Flood Plain and Channel Sand Reservoir in Deepwater Environment - A Case Study of 'Oyo-Dw' Field Niger Delta, Nigeria

Abstract: The Deepwater environment of the Niger Delta Basin is one of the hydrocarbon exploration frontiers believe to be promising and highly prolific if properly harnessed.Someofthereservoirunitsareaffectedbymulti-scalecompartmentalizationresultingfromstructural,stratigraphicand/ordiageneticprocesses.Reservoircompartmentalizationcancompromisethelateralandverticalconnectivityofothermicroreservoirsthushavingsignificantimpactontheestimationofoil-inplaceand/orrecoverablereserves,aswellastheplacementofexplorationdevelopmentandproductionwells.A3Dseismicdatasetandgeologicaldatafrom Oil Mining License 121inDeep-waterenvironmentofNigerDeltawasanalyzedtoassessandquantifythearchitecturalelementsthatinfluencethecompartmentalization ofdelineatedreservoirunits.ThekeyaimofthisstudywastoundertakedelineatethereservoirsandsindeepwaterenvironmentalNigerDeltaasitisapplicabletochannelreservoirsandfloodplain.Thisstudyinvolvedcalibrationofseismic-to-welltie,determinationofspatialdistributionpatternsofsubmarinechannels;establishmentofhydrocarboncontrol;evaluationofthereservoircompartmentalizationandtrappingmechanismovertheprospectarea.ItisimportanttounderstandthespatialdistributionofSubmarinechannelsbecausetheyaremadeupofimportantpotentialreservoirstrata.Largechannelswithnumeroussmallerchannelsarelaterally scatteredacrossthestudyarea.Attributeanalysisrevealedthedegreeofcompartmentalisationwithinthesub-channelandthesanddevelopmentpatternwithinthechannelsandthefloodplain.Theresultsofthisstudycanprovidesignificantcontributionstofurtherhydrocarbonexplorationindeep-waterareaofNigerDeltaandhenceleadtomorediscoveryandincreaseinthecrudeoilreserve.

Keywords: Deepwater, Floodplain, Channel Sand,flat spot, Chronostratigraphy.

1. Introduction

Deep water could literarily mean two different things to anyone that comes across it.In geological reference, it could mean deepwater system transported through gravity flow processin a marine environment. Sea depth more than 500m (1640ft) could ordinarily be referred to as deep water environment.Concerted effort and processes have been on-going for over four decades in exploring for reservoirslocatedinpresent-daydeepwater, and these have resulted into manyprolificdiscoveries.Deep-waterexplorationintheGulfofMexico,Brazil,andwestAfricaistargetingandfindingalargenumberofhydrocarbonpoolsindeep-watermarine-sandsystems, about1/5thofthesereservoirshadbeendevelopedrecently to about two decades ago.

Significant attention has been given to Deepwaterchannelsinthepetroleumindustryduringthepastdecade,and this is due totheimportantdiscoveriesthathavebeenmadeinseveraldeepwaterbasinsinwhichreservoirperformancewascriticaltodevelopmentdecisionsandstrategies.However, importanceofchannelsassandconduitsforbypasstothebasinfloorprobablywasnotfullyappreciateduntilrecently.Ever sincelargevolumesofsandwererecognizedtooccurdowndipofmuddyslopesystems(e.g.,AngolaandthenorthernGulfofMexico[13].

It has been discovered that Deep-watermarinesandstonesare oftenprolificreservoirswheretheyoccur.Theycommonlycontainoilfieldsbecauseoftheinterfingeringofgravity-flowsandstoneswithsource rocks that are marine in nature[14].TheinterfingeringoftheUpperJurassicsubmarinefansoftheUKNorthSeawiththeKimmeridgeClayFormationsourcerockis a practical example that occurs in theprovince,e.g.,theMagnusandClaymorefields.Deep-marinesandstoneshas been found out to exhibit reservoir quality that isamongthebestofthevarioussedimentaryenvironmentsthatcompriseresevoirs, petrophysical qualities such asporosities,permeabilities,andnet-to-grossratiosaretypicallyhigh.In some unfavorableconditions,deep-waterreservoir sandstonesmaybepondedandstackedverticallyintoverythick,sand-richintervals,examplesofthiscanbefindBonga,AgbamiandErhaofNigeria.

