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The Application of Seismic Velocity Pseudo Section in Interpreting Subsurface Stratigraphy in Offshore Niger Delta, Moonstone Field

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Abstract:*Recordsoffour (4) seismiclinesfromMoonstone Oil-field Niger Delta have been interpreted forthe structures, anticlinalhorizons and faults present. Porosityand velocity Pseudo Sections were constructedand interpretedfor the observed structures. Velocity pseudo section was usedtoidentify hydrocarbon accumulationzoneby checking for sudden reduction (velocity break and discontinuities) in its value, and regionalcompactiontrends was deducedsince interval velocity value increases with depth. The Porosity Sections for seismic lines M-016, M-020, M029, and M-031 show changes in porosity variation with depth. For line M-016, porosity discontinuities is seen at 4000-5000m, for line M-020 porosity discontinuities is seen at 3000m and 5000m respectively. The Porosity Sections for seismic lines M-029 and M-031 show the changes in porosity with depth and discontinuities at 5500m and 4000m respectively. Horizons were picked where there are lithological Changes. Velocity pseudo section for LinesM-016, M-020, M-029, andM-031, delineated four (4) layers. Layer1with velocity rangingfrom1490m/sto 2248m/s, ischaracterized by relatively strong and continuous reflection amplitudes. This layer consist of loose and porous sands of the Benin formation. Layers2and3aresimilarintheirreflectionpatterns, but with strongeramplitude reflections,mostofwhicharediscontinuous.Thevelocity within these layers vary from 2317m/sto 3532m/s and this sectiondoes not show the faults characteristic of the Agbada formation since geologic features are concentrated downdip. However, a porosityrangefrom 20-35% was obtained within these layers and is consistentwiththeestablished porosity values within the Agbadaformation in the Niger Delta. The fourth layer occurringatadepthofabout3000mischaracterizedbyirregularand discontinuousreflections with velocitiesrangingfrom2547m/sto3200m/s.Thenatureofthe reflectionsischaracteristicofshales,indicating a change in lithology from sandy shalesatthebaseoflayer 3 into shales of layer 4, this layer is the Akata formation. Thevelocities of the layers increases withdepth which is asa result ofthe increasingcompaction, depth of burial and age. ThePseudo-sectionswerecomparedwiththeSeismicamplitude sectionsofthefourlines (M-016, M-020, M-029 and M-031) and theresults obtainedshowagoodmatchbetweenthesetsof sections. The seismicrecordshow resultsofa subsurfacegeology thathasthreemajor subdivisions whichis Inagreementwiththeestablishedsubsurfacegeology oftheNigerDelta. Theresultsobtained in this study areveryusefulinthesitingofappraisalanddevelopmentwells however, it should be carried out on the entire field.*

Keywords*: Seismic amplitude, Velocity sag, porosity discontinuity, pseudosection.*

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I. Introduction

Moderntechniqueofextractingvelocitydatafromseismictraces,theirinterpretationand advancesinseismicdataprocessing, makesitpossibletoestimatelithologyandidentify hydrocarbonlocationonasectionbeforeawellisdrilled.Accuratepredictionofabnormal Pressure zonebefore drilling isvitaltothe drilling engineerand together withthe grosslithology extractedfromthevelocitydata, is aninvaluableservicetoreservoirengineering (Fitch, 1976).
Theapplicationofseismicintervalvelocitytohydrocarbondeterminationdefinesthe identificationofhydrocarbonlocationinseismicdataintermsofabnormalvelocityvariation (pull-down). ExplorationobjectivesincludeMapping ofsubsurfacegeologicalstructures, detectionofhydrocarbonaccumulations,estimationoftotalenergyreservesinanareaand reservoir monitoring (Water,

1987). Akey indicationofthepresenceofhydrocarbonisbrightspot (highamplitude anomaly); other indications includevelocitypull-down or sags,diffractionpatterns,polarityreversalattheedgesofgassands, ordim-spot (lowamplitudeorattenuationeffectswiththeselectiveabsorptionofhighfrequency components), (Dobrin, 1988; Fowler, 1984; Fagin, 1991; and Hilterman, 1975). Directdetectionofoilhasbeenachievedinthelocationofgas accumulationwhichconsiderablyreducetheseismicvelocityofthesedimentaryrocksinwhich they occur (Hubral and Krey, 1980).

