THE SHELFAL COLLAPSE PLAY – A CASE STUDY FROM A PRODUCING FIELD IN THE NIGER DELTA, OFFSHORE NIGERIA

Ndianefo U.K., Bassey N.E., Onyido I.M.*

**Mobil Producing Nigeria Unlimited*

The Shelfal Collapse Play ranks as one of the least understood and understudied plays in the petroleum industry. Interestingly, this play has one of the most unique, distinguishable and predictable genetic process associations that translates to a potential set of very distinctive prospects comprising good quality reservoirs and traps, as clearly observed and described in the Abang and Oso fields, offshore Niger Delta. The collapse of a shallow marine prograding wedge rich with sandy deposits at the Oso Field, led to the emplacement of sand-rich gravity deposits in favorable trapping configurations at the Abang Field. Instability caused by high rates of sediment supply without commensurate accommodation downdip and consequent loading of shelf-edge deltaic sediments on a decollement surface or zone is one of the leading mechanisms of this type of shelfal collapse. Multiple depositional styles have been observed on seismic within the accommodation created by the collapse. They typically involve the deposition of slumps and slides recognized as concave upwards rafted geometries in cross-section, passing downdip into debris flow identified as mostly chaotic and transparent seismic facies, followed by a capping succession of turbiditic deposits recognized by channel map patterns on amplitude extractions. A case study from the Abang Field using seismic and well logs will throw more light on these clear identification criteria, which can be used in finding similar prospects within the geologic record. The resourceful nature of this play will be highlighted by the Abang wells which produce oil from both the turbiditic and debrite facies with end of field life recovery factor estimated to be between 0.35 and 0.60.

1.0 INTRODUCTION

Shelfal collapse plays have been rarely identified or described in the Niger Delta Basin. Where they have been identified, explored and exploited, they play host to significant amount of hydrocarbon reserves due to a favorable conflagration of play elements especially relating to charge, traps and reservoir presence.

Unlike the Niger Delta Basin, detailed published descriptions exist of shelf margin collapse events from other basins around the world (Almagor, 1980; Lee et al., 1991; Field et al., 1982; Edwards, 1990; Edwards, 1991; Normark and Gutmacher, 1988; Edwards, 2000). Of particular interest is the description of retrograde failed shelf margins by Edwards (2000). What is unique about his work is the detailed description of key features and genetic models of retrograde shelf margins (caused by collapse) using examples from the Northern Gulf Coast Basin (USA), thus providing an understanding of the genetic relationships and recognition criteria that makes the shelfal collapse play a prolific one. He summarized the paucity of data conundrum when he said – "relatively few publications have described features that are unmistakably of the type covered in this paper. This is partly because most recent published studies are regional in scope and posited that older publications did not recognize them as distinct feature." This regrettably remains the case today, especially in the Niger Delta Basin. For example, the Qua Iboe Shelf Collapse – a large regional scale shelfal collapse within the Niger Delta Basin covering about 6000 sq.km with more than six (6) billion barrels of Oil Originally in Place – has very little detailed description and recognition criteria (Krukrubo et al., 2013; Onwude et al., 2013) in the public domain. The paucity of published detailed descriptions of this collapse could be related to its very large-scale nature (spanning multiple fields), making it difficult to have a synthesized description of all the architectural elements within the collapse.

Our study will describe a much smaller Tortonian Shelfal Collapse Play (The Abang Shelfal Collapse) comprising the Abang Field Discovery in the Niger Delta Basin, offshore Nigeria (Figure1). We intend to use this study to highlight the genetic features within the Abang Collapse and to describe the unique trapping configurations possible with similar plays. Wells and production data will also be used to highlight how prolific the deposits that constitute the reservoirs are. Ultimately, these observations can be scaled and used as analogues in similar or larger regional studies.