A rangeofsedimenttypesfromvery fine particle: clay-tocoarse and gravel-sizeparticlesthatincludebothterrigenousandorganic materialdeposits are representation of Floodplain sediments.Theimportanceoffloodplainsedimentsisdouble fold.First,thesedepositsrepresenteconomicallyimportantreservoirsofoil,naturalgas,andwater,andincludesignificantcoalreserves.Also,floodplainsedimentsrevealdetailedrecordsgeologicprocessesandcontinentalenvironments that happened in the past and also going on currently.[4].

Channels may be braided or meandering,this often leads to the development of a belt in which sands deposited by the channels will accumulate[8]

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Methodology used?
Most significant and specific(%) findings?

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2. RegionalSetting/GeologicalContext

TheNigerDeltalies aboveatriplejunctionofGulfofGuineaTranslationZone,SouthAtlanticspreadingridgesystemandBenueTroughand this ceasedtospreadfurther aftershort-livedsubductionepisode[1, 18].

The Basin wasformedduringthePrecambrianbybuild-up of sedimentsoveracrustaltractestablishedbyriftfaulting[17].The Niger Delta area and the connecting basins are also located in a tectonically active region and are exposed to pre/post deformation, gravity tectonism is responsible for primary deformation[15]. Most active is shale tectonism where gravity-driven fold and thrust belts are widely developed [7].TheNigerDeltaBasinisconfinedbytheBeninAxisLinetothenorthwestandtheCretaceousridgesontheAbakalikihightothenortheastwhiletheCameroonVolcaniclinemarkstheeasternoffshore extentofthebasin[16].

The Tertiary reservoirs of the Niger delta offshore are turbidites deposited within the shale prone Akata formation, and they are of Miocene to Pliocene in age. Turbidite reservoirs are charged by hydrocarbons expelled mainly by early Tertiary mobile shales. Intra reservoir shaly intervals have also been proven to be effective source rocks. Trap formation in area of study is mainly due to diapir uplift in combination with stratigraphic components. Turbidite deposits onlapsynsedimentary growing diapirs and drape then when sedimentation can compensate topographic relief, with channel lobe systems continuing the downdipflank of the diapir. Major sediment thickness is recorded within inter-diapir depocenters, indicating ponding effect within this portion of the slope. Genesis of major clastic sediment fairways, by which turbidite sediments are distributed throughout the continental slope to the basin plain, are likely linked to recurrent collapses of the shelf margin. Shelf margin disequilibrium and collapse phenomena are triggered by phases of rapid progradation occurring during the falling limb of relative sea level change.

The overall sequence architecture corresponds to the long-term evolution of the Niger delta offshore sedimentary basin, with more distal basin plain / lower slope facies overlaid by prograding middle to upper slope successions. The Middle/Upper Miocene succession is constituted by poorly confined and ponded depositional lobes deposited in the inter-diapir areas, rapidly shaling out on diapir flanks. In contrast, the Late Miocene/Pliocene succession is characterised by the occurrence of more confined upper/middle slope channel complexes trending NE-SW**.** The sandstone reservoirs, of sandstones and shales intercalations in quick succession within the Agbada formation account for oil and gas production in the delta[11]. There may be uncertainties in the extent of the Niger Delta but the sedimentary environments in the Niger Delta is heterogenous in nature indicating that it is s mix of fluvial, tidal, and wave-related deposits and landforms.[2]

3. Location of the Study Area

Only one petroleum system is identified with the Niger Delta Basin[9, 3] and this is referred to as here as the TertiaryNigerDelta(Akata–Agbada)PetroleumSystem.Theoverall maximumextentofthepetroleumsystemmatcheswiththeboundariesoftheprovince while theminimumextentofthesystemisdemarcatedbytheareal extent offieldsandcontainsknownproperties.

TheOyo-DWFieldislocatedwithin the deepwater environment of theNigerDeltainOML120approximately75kmfromthecoastline within the range of deepwater classification on the world map.TheOilMiningLicenseisboundedinthenorthbyAgip'sOML125,westbyEsso'sOML133,southbyOML121andontheeastbyCavendish'sOML110andChevron'sOML89.OML-120isaneight-sidedelongatedblockwithatotalareaof910.05km2.Waterdepthrangesfrom200mto900m,increasingfromtheNEtowardstheSW corner.

