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Well Logs Analysis Using Neuro-Fuzzy Technology (Case Study of Niger-Delta Region of Nigeria)

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Abstract: Petrophysical log interpretation is one of the most useful and important tools available to a petroleum geologist. Well logs help to define physical rock characteristics such as lithology, porosity, permeability and to identify productive zones, to determine depth and thickness of zones, to distinguish between oil, gas, or water in a reservoir and to estimate hydrocarbon reserves. This study presents the results of a study that used unsupervised Self Organizing Map (SOM) artificial neural networks and fuzzy rules derived from log characteristics for the determination of oil well lithology from open-hole geophysical well logs. The methodology proposed for the identification of oil well lithology was tested with case data obtained from an oil well located in the Niger delta region of Nigeria. The result shows that the fuzzy logic based log interpretation model used for the analysis of the clusters (log-facies) generated from the well logs can be used to identify and classify the lithology of oil wells without the use of core sample data.

Key words: Log facies, SOM neural networks, fuzzy logic, Niger-delta region

INTRODUCTION

Artificial Neural Networks are non-linear, sophisticated modeling techniques capable of modeling extremely complex functions (Statsoft, 2002). Artificial Neural Networks can transform a linearly inseparable problem into a linearly separable one. They learn by example and can be applied in virtually every situation in which a relationship between the predictor variables (independents, inputs) and predicted variables (dependents, outputs) exists. They are applicable even when the relationship may be very complex and not easy to articulate in the usual terms of "correlations" or differences between groups.

Artificial Neural Networks can be trained using either the supervised or the unsupervised learning or training techniques (Statsoft, 2002). In supervised learning, the correct results (target values, desired outputs) are known and are given to the network during training. The network can adjust its weights to match its outputs to the target values and the network learns to infer the relationship between the two. Training data is usually taken from historical records. The network is trained using one of the supervised learning algorithms of which the best-known example is the back propagation method.

Artificial Neural Networks that use the unsupervised learning paradigms are very simple, one-layer networks. In unsupervised learning there is no teacher and the network must self-organize according to some internal rules in response to the environment. A number of unsupervised learning algorithms exist. Some of these are the Hebbian and the Competitive learning methods (Statsoft, 2002). The Hebbian learning is the most common variety of unsupervised learning. The Oja's and Sangers unsupervised learning are variants of plain Hebbian learning that can be used for principal component analysis. The Sanger's learning procedure can also extract the principal components with respect to the output unit ordering.

The Kohonen Self-Organizing (feature) Map (SOM) network (Kohonen, 1995) uses the competitive learning method. The SOM network has only two layers of processing elements (or neurons). These are the input layer and an output layer of radial units (also known as the topological map layer). The units in the topological map layer are laid out in space, usually in two dimensions. The SOM artificial neural network which combines competitive learning with dimensionality reduction can be used for exploratory data analysis, classification tasks and novelty detection.

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The basic theory of fuzzy sets was first introduced by Zadeh (1965). Unlike classical logic, which is based on crisp sets of "true and false", fuzzy logic views problems as a degree of "truth", or "fuzzy sets of true and false". It is a methodology that was developed to obtain an approximate solution where the problems are subject to vague description. The major concept of fuzzy logic is the use of a linguistic variable which is a variable whose values are words or sentences in a natural or synthetic language. This also leads to the use of fuzzy if-then rules, in which the antecedent and consequents are propositions containing linguistic variables.

Neuro-fuzzy modeling is a technique for describing the behavior of a system using fuzzy inference rules within a neural network structure. The model has a unique feature in that it can express linguistically the characteristics of a complex nonlinear system. In recent years, fuzzy logic, or more generally, fuzzy set theory, has been applied extensively in many reservoir characterization studies (Nikravesh and Aminzadeh, 2002). This is mainly due to the fact that reservoir geology is mainly a descriptive science which uses mostly uncertain, imprecise, ambiguous and linguistic information. Fuzzy set theory has the ability to deal with such information and to combine them with the quantitative observations.