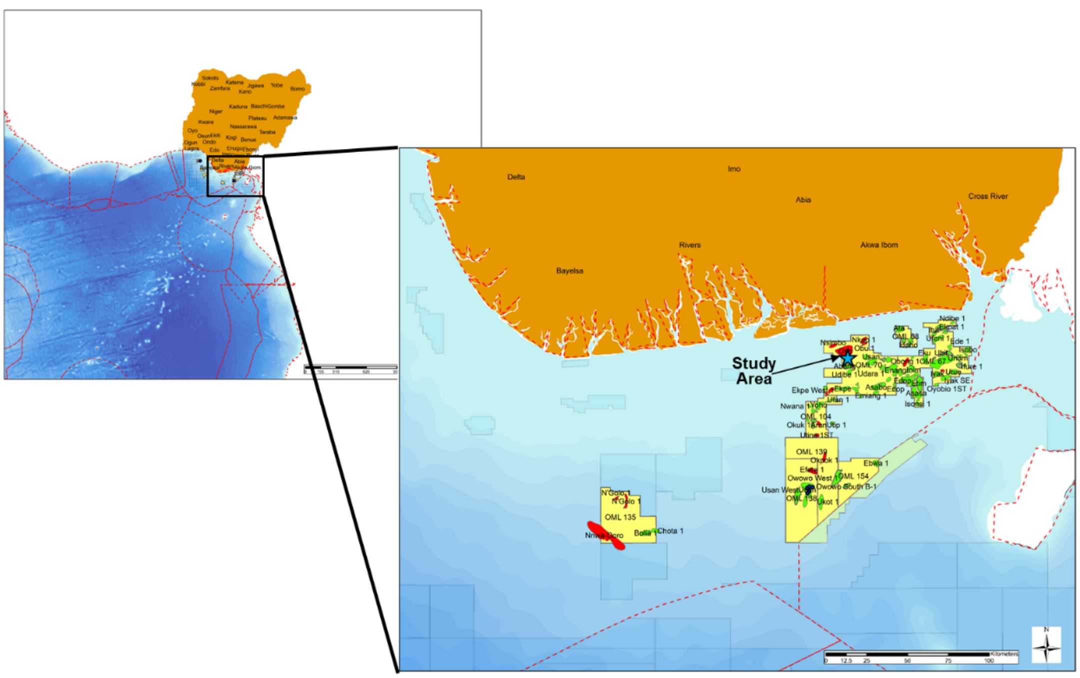


Figure 1: Location Map showing the study area location within the MPN-JV Acreage, off the coast of Nigeria

2.0 GEOLOGY BACKGROUND

The Tertiary Niger Delta is one of the world's largest and extremely prolific hydrocarbon province (Doust and Omatsola, 1990; Haack *et al*., 2000). It is listed in the "Top 25 Global Super Basins" with cumulative production and remaining oil and gas reserves exceeding five (5) billion barrels of oil equivalent (Sternbach, 2018) and overlies an area that covers over 256,000 sq.km (Adegoke et al., 2017).

The origin of the Niger Delta Basin is tied to the South Atlantic Rifting that led to the separation of the South American and African Plates (Short and Stauble, 1967; Whiteman, 1982; Doust and Omatsola, 1990). This led to the deposition of over 12 kilometers of thick Tertiary deltaic sediments characterized by prograding diachronous facies of continental to deep marine facies. These sediments are popularly grouped into 3 lithostratigraphic units (Dessauvagie, 1972; Reijers et. al., 1997; Whiteman, 1982) – the Akata Formation (marine mud, slope and basin floor turbidites), the Agbada Formation (Paralic - Shoreface, Lagoon, Distributary Channel, and Transgressive sands) and the Benin Formation (Continental Fluvial sands).

Rapid sedimentation (sediment supply >> accommodation) of the Benin and Agbada formations over the under-compacted and mobile shales facies of the Akata Formation is the leading cause of deformation within the delta (Adegoke et. al.,2017). This is evident in the abundance of structure building growth faults and shale diapers characteristic of syn-sedimentary deformation.

The rapid sedimentation rates, coupled with the dominance of fine-grained sediments towards the medial to distal portions of the delta has contributed to the formation of 3 main structural domains – the extensional, the translational and the contractional domains. In special cases, the instability associated with rapid sedimentation rates over the shelf-slope break can be the trigger for shelfal collapses which are sometimes aided by existing zones of weakness.

This study will focus on the Abang Shelfal Collapse (Figure 2) located within the extensional domain and of Tortonian age in the Abang-Oso Field area (Figure 3).