Theseismicmethodsofgeophysicalexplorationutilizes thefactthatelasticwavestravelwith differentvelocitiesindifferentrocks. Theprincipleistoinitiatesuchwavesatapointand determineatanumberofotherpointsthetimeofarrivaloftheenergy (signal) thatisrefractedor reflected by the discontinuities between different rock formations.This then enables the position of the discontinuities to be deduced (Parasnis, 1986). Therearetwodistinctseismictechniques,onemakinguseofthereflectionandtheother the refractionofelasticwavesinrocks.Thereflectionsandrefractionsarerecordedbydetecting instrumentsresponsivetogroundandwatermotions, these aregeophones forlandsurveyandhydrophonesformarinework. Velocityisalinkbetweenseismicdataandgeology, however depthsectiondoesnotalways coincidewithmigratedtimesection.Foraconstantvelocitylayer,thetraveltimecurveasa functionofoffsetisahyperbola.Thetimedifferencebetweenthetraveltimeatagivenoffset andatzerooffsetiscalledNormalmove-out(NMO). Thevelocity requiredtocorrectfornormal move-out (NMO) is called the normal move out velocity (Mayne, 1967). The interval velocity isthe average velocity in an interval between two reflectors. Several factors influenceintervalvelocitywithinarockunitwithacertainlithologiccomposition theseare, pore space, pore pressure, pore fluid saturation, confining pressure, and temperature etc. Inthisstudy,seismicintervalvelocitydatawereusedinprospectzoneidentificationandinthe knowledgeofregionalstratigraphy. This study utilizestheintervalvelocitydatageneratedfromvelocityanalysispointsonthe seismicreflectionsectionsobtainedfromMoonstonefield,offshoreNigerDeltatocreate pseudo-sectionsofporosity andvelocityforthedelineationof reservoir zones and subsurface geology using the pseudo sections created, aswellas the lithological characterization of the field. The significance ofthis study is that it utilizesthesensitivityofseismicvelocitiesto analyze lithofaciesand reservoirparameterslikeporosity,porefluidtype,saturationandpore pressure, withthepractical needtoquantifyseismic-to-rock-properties andtheneedtointerpret amplitudesforhydrocarbondetection,reservoircharacterizationandmonitoring

II. Geologic Setting

The MoonstoneOilfield is located in offshoreNigerDelta inthe southern partof Nigeria.The field is located withinlatitudes4°Nand5°Nandlongitude7°Eand8°E.Itislocated at about75Kmsoutheast of Port Harcourt with an area of about 742Km^2.The Niger Delta is situated on the Gulf of Guinea in the West coast of Africa. It is located at the southeastern end of Nigeria, bordering the Atlantic Ocean and extends from Latitude 4^0 to 6^0 North and Longitude 3^0 to 9^0 East. The tectonic framework of the Niger Delta is related to the stress that accompanied the separation of the African and south American plates (as proposed by Alfred Wegner), which led to the opening of the South Atlantic. The Niger Delta Basin is the largest sedimentary Basin in Africa with an area of about 75,000km^2, and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences (Stacher, 1995). The proto Delta developed in the Northern part of the Basin during the Campanian transgression and ended with the Paleocene transgression. Sedimentary deposits in the Basin have been divided into three large-scale lithostratigraphic units namely: (a) the basal Paleocene to Recent pro-delta facies of the Akata Formation. (b) Eocene to Recent paralicfacies of the Agbada Formation and (c) Oligocene to Recent, fluvial facies of the Benin Formation (Short and Stauble, 1967; Evamy et al, 1978 and Whiteman, 1982). These formations became progressively younger into the basinward, recording long-term progradation (seaward movement) of depositional environments of the Niger Delta into the Atlantic Ocean Passive Margin. The stratigraphy of the Niger Delta is complicated by the syndepositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation.

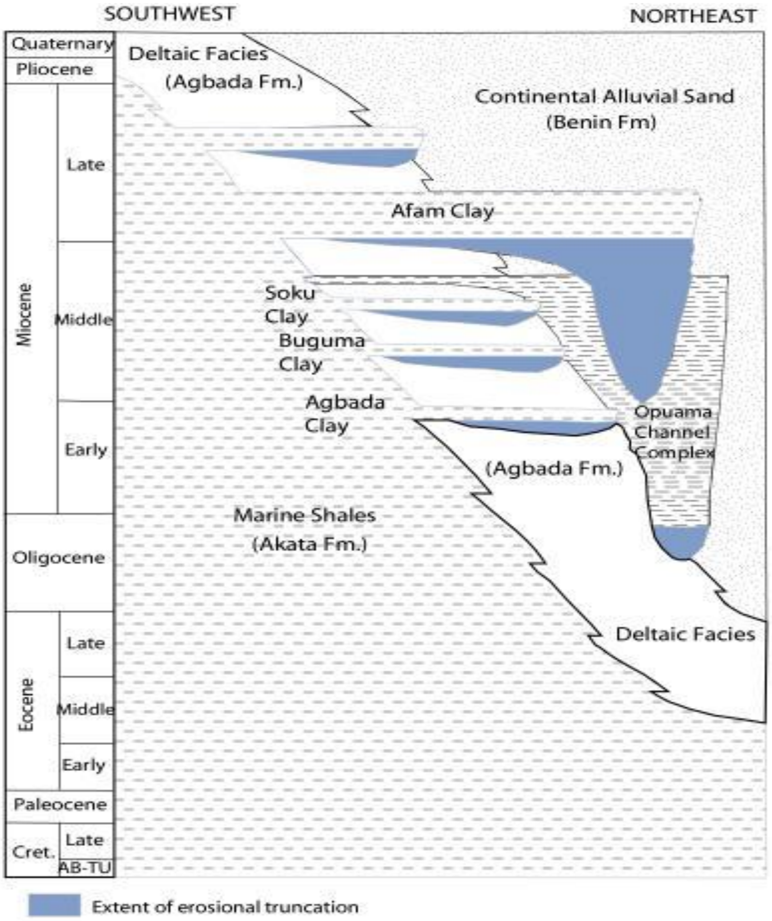

Figure 1: Stratigraphic column of the Niger Delta (Modified from Doust and Omatsola, 1989).

