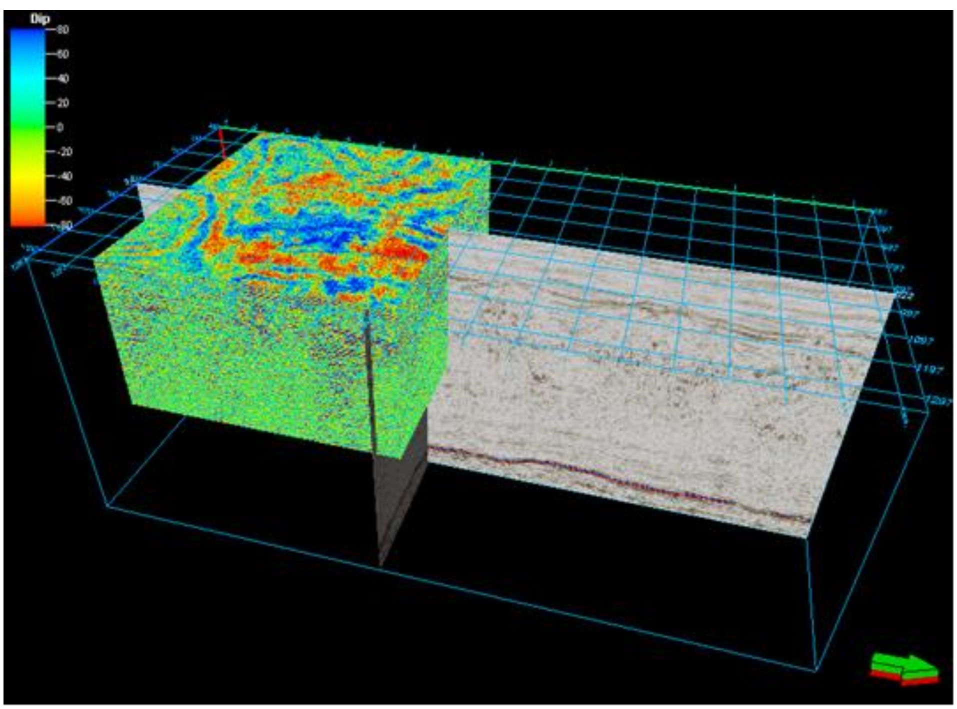

Fig.3. The raw-data (3D-Seismic Volume – Inline and Xline with a cropped volume of the study area)

4. Results and discussions

The result of the seismic volume shows a series of sediment packages 'pods' that have subsided into synforms (furrows) between salt walls (Figs. 4 & 5), initiated by the extension of the underlying Aptian salt.

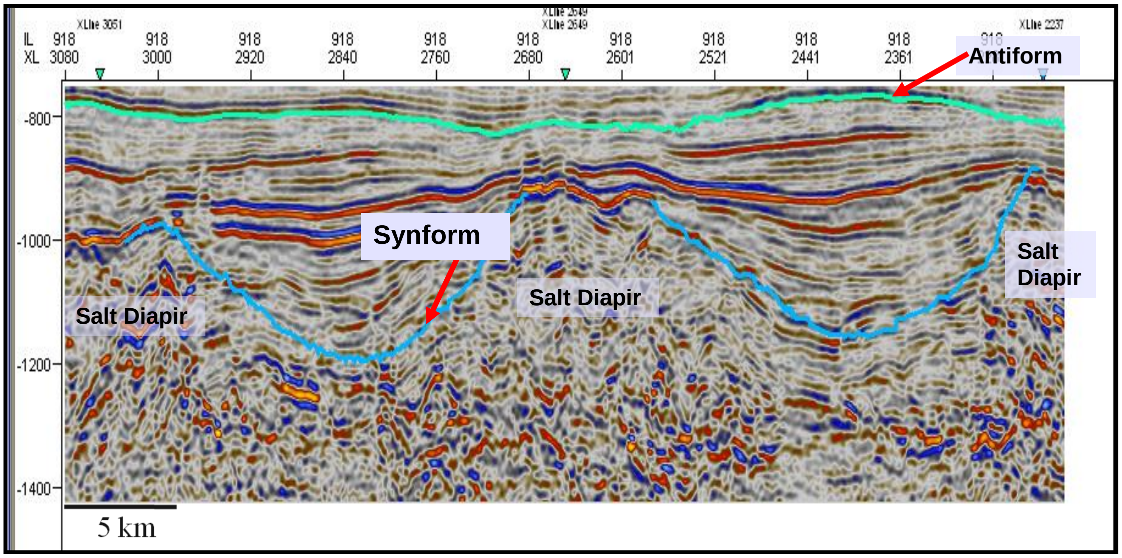

Fig.4. In-Line 918 showing the structural styles in the "Chaotic_Bumps" seismic volume

