فصل‌نامه زمین
علمی - پژوهشی
دانشگاه آزاد-واحد تهران شمال

تاریخ: ۱۳۹۰/۱/۱۸
پیوست: ۶۴۶
شماره: .....

به نام خداوندگار علم و دانش

مورد تأیید می‌باشد
دکتر علی کدخدایی
۹۰/۱/۲۰

جناب آقای علی اشرف شرفخانی

دانشجوی کارشناسی ارشد رشته زمین شناسی

با سلام و احترام؛

به اطلاع می رسانم که مقاله جنابعالی با عنوان:

طبقه بندی الکتروفاسیس های مخزنی به روش آنالیز خوشه ای با استفاده از اطلاعات پتروفیزیکی مخزن سروک در میدان نفتی هندیجان

نگارنده/نگارندگان : علی اشرف شرف خانی،دکتر علی کدخدایی،دکتر محمود الماسیان،مهندس شروین رسول زاده و مهندس علی چهرازی

مورد ارزیابی داوران فصلنامه قرار گرفت و قابل چاپ در فصلنامه زمین در پاییز ۹۰ قابل چاپ می باشد. با تشکر از شما به دلیل انتخاب این نشریه، امید است شاهد ارسال دیگر مکتوبات پژوهشی شما باشیم.

فصلنامه زمین
دانشکده علوم پایه-واحد تهران شمال

دکتر عکاشه
مدیر مسئول و سردبیر

آدرس پستی: تهران ـ میدان هروی – خ مکران جنوبی – بوستان دهم – دانشکده علوم پایه‌ی دانشگاه آزاد اسلامی – واحد تهران شمال – امور فصل‌نامه زمین

Electrofacies classification from petrophysical data using cluster analysis technique for Sarvak Reservoir, Hendijan Oilfield

Ali Ashraf Sharafkhani[1,3,4], Dr. Ali Kadkhodaie[2], Dr. Mahmoud Almasian[1], Shervin Rasoulzadeh[3,4] and Ali Chehrazi[5]

Abstract

Electrofacies are determined using well logs such as resistivity, gamma ray, sonic, density and neutron. The log values are measurements of the physical properties of the rocks. Therefore, estimated electrofacies can be assigned to one or more rock facies. Identifying facies is an essential component of petroleum prospecting and reservoir characterization. The aim of cluster analysis is to classify a data set into groups that are internally homogeneous and externally isolated on the basis of a measure of similarity or dissimilarity between groups.

Reservoir characterization is a prerequisite study for oil and gas reservoirs development. Identification of reservoir electrofacies plays an important role in petrophysical evaluation of hydrocarbon bearing intervals. In this study, electrofacies of the Sarvak Reservoir in the Hendijan Oilfield was determined by utilizing cluster analysis technique. In this method, data distance was first calculated and then using linkage functions they were connected together, spatially. Dendrogram function was used to extract cluster tree for the Sarvak Formation over the studied field.

Input Logs are PHIE, NPHI, DT, GR and RHOB which led to recognition of five reservoir electrofacies within this Formation. The results show that Cluster Analysis is a precise, rapid and cost-effective method for reservoir zonation and electrofacies classification in hydrocarbon reservoirs.

Keywords: Log data, electrofacies, cluster analysis, zonation, Sarvak reservoir

Introduction

Hendijan is an offshore oilfield discovered by Iran-Italian Oil Company (SIRIP) and is located in the northern Persian Gulf. The field has approximately 12 Km length and 4 Km width orientating in north-south direction. The location map of the Hendijan oilfield is shown in figure 1.

Multiple limestone, sandstone and dolomite reservoirs have been discovered in the field. The sand reservoirs are very porous and as a result oil-in-place and recoverable oil values are relatively high. The quantities of discovered hydrocarbons have been prolific throughout multiple levels of the stratigraphic column. This field consists of four separate oil reservoirs:

A) Ghar reservoir: a clastic reservoir composed of sandstone and shale which is member of the Asmari Formation. The Ghar reservoir has been petrophysically divided into 3 zones. Each zone is separated at the base by a thin shaly layer.

B) Asmari reservoir: a carbonate reservoir overlain by the Ghar clastic sediments. This reservoir is underlain by the Jahrum carbonate formation. Asmari reservoir is divided into four different zones based on petrophysical data and reservoir properties.

