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Stratigraphy and reservoir quality of the turbidite deposits, western sag, Bohai bay, China P.R.

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ABSTRACT

Stratigraphic and subtle reservoirs such as pinchouts, sand lenses and unconformities have been discovered in Bohai basin. These reservoirs occur in sub-basins and sag structures called depressions. A prolific depression is the Liaohe depression that has been filled with rapidly changing mixed alluvial fan deposit of the Cenozoic age. Attempts made at recovering residual hydrocarbon from the subtle reservoir have necessitated the re-evaluation of available data to characterize and model the prolific Shahejie Formation turbidite deposit occurring as pinchouts and sand lenses for hydrocarbon assessment, reservoir quality and possible recovery through enhanced methods. Methods employed covered well logs analysis, clustering analysis for electrofacies and fuzzy logic analysis to predict missing log sections. Stratigraphic and structural analysis was done on SEGY 3D seismic volume after seismic to well tie. Stochastic simulation was done on both discrete and continuous upscaled data. This made it possible to correctly locate and laterally track identified reservoir formation on seismic data. Petrophysical parameters such as porosity and permeability were modeled with result of clustering analysis. Result shows that electrofacies converged on 2 rock classes. The area is characterized by the presence of interbeded sand-shale blanket formations serving as reservoir and seal bodies. The reservoir quality of the formations as seen on the petrophysical analysis done is replicated in simulation volume results. Reservoir rocks have porosity between 0.1 and 0.25, permeability between 1 and 2mD and hydrocarbon saturation as high as 89%. Lithofacies are observed to be laterally inconsistent, sub-parallel to dipping and occurring as porous and permeable continuous beds or pinchouts hosting hydrocarbon. The stochastic stratigraphic model depicts rock units in associations that are synsedimentary. The prevalent configuration gotten from the model gave an insight into exploring and developing the field for enhanced oil recovery of the heavy hydrocarbon of this area.

1. Introduction

The Bohai bay is the edge of the area collectively called Bohai basin. It is a Cenozoic extensional basin along the eastern flank of Northern China as shown in Fig. 1 (Allen et al., 1997). The basin opened up between the younger Cretaceous and Oligocene. These created the parallel basins offshore and onshore. The age of the initial rifting becomes increasingly younger from east to west which makes for Paleocene-Eocene classification for the sub-basins of Bohai basin (Hu et al., 1989; Zhang et al., 1989, Zhiwu et al., 1989; Allen et al., 1997). Bohai basin is second in oil production after Songliao amongst China basins. The tectonic control on this marginal basin was probably subduction roll-back along the pacific plate relative to the eastern margin of Asia (Watson et al., 1987; Northrup et al., 1995 and Allen et al., 1997). The basin has rhomboidal central area and narrow extension trending northeast and southwest. The major sub-basin (Jizhong, Huanghua, Bozhong, Liaohe depression, Linqing depression and Jiyang depression) are initiated by four major internal uplifts (Chengning, Cangxian, Nichuang and Xingheng) as documented in Allen et al., 1997; Liu, 1989.

The various sub-basins and depressions earlier mentioned accepted deposits from older pre-rift strata which have been in turn conformably or unconformably overlaid by recent sediments. Allen et al., 1997, reports that Cenozoic successions of the basin can be divided into 6 Formations with Shahejie formation as the most hydrocarbon prolific. Shahejie formation has 4 members;

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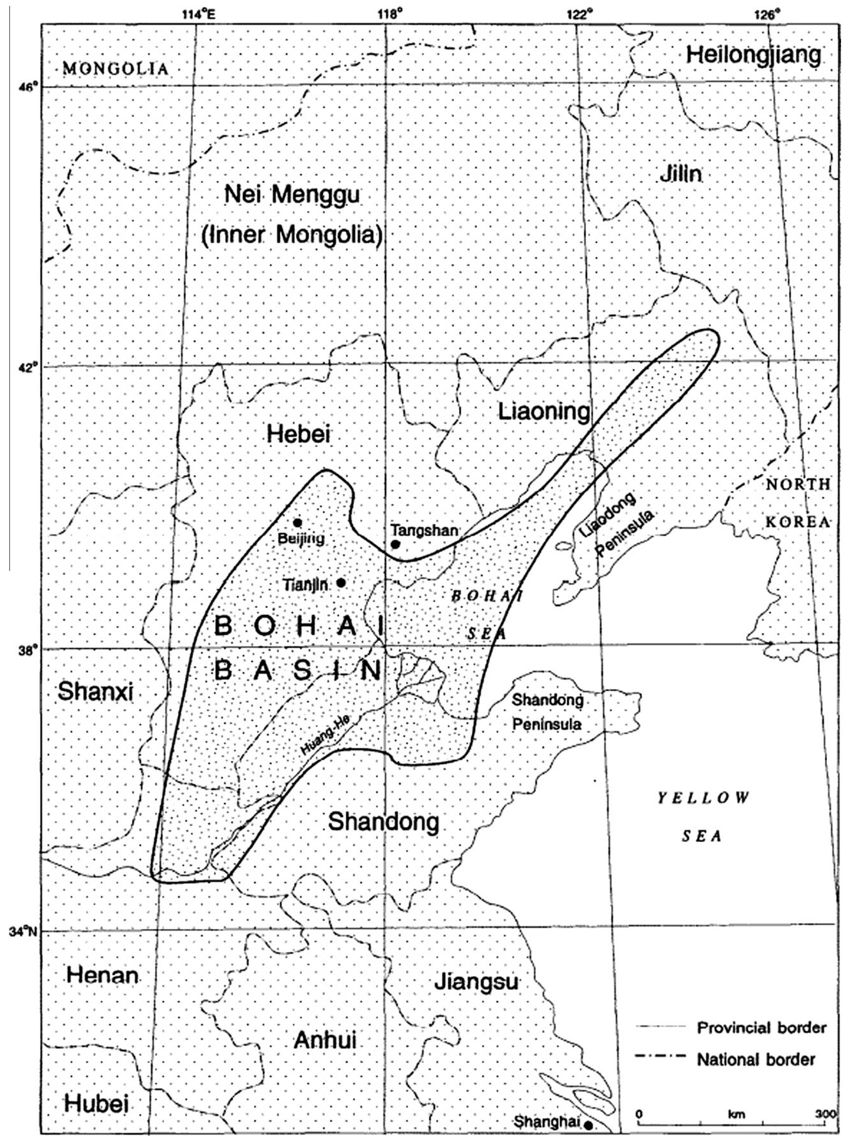

Fig. 1. Regional setting and location of Bohai basin (Allen et al., 1997).

Sha-1, Sha-2, Sha-3 and Sha-4, with Sha-2 and Sha-3 identified, encountered and studied in this work. The Shahejie formation on the average is 2500 m thick, it is a regression deposit probably formed in the time of decrease in tectonism. The upper Sha-2 is a fluvial-deltaic and shallow lacustrine deposit while the lower Sha-3 is characterized by deep water lacustrine with turbidites and Alluvial fan/deltaic sand sediments. They are both composed of organic rich lithified mud rock (shale), fine grained clastics (silts), sandstone and conglomeratic sandstones. Depositional induced association of the above sediments types is responsible for the subtle sandstone reservoirs of the Sha2 and Sha3. The 6 Formations has its' definition averse to standard international definition of stratigraphic units. This is because rock units in this sag structures are not ubiquitous but they include wide varieties of lithologies in different part of the same sag (depression). For instance, the third member of the Shahejie Formation (Sha-3) which is one of the prolific reservoir units contains rocks as diverse as lacustrine turbidite, sub-aerial alluvial fan conglomerates amidst silts and argillaceous rocks within single sag (Yan, 1990).