III. Materials and Method

The dataset used in this study was obtained from Moonstone Oilfield offshore Niger Delta, and consists of four Seismic sections and Velocity analysis data from four lines labelled as M-016, M-020, M-029, and M-031. Where M-016, M-020 represents the strike lines which runs NE-SW, and M-029, M-031 represents the dip lines which runs NW-SE. The sections show a common midpoint display (CMD) of seismic responses in the form of wiggles.

From each seismic section, three (3) time horizons H1, H2, and H3 were identified based on amplitude and continuity of the reflections. Thehorizonsareanticlinalonthedipsections.

H1 was picked between two way time 1.2 – 1.6 secondstothe leftofthesections;H1underliesa stratummarked by strong continuous reflections which likely contains the Benin Formation.Thesecondandthird horizons arebothmarkedbystrongerreflections.Thestrengthofthe reflectionsislikelyduetothestrongacousticimpedanceofthesandandshalesequencesofthe Agbada Formation.Fault mapping was done on each time section using the criteria proposed byDobrin and Savit (1988).

From the velocity analysis data, transit time was obtained for the variousvelocityanalysis points by taking the inverse of the velocity at each point using

$$\Delta t = \frac{1}{\Delta V} \quad (1)$$

The interval transit timewas then plottedagainst depthto acquire atransittime log. Thiswas doneoverallthevelocityanalysis pointsofthefourseismicsections.

Porosityforeachoftheseismicsectionswasdeterminedusingtheempiricalformulaebasedon field observations (Schlumberger, 1989). The equation is given as;

$$\emptyset_S = C\frac{t_{log} - t_{ma}}{t_{log}} \quad (2)$$

Where

C = 0.67 (correction factor);

Φ_S = sonic porosity;

tlog = transit time as calculated from the reciprocal of interval velocity;

tma= transit time of the matrix material (taken to be 55.5μs/ft for sandstones).

This relation was preferred because of its applicabilityto the uncompacted sands like those of the Niger Delta. Theporosityalongthevelocityanalysispointswasobtainedforeachofthefoursections, from which fourporosity pseudosections weregeneratedcorresponding toeach seismicsection.

Also the reflectivity coefficient series was calculated using the Zeoppritz equation

$$Rc = \frac{Z2 - Z1}{Z2 + Z1} \quad (3)$$

Where

Z_1= acoustic impedance of layer 1 (the upper layer) and $Z_2$is that of layer 2.

If Z =ρv, where ρ is the density of the rock and is assumed to be negligible or equal to unity (1). ThisimpliesthattheZeoppritzequation becomes reducedtothe form;

$$Rc = \frac{V2 - V1}{V2 + V1} \quad (4)$$

Where;

V_1= the interval velocityof the spatially upper layer; and V_2= the interval velocityof the spatially lower layer.

Thereflectivitycoefficientswereplottedagainstdepthonthevelocityanalysispoints on each seismic section and this was also compared with the seismic sections provided. Theobtainedintervaltransittime,porosityandacousticreflectivitycoefficientsections obtained from the four velocity analysis points were matched with the surface seismic section on which the velocity analysis point data was obtained.

Fromtheabove procedures, interpretationofthesubsurfacegeologicalstructures,delineationof thedifferentlithologies within the study area was facilitated.

The research design usedforthisworkis summarized in the flow chart (Figure 2).