1. Geology Department, Islamic Azad University, Tehran North Branch, Tehran, Iran
asharafkhani@fugro-jason.com; m_almasian@hotmail.com
2. Geology Department, Tabriz University, Tabriz, NW Iran
kadkhodaie_ali@yahoo.com; Kadkhodaie_ali@tabrizu.ac.ir
3. Fugro-Middle East Co., Abu Dhabi, UAE
srasoulzadeh@fugro-jason.com
4. c/o Petrokav Energy Co., Tehran, Iran
5. Iranian Offshore Oil Company, Tehran, Iran
chehrazi2001@yahoo.com

C) Sarvak reservoir: composed of limestone and light brown medium grained dolomite and underlain by the Gurpi shale and marls with an angular unconformity. In Sarvak reservoir, four different zones are distinguished based on petrophysical data and reservoir properties that is Sarvak- 1, 2, 3 and 4.

Sarvak-1: consists of limestone layers with interbeded dolomite.

Sarvak-2: This zone consists of homogeneous porous dolomite layers with good reservoir quality.

Sarvak-3: This zone starts with some limestone. It consists predominately of dolomite with limestone interbeds especially at the lower half part.

Sarvak-4: This zone consists of calcareous dolomite layers.

Sarvak formation is completely drilled in wells HD-01 and HD-02. Drilled thickness of formation in is 167 to 197 m (thickness increases toward to north and east.

D) Kazhdumi reservoir: composed of three lithological units; the top unit consists of shale. Limestone makes up the middle unit and sandstone layers make up the lower unit. Kazhdumi formation is divided into three different zones (Pars Petro Zagros report, 2005).

Dolomites, limestones and calcareous Sarvak reservoir layers are the main subject of this study. Well logs from seven available wells were used to identify reservoir electrofacies by implementing the cluster analysis technique.

