Journal of Earth Sciences 1 (2015) 41-54
ISSN 2372-5176

Betty Jones & Sisters Publishing
http://www.bettyjonespub.com

Characterization of Hydrocarbon Movability and Type of Reservoir Fluids using Resistivity and Sonic Logging Data in Sandstone Reservoirs, Western Desert, Egypt

G.M. Hamada

Chemical and Petroleum Engineering Department, Faculty of Engineering, UAE University, UAE

Abstract: The main role of petrophysics is to characterize saturation fluids encountered in the reservoir and targeting an accurate estimation of the initial oil reserve and also recoverable reserve. This target is achieved by using either logging while drilling or open-hole logging data of resistivity, gamma ray and porosity logs. In many cases of routine well logging data analysis, it is hard to answer the question why there is no oil show in well testing while the logging interpretation indicates pay zones. This study focuses on using shallow and deep resistivity readings and presents new factor of hydrocarbon movability (HCM), which monitors hydrocarbon recoverability and gives a good prediction of primary oil recovery. The value of HCM factor has a range from zero to one. But practically the tested zone is not economic, if HCM is greater or equals to 0.75 and it may be light oil for value less than 0.25. Sonic porosity data, compressional wave travel time (Δt_p) and shear travel time (Δt_s) are tested to investigate the type of reservoir fluids. Ratio ($\Delta t_p/\Delta t_s$) was calculated and it has shown higher sensitivity to change of fluids type from water to oil and to gas than the cases of only interpreting shear wave or compressional wave data. The better reservoir fluids identification depending on the ratio ($\Delta t_p/\Delta t_s$) has been mainly due to the different physical response of compressional wave and shear wave to change of fluids from oil to gas in the presence of water in the reservoir. Field examples from sandstone reservoirs showed that the factor HCM and the sonic ratio ($\Delta t_p/\Delta t_s$) helped to identify the type of reservoir fluids and the degree of hydrocarbon free movement and also to predict hydrocarbon recovery factor especially in water drive reservoir.

Key words: Hydrocarbon movability, resistivity logs, sonic logs, reservoir fluids.

1. Introduction

In oil field logging applications, the prime importance is directed to define the types and amounts of fluids encountered in the formations. Well logging formation evaluation is the process of interpreting a combination of measurements taken inside a wellbore to detect and quantify oil and gas reserves in the rock adjacent to the well and then characterize fluid types (Gas, Oil, and Brine) and the pore space saturation and recovery anticipated under the prevailing reservoir mechanism(s) and conditions.

Corresponding author: G.M. Hamada, Prof., Ph.D., research fields: formation evaluation/petrophysics, production logging, and artificial intelligence applications in formation evaluation/petrophysics. E-mail: ghamada@uaeu.ac.ae.

Oil recovery is a reflection of the mobility of hydrocarbons through porous media. Reservoir rocks, fluid properties, and pressure gradient control this mobility. Oil-in-place is calculated either by the volumetric method or by material balance equations. The recovery factor (RF) is determined from displacement efficiency studies or from correlations based on statistical studies of particular types of reservoir mechanisms [1-5]. A thorough analysis of a standard suite of open-hole logs can yield a quantitative assessment of oil, gas and water saturations. This is important information when all three fluids exist intermingled within a reservoir. Porosity, together with fluid saturations, both in the flushed zone and uninvaded zone, can be evaluated.

Analytical approaches were developed that are extensions of conventional log analysis methodologies [6-10]. Estimates of water saturation are needed when evaluating the potential of a reservoir. The problem facing the log analyst is to find a suitable equation for estimating the pore volume of the reservoir rock that is filled with water. It is generally assumed, unless otherwise, that the pore volume not filled with water is filled with hydrocarbons. The water saturation can be computed from numerous interpretation methods available. All these methods relate water saturation to resistivity, porosity and/or formation factor, and shale volume (V_{sh}); but few relate this parameter to velocity since the velocity of seismic waves is strongly dependent upon pore fluid [11-14].

The presence of compressible fluid, gas, in pore space of rock is known to have considerable influence on parameters like acoustic velocities and Poisson's ratio. Sonic travel time of compressional wave is generally used as porosity tool for given lithology. Introducing shear wave travel time is very helpful in determining mechanical rock properties. It is found that compressional wave velocity is a key for lithology and porosity prediction in petrophysical analysis (sonic logs). Shear wave velocity is very useful in determining mechanical rock properties. In oil and gas reservoirs, compressional wave velocity decreases and shear wave velocity increases. The increase of shear wave velocity is due to the decrease of density and the absorption of deformation by oil in pores and the decrease of compressional wave velocity is due to the decrease of bulk modulus of reservoir rocks; therefore the Vp to Vs ratio, Vp/Vs, will decrease and it is more sensitive to change of fluid type than Vp or Vs separately. The use of Vp/Vs is a key parameter in reservoir study and it plays a key role especially for lithology and fluid type prediction methods [15-20]. Recent work suggests that the Vp/Vs ratio may also serve as an indicator of bypassed oil in cased wells. Research on the acoustic properties of heavy oils indicates that under the proper conditions of temperature and viscosity, these oils may behave as solids and generate shear waves that may be detectable at different logging-tool frequencies [17, 21-24].