Over the years and especially in large hydrocarbon basins of China (Songliao and Bohai bay basins), some stratigraphic and subtle reservoirs were also discovered which has necessitated further study and subsurface modeling of reservoir lithologies especially in intra-cratonic basins (Guangming and Quanheng, 1982; Hu et al., 1984, 1986; Chengzao and Yinglin, 2004). Understanding the characteristic diversity observed in these sag deposits for reservoir and non-reservoir rocks is therefore the problem of exploration activities in this area. It is believed that this Tertiary syn-rift strata form the major hydrocarbon source rocks of the basin which are contemporaneous within the rifting. They are also the target for future oil and gas onshore exploration.

Turbidite sequences characterize alluvial fan settings. The Turbidite Cenozoic deposits of the western sag structure in the Bohai bay has been characterized for stratigraphy and reservoir quality. Making use of core data from a centrally located well, petrophysical property for other well locations has been predicted. The result logs constituted part of data used for clustering operation targeted at reflecting the stratigraphy of the deposits and also to match the reservoir quality for exploration purposes. Post-stack seismic volume data assisted in laterally delineating the rapidly changing rock units and also in revealing the prevalent synsedimentary structural pattern (Owoyemi and Willis, 2006; Tong et al., 2008, Bao et al.,

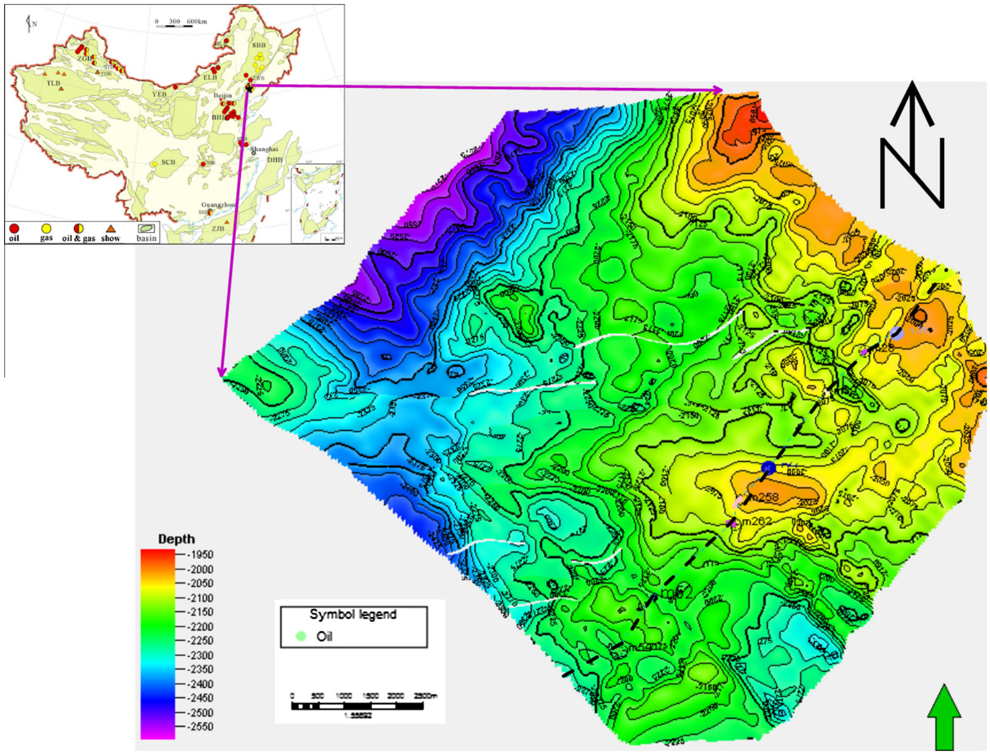

Fig. 2. Study area highlighting the location with east west trending tertiary fault system and an arbitrary correlation line.

2009; Allen et al., 1997; Reijers, 2011). All this has an implication in the exploration philosophy that is most suitable for recovering the heavy oil typical of this peculiar zone of interest. The objective of this study is targeted at redefining the stratigraphy of the turbidite reservoir formations and evaluating their homogeneity or heterogeneity. This is in view of the desired recovery of the bypassed hydrocarbon locked amidst the fairly continuous and unpredictable lithological units. Furthermore, the quality of the reservoir units from petrophysical rock properties will be established. This is important to deploying the expertise of drilling engineers as the shale associations within the clastic reservoir is quite significant and more often pose as permeable reservoir units in some portions thereby wrongly informing and misrepresenting the interest of explorers as viable locations of porous and permeable beds. These fairly lateral continuous beds varied thickness between 0.6 m and 55 m observed on analysis.

Parallel wells like m34 and m47 (Fig. 2) that are discovered to have sampled the same reservoir and hence must have similar reservoir thicknesses and petrophysical properties has not yielded substantial hydrocarbon. This has called for further investigation. The nature of the turbidite alluvial deposits suggests a definite mix of reservoir and non-reservoir rocks with trap and seal associations. The evaluation of this situation is the aim of the exploration program, hence this study.

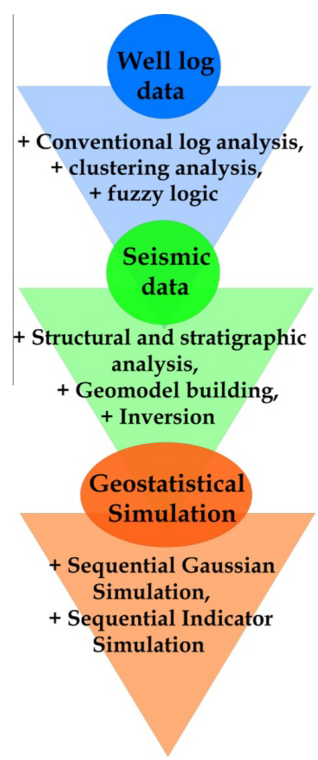

Fig. 3. Methodology flow chart.

2. Study area

The western sag of the Bohai bay popular known as the Xinglontai majuanxi is an alluvial fan buried hill structure known for its wrenching structure as enforced by the contrasting and alternating underlying controlling strike slip faults typical of the Bohai basin. This sub-hill structure has the prolific Shahejie formation as its major hydrocarbon reservoir, with series of deposition episodes recorded over the Paleogene to Neogene in the Cenozoic. The extensional setting of the Basin in Northern China was part of the tectonic changes that initiated the opening of the volcanic basements, fracturing it and creating the containment for accommodation for the emplacement of the sedimentary rocks (Zhenyan et al., 1999). Series of horst and graben developed in middle Eocene during the deposition of the middle Shahejie

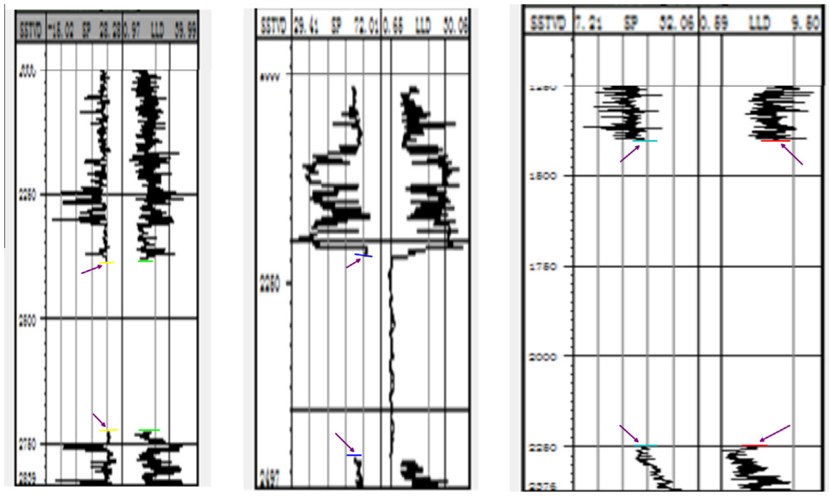

Fig. 4. Sample well logs before fuzzy logic Bin.