Thefieldwasdiscoveredwith Oyo-1,thefirstwelldrilledinthefieldin1995andfollowedbyOyo-2,-3&-4drilledbetween2006and2007.Oyo-2and-3foundoil/gasintheOyoWestarea,whileOyo-4appraisedtheOyocentraldiscovery.Oyo-5and-6weredrilledasproducersintoT1AreservoirinOyoCentralandOyoWestrespectivelyduring2008and2009.OyoFarEastisyettobetested.Also,thedeeperMioceneprospectsinOML120remainlargelyuntested.

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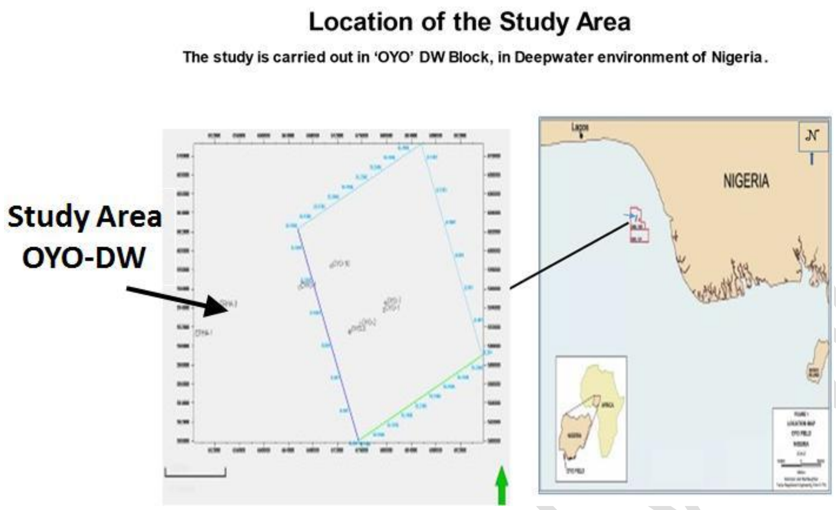

Figure 1. location and base maps of oyo field in niger delta.

4. Flat Events

FlateventsareknowntobeDirectHydrocarbonIndicatorsandcouldbeseenhereatalmostalllevelsofthehorizonpickedforthestudies. There is an always a close to horizontal positive reflections because of positive impedance contrast on the seismic data whenever a fluid contact such Gas/Oil, Gas/Water or Oil/Water is present in hydrocarbon reservoir. Whenever this occurs, it is termed a flat spot, and this is known to be a direct hydrocarbon indicator. This may appear tilted sometimes because of overlying velocity, but they may be unseen when data resolution is insufficient. However, Flat Spots are among the best hydrocarbon indicators. At other times, features such as porosity or cementation changes may produce flat spot not associated with current fluid contact but with former horizontal reflector.It is easy to recognize Flat spots reflections from the hydrocarbon-water contact because of their non-conformable flatness, the signs are always positive [5].

5. Statement of Problem

OYO10wasdrilledonthefieldasanexploratorywellwithintheNorthwestblockofthefieldonthefloodplainincontrasttoexistingwells onthefieldthatweredrilledwithinthechannelreservoirs.AllreservoirlevelswerepredictedusingDirectHydrocarbonIndicatoranalysis drapedonstructuralmaps.Electricloggingandmudloggingdataindicatedhydrocarbonlevelsafterdrilling,however,formationfluidsamplingsuggestthereservoirsarewetwithtracesofliquidhydrocarbondespitehighgasreadingswithgoodgaschromatographanalysis.Thisnecessitatedinvestigationintopossibilityofreservoircompartmentalization,sanddevelopmentandestablishmentoffloodplaindrillingofwellincontrasttodrillingwithinreservoirchannelsonthefield.

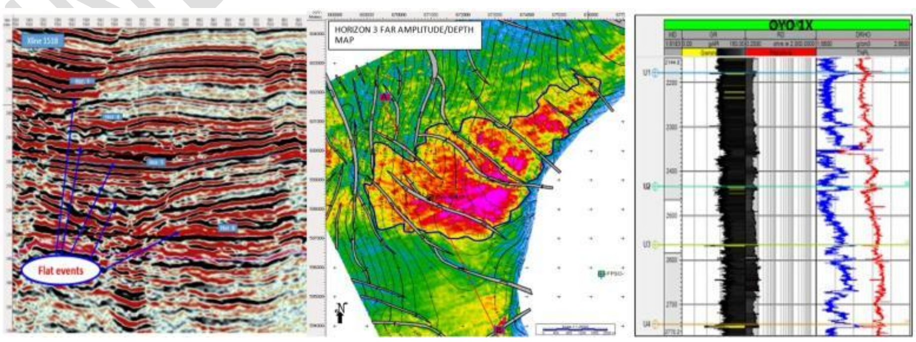

Figure 2. Predrill anplitude map extraction and Oyo 10 well log.