The prediction of lithofacies (that is, rock type identification) is important for many geological and engineering disciplines. The conventional method used for the identification of lithofacies is by direct observation of underground cores (Chang *et al*., 2002). These are small cylindrical rock samples, retrieved from oil wells at selected well depths. The recovery of cores is an expensive process and is not always total. In addition, different geologists may provide different interpretations for the retrieved core samples. This is why a lower-cost method providing similar or higher accuracy is desirable (Chang *et al*., 2002). In an attempt to solve such reservoir characterization problems using differed well logging measurements, some researchers in geosciences have employed statistical methods and the use of artificial neural networks. Some published research using some of these techniques to solve reservoir characterization and lithology determination or prediction problems include: Soto and Holditch (1999), Mohaghegh (2000), Chang *et al.* (2000), Ford and Kelly (2001), Barlai (2002) and Chikhi *et al.* (2004). Most of the researches used supervised neural networks trained with core samples to recognize rock types present in a fresh data set previously unseen by the neural network. Chang *et al.* (2002) reported the use of an unsupervised SOM network to generate clusters in log data and used classified core data for the lithology identification program.

From studies of well log characteristics the well logs that can be used for lithology determination are Gamma Ray (GR) log, Density (DEN) log, Neutron (NEU) log, Electrical Resistivity (RES) log. Gamma ray logs measure natural radioactivity in formations. Shale-free sandstones and carbonates give low gamma ray readings. As shale content increases, the gamma ray log response also increases. The resistivity log is a measure of a formation's resistivity. Most rock materials are essentially insulators, while their enclosed fluids are conductors. When a formation is porous and contains salty water, the overall resistivity will be low. When this same formation contains hydrocarbons, its resistivity will be very high. Shales show low resistivity values with high gamma ray values. The density log is a continuous record of a formation's bulk density. It is used mainly for the determination of porosity and the differentiation between liquids and gases (when used in combination with neutron log). When organic content is present, density is low. Variation of density indicates porosity changes. For example, low density indicates high porosity and vice-versa. On cross-plot of neutron and density logs, pure shale can be recognized by the high neutron value relative to the density value which gives a large positive separation to the logs while gas stands out distinctly giving a large negative separation.

This study presents the result of a study that proposed a methodology for the identification and classification of oil well lithology and fluid content using a SOM neural network to generate log-facies or electro-facies (Rider, 1996) from geophysical well logs and fuzzy rules generated from the known physical properties of the well logs. With the fuzzy rules the lithology of the wells can be determined without the use of core sample data. A case study program was implemented using case data from the Niger Delta region of Nigeria. The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta Province. It contains only one identified petroleum system referred to as the Tertiary Niger Delta (Akata-Agbada) Petroleum System (Tuttle *et al*., 1999). It is composed of mainly sedimentary rock and divided into three formations. These are Benin formation, Agbada formation and Akata formation. The Benin formation consists of mainly sand, the Agbada formation consists of sand and shale, while the Akata formation consists of shale. Limestone and salts are not found in the Niger Delta region. The depth of the Benin formation is about 6,000 ft, the Agbada formation about 17,000 ft and Akata formation about 6,000 ft. The source rocks for the petroleum system are located in the Akata formation while the petroleum reservoirs are located in the Agabda formation.

MATERIALS AND METHODS

The base data used for the lithology determination are the open-hole wireline subsurface well log data. Cross-plot techniques are employed in the analysis of well log data. The log data models the response of the subsurface rocks to the measuring instrument according to the rock properties. The cross-plots allow the nature of the rocks properties to be inferred from the logs. However, due to visualization problems, the cross-plots cannot handle more than 3-dimensional data. It was observed that the operation of the SOM based clustering algorithm is similar to plotting a multi-dimensional log cross-plot. It is noted that in the conventional cross-plot chart, if the dimensions of the chart are more than three dimensions, the visualization and interpretation of the cross-plot chart becomes more complex. The SOM based clustering algorithm has the advantage of not being limited to three dimensions.