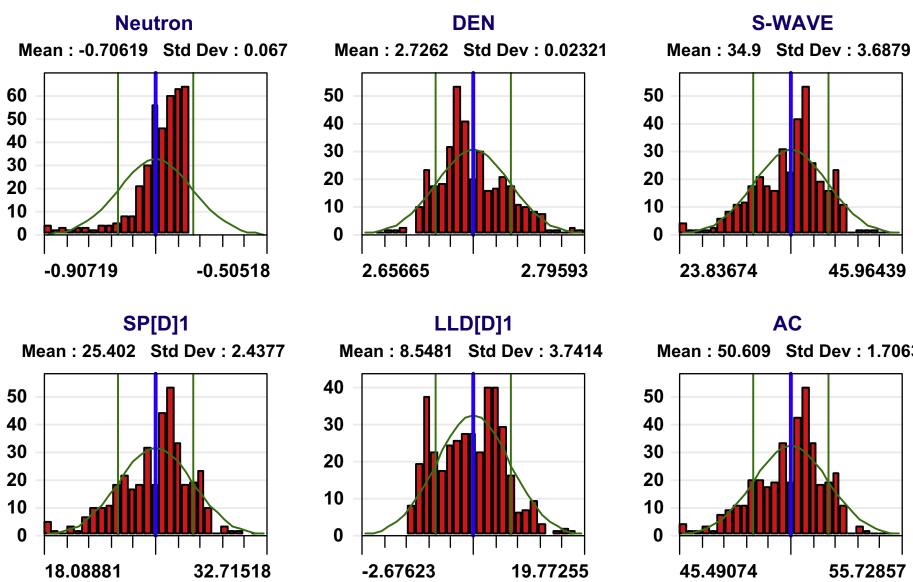

Fig. 5. Fuzzy logic Bin distributions.

formation. Consequently different architectural pattern emanated from the synsedimentary processes. Tertiary fault systems (Fig. 2) that are formed are seen to be predominantly dipping listric and thrust faults associated with some level of transtensional operations within the interfingering sandstone and shale formations.

3. Methodology

The stepwise procedure employed in this study is as illustrated by flow chart in Fig. 3. Suite of wells logs gotten from the field of study was the primary data employed for this study sequel to which 3D volume post-stack seismic data was integrated to give a robust lateral understanding of the reservoir units. The well log methods commenced with the preliminary investigation of the nature of the logs which are fair and incomplete. Thus there was need to predict values for the missing portion of the logs in order to have all locations accounted for in properties of rocks. Prediction of missing portion of logs was done with the fuzzy logic method (Cuddy, 1997; Demicco and Klir, 2004).

3.1. Fuzzy logic process

Mean, Standard Deviation (SD), curve bin size are some terms used in Fuzzy logic operation. The fuzzy logic method used the equally sampled bin size for continuous well log data that has gaps in them (Fig. 4) are analyzed and predicted. Figs. 5 and 6 are plot of fuzzy logic model statistics. A set of histogram plot presented on Fig. 5 is generated by plotting the input curve data values such as Density, SP, LLD, Sonic and Volume of Shale, in such a way that the bin size allocation will make it possible to fit a Gaussian distribution plot line (green line) on the histogram plot. This ensures that the data is normally distributed. The vertical blue line is the mean of the distribution while the standard deviations are the green lines flanking the mean. The number of bin classes is the number of histogram bars while the vertical axis has the data value binned. The crossplot for the fuzzy logic operation is in Fig. 6. It plots the bin mean value versus the bin number for each input curve. Standard deviation plots are the green vertical lines on both sides of the bin mean value (orange

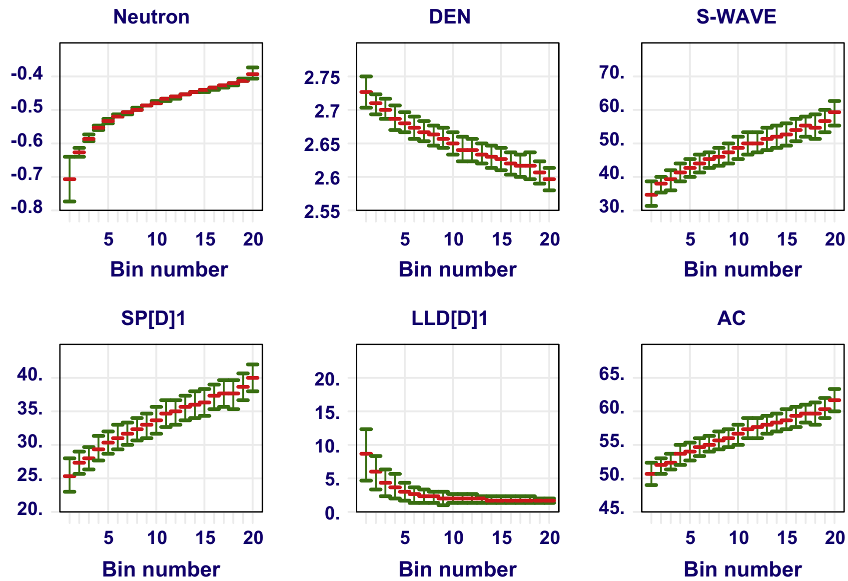

Fig. 6. Fuzzy logic Bins histogram.