Field examples from sandstone reservoirs in Western Desert, Egypt have been analyzed in order to test the applicability of shallow and deep resistivity readings to determine the hydrocarbon mobility factor (HCM) and to predict hydrocarbon recovery factor in a given well especially in water drive reservoir. Sonic ratio ($\Delta tp/\Delta ts$) has been determined using shear wave and compressional wave data. $\Delta tp/\Delta ts$ ratio was used to identify the type of saturating fluids (oil, water, and gas) in logged wells in the sandstone reservoir.

2. Characterization of Hydrocarbon Movability using Resistivity Logs

2.1 Theoretical Background

Estimate of water saturation and recoverability of the reserve are needed when evaluating the potential of a reservoir. The analysis methodology requires as a minimum a common modern logging suite of a density log, a neutron log and an appropriate resistivity logging suite that will provide values of virgin zone resistivity, flushed zone resistivity and invasion diameter. The technique of testing the hydrocarbon mobility and relevant recovery factor from resistivity logs is based on the concept of the tendency of reservoir fluid(s) due to mud filtrate invasion. The invasion profile is controlled by two factors: drilling fluid condition, and reservoir fluids and rock properties. The effect of drilling fluids becomes more or less effective depending on the type of drilling fluids and mud pressure. Among fluid and rock properties affecting the fluid invasion, fluid viscosity, rock permeability, and effective formation porosity are the most important factors. In clean formation there is always residual oil in addition to free water in the flushed zone, while in shaly formation there is a film of bound water and the volume of bound water depends on the type of clay mineral and formation water salinity [23, 25-28].

In clean sand formation, water saturation, Sw, and flushed zone saturation, Sxo, are determined from the clean formation water saturation model, Archie formula. Water saturation, Sw, is calculated as:

$$Sw = (aRw/Ø^{m}Rt)^{n} = (FRw/Rt)^{n} \quad (1)$$

Flushed zone saturation, Sxo, is calculated as:

$$Sxo = (aRmf / ØmRxo)n = (FRmf/Rt)n \quad (2)$$

Determination of hydrocarbon movability factor (HCM) and the predicted recovery factor from resistivity logs depends on the shallow log readings in flushed sand zone and deep log reading in non-contaminated sand section.

2.2 Fully Saturated Formation

In case of fully saturated water formation, formation resistivity factor (F) is a rock property and relates rock electrical property to its porosity and cementation factor. Formation resistivity factor is a rock property and is independent of saturating conditions and it is controlled by following equation.

$$F = a/Ø m = Ro/Rw \quad (3)$$

Formation resistivity factor depends on formation porosity and pore system pattern and it is also a function of rock resistivity, Ro, fully saturated with water of formation water resistivity, Rw.

2.3 Partially Saturated Formation

In case of partially saturated rock, the calculated formation resistivity factor will be different from its value in the section is 100% saturated with water.

In non-contaminated zone $Fd = Rd/Rw$ (4)

Fd is the apparent formation resistivity factor, Rd the deep log reading with Sw less than 100%, and Rw is formation water resistivity.

In flushed zone $Fs = Rs/Rmf$ (5)

Fs is an apparent formation resistivity factor, Rs shallow log reading in flushed zone, and Rmf is mud filtrate resistivity.

2.4 Hydrocarbon Movability

In water zones, it is found that F = Fs = Fd. This is based on the fact that, in water saturated zone, Rt can be considered equal to Ro, then F = Fd from Eq. (1). In the flushed zone, there is no residual oil (Sxo = 100%), and under this condition Fd = F from Eq. (2). In oil bearing formation, Fd and Fs values are greater than F value. The oil is considered immovable if the relative distribution of oil and water has not been changed after mud filtrate invasion, i.e., Sxo = Sw. This fluid saturation condition is expressed as Fd = Fs. In case of hydrocarbon movability, Sxo will be greater than Sw, i.e., Fd is greater than Fs factor. The degree of hydrocarbon movability is expressed by the HCM which equals to the ratio Fs and Fd. The quantity of movable hydrocarbon can be expressed per unit volume as the difference between flushed zone saturation and water saturation (Sxo – Sw), and the recovery factor can take the form of the ratio between movable oil and initial oil in place (1 – Sw). It will take the form

$$RF = (Sxo – Sw)/(1 – Sw) \quad (6)$$

Then, if F = Fs = Fd, it is water section; if F < Fs and Fs = Fd, it is hydrocarbon section, but it is immovable; and if F < Fs and Fd> Fs, it is hydrocarbon section and it is movable.

Using F values recovery factor (RF), defined in Eq. (6), can take the following form:

$$RF = [(1/Fd^{0.5} – 1/Fs^{0.5})/(1/Fd^{0.5} – 1/F^{0.5})] \quad (7)$$

The ability of hydrocarbon to move from one point to another can be identified by looking at flushed zone and virgin zone fluid saturation. Hydrocarbon movement ability can be defined using HCM.

$$HCM = (Fs/Fd)^{0.5} \quad (8)$$

The ratio (Fs/Fd) is a good indicator of hydrocarbon movability. This ratio varies from 0.0 to 1.0. From experience, it is found that if HCM is less than 0.75, the hydrocarbon is movable. When the value of HCM is less than 0.25 the movable hydrocarbon is either gas or light hydrocarbon. In case of HCM value between 0.25 and less than 0.75, the moving hydrocarbon is oil. On other side, when HCM is greater than or equal to 0.75, the existing oil is immovable. This HCM factor is helpful to define the ability of hydrocarbon movement and then the well productivity, also recognizing the type of movable hydrocarbon.