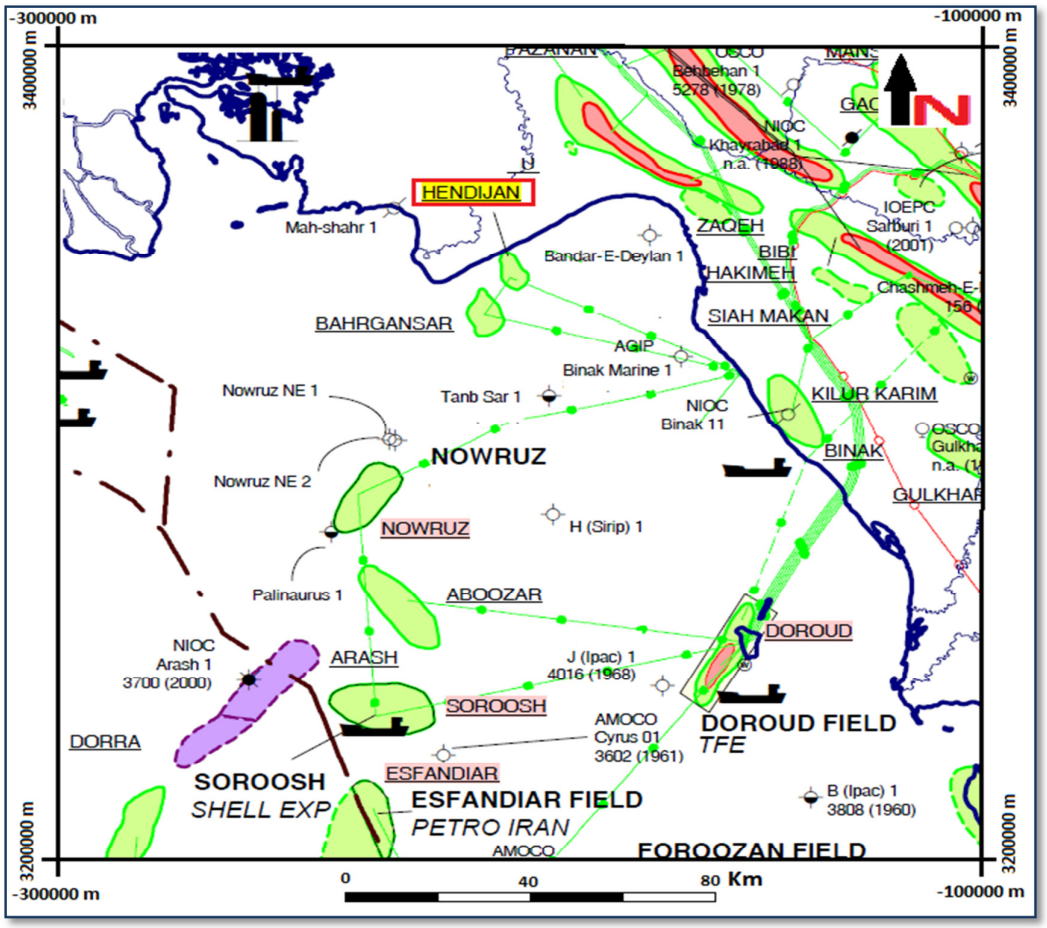

Figure 1. Location map of study Area (IHS Energy Group, 2002)

Regional Geology

The continental shelf of the Persian Gulf could be divided into 5 hydrocarbon zones based on the stratigraphy, structure, source rock, reservoir rock and cap rock. Figure-2 shows the hydrocarbon fields and hydrocarbon zones.

Zone 1: North West of the Persian Gulf which is rich in hydrocarbon. The reservoir rocks in this area are mainly sandstone. Kazhdumi or Burgan, sandstone member of Asmari (Ghar) and Gadvan or Zubair formation are the main reservoirs. The carbonate reservoir is mainly in Asmari, Dariyan and Fahliyan formations. Aboozar, Esfandiar, Bahregansar, Khark, Dorood, Soroush, Foroozan, Nowrooz, Hendijan and few other fields are the existing oil and gas fields in this area. The anticline structures of this zones trending north-south and in parallel to geological structures of Saudi Arabia (e.g Nowrooz and Dorood). Few fields have different trend and are mostly low amplitude structures like Aboozar and Soroush fields.

Zone 2: The reservoir rock in this area is mainly carbonate rocks and the anticline structures follow the salt diapirism structures. These features are different from the other parts of the Persian Gulf and Zagross structures. The thickness of the layers at the crest of the structure are thin as compared to the flanks which is due to the salt movement. Therefore the cap rock is weak at the crest and the hydrocarbon moves upward to the upper layers. The example of this effect is seen in Farsi field.

Zone 3: This area covers the eastern and northern part of the Qatar highland. World's biggest gas field (South Pars field) is located in this zone.

Zone 4: located between Qatar high land and Strait of Hormoz. Reservoir rocks of this area are mainly coronate rock. Sarvak, Dariyan, upper part of Surmeh Formation (Arab member) and among the major reservoir formations.

Zone 5: This area is covering the strait of Hormoz. Reservoir rocks are mainly carbonates and consist of Sarvak and Dariyan formations. Figure 2 shows the hydrocarbon zones of the Persian Gulf (IHS Energy Group, 2000).

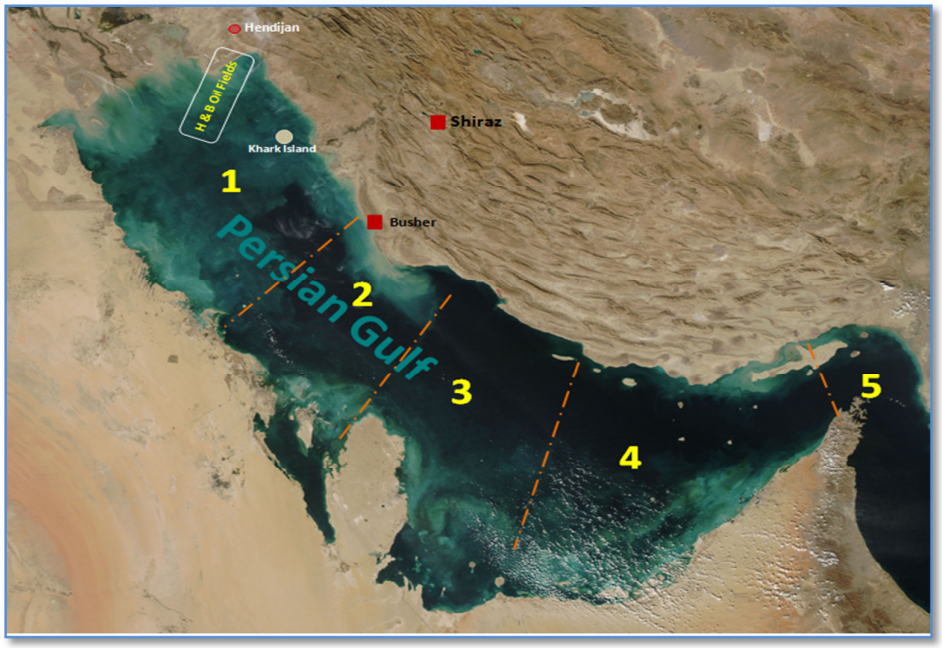

Figure 2. Shows the hydrocarbon zones of Persian Gulf basin.