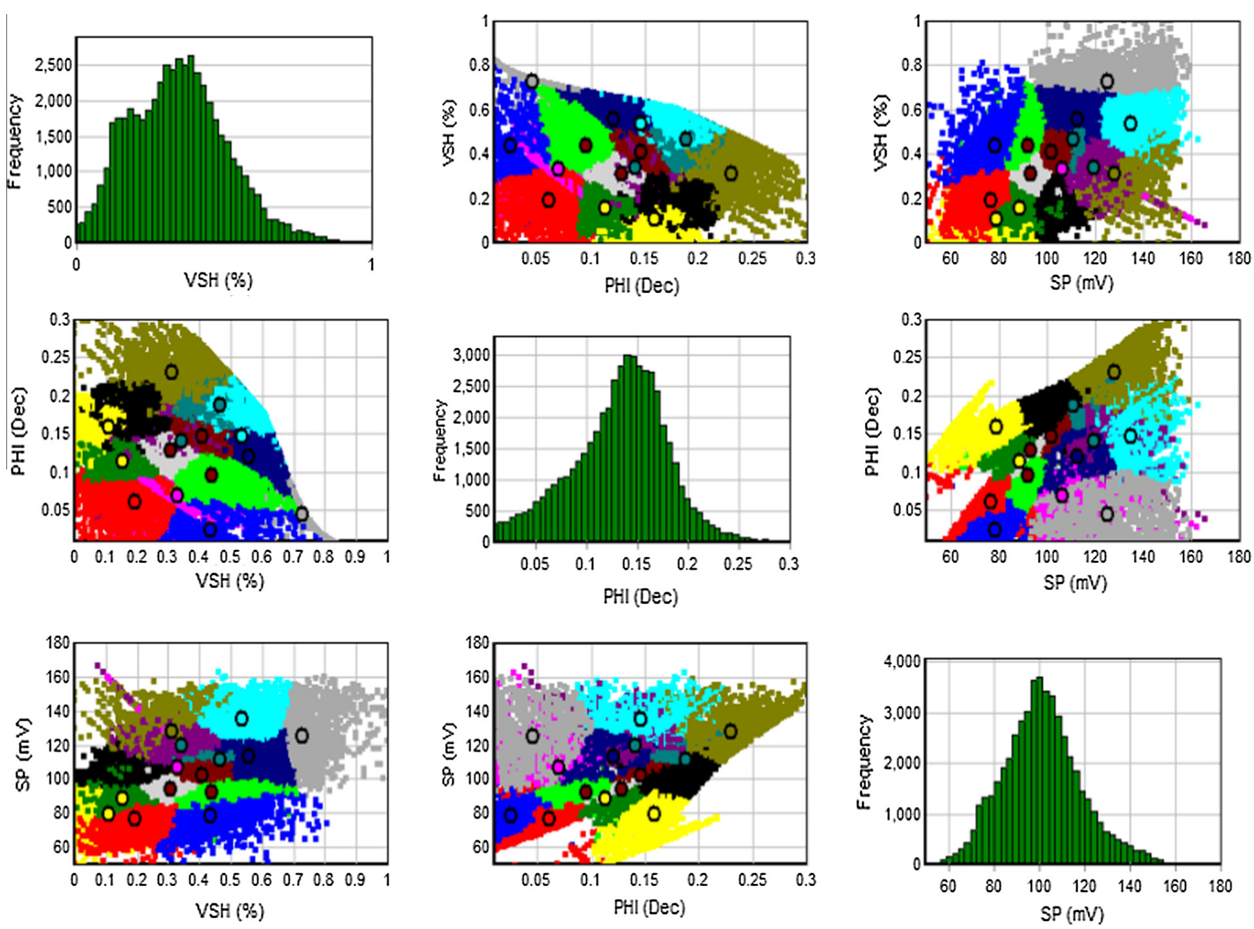

Fig. 7. Crossplots and histograms for the clustering run showing mean of clusters for 13 classes.

horizontal bar). These two plots are outputs of the model statistics that are observed and analyzed for the fuzzy logic operation. Multiple data can be used as input to predict a target log based on a degree of falsehood or truthfulness. This was targeted on bin classes at the depth of missing log on the sample well. Neutron, Density S-wave, SP, LLD, Sonic, Volume of Shale (V_{sh}) and porosity are some logs used in the fuzzy logic operation. The fuzzy logic operation was followed by clustering analysis for electrofacies characterization/rock typing. The model statistics in histogram and crossplots was available to correct for necessary associated errors in choices made for the model variables in the statistical package used (Figs. 5 and 6).

Table 1
Zones formation properties of well logs interpretation.

Zone/Fm	Lithology	Top	Bottom	Gross	Net	*N/G*	Av Phi	Av Sw	Av V_{sh}
1/A	Sand silt clay	1980.88	2141.38	160.50	149.88	0.934	0.184	0.639	0.257
2/B	Sand silt	2141.38	2189.63	48.25	45.25	0.938	0.174	0.586	0.208
3/C	Sandy clay	2189.63	2304.25	114.63	89.88	0.784	0.185	0.921	0.394
4/D	Sand silt	2304.25	2356.13	51.88	51.00	0.983	0.178	0.556	0.153
5/E	Sand silt clay	2356.13	2394.75	38.63	37.13	0.961	0.175	0.621	0.211
6/F	Sand silt	2394.75	2450.75	88.00	87.88	0.999	0.167	0.565	0.163

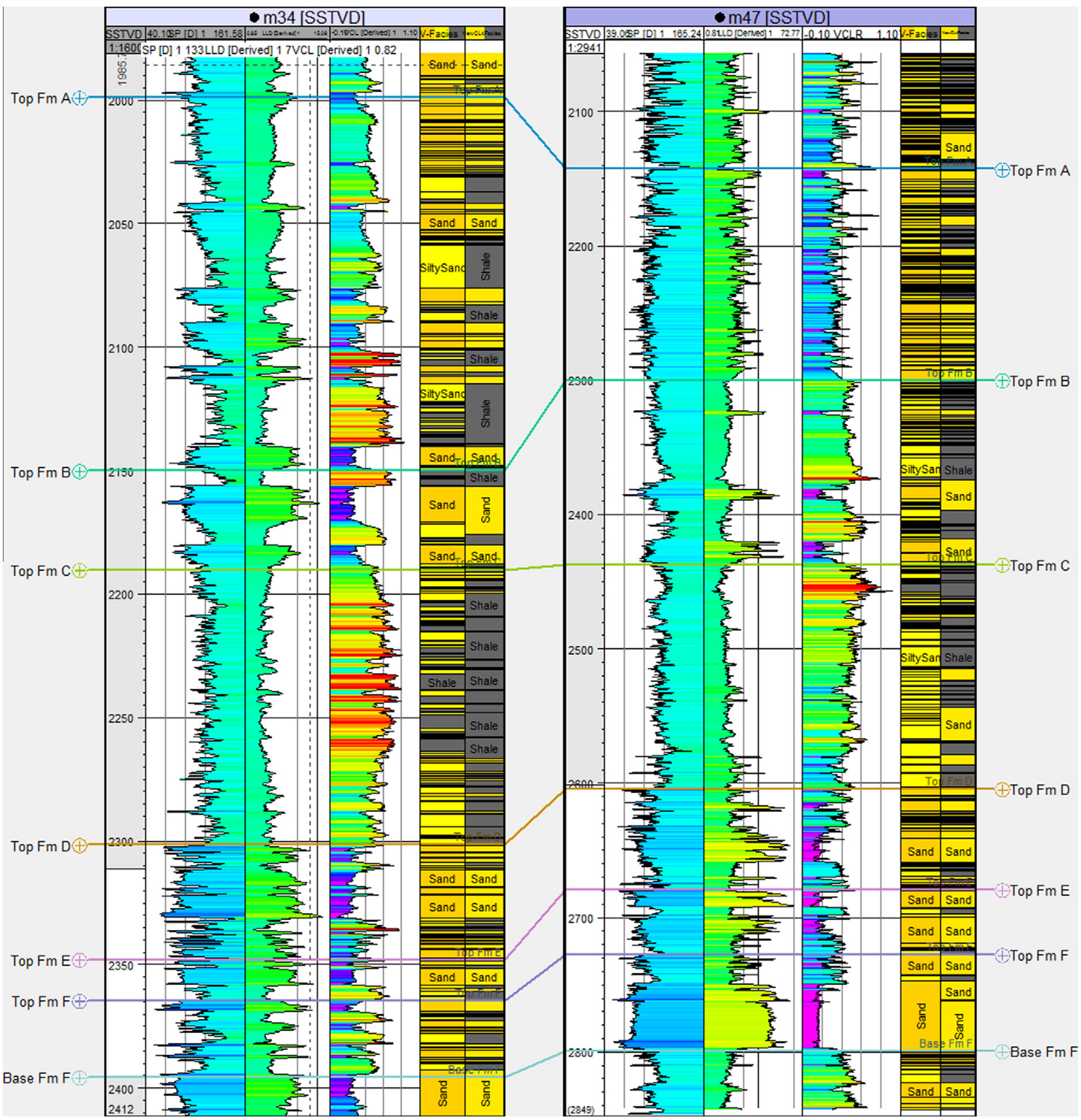

Fig. 8. Correlation panel for the two study wells m34 and m47.