2.5 Assumptions

This approach of testing hydrocarbon movability and predicting hydrocarbon recovery factor from shallow and deep resistivity readings is subjected to two assumptions: 1) There is no significant change in rock properties; permeability and porosity in the area (invaded and non-invaded) around the borehole during logging job and later at the time of production and 2) Fluid flow regime during mud invasion is similar to fluid flow regime during production.

2.6 Benefits

The proposed technique of determining hydrocarbon recovery factor and oil movability from open hole resistivity logs provides the petrophysicist with the following benefits:1) At early stage of the well life, resistivity derived recovery factor (RF) might be a good indicator for further action required, especially in case of water drive reservoir, 2) HCM factor is a good indicator of hydrocarbon movability either due to immaturity or high viscosity, and 3) Values of HCM factor can characterize oil properties and then helps in perforation zones selection.

2.7 Field Examples

This section presents field examples from sandstone reservoir, Western Desert, Egypt. Producing sections in these examples are mainly sandstone with shalys and sections. Petrophysical interpretation of the field examples focuses on the analysis and interpretation of the hydrocarbon movability factor and the deduction of the recovery factor using open-hole logging data.

Field example A. This example, Fig.1 illustrates the application of open-hole logging data of GR, porosity logs and resistivity logs in tracks 1, 2, 3 and 4. Track 5 shows porosity derived from density log in Abu-Rewash G sandstone formation and track 6 shows water saturation (Sw) and flushed zone saturation (Sxo) and track 7 presents permeability in md derived from empirical porosity permeability relation in the field. Track 6 presents the hydrocarbon mobility factor which has values less than 0.60, this means that it is moveable hydrocarbon and then it is expected to have a good recovery factor. Track 6 shows a curve of recovery factor which has an average of 30% curves. Fig. 2 shows the results of repeat formation tester (RFT), results show that Abu-Rewash layers C and G are hydrocarbon layers while Kharita (KHA) layer is water layer. Results of RFT confirm the interpretation of open-hole logging data and later it has been finally confirmed by fluid samples test data, well production average rate from Abu-Rewash layer 600 bod.

Field example B. In this example, the same open-hole well logging package was used, Sw and Sxo shown in tracks 5 and 6 , Fig. 3 were derived using the constant aRw and m factor for water saturation Eqs 1&2 were derived from Picket plot in Fig. 4 and saturation exponent is considered 2 based on water wet sandstone formation. Water saturation values in track 5 of Fig. 3 indicate that A/R formation has oil section interval 2,500-2,515 m. The HCM factor illustrated in track 4 shows the oil section is movable in the interval 2,507-2,515 (HCM is the range of 0.58), while the interval 2,500-2,507 has immovable oil (HCM is greater than 0.80). Oil immaturity in the upper interval and maturity in the lower interval indicates that this well was drilled in an area where A/R F started to move from source rock formation to a producing formation. This conclusion has been confirmed after drilling a well in a nearby area and A/R F formation was tested as oil producing. Results of RFT shown in Fig. 5 indicate that Abu-Rewash G produces gas and Bahryia produces oil and Kharita is a water formation. This well produces 570 bod and 12.8 MM SCF/D from Abu-Rewash formation and 1445 bod from Bahryia formation and free water level was detected at 2873 m.