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Predrilldataandstudyshowalotofpositiveindicationsthatthelocationwouldbeproductive.FlateventswhichwereDirecthydrocarbonindicatorsmatcheshighamplitudewhichalsosupportsthefactthatdrillingwilldetecthydrocarbonbearingsands.

Despiteallpositivenessinthepredrillstudiesandindicatorsofhydrocarbonthatwerecarefullyanalyzed, theresulthoweverdidnotmatchthepredrillstudies.Thesandispoorlydevelopedtohaveallowedaccumulationofhydrocarboninco mmercialquantity.Theresistivityvaluesareextremelylowcomparedtoresistivityrecordedonproducingwellswithinthefield,Density/Neutronlogsdidnotindicatethepresenceofhydrocarbonofcommercialquantity,whilefluidsamplingreveals90%ofwaterinsupposedreservoirs.

6. Materials and Methodology

AvailableDatainclude,3DSeismicdata,Checkshotforthewells,deviationsurveys,welllogsinlasfileformatandbiostratigraphy data.Petrelversion2018

7. Results and Discussions

It is quite possible fordifferent lithologies of sedimentary rocks to be form at different locations sincedepositional environments vary from place to place geographically. The term Chronostratigraphyrepresent both stratigraphy concept and timing principle of rocks in geological history of the earth.Chronostratigraphy correlation ties rocks that were formed during the same time in history although may be of different petrologies.[10]

ThechronostratigraphiccorrelationdonerevealthatallthewellsthatproducedhydrocarboninthestudyareafallwithinthetwochannelsthatwereidentifiedaschannelX1andX2whereasthewellbeingconsideredislocatedoutsidethesetwochannelsonfloodplain.

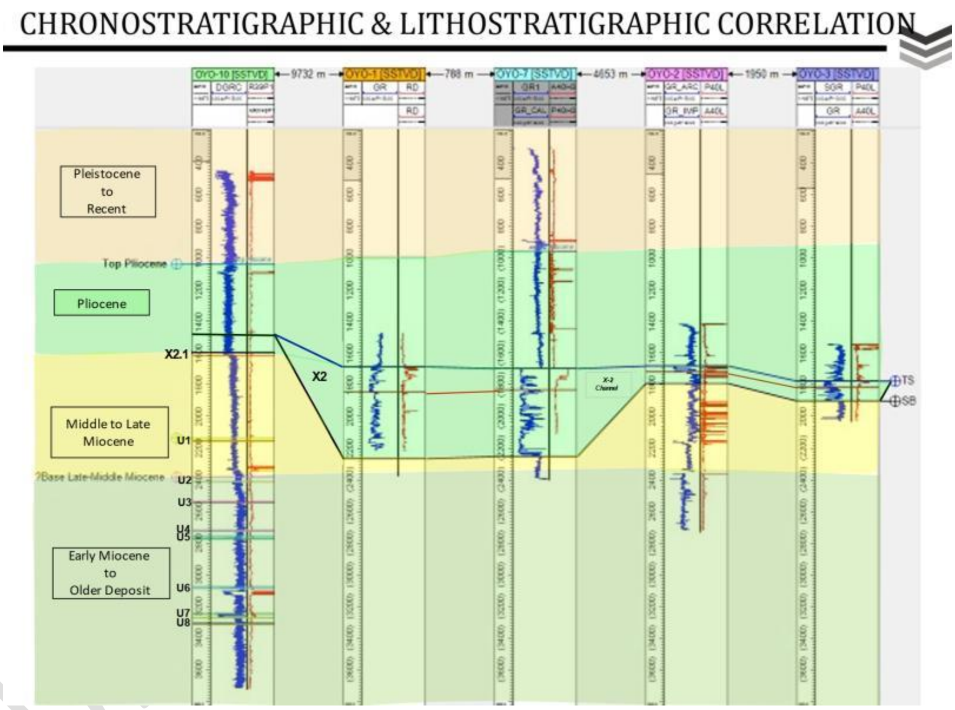

Figure3. *ShowingChronostratigraphic correlation.*

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FLOODPLAIN AND CHANNEL COMPARTMENTS