Procedure / Workflow

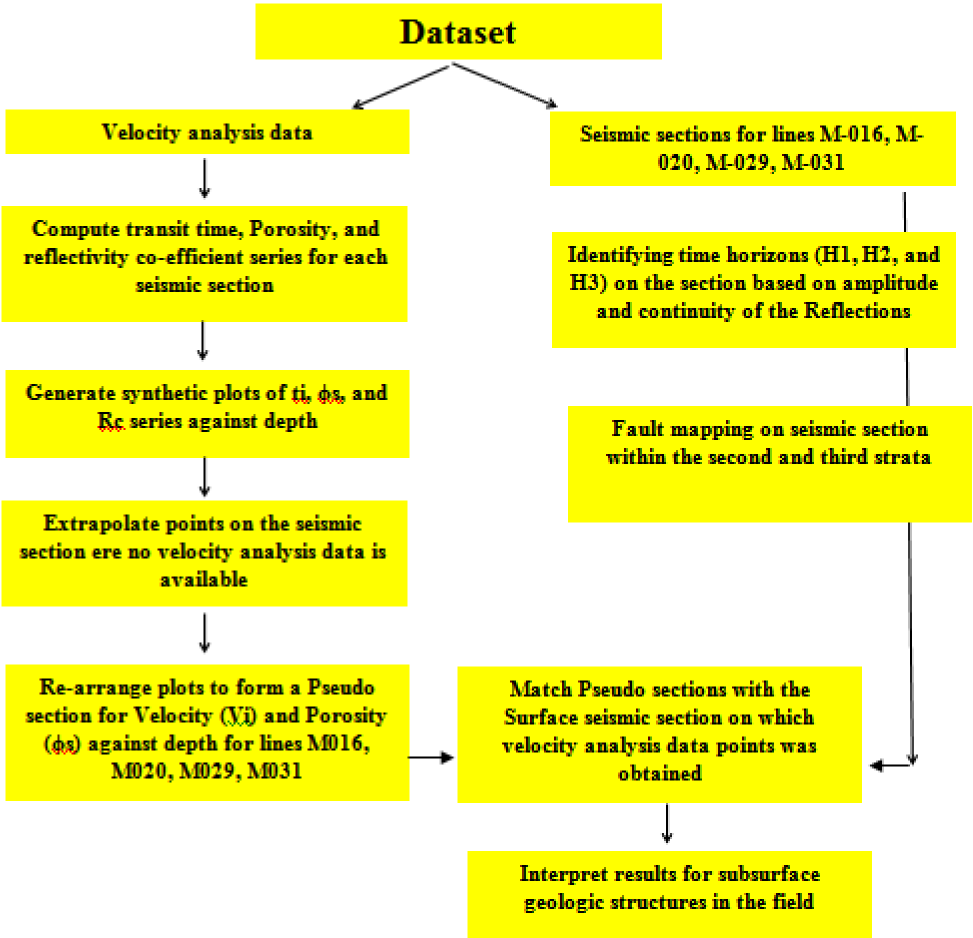

Figure 2: Flow chart showing the research workflow.

IV. Results, Interpretation and Discussion

1.1 PorositySection

Porosity pseudo Section which show changes in porosity with depth for the particularlineforwhichitwasmeasured were plotted and from the section, horizonscanbeidentified and pickedwherethereare lithological changes. This was done for lines M-016, M-020, M-029, and M-031.

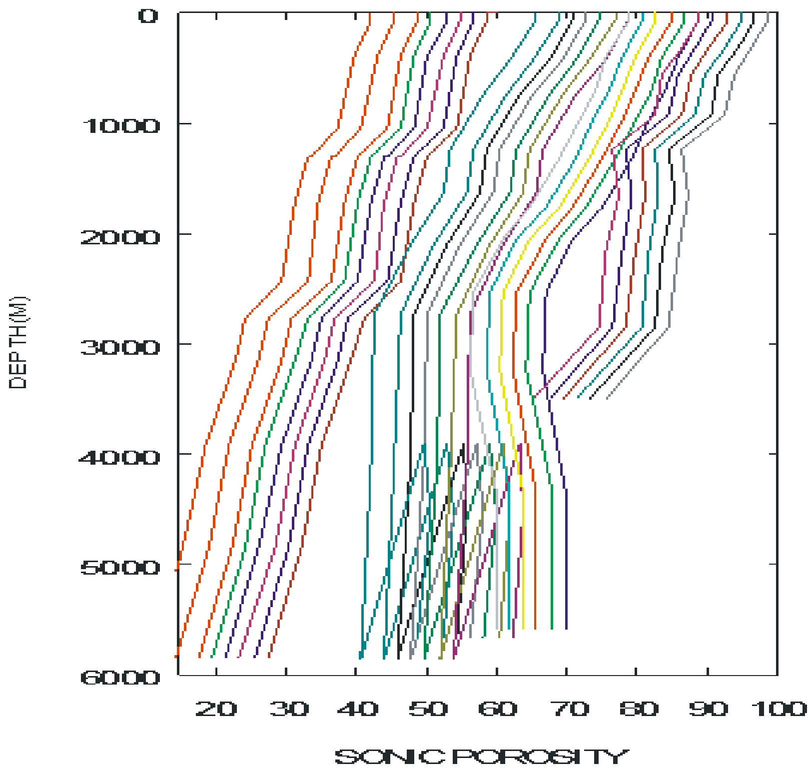

Figure 3: porosity pseudo section for seismic line M-16.

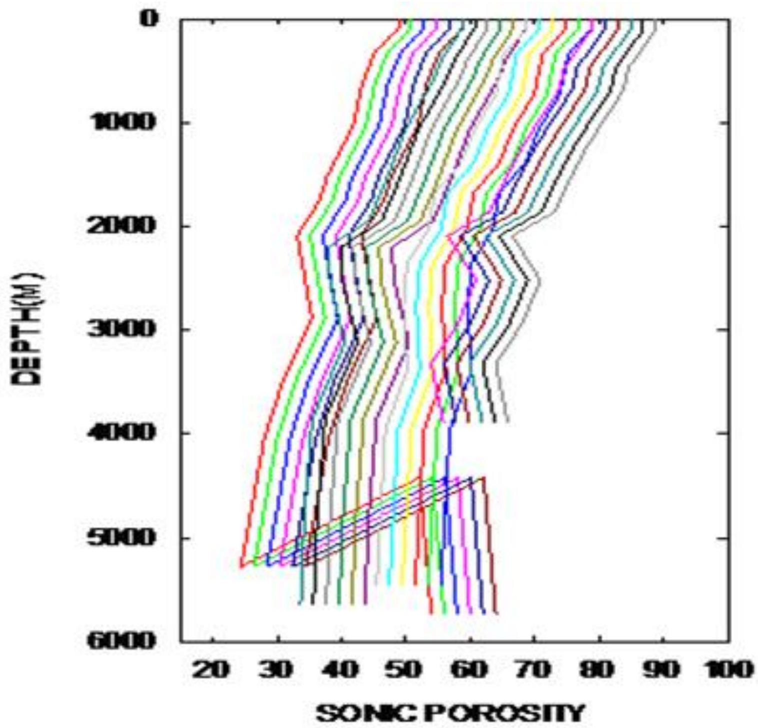

Figure 4: porosity pseudo section for seismic line M-20.