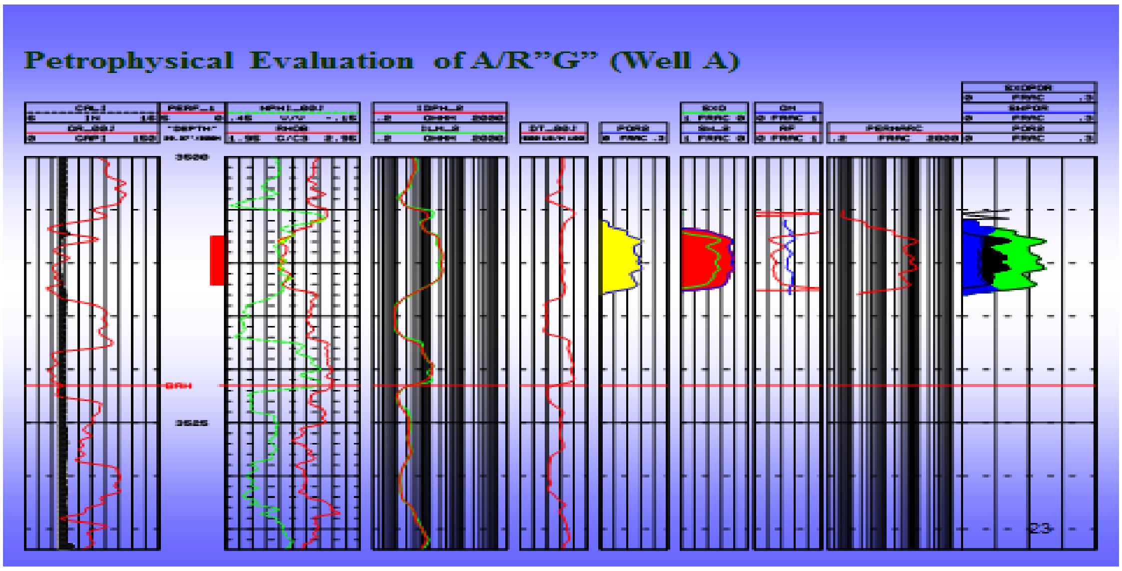

Fig.1 Log example shows hydrocarbon movability and recovery factor in Abu Rewash G formation, western desert, Egypt.

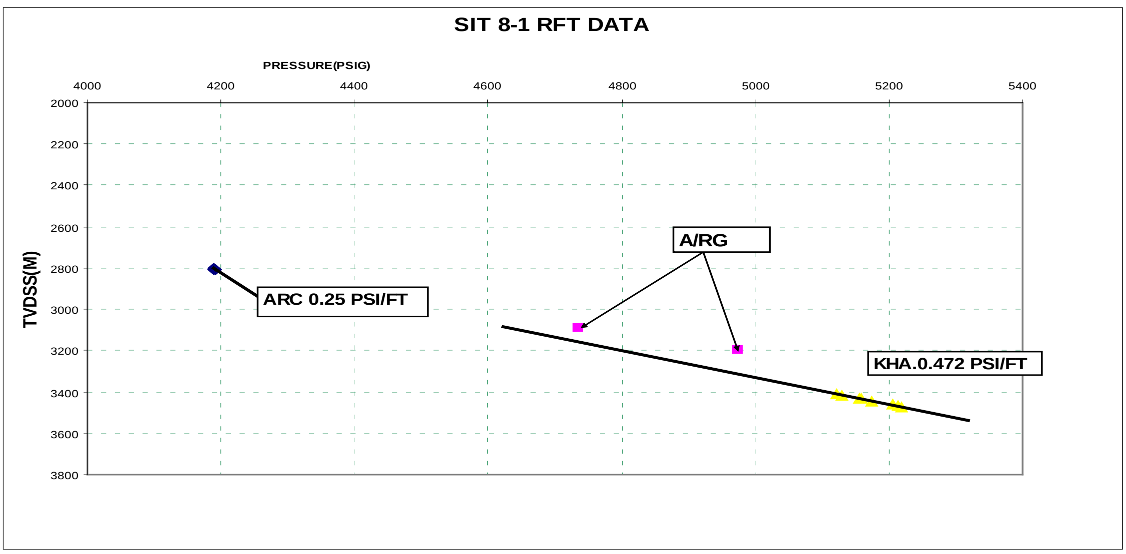

Fig. 2 Pressure gradient for Abu-Rewash C and G and Kharita formations, western desert, Egypt.

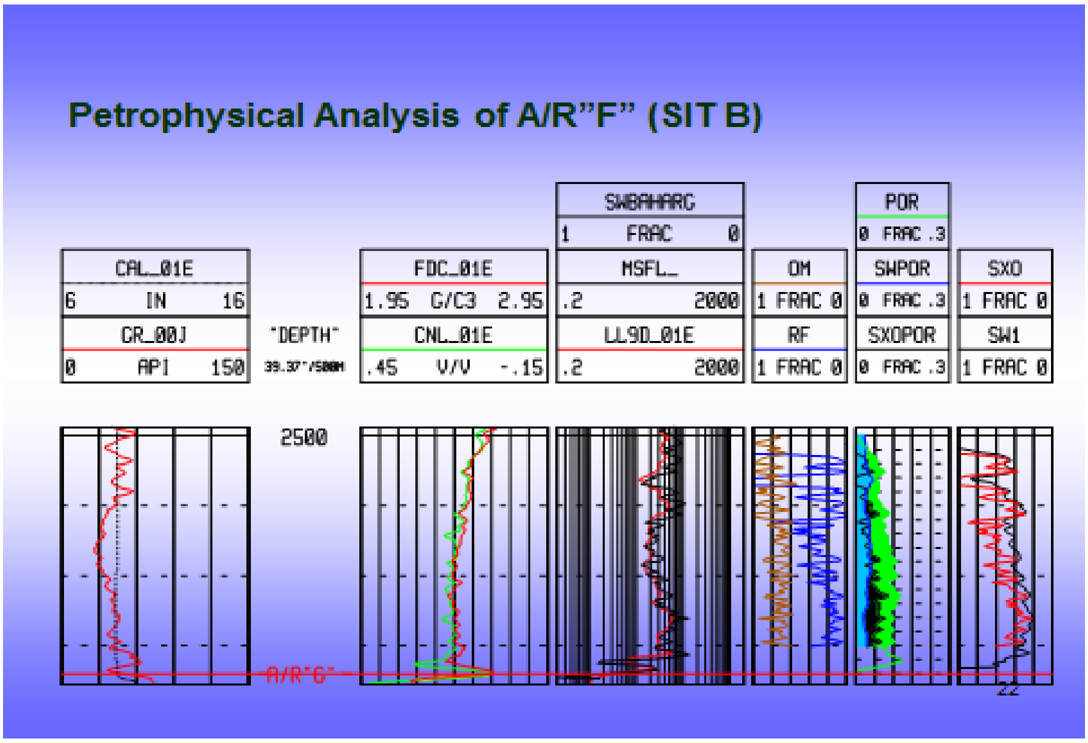

Fig. 3 Logging data with interpretation for Abu Rewash F formation, Western desert, Egypt.