The analysis of the well logs begins by first cleaning the log data. Erroneous data items and outliers were removed from the raw well log data. A correlation test was performed on the log values to determine if there was any relationship between the log data values. Knowing the nature of the relationships also helps in the selection of the appropriate log variables when similar data items are present in the data records. The data elements were normalized (between the range 0 and 1) to renders the input data dimensionless and remove the effect of scaling. The neural network was then trained using a training data set.

After training the SOM, the neural network would have learned the structure of the input data. The testing data file, which contains the data that is to be clustered, is now submitted to the trained SOM network, which then identifies the clusters it has recognized during the training process. The test data file may be the same as the training data file or any other data file, which is to be classified, based on the clusters identified by the training data set. The data samples are assigned to cluster groups by the SOM software and the result saved in either a spreadsheet file or an ASCII text file. Each data sample is assigned a label (number) showing the cluster to which it has been assigned. The output file is imported into a spreadsheet file, sorted to group data samples belonging to the same clusters together and then the mean and standard deviation of each cluster group computed.

The computed mean of the log values were used to infer the lithology and fluid content of the rock species that characterize the geological formation of the oil well being investigated by determining their fuzzy value. In a fuzzy system, the general inference process proceeds in the following steps.

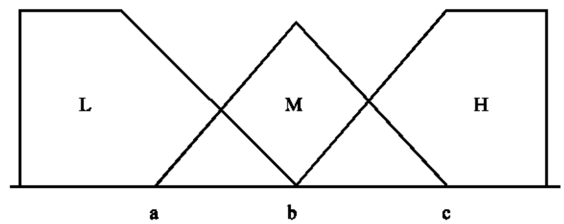

Fig. 1: Fuzzy membership functions

- Fuzzification which involves the conversion of numeric data in real world domain to fuzzy numbers in fuzzy domain.
- Fuzzy inference which involves the computation of the truth value of each rule and its application to the conclusion part of the rule.
- Composition of the output variables of sub rules which can fire in parallel for the purpose of drawing a global conclusion.
- Deffuzzification, which is optional, involves the conversion of the derived fuzzy number to the numeric data in real world domain.

The fuzzy value of the logs can be modeled by four fuzzy membership functions which correspond to the linguistic values High (H), Moderate (M), or Low (L) as shown in Fig. 1.

The fuzzy values are used to generate fuzzy rules for the identification of rock lithologies represented by log data clusters generated by the SOM software. Mathematically this can be represented by Eq. 1 as:

$$x_j = \begin{cases} H \text{ if } b \geq x \leq c \\ M \text{ if } a > x < b \\ L \text{ if } x \leq a \end{cases} \quad (1)$$

Where,

x_j represents mean value of subset j (of log reading)
a, b and c represents threshold values

In determining, the threshold value a, b and c used in this work the following were noted:

- The gamma ray log value in shales varies enormously in any one area or well and it ranges between 40 and 112 API and in sandstones ranges between 10 and 50 API (Rider, 1996). The threshold values used for the Gamma Ray log (GR) are:

  a = 40 API, b = 50 API, c = 112 API

- There are no characteristic resistivity limits for shales, limestone and sandstone (Rider, 1996).

However, it is noted that resistivity values are low for shales, sandstone and water. It is high for hydrocarbons (oil/gas). The threshold values used for the un-invaded resistivity log (RES) are:

a = 10 ohm-m, b = 100 ohm-m, c = 300 ohm-m

- In shales the density log value ranges between 1.18 and 2.75 g cm^{-3}, while in sandstones it ranges between 1.9 and 2.65 g cm^{-3}. Since oilfield densities are usually between 2.0 and 3.0 g cm^{-3} and the mean apparent dry bulk density for shales is 2.45 g cm^{-3} (Rider, 1996). The threshold values used for the Density (DEN) log are:

a = 2.45 g cm^{-3}, b = 2.65 g cm^{-3}, c = 3.0 g cm^{-3}

In order to generate the fuzzy rules to be used for the analysis of the clusters a rock properties determination matrix was created using the known log properties. Using three fuzzy membership functions and three logs gave 27 unique combinations. Not all the rules are physically feasible. However, since the known primary lithology is sand and shale, this provides a way for reducing the number of rules generated to a more manageable and effective number by selecting only the rules relevant to the objective of the study. These are the rules for determining the well lithology which is classified as being shale, sandy-shale, pay sand and wet sand. The relevant combinations are presented in Table 1. In deriving the rules, the following were considered:

- The gamma ray log, which is the primary lithology log, was used to determine the primary lithology of the rock type.
- Next, the resistivity log was used to determine if there is any hydrocarbon presence indicated by a high resistivity log value.
- Finally, the density log was used to further characterize the lithofacies.

The fuzzy rules inferred from the rules determination matrix are:

1. If (GR = H) and (RES = L) and (DEN = H or M)
   Then (Lithology = Shale)
2. (GR = L) and (RES = L) and (DEN = H or M)
   Then (Lithology = Sandy-shale)
3. If (GR = L) and (RES = H) and (DEN = M)
   Then (Lithology = Pay Sand)
4. If (GR = L) and (RES = H) and (DEN = L)
   Then (Lithology = Pay Sand)
5. If (GR = L) and (RES = M) and (DEN = M)
   Then (Lithology = Pay Sand)
6. If (GR = L) and (RES = M) and (DEN = L)
   Then (Lithology = Pay Sand)
7. If (GR = L) and (RES = L) and (DEN = L)
   Then (Lithology = Wet sand)

RESULTS AND DISCUSSION

Case studies using well log data from the Niger Delta region of Nigeria (obtained from Shell Petroleum Development Corporation with the permission of the Department of Petroleum Resources, Nigeria) were carried out. The log data contains the Depth (DEP), the True Vertical Depth (TVD), Gamma Ray log (GR), Resistivity log (RES) and Density log (DEN). The log had 3941 data elements which ranged from 7000-11870 ft. A correlation test was carried out on the input data. The result showed that the Depth (DEP) and True Vertical Depth (TVD) were highly correlated hence, only the Depth (DEP) values were used. The well logs were then normalized. The data was then used to train the SOM software and clusters were generated. The mean log value

Table 1: Fuzzy rules determination matrix

	GR value	RES value	DEN value	Indicated lithology
1	H or M	L	H or M	Shale
2	L	L	H or M	Sandy-shale
3	L	H	M	Pay sand
4	L	H	L	Pay sand
5	L	M	M	Pay sand
5	L	M	L	Pay sand
6	L	L	L	Wet sands

Table 2: Clusters generated by SOM software

Cluster	No. of samples		GR	RES	DEN
1	18	Mean	33.01778	493.666668	2.375
		SD	3.345639	120.187046	0.025029394
2	3	Mean	40.89333	567.64331	2.33666667
		SD	1.247812	4.1311504	0.04163332
3	56	Mean	35.73875	91.053929	2.43821429
		SD	3.162037	54.191674	0.02249098
4	599	Mean	85.81002	21.328431	2.53435726
		SD	22.72294	27.803078	0.04879703
5	6	Mean	39.42667	1441.0467	2.30666667
		SD	1.456896	250.23838	0.01966384
6	92	Mean	32.23467	5.61130435	2.428695652
		SD	4.573356	0.5782566	0.022833241
7	64	Mean	36.40203	49.0335937	2.41921875
		SD	3.837196	30.0236259	0.046369965
8	94	Mean	34.19521	225.854576	2.372765957
		SD	3.162344	88.2995406	0.029924789
9	162	Mean	91.79079	18.2691089	2.499517327
		SD	28.73966	35.3942291	0.082534254
10	578	Mean	114.4018	4.80583045	2.621557093
		SD	12.52467	1.71185725	0.040848849
11	3	Mean	34.08	54.753334	2.406666667
		SD	3.016768	6.50432495	0.015275252
12	812	Mean	104.117	9.53756159	2.483054187
		SD	24.15951	10.3751173	0.044311775