WELLS		COMPARTMENTS
OYO-10	structure	Floodplain (outside channel axis)
OYO-2 & 3	Stratigraphy	Channel-B
OYO-1 & 7	Stratigraphy	Channel-A

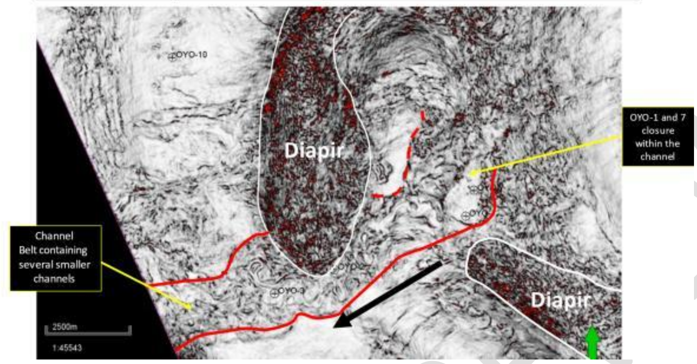

Figure4. *CompartmentalisedChannel.*

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UsingVarianceseismicattributes,itisequallyobservedthatmajorchannelsX1andX2aremadeupofothermicrochannelssotherearechannelswithinthemajorchannelsasseeninfigure4.

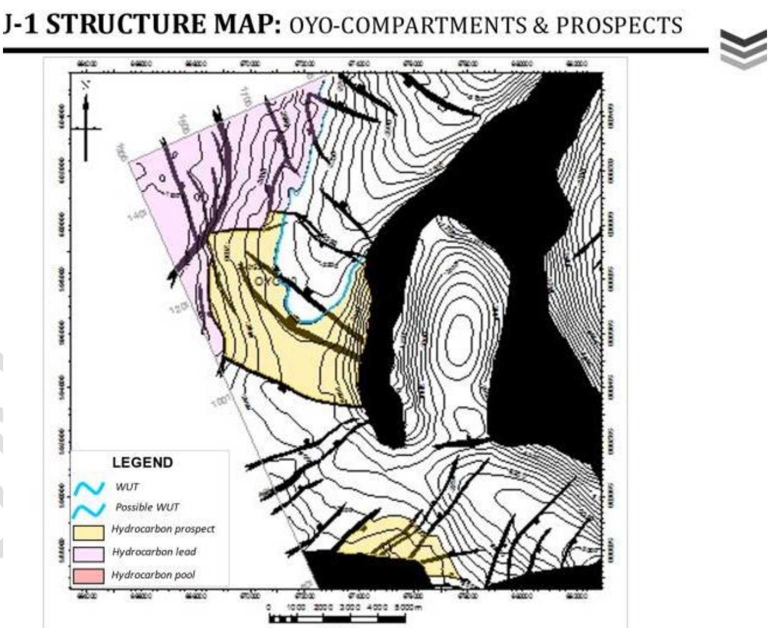

Figure5. *TimeMapwithChannelPolygon.*

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Timemapwas superimposedontheChannelpolygon (Figure 5), contourscanbeseenenclosingagainsttheshalediapirwhereasthesamethingcouldnotbesaidaboutthefloodplainwhereOYO10islocated.Inaddition,bothstructuralandstratigraphictrapscouldbeseeninplaywithinthechannelreservoirbutonthefloodplainwhereOYO10islocated,samecouldnotbementioned.Thecontoursalongthefaultplaneareconstantdepictedthatthediscontinuitiesmaybef racturesandprobablynotfaultswithremarkabledisplacements.