Methodology

In this study cluster analysis technique was applied for grouping data and identifying reservoir electrofacies. Cluster analysis is the classification of objects into different groups, or more precisely, the partitioning of a data set into subsets (clusters), so that the data in each subset (ideally) share some common trait - often proximity according to some defined distance measure. Data clustering is a common technique for statistical data analysis, which is used in many fields, including machine learning, data mining, pattern recognition, image analysis and bioinformatics. Besides the term data clustering (or just clustering), there are a number of terms with similar meanings, including cluster analysis, automatic classification, numerical taxonomy, botryology and typological analysis (Jain et al., 1999).

1- Finding distance between data object

An important step in any clustering is to select a distance measure, which will determine how the similarity of two elements is calculated. This will influence the shape of the clusters, as some elements may be close to one another according to one distance and further away according to another. For example, in a 2-dimensional space, the distance between the point (x=1, y=0) and the origin (x=0, y=0) is always 1 according to the usual norms, but the distance between the point (x=1, y=1) and the origin can be 2, $\sqrt{2}$ or 1 if it take respectively the 1-norm, 2-norm or infinity-norm distance.

Common distance functions are as below:

a) Euclidean distance (MATLAB user's guide, 2009):

$$d_{rs}^2 = (x_r - x_s).(x_r - x_s)^t \qquad \text{Eq. (1)}$$

b) Standardized Euclidean distance (MATLAB user's guide, 2009):

$$d_{rs}^2 = (x_r - x_s)D^{-1}(x_r - x_s)^t \qquad \text{Eq. (2)}$$

Where D is the diagonal matrix with diagonal elements given by, which denotes the variance of the variable Xj over the m objects.

c) Mahalanobis distance (MATLAB user's guide, 2009):

$$d_{rs}^2 = (x_r - x_s)V^{-1}(x_r - x_s)^t \qquad \text{Eq. (3)}$$

Where V is the sample covariance matrix.

d) City Block metric (MATLAB user's guide, 2009):

$$d_{rs} = \sum_{j=1}^{n} |x_{rj} - x_{sj}| \qquad \text{Eq. (4)}$$

e) Minkowski metric (MATLAB user's guide, 2009):

$$d_{rs} = \left\{ \sum_{j=1}^{n} |x_{rj} - x_{sj}| \right\}^{(1/p)} \qquad \text{Eq. (5)}$$

2- Linking between distance data

Usually the distance between two clusters s and r is one of the following:

a) The maximum distance between elements of each cluster which is also called complete linkage clustering (Chiu, 1994):

Eq. (6)

$$d(r,s) = \max(dist(x_{ri}, x_{sj})), i \in (i,...,n_r), j \in (1,...,n_s)$$

b) The minimum distance between elements of each cluster that is also called single linkage clustering (Chiu, 1994):

Eq. (7)

$$d(r,s) = \min(dist(x_{ri}, x_{sj})), i \in (i,...,n_r), j \in (1,...,n_s)$$

c) The mean distance between elements of each cluster which is also called average linkage clustering (Chiu, 1994):

$$d(r,s) = \frac{1}{n_r n_s} \sum_{i=1}^{n_r} \sum_{j=1}^{n_s} dist(x_{ri}, x_{sj}) \qquad \text{Eq. (8)}$$

d) The distance between centroid elements of each cluster that is also called centroid linkage clustering (Chiu, 1994):

$$d(r,s) = d(\bar{x}_r, \bar{x}_s) \qquad \text{Eq. (9)}$$

3- Dendrogram generation

A Dendrogram consists of many U-shaped lines connecting objects in a hierarchical tree. The height of each U represents the distance between the two objects being connected. If there were fewer data points in the original dataset, each leaf in the Dendrogram corresponds to one data point. If there were more data points, the complete tree can look crowded, and Dendrogram collapses lower branches as necessary, so that some leaves in the plot correspond to more than one data point. A schematic diagram of a cluster tree or Dendrogram is shown in figure 3.