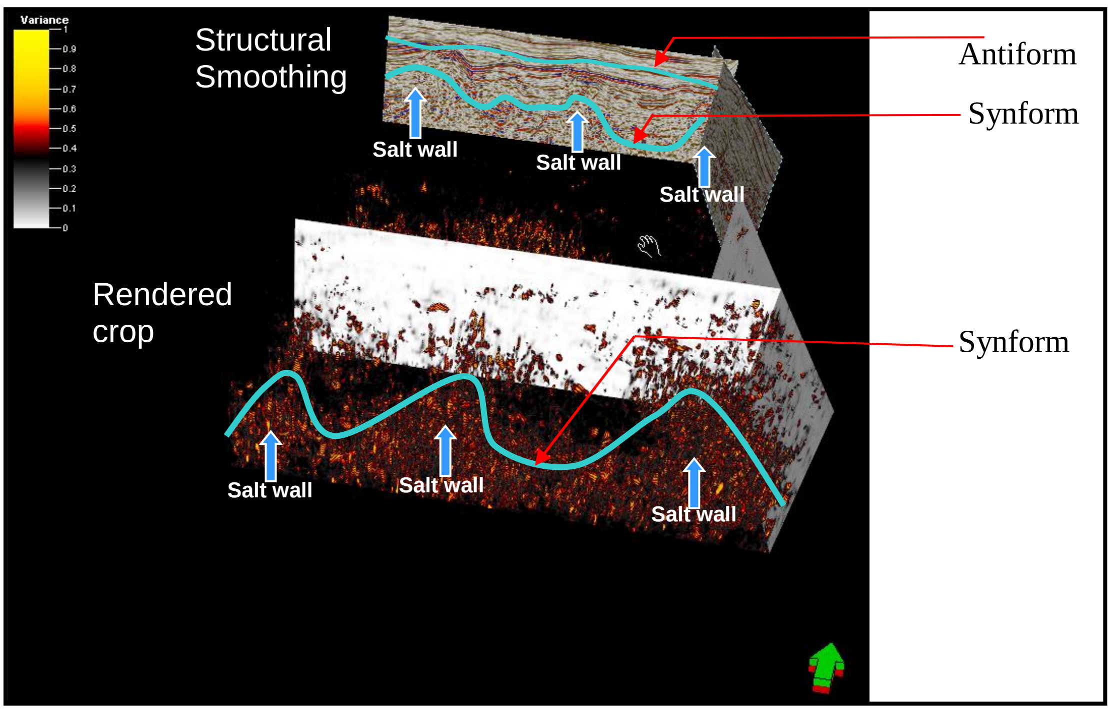

Fig.5. Rendered crop volume and structural smoothing Inline/Xline, showing the synform and antiform structural style and the salt dome withdrawal