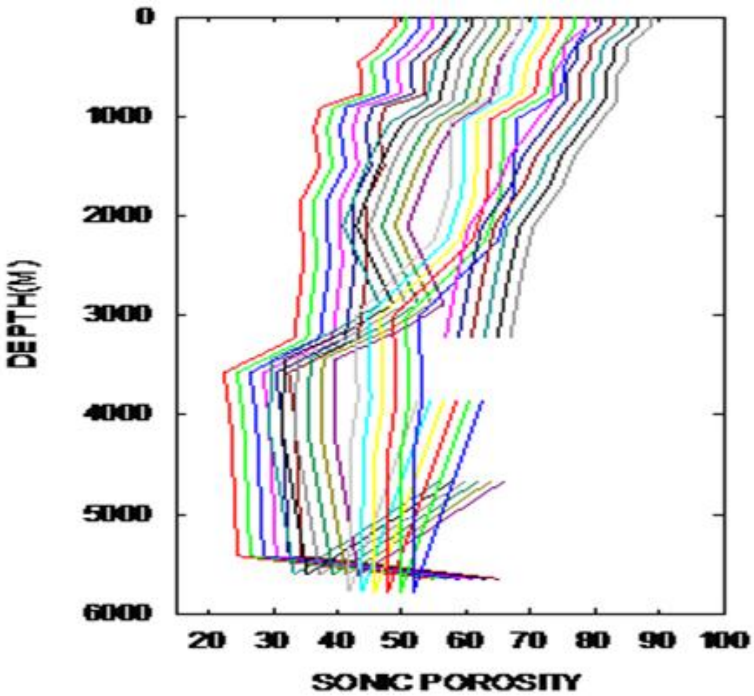

Figure 5: porosity pseudo section for seismic line M-29.

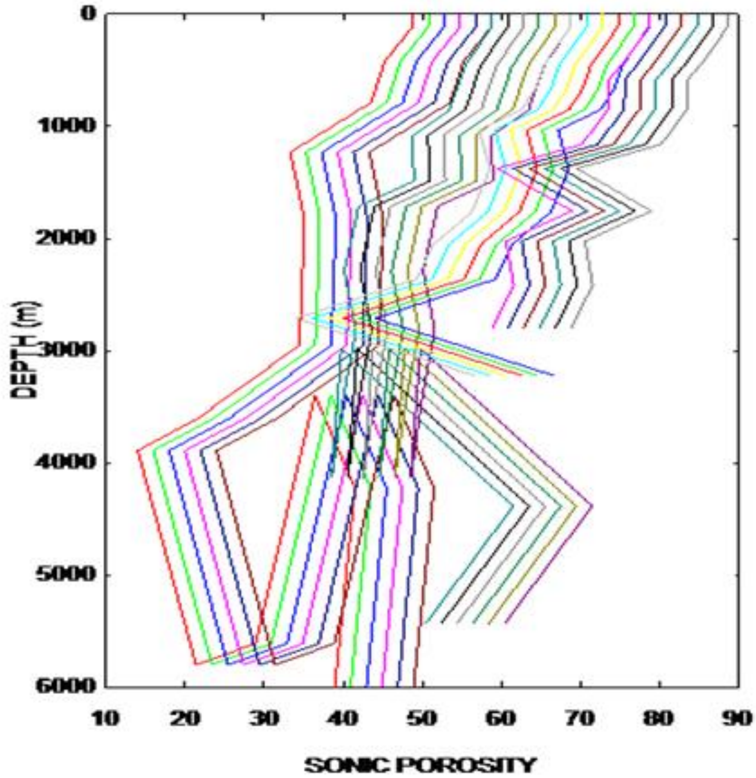

Figure 6: Porosity Section for Seismic Line M-31

1.2 Velocity Section

VelocityPseudoSectionsshowthesamevariationsoverthelithologiesasthePorositysections above. Intervalvelocitiesareexpectedtoincreasewithdepthalmostlinearly. However, suddenvelocityresponsecalled velocitypull-downorsags, which occurattheedgesofgassands oronthetopofoverpressurezones, canbeusedasindicatorsofzonesof hydrocarbon occurrence. Figures 7 –10, shows the Velocity pseudo sections created for analysis.