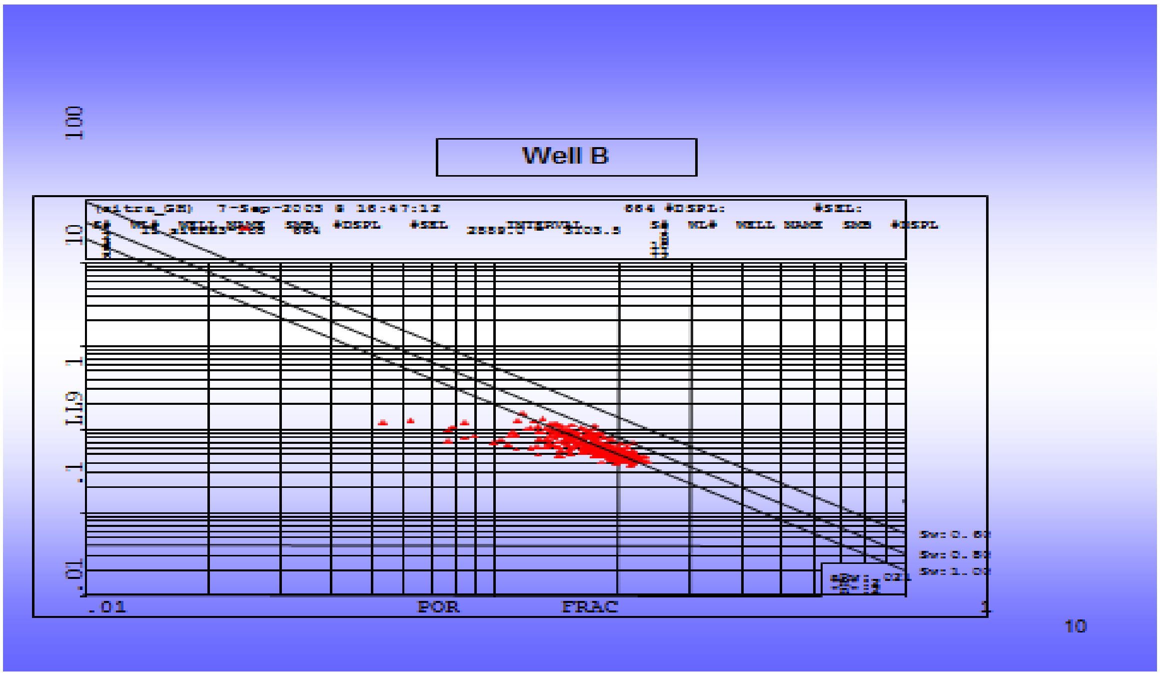

Fig. 4 Picket crossplt for well example B.