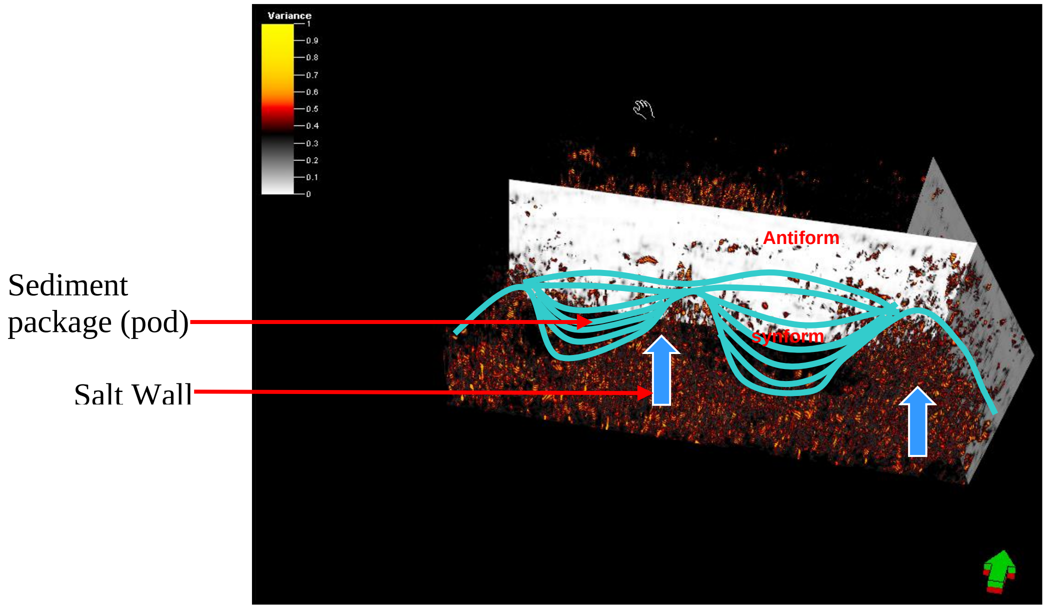

Fig.6. Rendered crop volume with Inline/Xline, showing sediment packages (pods) between chaotic salt walls

This observed sediment synforms and salt walls (antiforms) confirm the model for the evolution of salt walls and sediments by Hodgson et al. [6]. Such salt tectonics is strictly tied to regional extensional deformation because salt is weak and does not undergo compaction. In this kind of setting, salts can rapidly rise to the surface through the space created by thinning and separation of the fault blocks by passive diapirism and spread over the sediments as allochthonous salts. The salt observed in this study did not form sheets, but formed salt walls that separated the sediment pods. The topographic lows are infilled with post - salt marine sediments which progressively displaced the salt under the pods (Fig. 5). The pod subsidence ceased when the salt has been completely displaced (salt welds) and the pods no longer provide accommodation at the surface. This observation agrees with those of Jackson and Talbot [8], in their work in the Gulf of Mexico, where these grounding surfaces were also observed. The displacement of these salts was as a result of salt withdrawal downdip; to build other salt walls as crustal extension continues. Salt dissolution could also cause salt withdrawal in this type of basin [9]. As the salt continued to withdraw downdip, the old pods became relative highs as synforms form over collapsing salt walls. Series of these sediments as seen in Figures 4-6 form bumpy horizons, with the antiforms having the usual trapping attributes of anticlines.

4.1. Hazards associated with salt-bearing sequences

Thick salt-bearing sequences like those encountered in the study area form sealing complexes in many oil and gas regions of the world. Such sedimentary basins have accumulations of hydrocarbons and brine with abnormally high fluid pressure (AHFP) [6-7]. Mapping of these evaporate sequences and prediction of their over-pressured intervals are indeed a challenging problem. This is because of the absence of transition zones in evaporates, unlike what is obtained in typical clastic seals. As a result, there are no indications of approaching over-pressured intervals, as can be observed in clastics. So, reservoir pressure within these formations changes abruptly, with no gradual transition [10]). Another complicating factor in such evaporate seals is their non-uniform gas saturation, which gives an erroneous information on the amount of gas build up within the salt interval [10].

Over-pressured fluid accumulations are usually encountered immediately underneath the salt section, which is drilled easily and at a high rate. It is rather very difficult in such an environment to observe an increase in drilling rate caused by a decrease in the rock strength or by a decrease in differential pressure between the borehole and the reservoir.

Because of the peculiar physical and chemical nature of salts relative to the surrounding sediments, all indirect techniques should be utilized in the abnormal pressure forecast. Such indirect methods must afford to establish patterns of the geologic evolution of regional or local structures and associated hydrocarbon accumulations. For reliable AHFP forecast, it is necessary to delineate the salt plugs, walls, and sheets, with their corresponding depths using 3-D seismic interpretation software as applied in this study. This will enable the wellsite geologist to apply appropriate mud pressure within these delineated intervals to keep the formation fluid in check during drilling. The predictive precursors of the AHFP include the evidence of vertical gas migration along flanks of salt plugs and associated fracture zones (and faults); the appearance of "gas clay" in circulating mud (i.e., plastic greenish-grey and brown clay with gas bubbles).