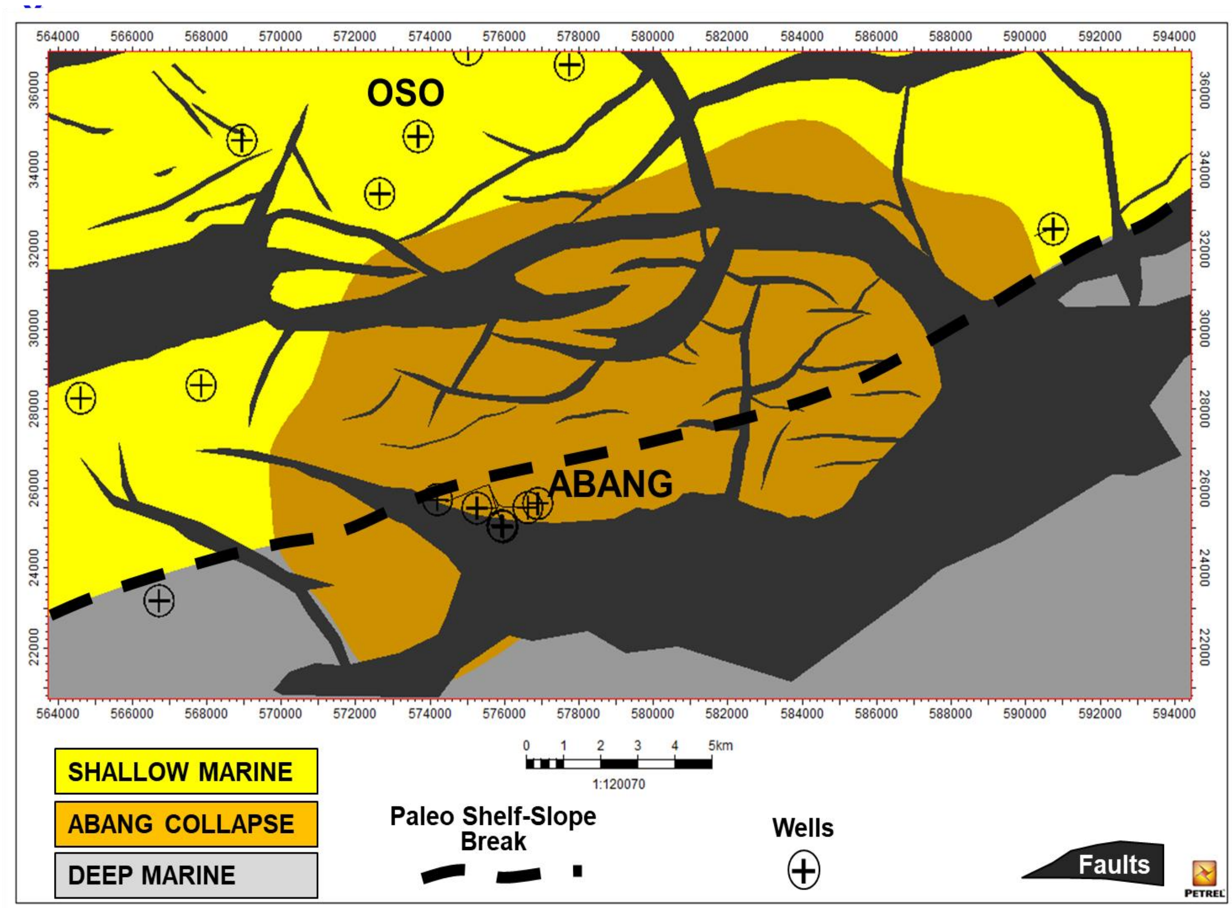


Figure 2: Outline of the Abang Shelfal Collapse

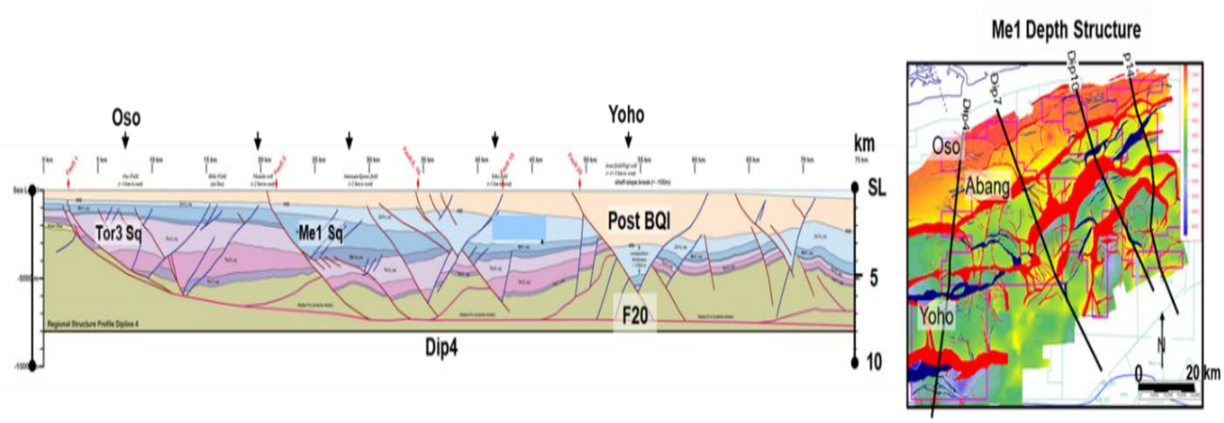


Figure 3: Dip-section highlighting the location of the Oso-Abang Area within the extensional domain

3.0 METHODOLOGY AND RECOGNITION CRITERIA

Several architectural elements have been identified within the Abang Collapse (Figure4), consistent with descriptions and observations made by Edwards (2000) from the Northern Gulf Coast Basins (the Hackberry Collapse in particular). Identification of these elements were aided by 3D seismic data, well and production data within the Abang-Oso area

Collapse

The Abang Collapse is a relatively small scale collapse that covers an approximate area of 85 sq.km. It occurred in the Tortonian and its base (a discontinuity surface) can be observed on 3D seismic data as mappable arcuate-shaped decollement or truncation surface (Figures 4 & 5). The decollement surface is generally coincident with the Tortonian 3 defined Sequence Boundary (Unconformity) in the downdip areas while its headscarp (Mosher et al., 2010) is easily recognizable as the boundary between semi-continuous/continuous reflectors (outside the Collapse) and chaotic/discontinuous reflectors (within the Collapse) (Figure 5). According to Edwards (2000), this is a key geometrical feature of a retrograde failed shelf margin and can sometimes be misinterpreted as a fault. The collapse is believed to have been initiated during the Tortonian Lowstand due to sediment loading within the Oso shelf edge delta, north of Abang. The high sedimentation (sand-rich) rate at Oso coupled with the presence of a possible plane of weakness, created conditions that allowed for the collapse of the Tortonian 3 (and possibly the Upper Tortonian 2) deposits. An approximate volume of thirty-nine cubic kilometers (39cu.km) of sand rich sediments is believed to have collapsed into the bathymetric low, and transported downdip via gravity flow processes.