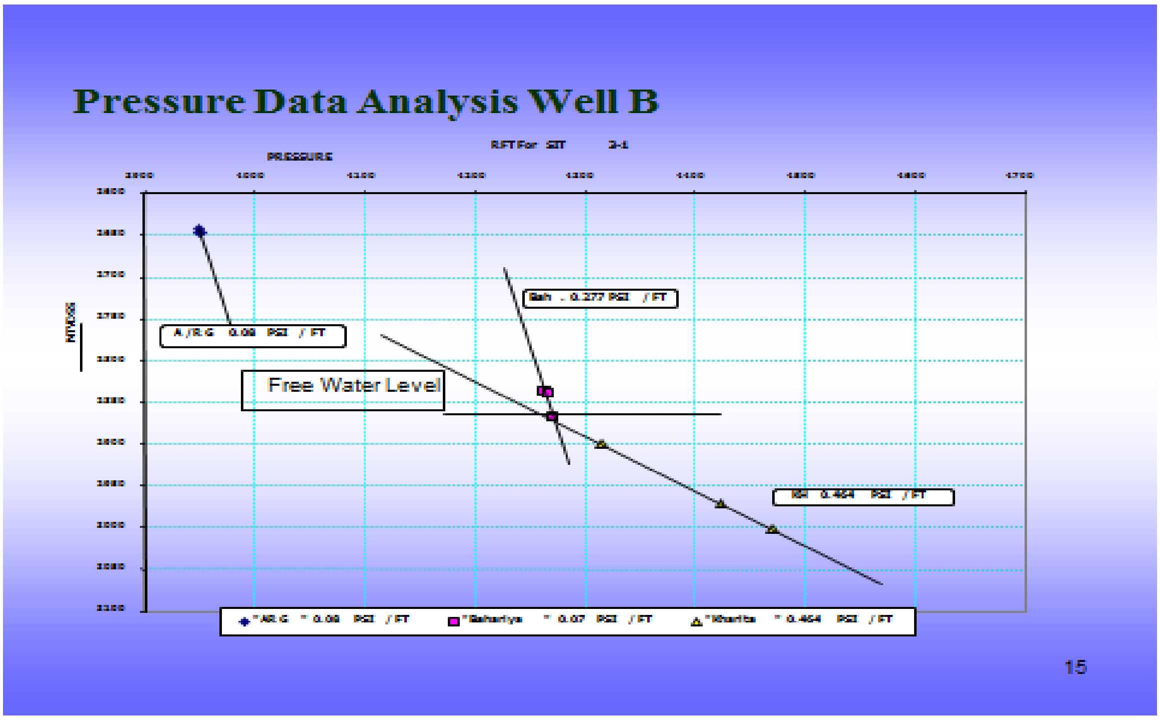

Fig. 5 Pressure gradient for Abu-Rewash G, Bahryia and Kharita formations, western desert, Egypt.

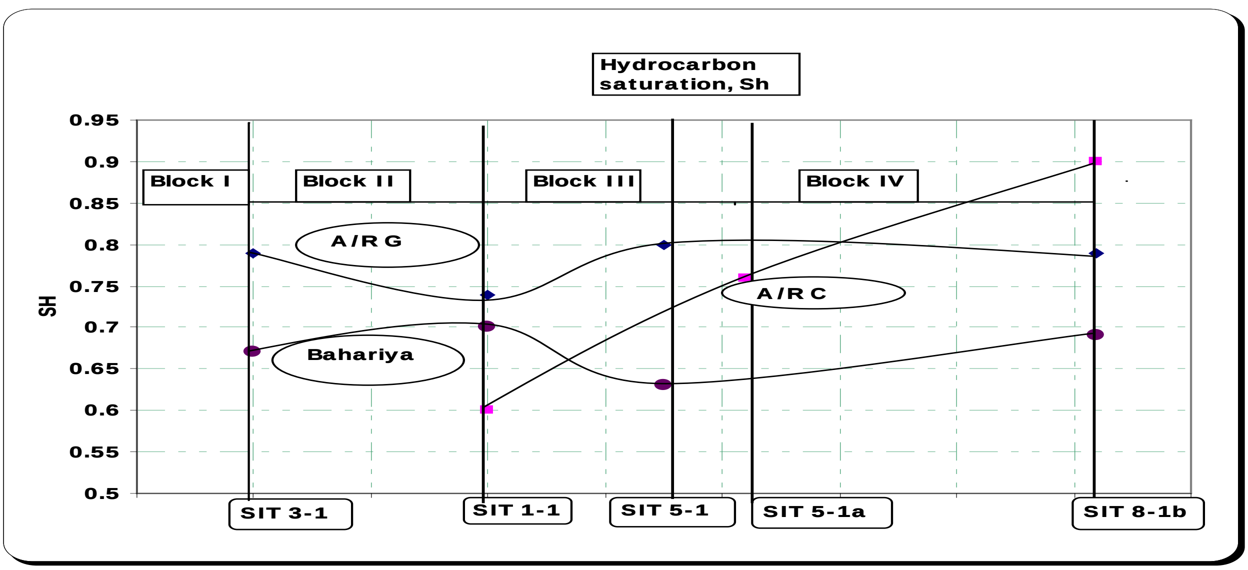

Fig. 6a Distribution of hydrocarbon saturation in Sitra field.

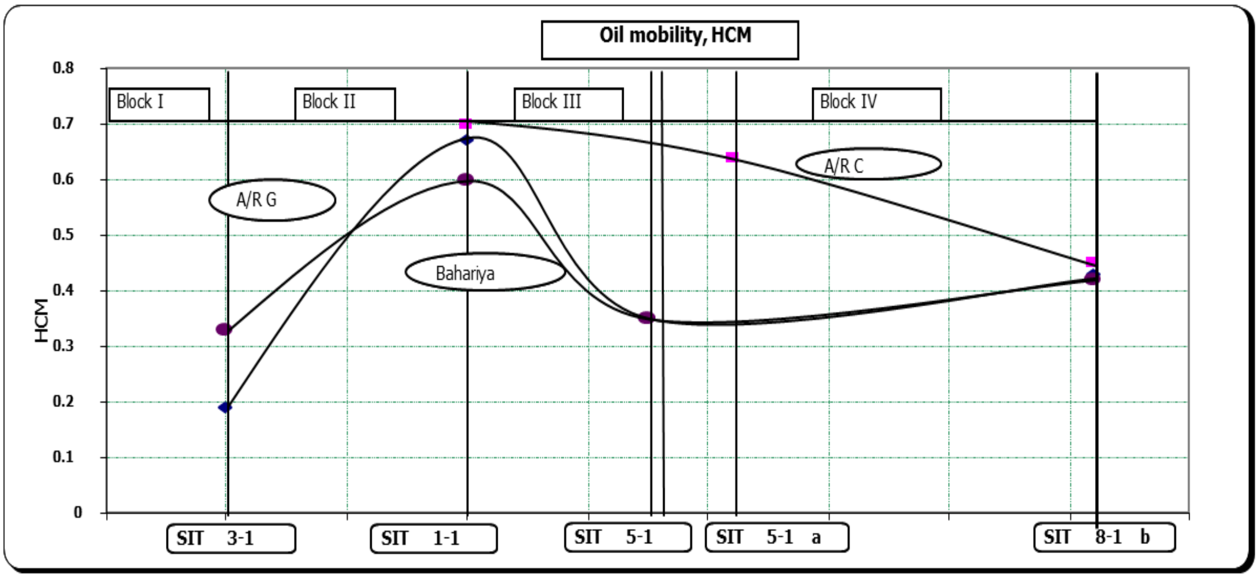

Fig. 6b Distribution of hydrocarbon movability in Sitra field.