3.2. Clustering analysis

Clustering analysis is a process that uses regular statistical techniques that randomly distributes data into groups. This is a non-parametric method of rock typing. It is based on the records of the input properties and some averaging patterns that is a function of the disparity or similarity of the data value (Anil and Richard, 1988; Euzen et al., 2010; Sharma et al., 2011; Euzen and Power, 2012). For this aspect, log data with value indices that represent rock properties are the data used. Cluster analysis for geological interpretation and reservoir formation from well log data results in electrofacies log. With support and clarification from core data, this is often used to correlate geological facies as it is the approach used here. This requires building an initial model with similar logs available especially those logs that bear unique physical properties to the one desired to be predicted. With the

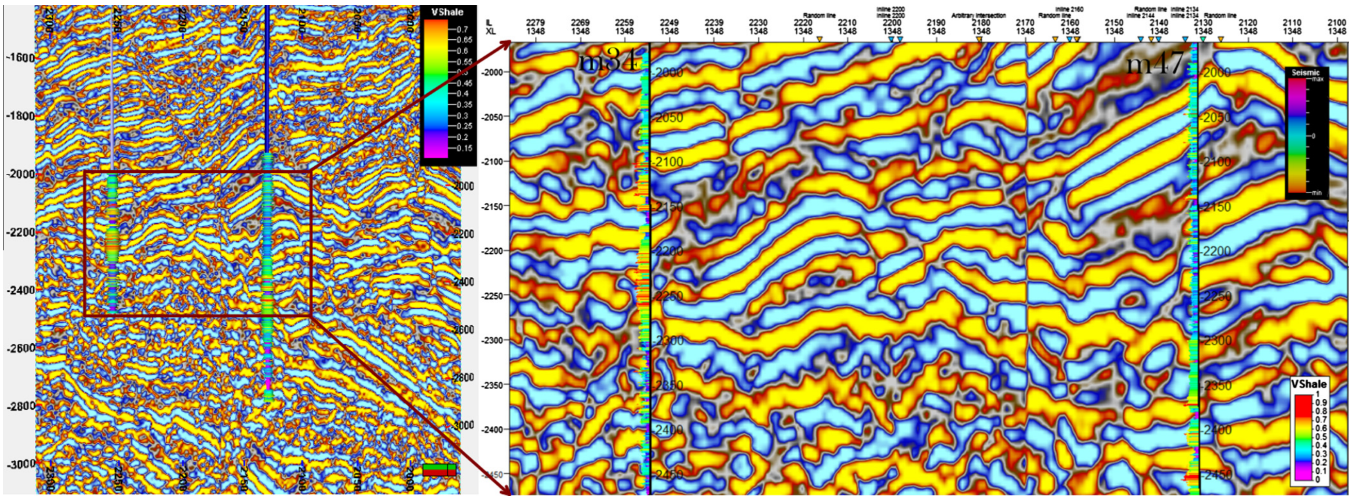

Fig. 9. Crossline 1348 with wells and logs. Picture on the right is a closer view of the region of interest.

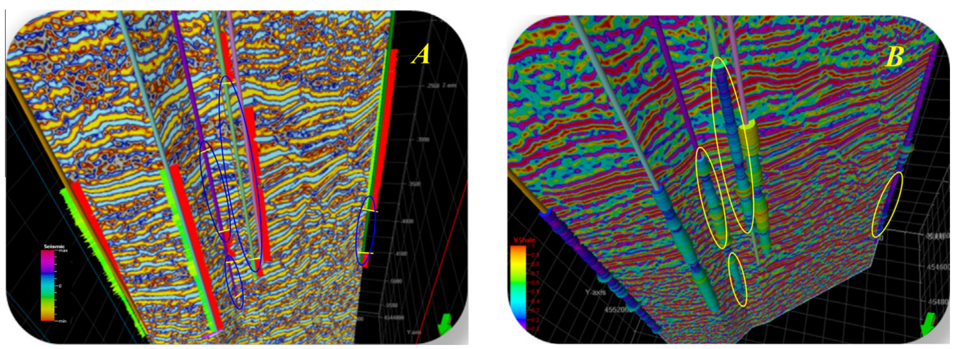

Fig. 10. Correlation line with logs and arbitrary seismic. Location of missing log portions (gaps) with high and low amplitude reflections seen within rock column.

input logs appropriately chosen, the model was created first for some individual wells then a correlation line model was built. The result of the statistical prediction complemented the other logs available and all was used in the clustering analysis done for electrofacies. The clustering technique used was an integrated module in the Interactive Petrophysics software. Data from Spontaneous Potential (SP) and Deep Laterolog (LLD) were used as inputs in the first phase of clustering run prior clustering analysis with petrophysical logs (Fig. 7). A vast amount of oil and gas produced today comes from accumulations in the pore spaces of some clastic and carbonate reservoir rocks; the Gamma ray (GR) log is often used for lithology identification in differentiating between reservoir and non-reservoir rocks (Asquith, 2004). However, for the purpose of reservoir formation identification, the Spontaneous Potential logs (SP) is the available lithology log and was used in the absence of Gamma ray log and validated as well using deep Laterolog (LLD).

Conventionally by design, SP logs are meant to respond to salinity contrast of formation during logging operations. The movement of ions of different salinity causes potential difference that is recorded. The records of potential difference reading gotten from different bed responses to current flow are presented in ohms/m. Left signature deflection on SP log reading suggest the presence potential reservoir sand unit, while a right deflection typifies a more conductive bed such as shale. This inference is further substantiated by picking a corresponding right signature deflection on the Resistivity log for the potential reservoir (more resistive fluid hosting) sand unit. Deep Laterolog (LLD) being the available resistivity log was used. Other log types were subsequently used to substantiate this. SP and LLD logs became the first log set from which reservoir formations were inferred. This also served as the basis for using the logs for the first phase of clustering analysis.

In all cases, all logs operations were preceded by Normalization as a means of correcting some acquisition and environmental flaws on them (Neinast and Knox (1973), Patchett and Coalson (1979), Lang (1980), Doveton and Bornemann (1981), Reimer (1985), and Shier (1997, 2004).

Defining heterogeneity and homogeneity was therefore easy after clustering rock units and seeing them in the light of their petrophysical rock properties. Stochastic simulation, visual examination and comparative analysis were the last operation in the methodology step. The vertical boundaries of the simulation casing were surfaces produced from lateral tracking of horizon on seismic data after well tying.