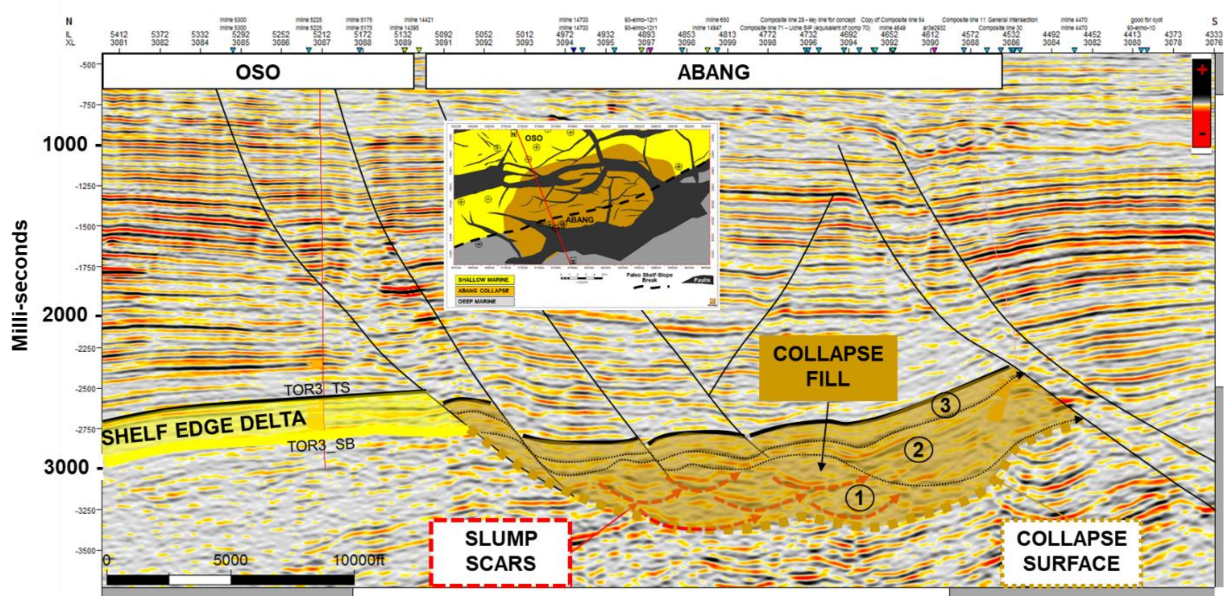


Figure 4: Seismic section highlighting the main architectural elements that make up the Abang Collapse (1. Slump Blocks; 2. Sandy Debrites; 3. Turbidites)