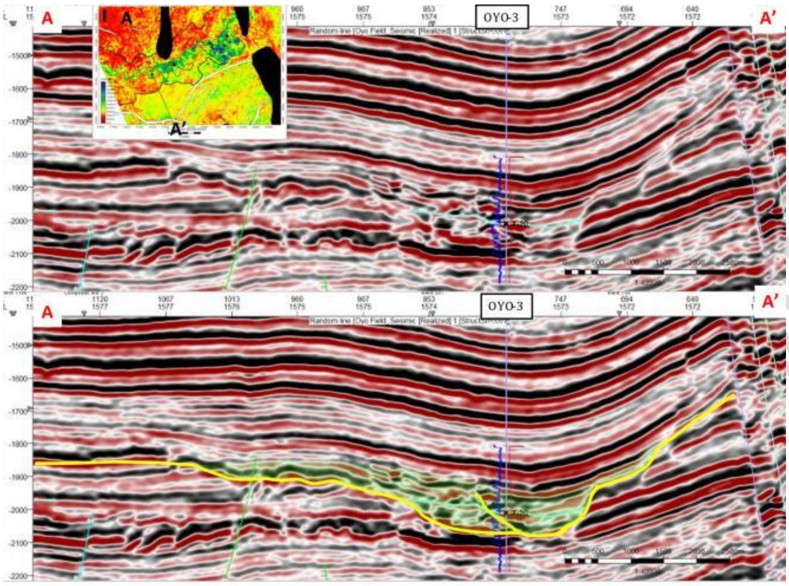

Figure6. *Seismiccrosssectionofwell3withinthechannelreservoirsand.*

Figure6.showsOYO3welllocatedwithintheChannelX2andwashydrocarbonbearing.OYO1and7whichwerebothproducingatasustainableratewerebothlocatedwithinchannelsandreservoirintheTopMioceneage.TheT1AsandandT1Bweredemarcatedwithawell-definedfluid contact. That is GasOilContact(GOC)andWaterOilContact(WOC)(Fig.7.)Amplitudeanomalyalsosupportedthefindings.i.e.highamplitudeisassociatedwithchannelssand.

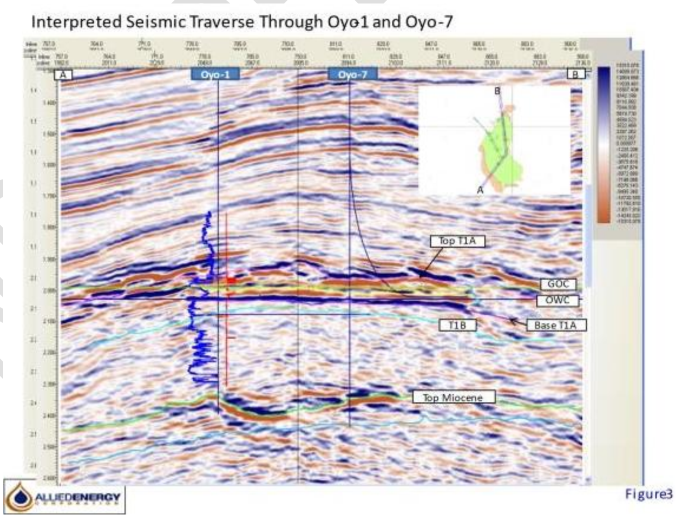

Figure7. *OYO-1and7locatedwithintheChannelSandCourtesyAlliedEnergy*

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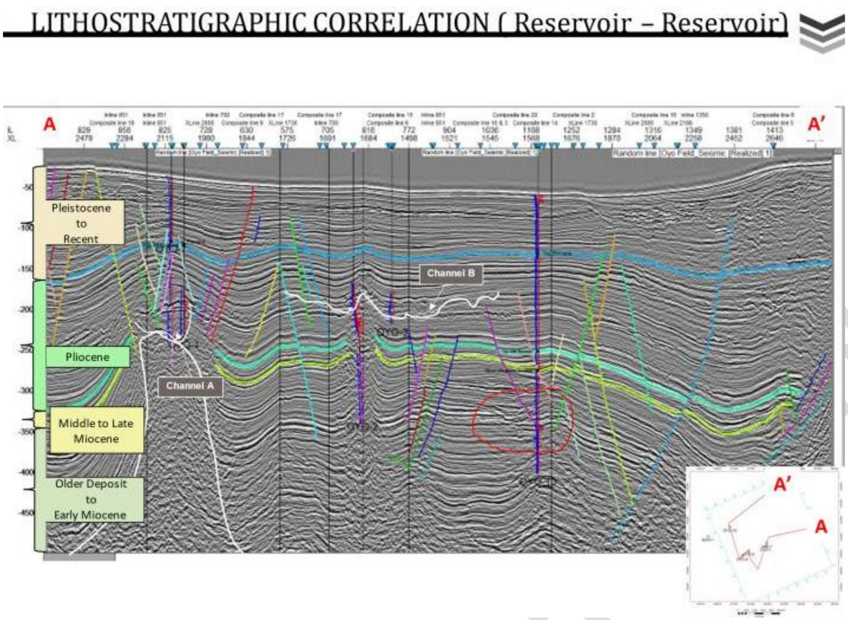

Figure8.
LithostratigraphicCorrelationshowingChannelsonseismic.