2.8 Integrated Petrophysical Evaluation

This study was conducted in sandstone formations for 5 wells drilled Sitra oil field, western desert, Egypt. Fig.6a shows the distribution of hydrocarbon saturation (Sh) and Fig. 6b illustrates the change of hydrocarbon movability (HCM) along the five wells. First well SIT 1 was drilled in the crest of the faulted anticline structure and routine petrophysical data has shown oil saturation in Bahryia and Abu-Rewash C & G formations, but the well was producing only water. Examination of HCM factor in well SIT 1 showed values greater than 0.75 in Abu-Rewash G & C which means that the oil in reserve was immovable and may be due to immaturity. Wells 3, 5 and 8 drilled on the two flanks of the anticline and produced oil from Bahryia and oil/gas from Abu Rewash formations.

3. Characterization of Reservoir Fluids Type using Sonic Logs

3.1 Factors Affecting Seismic Waves Velocity

The most important aspect in which rocks differ from homogeneous solids is in aging granular structure with voids between the grains. These voids are responsible for the porosity of rocks and porosity is an important factor in determining velocity. Seismic wave velocity is affected by rock density in such way the dense rock has higher velocity either S-wave or P-wave. Increasing of rock density indicates higher rock compaction and greater depth and overburden pressure. An empirical formula relates velocity and density takes the form (density, g/cc) $\rho = 0.23V^{0.25}$. The saturating fluids also affect seismic wave velocity. It is found that seismic wave velocity shows a significant decrease when the saturating fluids water or oil is replaced by gas.

3.2 Compressional Waves, Vp

The particle motion associated with compressional waves consists of alternating condensation and rarefactions during which adjacent particles of the solid are closer together and farther apart during successive half cycles. The relation between compressional velocity Vp and density (ρ) and elastic constants can be expressed as following:

$$\begin{aligned} Vp &= [(k + 4/3\ \mu)/\rho]^{0.5} \\ &= [(E/\rho\ (1-\sigma))/((1-2\sigma)\ (1+\sigma))]^{0.5} \\ &= [(\lambda + 2\mu)/\rho]^{0.5} \end{aligned} \quad (9)$$

Where Vp compressional wave velocity; E Young modulus; σ Poisson ratio; λ Lame constant; μ rigidity modulus and ρ rock density.

3.3 Shear Waves, Vs

When shear deformation propagates in an elastic solid, the motion of individual particles is always perpendicular to the direction of wave propagation. The velocity Vs of shear waves equal to $(\mu/\rho)^{0.5}$. This velocity can be expressed in terms as indicated by the relation.

$$Vs = (\mu/\rho)^{0.5} = [(E/\rho)\,(1/2(1+\sigma)]^{0.5} \quad (10)$$

Where: Vs shear velocity; E Young modulus; σ Poisson ratio; μ rigidity modulus and ρ rock density.

3.4 Vp/Vs Ratio

Comparing P-wave velocity Eq. 10 and shear wave velocity equation Eq. 11 results in the following relation:

$$Vp/Vs = [\,(\lambda + 2\mu)/\mu]^{0.5} = [(k + 4/3\mu)/\mu]^{0.5} = [(1-\sigma)/(0.5-\sigma)]^{0.5}. \quad (11)$$

where k is the bulk modulus of rock. Values of Poisson ratio σ vary from 0.0 to 0.50. Either expression tells us that the compressional velocity will always be greater than the shear velocity in a given medium. If σ is 0.25, the Vp/Vs ratio equals to √3. It is worth noting that for most consolidated rock materials, Vp/Vs is between 1.5 and 2 and σ is between 0.1 and 0.33. The seismic Vp/Vs ratios for sandstones varied between 1.66 to 1.81 and for carbonates, 1.81 to 1.98.

The time average equation is often used to relate the velocity, V and porosity, ϕ. It has the following form:

$$1/V = \varphi/Vf + 1 - \varphi/Vm \quad (12)$$

Equation (13) can take the following form for P-wave:

$$1/Vp = \Phi/V_{pf} + 1 - \Phi/V_{pm} \quad (13)$$

$$\Delta_{Tp} = \Delta_{Tpf}\varphi + (1-\varphi)\,\Delta_{Tpm} \quad (14)$$

and for shear wave the form:

$$1/Vs = \Phi/V_{sf} + 1 - \Phi/V_{sm} \quad (15)$$

$$\Delta_{Ts} = \Delta_{Ts}\varphi + (1-\varphi)\,\Delta_{Tsm} \quad (16)$$

Where Δ_{Tp} is P-wave transit time and Δ_{Ts} is S-wave transit time. Seismic velocity (Vp or Vs) in the Equations (12-16) is a function of three variables; fluid velocity, Vf, porosity, Φ and matrix velocity, Vm. Solution of any of these equations for one variable requires the other two variables being known. In oil and gas reservoirs, compressional wave velocity decreases and shear wave velocity increases. Equations (12-16) can be solved for fluid velocity instead of formation porosity with the assumption of known porosity and matrix velocity. Table 1 resumes travel time ΔT for S-wave and P-wave in most reservoir rocks.