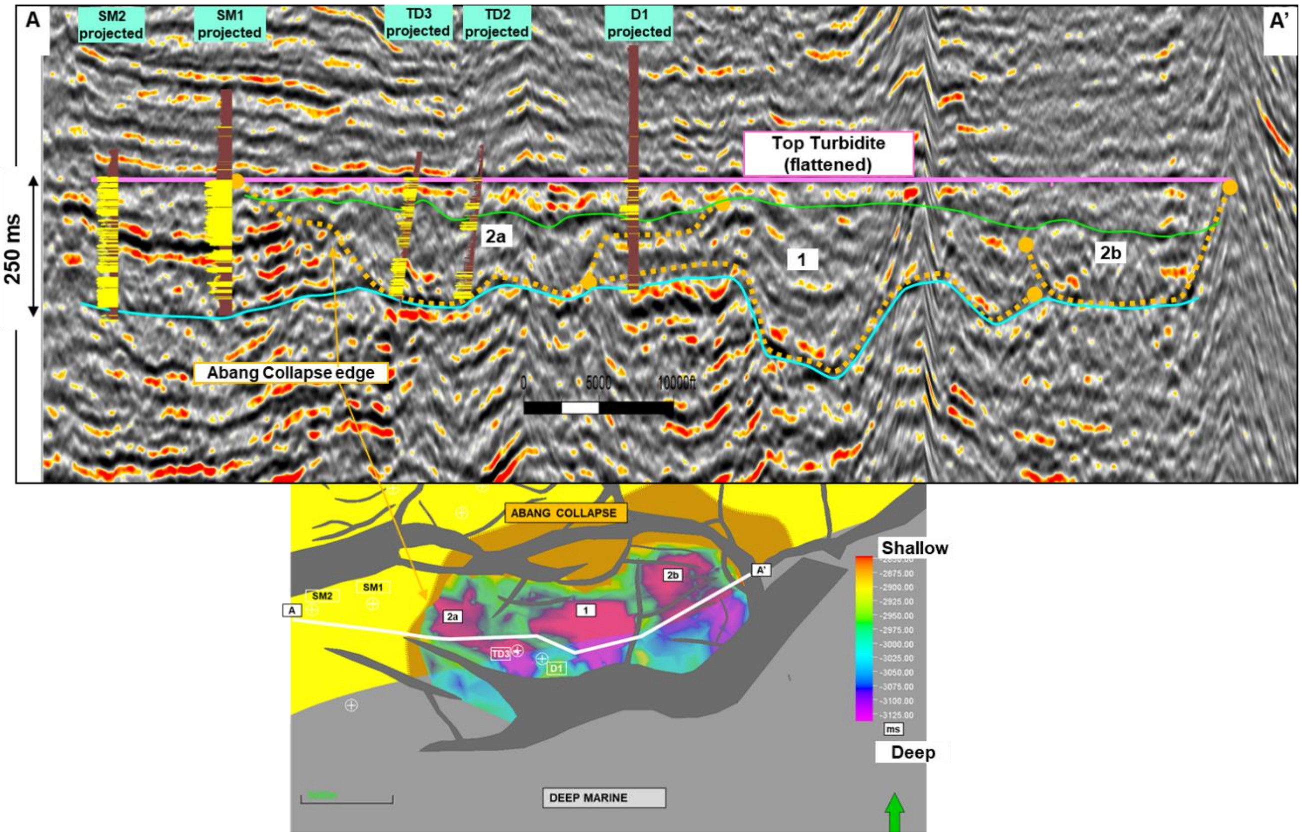


Figure 5: Seismic section showing boundary between semi-continuous/continuous reflectors (outside the Collapse) and chaotic/discontinuous reflectors (within the Collapse).

Rotational Slump Blocks

Rotational Slump blocks as defined by Easterbrook (1999) have been observed within the Abang Collapse manifesting as detached blocks of rock which slid along a concave upward slip surface with rotation about an axis parallel to the slope. These blocks are more prevalent closest to the headscarp (Mosher et al. 2010; Figure 4) and rest on the unconformity surface, and in some cases, on other slump blocks within the collapse. In general, the identified scarps indicate a stairstep pattern of displaced blocks. Though unpenetrated in Abang, it is believed that these slump blocks are sand-rich due to the close proximity to the paleo sand-rich shelf-edge delta that initiated the collapse at Oso, as well as the presence of sand prone facies in the downdip debris flow (Figure 4). Edwards (2000) described similar slump blocks in the Gulf Coast Basin as comprising shallow water deposits of interbedded sands and silty shales, supporting the plausible interpretation of a collapsed shelf edge delta.

Debris Flows

Downdip of the slumps, debris flows (Lowe, 1979) or slope aprons (Edwards, 2000) were deposited. These partially fluidized flows are a manifestation of the bathymetric low (deepwater) created by the evacuation of strata during the collapse. They can be erosive due to the high shear stress associated with their transportation and are observed to lie side by side with deepwater hemipelagic/pelagic deposits (Haughton et al., 2003; Amy and Talling, 2006; Sumner et al., 2009). In Abang, three major debris flow fairways have been observed (Fig. 6). These fairways were recognized via a combination of depositional profiles, seismic facies character and well data. Subtle thickness variations highlights fairways characterized by longitudinal thicks. On seismic they are characterized internally as transparent to chaotic seismic facies (Figure 5). Well data from one of the fairways confirm significant high quality sand deposition (Fig. 7). The considerable net sand deposition within the debris flow deposit in Abang is likely tied to the up-slope presence of a shallow marine sand-rich shelf edge delta at Oso (Fig. 4). This, in combination with the Lowstand setting at this time contributed to creating sediments fairways favorable to sand-rich deposits by gravity processes.