DEP		DEP		DEP		DEP		DEP		DEP		DEP		DEP		DEP		DEP		DEP		DEP	
9900	9	9955	9	10010	9	10065	9	10120	9	10175	9	10230	9	10285	9	10340	9	10395	9	10450	9	10505	6
9901	9	9955.5	9	10011	9	10066	9	10121	9	10176	9	10231	9	10286	9	10341	9	10396	9	10451	9	10506	6
9901	9	9956	9	10011	9	10066	9	10121	9	10176	9	10231	9	10286	9	10341	9	10396	9	10451	9	10506	6
9902	9	9956.5	9	10012	9	10067	9	10122	9	10177	9	10232	9	10287	9	10342	9	10397	9	10452	9	10507	6
9902	9	9957	9	10012	9	10067	9	10122	9	10177	9	10232	9	10287	9	10342	9	10397	9	10452	9	10507	6
9903	9	9957.5	9	10013	9	10068	9	10123	9	10178	9	10233	9	10288	9	10343	9	10398	9	10453	9	10508	9
9903	9	9958	9	10013	9	10068	9	10123	9	10178	9	10233	9	10288	9	10343	9	10398	9	10453	9	10508	9
9904	9	9958.5	9	10014	9	10069	2	10124	9	10179	9	10234	9	10289	9	10344	9	10399	9	10454	9	10509	6
9904	9	9959	9	10014	9	10069	5	10124	9	10179	9	10234	9	10289	9	10344	9	10399	9	10454	9	10509	6
9905	9	9959.5	9	10015	9	10070	5	10125	9	10180	9	10235	9	10290	9	10345	9	10400	9	10455	9	10510	6
9905	9	9960	9	10015	9	10070	5	10125	9	10180	9	10235	9	10290	9	10345	9	10400	9	10455	9	10510	6
9906	9	9960.5	9	10016	9	10071	5	10126	9	10181	9	10236	9	10291	9	10346	9	10401	9	10456	7	10511	6
9906	9	9961	9	10016	9	10071	5	10126	9	10181	9	10236	9	10291	9	10346	9	10401	9	10456	7	10511	6
9907	9	9961.5	9	10017	9	10072	5	10127	9	10182	9	10237	9	10292	9	10347	9	10402	9	10457	9	10512	6
9907	9	9962	9	10017	9	10072	1	10127	9	10182	9	10237	9	10292	9	10347	9	10402	9	10457	9	10512	6
9908	9	9962.5	9	10018	9	10073	1	10128	9	10183	9	10238	9	10293	9	10348	9	10403	9	10458	9	10513	6
9908	9	9963	9	10018	9	10073	8	10128	9	10183	9	10238	9	10293	9	10348	9	10403	9	10458	9	10513	6
9909	9	9963.5	9	10019	9	10074	0	10129	9	10184	9	10239	9	10294	9	10349	9	10404	9	10459	9	10514	6
9909	9	9964	9	10019	9	10074	2	10129	9	10184	9	10239	9	10294	9	10349	9	10404	9	10459	9	10514	6
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9911	9	9965.5	9	10021	9	10076	2	10131	9	10186	9	10241	9	10296	9	10351	9	10406	8	10461	9	10516	6
9911	9	9966	9	10021	9	10076	9	10131	9	10186	9	10241	9	10296	9	10351	9	10406	8	10461	9	10516	6
9912	9	9966.5	9	10022	9	10077	9	10132	9	10187	9	10242	9	10297	9	10352	9	10407	7	10462	9	10517	6
9912	9	9967	9	10022	9	10077	9	10132	9	10187	9	10242	9	10297	9	10352	9	10407	7	10462	9	10517	6
9913	9	9967.5	9	10023	9	10078	9	10133	9	10188	9	10243	9	10298	9	10353	9	10408	9	10463	9	10518	6
9913	9	9968	9	10023	9	10078	9	10133	9	10188	9	10243	9	10298	9	10353	9	10408	9	10463	9	10518	6
9914	9	9968.5	9	10024	9	10079	9	10134	9	10189	9	10244	7	10299	9	10354	9	10409	9	10464	9	10519	6
9914	9	9969	9	10024	9	10079	9	10134	9	10189	9	10244	7	10299	9	10354	9	10409	9	10464	9	10519	6