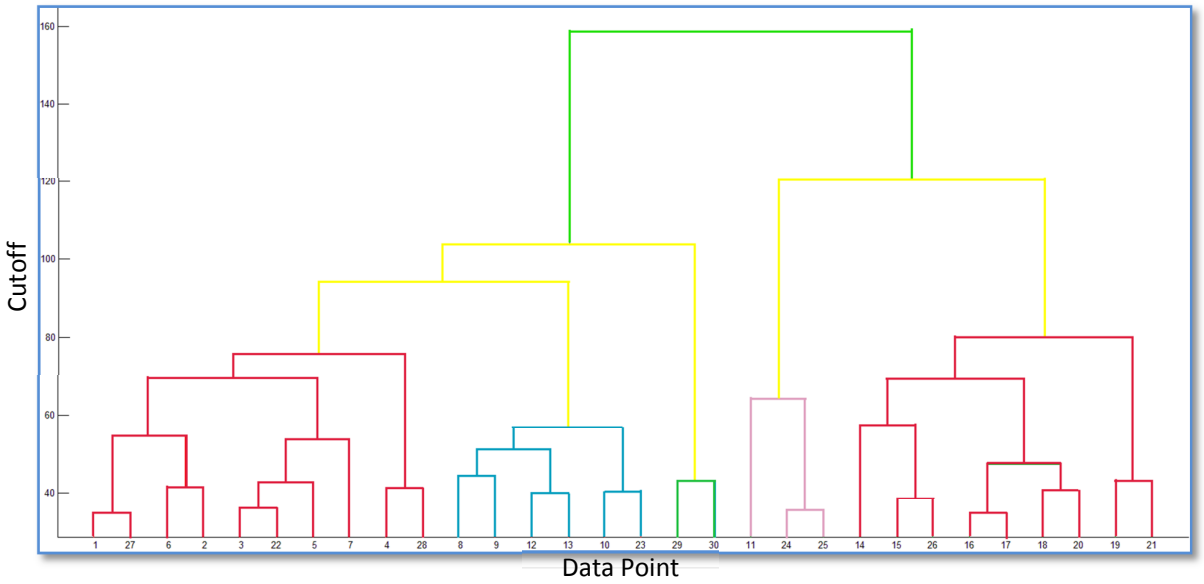

Figure 3. Extracted Dendrogram for Sarvak Reservoir with color display in Hendijan Oilfield.

4- Cluster generation

The final step in cluster analysis is generation of data cluster using a set of cut-off values. In present research, several groups of data clusters were generated by identifying different cut-off values or thresholds. An examination based on trial and error revealed that the case of extracting five clusters is more compatible with previous petrographic studies result. In the meantime, identifying more clusters will complicate facies analysis and their modeling and less clusters cannot cover the entire domains (reflect the reservoir heterogeneity). So, cluster generation function was run and five cluster representing five electrofacies were extracted over the seven wells penetrating into Sarvak reservoir.

Results and discussion

Five logs (PHIE, NPHI, DT, GR and RHOB) selected from seven wells of the Hendijan field were analyzed in this study. Cityblock function of MATALB software was used to calculate the distances of the data. The Complete linkage function, Eq. 6, was used to link among distances data. The clustering tree was generated to identify the number of proper clusters. Figure 3 shows the acquired Dendrogram from the Hendijan wells. Five clusters were identified in the tree. The identified clusters were controlled by plotting against the available logs at the wells. As an example, figure 4 represents the resulted electrofacies for well HD-02. The electrofacies have been plotted as stair diagram and color map at columns 6 and 7, respectively. The presented logs are from the left: effective porosity, total porosity, sonic, gamma ray and density logs.