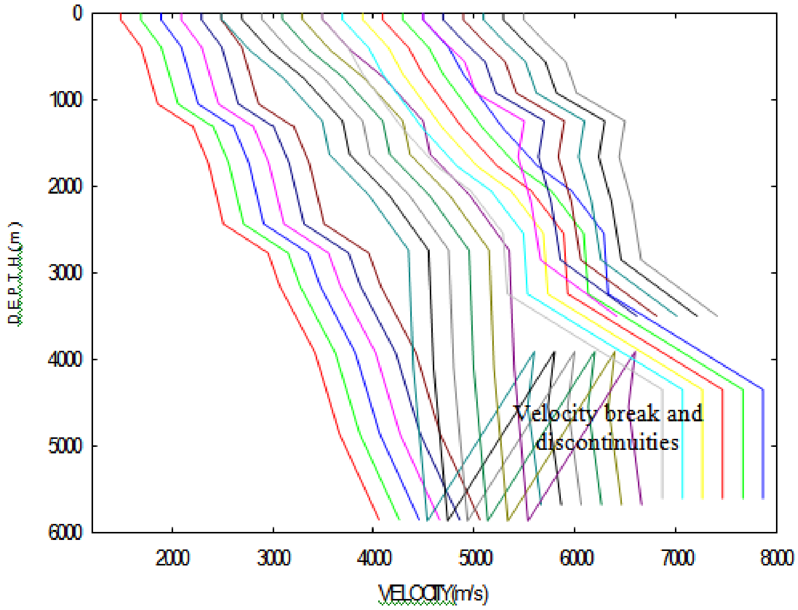

Figure 7: Velocity pseudo Section for Line M –16

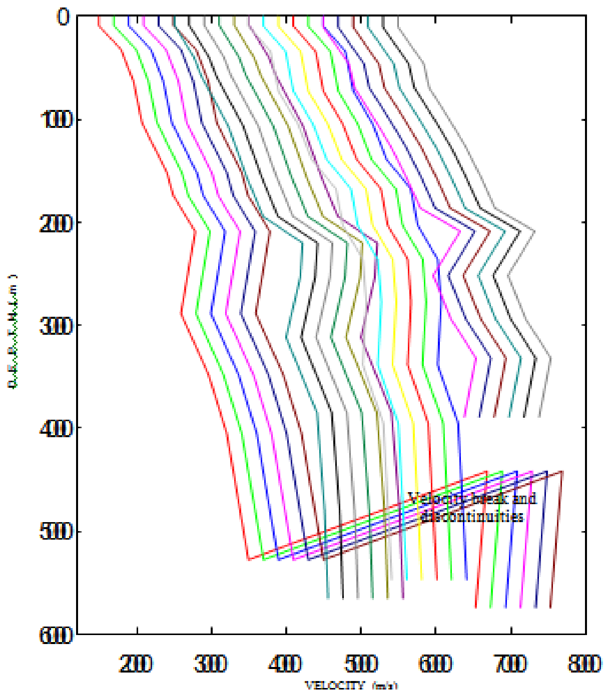

Figure 8: Velocity pseudo Section for Line M –20.

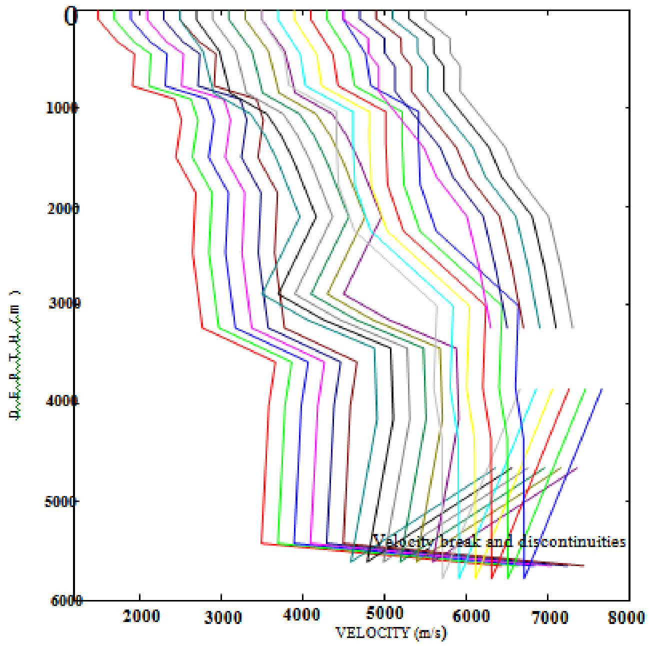

Figure 9: Velocity pseudo Section forLine M –29.

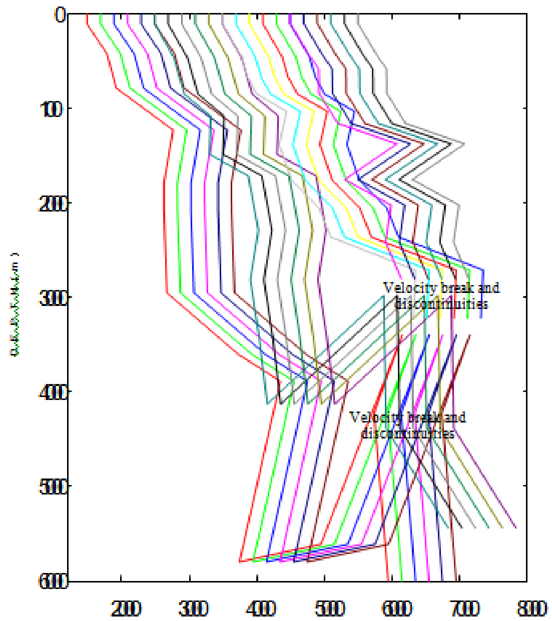

Figure 10: Velocity pseudo Section for Line M -31.