4. Results and discussion

4.1. Clustering result, lithology identification and stratigraphy

An arbitrary correlation line was used to link and access the wells along the zone of interest. This correlation line cuts across 6 of the wells as shown in Fig. 2. The sample well of interest m34 and m47 are included. Summary of the well log interpretation indicates lithology such as lithified clay, silt and sand as seen in zone/formation of Table 1. The rocks of these zones have a mix of sand and shale units with a total thickness of approximately 510 m. This is confirmed from the clustering analysis result used for shown on tracks 4 and 5 of Fig. 8. This became the input discrete data used for facies simulation process. On seismic data, the rock facies typified

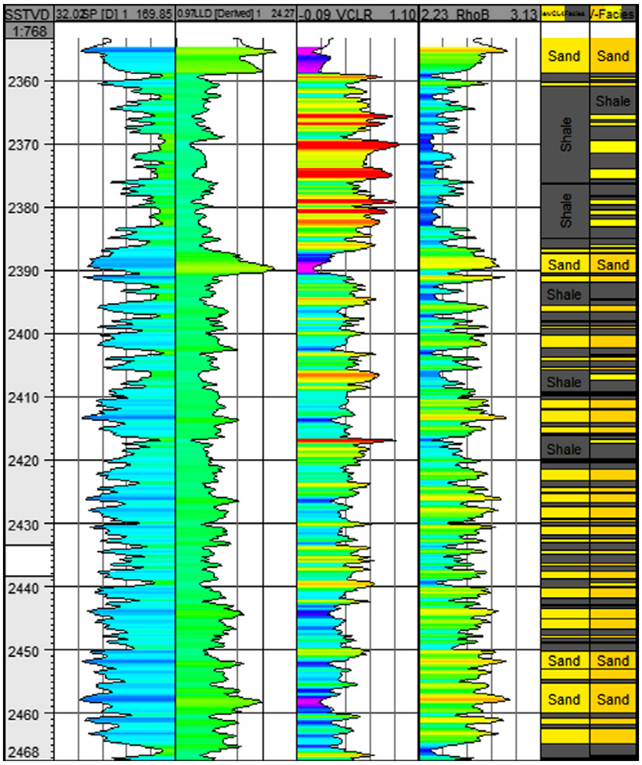

Fig. 11. Well panel with result of clustering analysis on tracks 6 and 7. Track 7 has the better result as it displays clearer delineation of lithologies especially the upper portion of the plot panel. The thick upper portion lumped as shale bed on track 6 has been reanalyzed and shown on track7 that there are other rock types present.

by the zone is sub-parallel, sigmoidal to chaotic characteristic of turbidites (Fig. 9). The sub-parallel facies occurs at varied depth on both wells overlying and occurring amidst the non-parallel facies–sigmoidal/chaotic (Figs. 9 and 10). Thus lateral continuity of particular strata identified on one well to the other is brief from seismic resolution of the seismic-well trajectory shown on Fig. 9. Well m47 is located in the north-eastern direction from m34 and the offset distance is more than 3000 m (Fig. 2). Most reservoir rock units are sandwiched between other rock types (Figs. 8–10). These units are the hydrocarbon bearing portions of the interpreted zone, they have been designated sand_34a–sand_34f and sand_47a–sand_47f for zones A–F on each well.

Fig. 10 projects seismic intersections of a correlation line opened in a bid to assist in proper understanding of the rock units. Portions of the missing well logs sections predicted is displayed. The left picture A shows the missing gaps marked with yellow ticks and captured in blue ovals while the right side picture B shows the now filled log sections captured in yellow. The nature of the rock units can be spatially observed along an arbitrary line. The variations in bright and dim reflections as typified by amplitude contrast are also clearly seen. This contrast are seen in the light of the well logs displayed alongside the intersection plane with the seismic data. The resolving power of the survey frequency and nature of the terrain accounts for the seismic quality.

Rock unit information along the reflectors as it transforms into another is clearly seen in Fig. 10 which is a seismic section obtained from computation of volume attributes that combines principal component analysis, trace gradient with second derivative of seismic trace. This made the contrast in amplitude wavelet a basis for laterally tracking horizons and eventually defining the containment boundary for simulation operations.

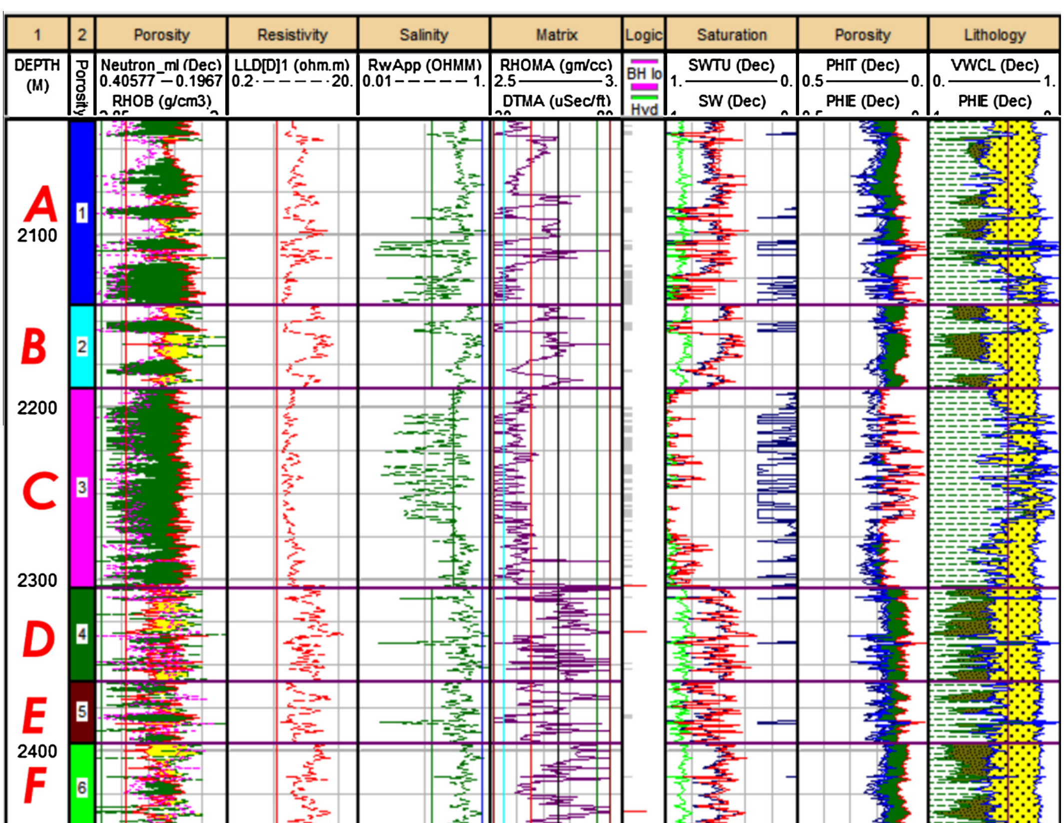

Fig. 12. Well m34 panel showing N–D crossplots showing sand/shale discrimination and lithology section track with sandstone, shale and silt. Delineated reservoir units are shown numbered 1 to 6 on the second track.