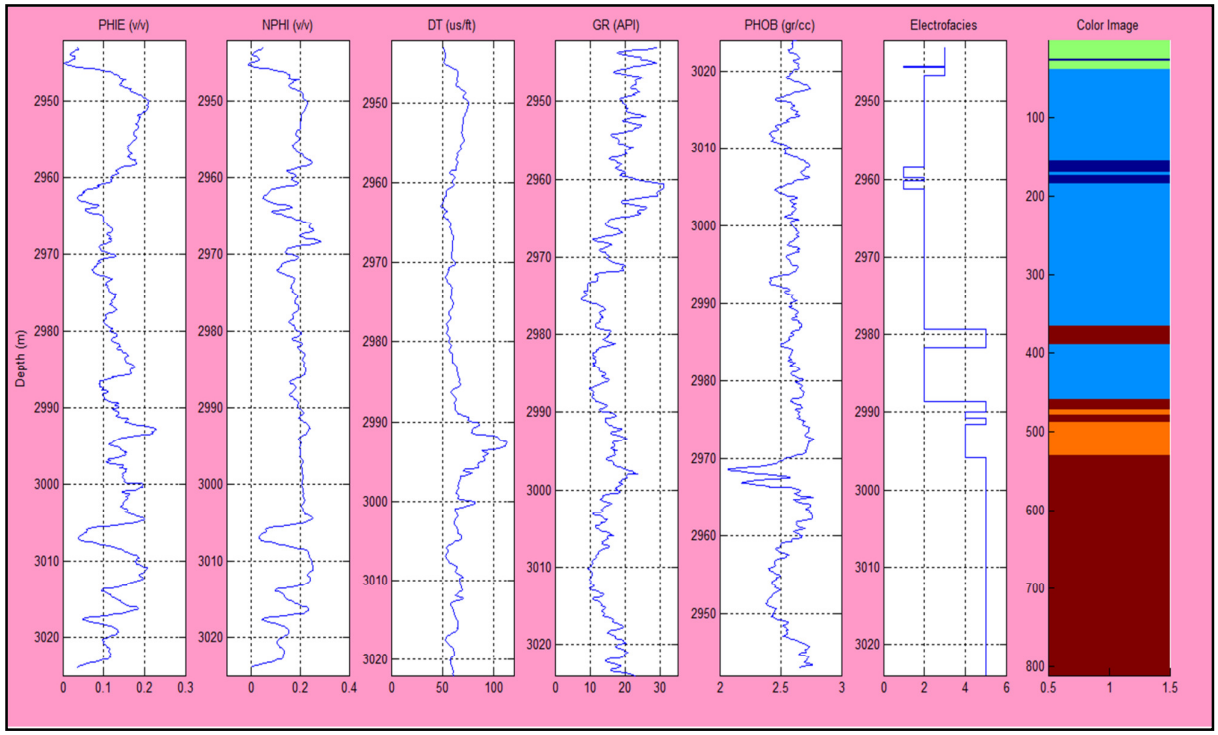

Figure 4. Electrofacies plot along with input well log data for Sarvak Reservoir, HD-03.

The process was repeated for all available seven wells and the results are compared in figure 5. As it is shown the cluster analysis has helped to differentiate log groups in each well which could be referred to as electrofacies.