1.3 Analysis and discussion of Results

The Porosity Section for seismic line M-16(figure 3) shows the changes in porosity variation with depth for line M-16 forwhichitwasmeasured. Horizonscanbepickedwherethereare lithological changes. FromthePorositySectionof line M-20 (figure 4), weobservethatthechangeinporosityforwhichwepicked our H1from Section M-16 hasshifted froma depthof about 1000mtonearly 2200m.Since both sectionsaredipsections,itimpliesthattheHorizondipsinaNW-SE direction. The Porosity Section for seismic lines M-29 and M-31 (figures 5 and 6) show the changes in porosity with depth for both lines and horizonscanbepickedwherethereislithological Changes. BetweenHorizons1and2 for both lines, therearediscontinuitiesbetweentheplotsobtainedatthe differentpoints.Thisindicatesthefaultednatureofthelayeranditcorrespondsindepthto bottom of Agbada and top of Akata formations of the Niger Delta. However, thediscontinuitiesso delineated are much more evident on line M-31 than that observed on theSection of M-29.

Velocity pseudo section onLine M-016 delineated four (4) layers. Layer1isabout1220mthick, with velocity rangingfrom1490m/sto 2248m/s.It ischaracterized by relatively strong and continuous reflection amplitudes.

This layer is more likely to consist of loose and porous sands of the Benin formation. Layers2and3aresimilarintheirreflectionpatternsandamplitudes.Theyaremarkedby strongeramplitudesofreflections,mostofwhicharediscontinuous.Thestrataare1400mthick and velocity within these layers vary from 2317m/sto 3532m/s. This sectiondoes not show the faults characteristic of Agbada formation since geologic features are concentrated downdip.However,theporosityrangefrom20–35% is consistentwiththeestablished porosity values within the Agbada formation in the Niger Delta. The fourth layer occurringatadepthofabout3000mischaracterizedbyirregularand discontinuousreflections.Ithasvelocitiesrangingfrom2547m/sto3200m/s.Thenatureofthe reflectionsischaracteristicofshales,inthiscase a change in lithology from sandy shalesatthebaseoflayer 3 into shales of layer 4. This layer is the Akata formation. Also velocity pseudo section onLine M-029, delineated four (4) layers. Layer1isabout1225mthick.Itbeginsatadepthofabout1200monthe left, risestoabout1682mandfallsbackto1342montheleft.It hasvelocitiesrangingfrom1490m/sto2248m/s.Itischaracterizedbyrelativelystrongandcontinuousreflectionamplitudes.This layer is more likely to consist of loose and porous sands of the Benin formation. Layers2and3aresimilarintheirreflectionpatterns, amplitudes, thickness and velocity range as that in line M-016 discussed above. The noticeable difference is in the fault pattern in these layers within their depthof occurrence.Thesefaultzonesarerecognizedontheporosityandvelocitypseudosections ashighly irregular responses. These responsesshow thestratigraphicalvariations within the individual layers. Theanticlinalstructuresaredisplayedonthepseudosectionsasdisplacedeventsasonemoves from the left to the right of the sections. The fourth layer occurringatadepthofabout3000mischaracterizedby irregularand discontinuousreflections, and is similar in characteristics with the fourth layer delineated in line M-016.Thevelocities of the layers increases withdepth which is asa result ofthe increasingcompaction, depth of burial and age. The seismicrecordshow resultsofa subsurfacegeology thathasthreemajor subdivisions whichisinagreementwiththeestablishedsubsurfacegeology oftheNigerDelta.

A Comparism was made between PorosityandVelocity Sections for Seismic lines M-16 and M-29 withtheoriginal Seismic section to show correlation of the major formations ofthe Niger Delta, as well as delineationofthereservoirformation.Twosectionswerepicked,adipandstrikesectioneach.