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Marine sandstone systems from Deepwater environment may often be tough to characterized in the subsurface and the major challenge is trying to differentiate between sheet sandstones and channel reservoirs. Deep-watermarinesandstonesystemscanbedifficulttocharacterizeinthesubsurface.Thebasicproblemisintryingtodifferentiatesheetsandstonesfromchannelcomplexes.Sheetsandstonesarecharacteristicallywellconnectedlaterallyandcanbeveryprolific, whereas large-scalereservoirconnectivityofchannelcomplexescanbe very good,wheretheyhavemergedintoconnectedbodies,or could be none productive where they are isolated during deposition.

Thestudyrevealsthatthepresencebothstructuralandstratigraphicbarriers.Forthestructuraltrapsarecreatedbydiapiricstructuresresultingininintensestratigraphiccompartmentalizationofthereservoirs.Stratigraphicfeaturessuchaschannelsalsotendstocreatestratigraphiccompartment(s)atthesouthofX-2reservoir.Thesecompartmentscreatetrapsforhydrocarbonaccumulationandwerethereforeidentifiedanddelineatedduringthestudy.

TheX-2reservoirisPlioceneinage.ThisintervalwaspenetratedbyalltheOYOwells.Atthenorthofthisinterval,thereservoirwasencounteredbyOYO-10.Atthesouth,OYO-1,-7,-2and-3encounteredtheX-2sandwithinaNE-SWtrendingmeanderingchannel.OtherreservoirssuchasU-1,-2,-3,-4,-5,-6,-7and-8areoldertomiddleMioceneinagewereencounteredbyonlyOYO-10.

ThecontemporaryslopeandoutershelfoftheNigerDeltaarecharacterizedbyfault-boundedsedimentarydepocentresandinterveningshalediapirs.TheshalestructuresweredefinedbyLateMiocenetime,perhapsinrejoindertolateralshalewithdrawalfrombeneaththeprogressingdeltaicload,jointlywithcompressionalupliftandfoldingofpro-deltalayers.DuringPlioceneandPleistocenetime,thesestructureswereconcealedbytheprogradingdelta,andextensionalgrowthfaultingcommenced[6]

TheX-2ischaracterizedbystructuralandstratigraphiccompartmentalization.AttheNorth,TheX-2reservoirinOYO-10isstructurallycompartmentalizedbythefaultstructureagainsttheshalediapirs.Thisthereforedefinesthestructuraltrapwithinthereservoir.OYO-10penetratedtheflankofthestructure.Atthesouth,theX-2reservoirisstratigraphicallycompartmentalized,asthereservoirswereencounteredbyOYO-2,-3,-1and-7withintheNE-SWtrendingmeanderingchannel.Withinthechannelaxis,highernetsandispresentattheOYO-1andOYO-7areaattheeastofthechannelandlowernetsandwasobservedattheOYO-2andOYO-3areaatthewestofthechannel.Thesanddevelopmentisbetterwithinthechannelsandthisfavoraccommodationofhydrocarbonwhichestablishesthefactthatthechannelsandsarebetterreservoirswithinthisblock.

It looks like OYO 10 well narrowly missed the channel which could have increased the chances of the prospect just like other producing well on other channels (figure 8). The horizon was mapped with an arbitrary line taken SE-NW across the seismic section (Figure 9). It was duly observed that the supposed channel seen on the seismic does not actually exist when variance attributes was run across same section as seen on. This is because the chaotic signatures that normally characterize channel reservoir was never observed on the variance attributes, instead, the area is characterized by structural traps resulting from the faults.