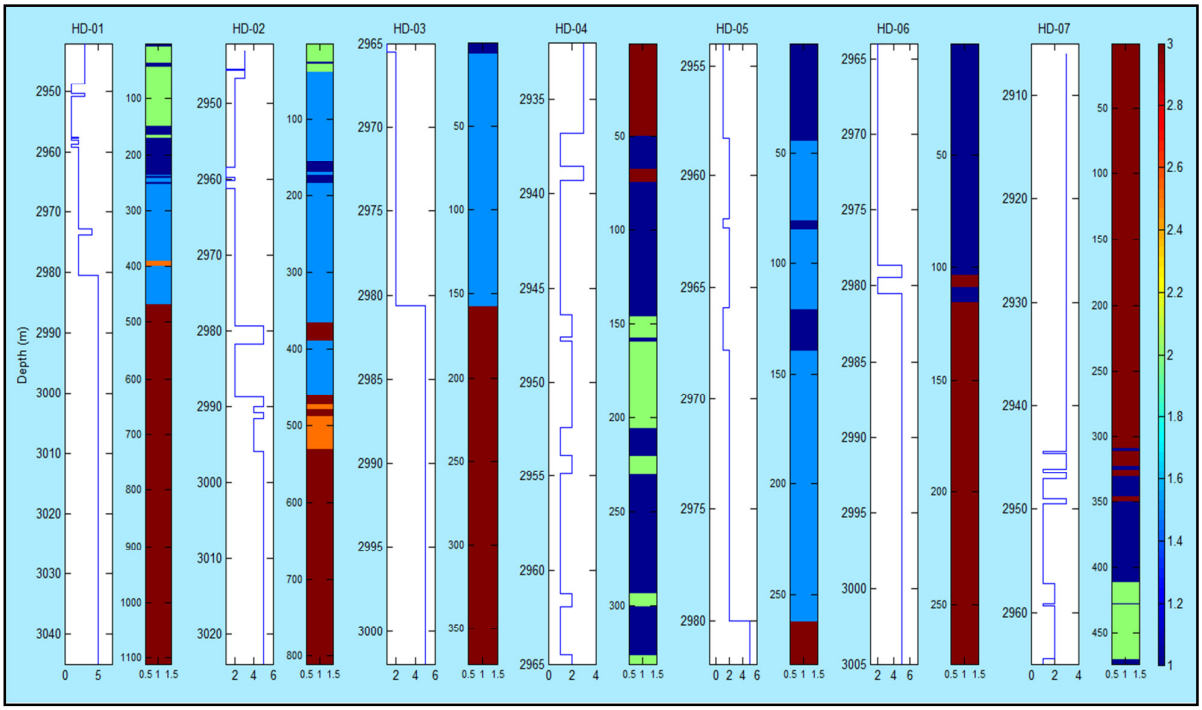

Figure 5. Electrofacies color map for Asmari Reservoir in wells HD-01 to HD-07.

In order to correlate the resulted electrofacies to reservoir zones, average of well log properties were calculated individually for each electrofacies and compared to the identified electrofacies (table 1).

Table 1. Average log properties for extracted Electrofacies in Sarvak Reservoir.

Electrofacies	PHIE	NPHI	DT	GR	RHOB	Rank
4	0.15	0.21	94.46	17.99	2.57	**1**
5	0.10	0.13	60.19	17.09	2.61	**2**
2	0.09	0.13	59.89	20.26	2.59	**3**
3	0.09	0.10	57.66	20.65	2.60	**4**
1	0.06	0.09	56.62	28.57	2.63	**5**

Based on the results presented in Table 1, electrofacies No. 4 has the first rank due to representing better reservoir properties (higher effective porosity, sonic transit time, lower density and shale content). The other priorities from the reservoir quality point of view are electrofacies 5, electrofacies 2, electrofacies 3 and electrofacies 1. The methodology presented in this study for identification of the electrofacies could actually be applied for all other oil and gas fields. It best describes the reservoir quality based upon reservoir properties and heterogeneities.

The facies could also be divided into two groups based on the similarity of average values the DT and RHOB. Facies 4 as group one and facies 1, 2, 3 and 5 as 2nd group. The acoustic impedance (RHOB/DT) values for these groups are: Group 1: about 56270 (g/cc × m/s) and Group 2: about 13208 (g/cc × m/s).

The acoustic impedance difference suggests that these groups could be identified by reflection seismic data. Therefore more investigations are suggested to be conducted to extract a relationship between seismic data and the established electrofacies. Once achieved the relation can be used in seismic reservoir characterization studies. The seismic data can be used to better understand the reservoir in the places where no wells and logs are presents (Fugro-Jason report 2009).

Conclusion

In this study a cluster analysis technique was applied for identification of the reservoir electrofacies for the Sarvak layer. The results obtained indicated five electrofacies could better represent the reservoir heterogeneity. It is a fast, robust, accurate and cost-effective method for electrofacies determination and reservoir zonation. The results and methodology of this study could be generalized and implemented for the other hydrocarbon fields of Iran. The outputs of this study will be used as inputs for facies modeling. A feasibility study is recommended to be carried out to investigate relation of the estimated facies to the seismic data in order to use the current method of electrofacies modeling in the seismic reservoir characterization studies. The research in this area is ongoing…

Acknowledgments
We would like to express our thanks to Islamic Azad University - Tehran North Branch Geology department and R&D department of Iranian Offshore Oil Company for financial support, data preparation and permission to prepare this paper. Also special thanks go to Dr. Mohammad Mokhtari, Dr. Iraj Abdollahie Fard, Mr. Abdollah Barabadi, Mr. Emad Abdollahie, Mr. Mehdi Hosseinifar and all people who encouraged and helped me to do this work.

References

Fugro-Jason report, 3D seismic data interpretation and Reservoir Characterization final Report, Fugro-Jason Co., 2009

Hendijan Full Field Reservoir Study-Phase - 02, Reservoir Characterization Report, Pars Petro Zagros Co, 2005.

Jain, A.K., Murty, M. N., Flynn, P. J., 1999. Data clustering: a review. ACM Computing Surveys, 31(3):264–323.

IHS Energy Group Study (2000 and 2002)

MATLAB user's guide, 2009.

S. Chiu (1994): “Fuzzy model identification based on cluster estimation.