9915	9	9969.5	9	10025	9	10080	9	10135	9	10190	9	10245	7	10300	9	10355	9	10410	9	10465	9	10520	6
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9916	9	9970.5	9	10026	9	10081	9	10136	9	10191	9	10246	7	10301	9	10356	9	10411	9	10466	9	10521	6
9916	9	9971	9	10026	9	10081	9	10136	9	10191	9	10246	7	10301	9	10356	9	10411	9	10466	9	10521	6
9917	9	9971.5	9	10027	9	10082	9	10137	9	10192	9	10247	7	10302	9	10357	9	10412	8	10467	9	10522	6
9917	9	9972	9	10027	9	10082	9	10137	9	10192	9	10247	7	10302	9	10357	9	10412	8	10467	9	10522	6
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9921	9	9975.5	9	10031	9	10086	9	10141	9	10196	9	10251	7	10306	9	10361	7	10416	7	10471	9	10526	6
9921	9	9976	9	10031	9	10086	9	10141	9	10196	9	10251	7	10306	9	10361	7	10416	9	10471	9	10526	6
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9925	9	9980	9	10035	9	10090	9	10145	9	10200	9	10255	9	10310	9	10365	8	10420	8	10475	9	10530	6
9926	9	9980.5	9	10036	9	10091	9	10146	7	10201	9	10256	9	10311	9	10366	8	10421	8	10476	9	10531	6
9926	9	9981	9	10036	9	10091	9	10146	7	10201	9	10256	9	10311	9	10366	8	10421	8	10476	9	10531	6
9927	9	9981.5	9	10037	9	10092	9	10147	7	10202	9	10257	9	10312	9	10367	8	10422	8	10477	9	10532	6
9927	9	9982	9	10037	9	10092	9	10147	7	10202	9	10257	9	10312	9	10367	8	10422	9	10477	9	10532	6
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DEP		DEP		DEP						DEP		DEP		DEP		DEP		DEP		DEP		DEP	
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11269	4	11324	4	11379	12	11434	10	11489	4	11544	10	11599	4	11654	4	11709	4	11764	4	11819	10		
11269	4	11324	4	11379	3	11434	10	11489	12	11544	10	11599	4	11654	4	11709	4	11764	4	11819	10		
11270	4	11325	4	11380	3	11435	10	11490	3	11545	10	11600	10	11655	12	11710	4	11765	4	11820	10		
11270	4	11325	4	11380	3	11435	10	11490	11	11545	10	11600	10	11655	12	11710	4	11765	4	11820	10		
11271	4	11326	4	11381	3	11436	10	11491	2	11546	10	11601	10	11656	4	11711	12	11766	4	11821	10		
11271	4	11326	4	11381	3	11436	10	11491	3	11546	10	11601	4	11656	4	11711	4	11766	4	11821	10		
11272	4	11327	4	11382	3	11437	10	11492	1	11547	10	11602	4	11657	4	11712	12	11767	4	11822	10		
11272	4	11327	12	11382	3	11437	10	11492	1	11547	10	11602	4	11657	4	11712	4	11767	4	11822	10		
11273	4	11328	12	11383	3	11438	4	11493	1	11548	10	11603	4	11658	12	11713	10	11768	4	11823	10		
11273	4	11328	4	11383	3	11438	10	11493	1	11548	10	11603	4	11658	4	11713	10	11768	4	11823	10		
11274	4	11329	10	11384	3	11439	10	11494	3	11549	10	11604	4	11659	4	11714	10	11769	4	11824	10		
11274	4	11329	10	11384	2	11439	10	11494	2	11549	10	11604	10	11659	4	11714	10	11769	4	11824	10		
11275	4	11330	4	11385	11	11440	10	11495	3	11550	10	11605	4	11660	12	11715	10	11770	4	11825	10		