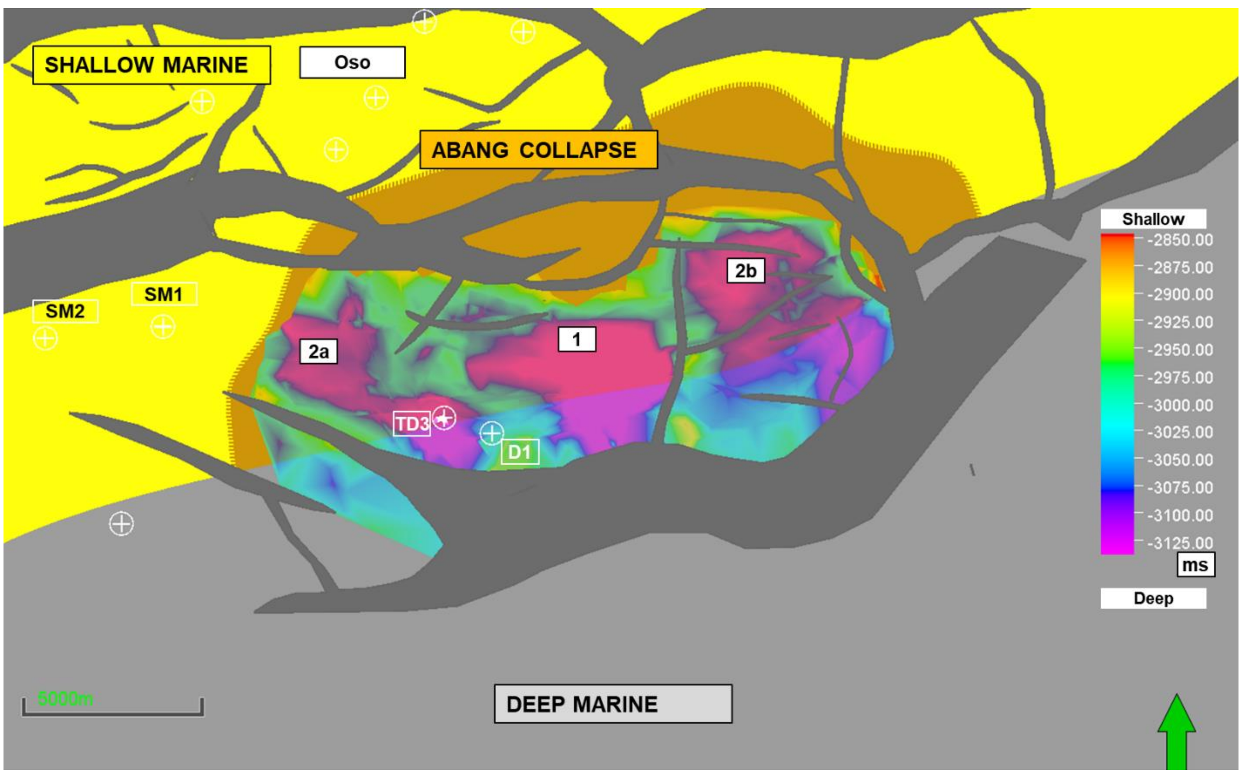


***Figure 6:** Depositional profile of the base of the debritic section interpreted on a flattened seismic volume shows 3 major fairways (1, 2a and 2b) within the Abang Collapse. Fairways 1 and 2b are unpenetrated and are the targets of near term delineation/exploration*

Turbidites

Increasing levels of fluidization led to the deposition of turbidites. On seismic, these deposits are generally layered above the slump and debris flow deposits and are characterized by relative bright amplitude semi-continuous to continuous reflections with clear linear amplitude trends originating from the headward portions of the collapse (Figure 7). It is also possible that, further down the depositional profile (outside the study area), the debris flow deposits transitions to turbidity flow deposits (Haughton et al., 2003; Amy and Talling, 2006; Sumner et al., 2009).

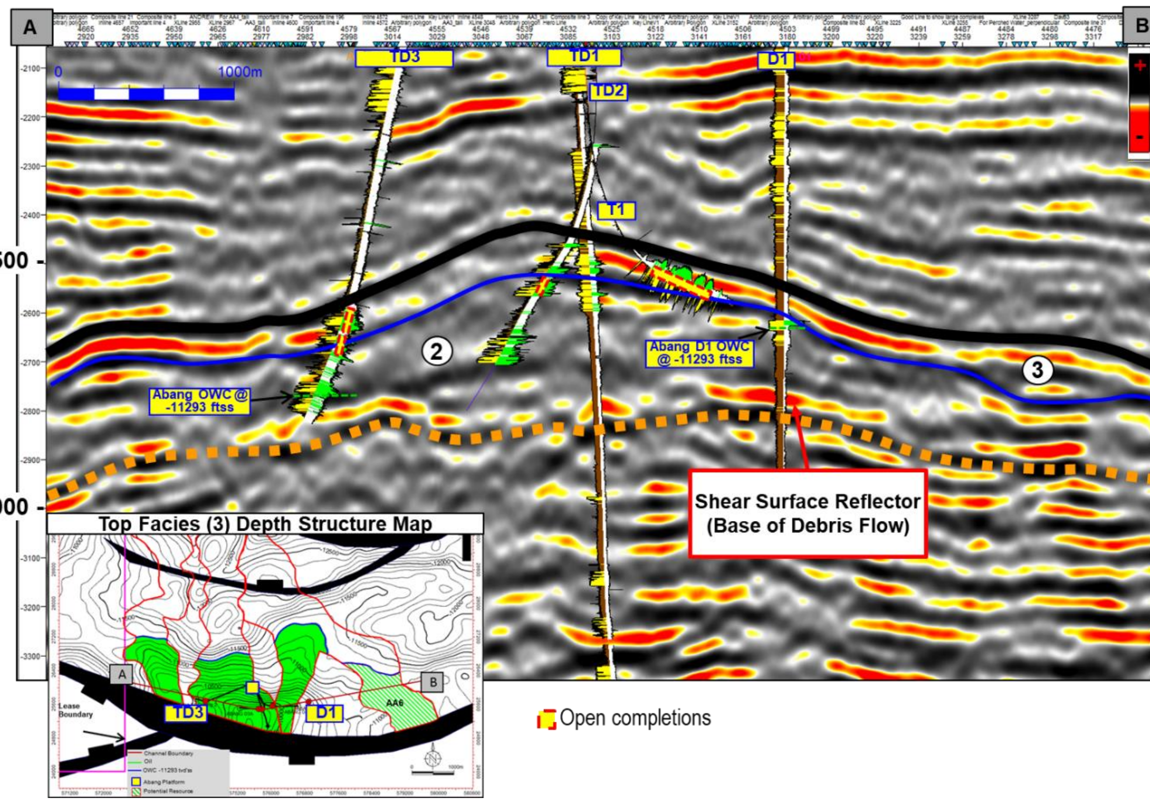


Figure 7: Seismic Section showing the transparent seismic facies nature of the sandy debris facies. Well data confirm presence of good quality sand in these transparent debritic facies (2. Sandy Debrite; 3. Turbidites). The Top Facies-3 depth map also shows the outlines of the turbidite facies fairways.