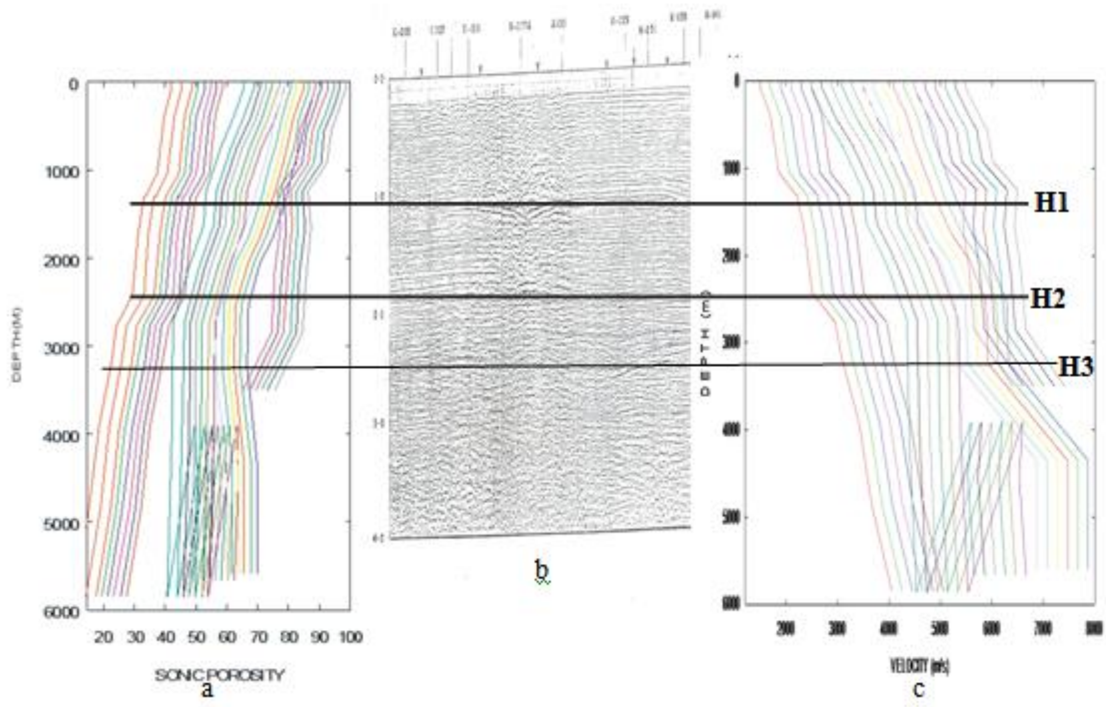

Figure 11: Line M-016 (a) Sonic Porosity. (b) Original Seismic section, (c) Velocity. Horizons H1, H2, and H3 are seen running across the various discontinuities observed in a and c. This correlates with amplitude anomalies observed in the seismic section in (b).

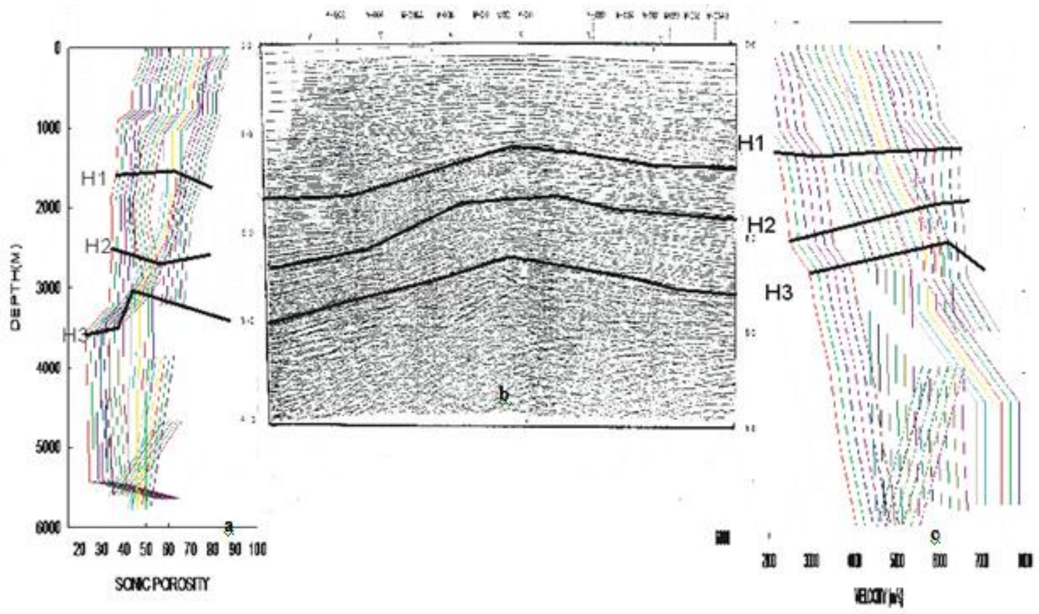

Figure 12: Line M-029 (a) Sonic Porosity. (b) Original Seismic section, (c) Velocity. Horizons H1, H2, and H3 are seen running across the various discontinuities observed in a and c. This correlates with amplitude anomalies observed in the Seismic section in (b).

V. Conclusion

We have interpreted recordsoffourseismiclinesfromMoonstone Oilfield Niger Delta forthe structures, anticlinalhorizonsand faults present.Pseudo Sections ofPorosityand Velocity were also constructedand interpretedfor the observed structures andreservoirparameters. Velocity pseudo section was usedtoidentify hydrocarbon accumulationzoneby checking for sudden reduction (velocity break and discontinuities) in its value, also regionalcompactiontrend was deducedfromintervalvelocitysinceitsvalue increases with depth and topof the overpressuredshalemass canbeidentifiedfromsuddenchangeincompaction trend. ThePseudosectionswerecomparedwiththeSeismicamplitude sectionsofthefourlines, and theresultobtainedshowsagoodmatchbetweenthethreesetsof sections. Theresultsobtained in this study areveryusefulinthesitingofappraisalanddevelopmentwells however, it should be carried out on the entire field.

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