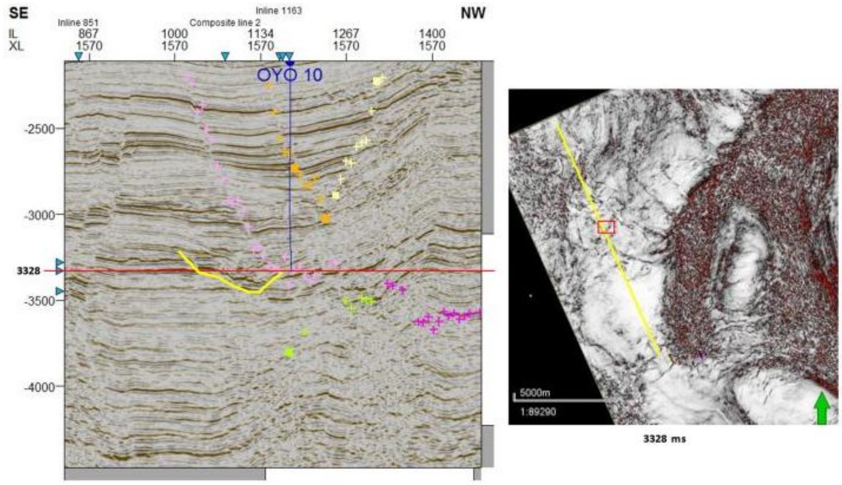

Figure9.
MappingofhorizonthroughOYO10Channel.

8. Recommendation

Withjustonewellwithinthenorthwestpartoftheblockwhichfallswithinthefloodplainofthefield,itmaynotbeconclusivethathydrocarbonincommercialquantitycanonlybefoundinthechannelreservoirsandsofthefieldaloneandnotinthefloodplain.Therefore, morestudiesshouldbecarriedouttotargettheOYO-10stratigraphy/structureandthechannelsandandtogivecredence tothisclaim.

References

[1] BurkeandDewey,1973:Plume-generatedtriplejunctions,keyindicatorsinapplyingplatetectonicstooldrocksJ.Geol.,81(4)(1973),pp.406-433.

[2] Chinotu F.G; David I.M.M; Matteo S. (2019)Deltaic sedimentary environments in the Niger Delta, Nigeria

[3] Ekweozor,C.M.andDaukoru,E.M.(1984)PetroleumSource-BedEvaluationoftheTertiaryNigerDelta.AmericanAssociationofPetroleumGeologistBulletin,68,390-394.

[4] GerardV.M.etal2003:EncyclopediaofSedimentsandSedimentaryRockspp285–287.

[5] Qiang Guo, Nayyer Islam, and Wayne D. Pennington (2014) – Tunning of flat spots with overlying bright spots, dim spots, and polarity reversal.

[6] HarveyA.Cohen;KenMcKlay1996;SedimentationandshaletectonicsofthenorthwesternNigerDeltafront–MarineandPetroleumGeology.Volume13,Issue3Pages313-328.

[7] Jia-Jia Zhang et al (2023) Sedimentary tectonic interaction on the growth sequence architecture within the intraslope basins of deep-water Niger Delta Basin

[8] Jon Gluyas and Richard Swarbrick (2004) – Petroleum Geoscience - Library of Congress Cataloging-in-Publication Data pg 131

[9] Kulke,H.(1995)Nigeria.In:Kulke,H.,Ed.,RegionalPetroleumGeologyoftheWorld,PartII,Africa,America,AustraliaandAntarctica,GebruderBorntraeger,Berlin,143-172.

[10] MarkW.Hounslow,2021:EncyclopediaofGeology(SecondEdition),2021Volume3.

[11] Emudianughe J.E. and Ekechikwe O.M. (2022) Reservoir Evaluation of Sand beds in Sapele Field Onshore, Niger Delta.

[13] PaulWeimer;R.MSlatt;R.Bouroullec;R.Fillion;H.Penttingill;M.Pranter;G.Tari2006–Deepwater–ReservoirElements:ChannelandtheirSedimentaryfill–AmericanAssociationofPetroleumGeologists–Vol57

[14] Shepherd,M.,2009,Deep-watermarinereservoirs,*in*M.Shepherd,Oilfieldproductiongeology:AAPGMemoir91,p.295-300.

[15] Suyi Lawrence Fadiya (2013) Impact of wellsite biostratigraphy on exploration drilling in deepwater offshore Nigeria

[16] Tutle L.W.M, Charpentier R.R. and Brownfield E.M. (1999) The Niger Delta Petroleum System: Nigeria Cameroon and Equitorial Guinea, Africa. – US Geological survey open file report 99-50H Denver, 70.

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Comment [UoK17]: Most of citations are back to more than 7 years.
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[17] Weber, K.J.; Daukoru, E.M. 1975: Petroleum geology of the Niger Delta.

[18] Whiteman,A.J.1982:Nigeria:ItsPetroleumGeology,ResourcesandPotential,2,GrahamandTrotman,London(1982)