Shelf Deposits

Shelf edge delta progradation past the collapse region led to the deposition of shelfal/deltaic sediments above the Collapse fill. In Abang, this deposition coincides with the late stages of the Tortonian-3 Lowstand when relative sea-level was just beginning to rise. Eventually, the collapse deposits became capped by distal shelf shales on the Transgressive Systems Tract (TST). In Figure 4, the TOR3_TS marks the onset of shelfal deposition.

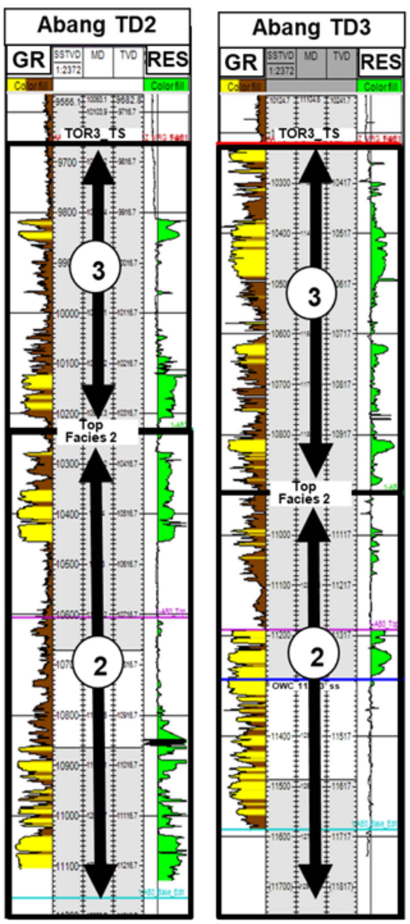
4.0 RESULTS

The Abang Field (STOOIP in excess of 120 Million Barrels of Oil) was discovered in 1992 and streamed in 2012.

Reservoir Characterization

As previously described, the Abang Collapse fill comprises slumps, overlain by sandy debrites and turbidites, eventually capped by dominantly muddy shelf deposits. The Abang reservoir comprises 2 main facies – the turbidite facies and the sandy debrite facies. These have reasonably good reservoir properties (Table 1). No penetration of the slump facies has been made yet, while the shelfal deposits are mostly shales.

Table 1: Reservoir properties of the producing facies in Abang



Reservoir Characteristics

	Facies 3 (Turbidites)	Facies 2 (Sandy Debrites)
Drive Mechanism	• Solution Gas • Weak aquifer support	• Solution Gas • Weak aquifer support
Avg NTG	0.60	0.62
Porosity (%)	27	25
Permeability (mD)	100-500	100-500
HC Saturation (%)	82	80

Trapping Configuration

The Abang Field is an updip, fault dependent 3 way closure with some lateral stratigraphic trapping observed locally (Figure 7). Pressure data suggest communication across the reservoir bearing sub-units. Contact information from the wells indicate that the hydrocarbon accumulation is constrained by the spill point of the shallowest reservoir sub-unit (Unit 3), though trapped (perched) water as witnessed in Well D1 can occur locally due to local topographic variations (Figure 7)

Field Production

3 production wells have been drilled till date (Fig. 7). The Abang T1 and TD2 wells are producing from turbidite facies (facies 3); while the Abang TD3 well is producing from the sandy debrite facies (facies 2). The Abang producers have good reservoir properties (Table 1), each producing an average of 7 thousand barrels of oil per day, with more producer wells planned in the near term.

5.0 CONCLUSION

The Abang Collapse presents a rare opportunity to study the geometry and characteristics of the architectural elements that constitute the fill of a relatively small-scale shelfal collapse. Shelfal collapse regions are filled with sediments that have very complex and variable facies distributions. The reason for shelfal collapses have been debated, but a plausible cause associated with this study is one due to shelfal instability from sediment loading and sudden failure by shelf edge deltas. In Abang, the collapse is an arcuate shaped depression that created a bathymetric low for sediments to be funneled via gravity processes (Figure 4).

The initial space is filled by arcuate shaped slump blocks, which transition to debris flow deposits, turbidites and then capped by shelfal sediments as the collapse is eventually filled up. The updip-depositional presence of correlate-able sandy shelf edge deltas (Oso) increases the likelihood of having significant sandy facies with good reservoir properties within the collapse. The Abang debris flow and turbidite facies have good reservoir properties. This is especially note-worthy for the debris flow deposits, whose transparent character on seismic might lead to a shaly facies mischaracterization. Under favorable trapping conditions, these sandy debrites and turbidite facies can hold significant hydrocarbon volumes as evidenced in Abang.

ACKNOWLEDGEMENTS

The authors wish to appreciate the Nigerian National Petroleum Corporation for approving the release of the material presented in this work as well as Mobil Producing Nigeria Unlimited for permission to present this work

REFERENCES

Adegoke, O. S., Oyebamiji, A. S., Edet, J. J., Osterloff, P. L., Ulu, O. K., (eds.) 2017. Cenozoic foraminifera and calcareous nannofossil biostratigraphy of the Niger Delta. Elsevier, Netherlands.

Almagor, G., 1980. Halokinetic deep-seated slumping on the Mediterranean Slope of Northern Sinai and Southern Israel. Mar. Geotech.; v. 4; p. 83-105.