Cluster No	Lithology	Legend
1	Pay sand	1
2	Pay sand	2
3	Pay sand	3
4	Shale	4
5	Pay sand	5
6	Wet sand	6
7	Pay sand	7
8	Pay sand	8
9	Shale	9
10	Shale	10
11	Pay sand	11
12	Shale	12

Fig. 2: Well stratigraphy chart

Table 3: Interpretation of SOM software clusters

Cluster No	Lithology
1	Pay sand
2	Pay sand
3	Pay sand
4	Shale
5	Pay sand
6	Wet sand
7	Pay sand
8	Pay sand
9	Shale
10	Shale
11	Pay sand
12	Shale

and standard deviation of the cluster groups were computed. The standard deviation measures the spread of the data about the mean value gives an indication of the effectiveness of the clusters generated. Table 2 presents the clusters (represented by a number label) identified in the log data, their mean values and their standard deviation.

The fuzzy inference process started with the fuzzification subprocess where the membership functions defined on the input variables were applied to their actual values to determine the degree of truth for each rule premise. If a rules premise has a non-zero degree of truth, then the rule fires. In the inference subprocess, the truth-value of each rule was computed and applied to its conclusion part. The fuzzy 'max' rule of composition of inferences was then applied. The results showing the lithology of the well inferred from the cluster groups is presented in Table 3.

Figure 2 presents a chart of the oil well showing the location of the different types of rock materials in the well. On the chart, the depth intervals containing pay sand is represented by the yellow colored regions, depth intervals containing wet sand with water content is represented by the blue colored regions. Regions where shales (or shaly rock materials) can be found are shown in ochre. Clusters 4, 9, 10 and 12 represent shales. It can be observed that the difference between these shale clusters is a progressive increase in the shale density. Clusters 1, 2, 3, 5, 7, 8 and 11 represents pay sand clusters. It can also be observed that there is a reduction in pay sand density with increase in pay sand resistivity values. Cluster 6 represents a wet sand cluster. A log analyst that was familiar with the data set used verified the result of the case study program. The chart shows relatively thin layers of sand interbedded within thick and expansive shale units (Adesida *et al*., 2006).

CONCLUSION

In this study, the SOM neural network has been used to analyze well log data obtained from the Niger-Delta region of Nigeria in order to extract knowledge from the well log data. The fuzzy inference methodology adopted in the interpretation of the clusters were derived from the methods used in the interpretation of traditional graphical cross-plots by log analysts. Well logs characteristic response in different rock materials were used to formulate fuzzy rules, which were used to identify the lithology represented by the clusters generated by the SOM from well log data.

While it is only the fuzzy rules relevant to the lithology determination program that have been extracted in this research, it is noted that the rule base actually accommodates all possible rock materials that may be of further interest in future research work. With the three logs used that is gamma ray log, resistivity log and density log, lithology discrimination has been achieved. However, better resolution could still be obtained with associated fluid content determination carried out by using logs that can be used to discriminate between fluids like the neutron log, although this tends to increase the number of fuzzy rule that can be derived from the logs.

The fuzzy rules can form the basis for the development of a software tool. A neuro-fuzzy expert system which can use the SOM neural networks clustering algorithm as a pre-processor for a fuzzy classification module. Or a fuzzy logic expert system since the fuzzy rule can also be incorporated into a software application that can directly classify the log values by fuzzify them, analyzing them and then classifying the individual log elements using the fuzzy rules. The software tool can be used by log analyst to determine the lithology and fluid content of an oil well prior to further processing of the log data in absence of core data.

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