Currently, the available techniques for the identification of over-pressured zone are based on well logs obtained during drilling (MWD). This means that an abnormally high pressure zone is identified within the localized vertical wellbore; with an unknown areal extent. This prevents the undertaking of protective measures in the nearby wells drilled subsequently. As a result, unexpected abnormal high pressure can be encountered at different stages of hydrocarbon exploration and development. However, we can mitigate this problem if a detailed seismic analysis has been undertaken to identify the salt bodies and their geometries. For instance, where the salt forms large canopies – there is a higher tendency for anomalously high fluid pressure beneath; and if it is more of salt walls – the impact may be less than that of canopy although that could lead to compartmentalization of pressure. In essence, by accurately analysing the architecture and geometry of the salt bodies, in addition to delineating their depth of occurrence as we have done in this study; can serve as the first step in predicting the potential hazards.

5. Conclusion

The salt- related tectonics in the Kwanza Basin is principally influenced by crustal extension, which allows salt to flow laterally from areas of high load to areas of lower load, restricted only by friction on the edges of the salt and the weight of the overburden. This load gradient was as a result of the regional extension, lateral variations in the weight of overburden and temperature gradients in salts which cause dissolution and subsequent salt withdrawal.

Aptian salt was progressively displaced from under the sediment pod to form salt walls and ridges, while the intervening topographic lows were filled up with marine sediments. Because these salt layers formed efficient regional decollements, they, therefore, controlled the style of sedimentation and deformation in the Kwanza Basin. On the other hand, thick salt-bearing sequences like that in the Kwanza Basin form hydrocarbon sealing complexes with abnormally high fluid pressure. Proper delineation of these salt intervals in a basin leads to better forecasting of the subsurface pressure build up, which invariably reduces the risk of well kicks and subsequent blow-out. This requires special seismic imaging techniques to enhance better high pressure forecast.

References

[1] Hudec MR, and Jackson MPA. 2004. Regional restoration across the Kwanza Basin, Angola: Salt tectonics triggered by repeated uplift of a metastable passive margin. AAPG Bulletin, 2004; 88(7) 971-990.

[2] Brink AH. Petroleum geology of Gabon basin: AAPG Bulletin, 1974; 58: 216-235.

[3] Karner GD, Driscoll NW, McGinnis JP, Brumbaugh WD, and Cameron NR. Tectonic significance of syn-rift sediment packages across the Gabon–Cabinda continental margin. Marine and Petroleum Geology, 1997; 14: 973-1000.

[4] Huc AY. Petroleum in the South Atlantic. Oil and Gas Science Technol. Rev. IFP, 2004; 59(3): 243-253.

[5] Nombo-Makaya NL, and Han CH. 2009. Pre-Salt Petroleum System of Vandji-Conkouati Structure (Lower Congo Basin), Republic of Congo. Research Journal of Applied Sciences, 2009; 4(3): 101-107.

[6] Hodgson NA, Farnsworth J, and Fraser AJ. Salt-related tectonics, Sedimentation and hydrocarbon plays in the Central Graben, North Sea, UKCS. *In:* R. F. P. Hardman (ed.) 1992. Exploration Britain: Geological insights for the next decade. Geological Society Special Publication, 69:31-63.

[7] Zilberman VI, Serebryakov VA, Gorfunkel MV, Chilingar GV, and Robertson-JR JO. Prediction of Abnormally High Pressure in Petroliferous Salt-bearing Sections. Journal of Petroleum Science & Engineering, 2001; 29(1):17-27.

[8] Jackson MPA, and Cramez C. Seismic recognition of salt welds in salt tectonic regimes. Tenth Annual Research Conference, Gulf Coast Section, Society of Economic Paleontologists and Minerologists Foundation, Programs and Abstracts, 1989; 66-71.

[9] Jackson MPA, and Talbot CJ. Salt Canopies. Tenth Annual Research Conferene, Gulf Coast Section, Society of Economic Paleontologists and Minerologists Foundation. Programs and Abstracts, 1989;72-78.

[10] Hudec MR, and Jackson MPA. 2007. Terra infirma: Understanding salt tectonics. Earth Science reviews, 2007; 8 (1-2): 1-28.

[11] www.rpsgroup.com/Angola.aspx

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