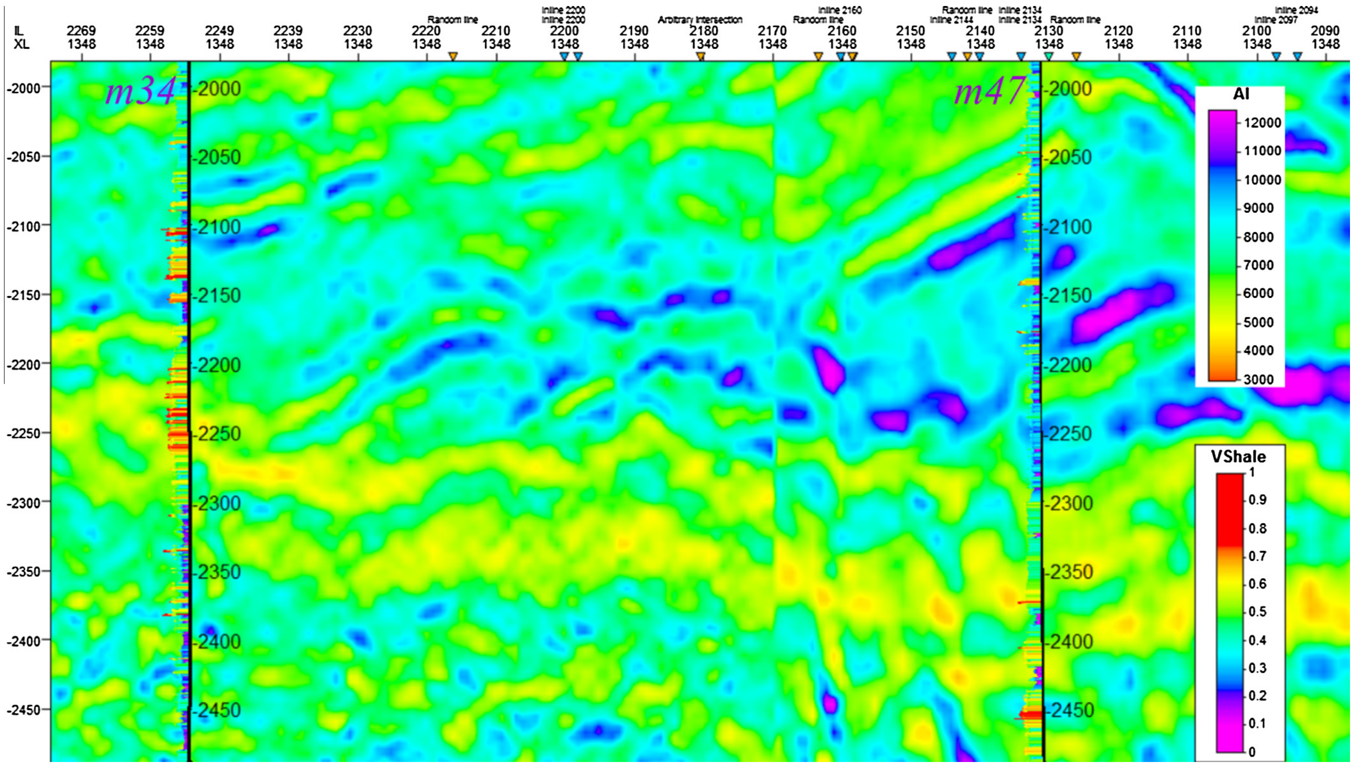

Fig. 13. Tying well 34 with inline 1348 displaying the contrasting bands of high and low impedance points as they matches the sand and shale on lithology section tracks.

Table 2
Petrophysical properties of delineated zone sand units from wells.

Reservoir	Av. thickness (m)	Av. porosity (ϕ)	Av. permeability (K) mD	V_{sh}	Shc
Sand_34a	22.50	0.19	1.1	0.25	0.51
Sand_34b	26.86	0.18	1.2	0.18	0.56
Sand_34c	–	–	–	–	–
Sand_34d	51.04	0.24	1.0	0.15	0.68
Sand_34e	12.81	0.20	0.9	0.21	0.64
Sand_34f	57.21	0.23	0.7	0.16	0.65
Sand_47a	94.25	0.20	1.2	0.22	0.60
Sand_47b	116.88	0.18	1.6	0.21	0.89
Sand_47c	6.75	0.15	1.5	0.10	0.49
Sand_47d	25.06	0.18	1.3	0.16	0.48
Sand_47e	–	–	–	–	–
Sand_47f	114.23	0.16	1.4	0.11	0.53

From preliminary investigations both on well logs and seismic data, cross sections revealed that the lithological units have various associations of sand, shale and mixed silty clay with sandy shale units. This can be seen in the on the results of both the clustering run (Fig. 11) and the crossplots laid out well logs interpretation that made use of the series of signatures observed on both spontaneous potential and resistivity logs. The neutron–density crossplots, porosity inferred crossplots with Bulk volume water and a section of lithology flags (Fig. 12) shows the nature of the rock units as stacked lithologic formations fairly water saturated (Table 1). The parallic shale blanket serves as potential seal (flow barrier) to hydrocarbon migration into sandstone reservoir.

4.2. Reservoir geology

The lithologies identified from the well logs are as shown on log plot panel in Fig. 12. The plot panel comprises 10 tracks. While Track-1 is the depth (TVDSS) column; Track-2 is for identified lithologies. The first log bearing track, Neutron–Density (N–D) porosity cross-plot is on Track-3. It has green and yellow color coding within the cross over spaces. The green color indicates presence of argillaceous rock (fine grained clay, shale and silt), while the yellow represents sand units. The size of the cross-over is a function of the proportion and abundance of each rock type. Resistivity and Salinity (RwApp) are listed in Track-4 and 5 respectively. Matrix density is presented on Track-6; while water saturation (Sw), porosity (effective and total) and lithology type (based on effective porosity) are in Track-8, 9 and 10 respectively. The rock column is divided into 6 portions. This demarcation carefully done accounts for prevalent properties observed on N–D crossplot of track 3, resistivity values and effective porosity constrained lithology discrimination of track 10 (Fig. 12). These initial demarcations are rock deposits (1–6) that are not easily termed reservoir tops because of their varied composition and heterogeneity.

Deposit 1 is a stack of conical patterned feature on the crossplot of track 3. The resistivity signatures are fairly distributed with the lower portion being less resistive. Tracing the lower portion on the matrix density track gave the average density of between 2.35 and

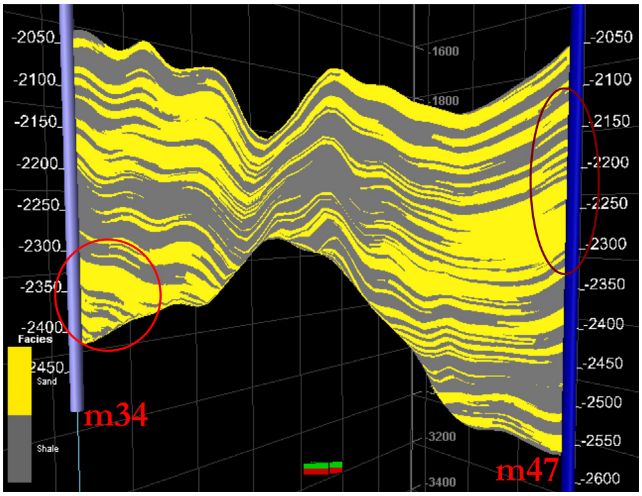

Fig. 14. Well m34 and m47 intersection result of stochastic facies simulation.

2.7. Water saturation for this deposit varies between 0.5 and 0.85. The porosity flag value amounts to between 0.15 and 0.25 as seen on track 9. Lithologies identified include sand, silt and shale. They appear as interfingering deposits indifferent proportions directly corresponding to the earlier observed patterns on other logs and the N–D crossplot.

Deposit 2 is brief and covers 52 m approximately. Alternating sand and shale color coded sections are seen in a seemingly equal proportion. The crossplot is brief and with confirmation from analysis of other logs, the deposit has recoverable hydrocarbon. The resistivity log reads high in yellow (sand) region and low in green region. Porosity value is similar to the overlying deposit, but with lower value of water saturation. More of sand formation has been delineated here as against silt and shale counterparts seen on track 10 (Fig. 12).

Deposit 3 is a massive zone with an almost featureless resistivity log signature. The crossplot shows a larger portion of it predominantly coded in green color. This is an indication that the lithology association of this zone is more of consolidated clayey rock unit (shale) and minimal sand. The density is low at predominantly less than 2.65. Water saturation reads high as seen on track 7. The porosity is also low at 0.2 on the average.