Amy, L. A., and Talling, P. J., 2006. Anatomy of turbidites and linked debrites based on long distance (120 by 30 km) bed correlation, Marnoso Arenacea Formation, Northern Apennines, Italy. Sedimentology; v. 53; p. 161–212.

Dessauvagie, T. F. J., 1972. Biostratigraphy of the Odukpani (Cretaceous) Type Section, Nigeria. In: Dessauvagie, T. F. J., and Whiteman, A. J., (eds.); African Geology, Univ. Ibadan, Nigeria; p. 207-218.

Doust, H., and Omatsola, E., 1990, in, Edwards, J. D., and Santogrossi, P.A., eds. Divergent/passive margin basins, AAPG memoir 48: Tulsa, American Association of Petroleum Geologists; p. 239-248

Easterbrook, D. J., 1999. Surfaces, processes and landforms (2nd ed.). Prentice hall, ISBN 978-0138609580

Edwards, M. B., 1990. Stratigraphic analysis and reservoir prediction in the Eocence Yegua and Cook Mountain Formations of Texas and Louisiana. In: Sequence stratigraphy as an exploration tool: GCSSEPM Foundation, 11th Annual Res. Conf.; p. 151-164.

Edwards, M. B., 1991. Control of depositional environments, eustacy, and gravity and salt tectonics on sandstone distribution in an unstable shelf edge delta, Eocene Yegua Formation, Texas and Louisiana. Gulf Coast Association of Geological Societies Transactions; v. 41; p. 237-252.

Edwards, M. B., 2000. Origin and significance of retrograde failed shelf margins; Tertiary Northern Gulf Coast Basin. Gulf Coast Association of Geological Societies Transactions; v. L; p. 81-94.

Field, M. E., Gardner, J. V., Jennings, A. E., Edwards, B. D., 1982. Earthquake-induced sediment failures on a 0.25-degree slope, Klamath River Delta, California. Geology; v. 10; p. 542-546.

Haack, R. C., Sundararaman, P., Diedjomahor, J. O., Xiao, H., Gant, N. J., May, E. D., Kelsch, K., 2000. Niger Delta Petroleum Systems, Nigeria. In: Mello, M. R., Katz, B. J. (eds.), Petroleum Systems of South Atlantic Margins. AAPG Memoir; v. 73; p. 213-231.

Haughton, P. D. W., Barker, S. P., McCaffrey, W. D., 2003. ‘Linked’ debrites in sand-rich turbidite systems – origin and significance. Sedimentology; v. 50; p. 459-482.

Krukrubo, G. J., Nwakwue, J. E., Babafemi, O. A., Young, R. H., Ogunnusi, H. O., 2013. Optimal infill drilling using simulation and cross-functional integration – Ubit Field Example. IPTC Paper 17163, presented at the International Petroleum technology Conference in Beijing, China, 26-28 March 2013

Lee, H. J., Schwab, W. C., Edwards, B. D., Kayen, R. E., 1991. Quantitative controls on submarine slope failure morphology. Mar. Geotech.; v. 10; p. 143-157.

Lowe D. R., 1979. Sediment gravity flows: Their classification and some problems of application to natural flows and deposits. SEPM Special publication; v. 27; p. 75-82.

Mosher, D. C., Shipp, R. C., Moscardelli, L., Chayto, J. D., Baxter, C. D., Lee, H. J., Urgeles R., (eds.) 2010. Submarine mass movements and their consequences – 4th International Symposium. In: Advances in Natural and Technology Hazards Research, Springer, Dordrecht; v. 28; ISBN 978-90-481-3071-9

Normak, W. R., and Gutmacher, C. E., 1988. Sur Submarine Slide, Monterey Fan, Central California. Sedimentology; v. 35; p. 629-647.

Onwude R. J., Jackson, C., Anidi, A., Ojo, A., Obere, F., Wanorue E., 2013. Maximizing recovery from gas injection in a complex channel system – Edop Field Case Study. SPE Paper 167592, presented at the Nigeria Annual International Conference and Exhibition held in Lagos, Nigeria, 30 July – 1 August 2013.

Reijers, T. J. A., Petters, S. W., and Nwajide, C. S., 1997. The Niger Delta Basin, in Selley, R.C., ed., African Basins – Sedimentary basin of the World 3: Amsterdam, Elsevier Science; p. 151-172.

Short, K. C., and Stauble, A. J., 1967. Outline of geology of the Niger Delta. American AAPG Bulletin; v. 51; p. 761-779.

Sternbach, C. A., 2018. Exploration creativity in the golden age of Super Basins - AAPG Initiatives: An african perspective. Search and Discovery Article 11167, adapted from oral presentation given at 2018 International Conference and Exhibition, Cape Town, South Africa, 4th November – 7th November, 2018.

Sumner, E. J., Talling, P. J., & Amy, L. A. (2009). Deposits of flows transitional between turbidity current and debris flow. Geology, v. 37; no. 11*;* p. 991-994. https://doi.org/10.1130/G30059A.1

Whiteman, A., 1982. Nigeria: Its Petroleum Geology, Resources and Potential: London, Graham and Trotman, 394 p.