Deposit 4 is approximately 55 m thick. The patterns on the crossplot indicate mixed lithologies as seen in the color patches. Resistivity log signature is also moderate. Matrix density is not less than 2.6 and water saturation is between 0.65 and 0.85. Effective porosity measures between 0.15 and 0.3. The deposit has a proportionate distribution of sand and other rock units.

The underlying bed (deposit 5) has a thickness of less than 50 m. The crossplot feature bears a similarity with overlying deposit 4 but for the increased quantity of shale units characterized by the bigger green color crossplot pattern. Effective porosity is between 0.15 and 0.23. The lithology shows more of consolidated clay (shale) and silt than of sand.

Deposit 6 is at the base of the interpreted rock sequence. It has an average thickness of more than 90 m. the crossplot pattern show more of yellowish filled balloon than the green variety. The deflection of the resistivity log is fair and corresponds well with the crossplot inferred lithologies. Matrix density is between 2.5 and 2.7. Effective porosity values ranges between 0.1 and 0.25. The lithology plot on track 10 has distinct shapes and patterns such as the fining upward pattern seen as the base. The middle portion has a crescent shaped pattern while the top is more of coarsening upward sequence. These patterns are not clean formations but have mixed lithologic associations of sand, silt and shale. This is as displayed on the sample output of clustering analysis result is shown on tracks-5 and 6 of Figs. 8 and 11, prior to simulation.

Intercalations of lithologies are obvious on the panel shown and this was confirmed on the acoustic impedance inverted seismic volume (Fig. 13).

These units were seen as fairly continuous reflection patterns on vintage seismic and also characterized by inconsistent abrupt termination both as pinch out stratigraphic traps and also against fault planes that numerously separates trending reflections.

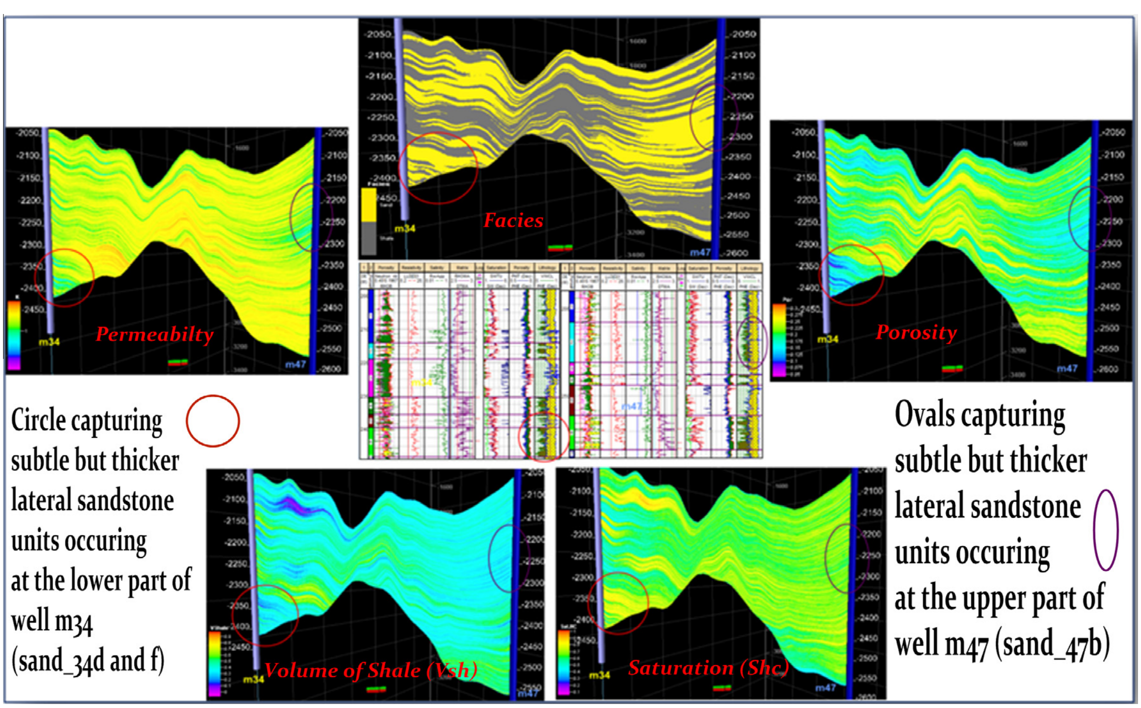

Fig. 15. Wells m34 and m47 captured within an intersection showing some of its petrophysical rock properties with emphasis captured for *sand _34d and f* and *sand_47b*.

4.3. Petrophysical properties evaluation

In an attempt to view the strata in the light of their petrophysical properties having earlier used it for clustering analysis, cross sections were opened in the vicinity of the wells. This is to assess hydrocarbon saturation in the light of how porous and permeability each rock units are and also the volume of shale associated with the reservoir rocks of interest (sand_34a-f and sand_47a-f). Table 2 summarizes the petrophysical properties.

The characteristics of the reservoir units interpreted in 'Hems field' studied is collectively presented in Fig. 15. The simulation result from the facies clustering analysis (electrofacies) is seen in Fig. 14. This is a graphic presentation of the stochastic occurrence of the different interpreted facies within the subsurface column interpreted. The beds are non-planar and undulating. The undulation is probably as a result of the basement volcanic which has experienced the effect of the Tanlu fault and Tian Dawa (Hong and Yang, 1984; Tong et al., 2008). These left-lateral regional strike-slip faults are believed to be the complicated geological architecture that has shapened the structural attitude of the overlying sediments. The Xinglongtai majuanxi area is a sub-hill and sag structure, the rock units have taken the present form as they are being deposited unconformably on the basement. Huang et al., 2009, reported that the basement is formed into a fractured unconformity lateral drape structure within a buried hill having burial depth of beyond 4000 m.

Stratigraphically, single sandstone reservoir units range in thickness between 0.6 m and about 50 m with sandwiched shale units (Figs. 12–15). Some of the portions with subtle imprints are captured in circles and ovals in Fig. 15. On well m34, the sand_34d is located between 2305 m and 2356 m (51 m) while sand_34f occurs between 2393 m and 2450 m (57 m). Well m47 has a thicker portion of sand body though not clean as seen in the facies oval in Fig. 15. It is sand_47b occurring between 2153 m and 2316 m (163 m). Petrophysical rock property values for this portion has been extracted and summarized in Table 2. The porosity for these sandstone units is in the range 0.1 to 0.25; the permeability observed is between 1 and 1.8mD. The volume of shale values is between the range of 0.2 and 0.4 for the sand zones and hydrocarbon saturation for this portions is as high as 65% in locations with thin lateral units and as high as 89% in the portions seen and captured in oval on well m47 (Fig. 15). All these within the context of the structural elements prevalent after the initial episodes of production indicates the potency of the area for further recovery of the remaining heavy oil and gas through various enhanced oil recovery methods.

5. Conclusion

The stratigraphy of portions of the turbidites deposits in Hems field has been studied using well logs and seismic data. A method of predicting missing logs and also of clustering for electrofacies population has been explored. The result shows occurrence of as high as 89% hydrocarbon saturated units locked within blanket of shale sediments. The shale sediments act as both source rocks and as seals for the porous and permeable sandstone reservoirs rocks. On the overall, the reservoir quality of the Hems field is high from the observed petrophysical rock properties realized although they occur as subtle and easily by-passable units hosting heavy hydrocarbon. However with the use of recent advances in enhanced oil recovery methods, steam injection method (SAGD) would do well in sweeping and driving the remaining hydrocarbon to proximal producing wells.

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