Table 1 Shear and compressional waves travel time (μs/ft).

Rock Type	ΔTp	ΔTs
Limestone	47.5	90
Dolomite	43.5	76
Sandstone	56	86
Water	189	350

4. Characterization of Reservoir Fluids using Vp/Vs Ratio

From observation, it is found that light hydrocarbon saturation decreases the velocity of compressional wave and increases the velocity of shear wave through porous rocks relative to formation water saturation. Either shear wave or compressional is conjugate affected by rock density and elasticity. There is a smooth decrease of density with the replacement of water by light hydrocarbon or gas. Elasticity, however, is different; all deformation (expressed by μ) is readily absorbed by gas in reservoir. This is true whether the water saturation in the pore is 10%, or 40%, or 70%; the remaining gas absorbs deformation. Over this range of water saturation, therefore, the elasticity remains substantially constant, while the density decreases; it follows the shear velocity increases with the gas saturation increase. When the water saturation approaches 100%, the velocity must rise considerably; there is no gas left to absorb the deformation and the deformation is resisted appreciably by the water. All change between gas saturated velocities and water saturated velocities therefore occurs with the very first bubble of free gas within the pore. The fact that compressional wave is affected by change in size and deformation, the replacement of water by gas will decrease density and also elasticity (change in size, bulk modulus k and deformation, shear modulus μ; only deformation will be absorbed by gas) in a conjugate effect; causing a decrease in compressional wave. When gas saturation reaches residual gas saturation and the water becomes the major fluid, there is no gas free to absorb deformation, shear wave will suddenly increase. On the other side, compressional wave velocity will not be much affected and it will keep the same increasing trend with the increase of water saturation. Fig. 7 illustrates ΔTp/ΔTs crossplot for different reservoir rocks, the three lines are limestone water base line, dolomite water base line and sandstone water base line. For a specific case, e.g., sandstone line, points lie on the sandstone line or above are water points, the point lie below sandstone line are oil or gas points. Light hydrocarbon or gas will cause a decrease in shear travel time and an increase in compressional travel time with respect to water point. This will shift the water point to south west corner of the crossplot, defined as gas arrow effect in the crossplot. Gas points will show more departure from sandstone water base line than oil points and more shifted to the left of greater shear travel times [8, 11, 17].

Following are examples of the application Vp/Vs ratio to identify reservoir saturation fluids in three wells in sandstone oil reservoir, Western Desert, Egypt, the used seismic data are the array sonic tool (AST) to provide travel time for compressional and shear waves. This technique can be applied for limestone or dolomite reservoir rocks. The use of Vp/Vs crossplot has proved capable for fluid identification for given reservoir rock (same porosity and matrix) especially in gas reservoir.

Field example C. This is gas Producing well with water section at deeper depth, the well has been tested to shows fluid nature of different sections. Fig. 8a shows Vp/Vs crossplot for Abu Rawash G unit 5 in well C, the points cluster are located far from from sandstone water line which indicates gas producing unit. Fig.8b is the Vp/Vs crossplot for Kharita formation Unit 1 in well C, the points of Vp/Vs crossplot lie around the water line showing that the unit 1, well Cis water producing. Well test results of the two units have confirmed the interpretation of Vp/Vs crossplot, unit 5 of AbuRawash formation was a gas unit and unit 1 of Kharita formationwas water unit.

Field example D. This example demonstrates how Vp/Vs crossplotcan distinguish between water zone and oil zone. AST data were recorded in oil producing well with lower water aquifer (Kharita formation), Western Desert, Egypt. Fig. 9a is the Vp/Vs crossplotfor in Kharita, formation E1, well D, plotted points shows very clearly that it water layer. Fig. 9b illustrates VP/Vs crossplotpoints in Baharyiaformation, well D. It is observed that plotted points on the crossplot are shifted downward from the sandstone water line. This indicated that the tested section is oil producing. The oil potential of Baharyia formation and water saturation of Kharita formation have been confirmed by well testing data.

From field examples of Western Desert, Egypt and other studies, we can confirm that compressional wave velocity is a key for lithology and porosity prediction in petrophysical analysis (sonic logs). Shear wave velocity is very useful in determining mechanical rock properties. In oil and gas reservoirs, compressional wave velocity decreases and shear wave velocity increases. The increase of shear wave velocity is due to the decrease of density and the absorption of deformation by oil in pores and the decrease of compressional wave velocity is due to the decrease of bulk modulus of reservoir rocks; therefore the Vp/Vs ratiois more sensitive to change of fluid type than Vp or Vs separately. The use of Vp/Vs is a key parameter in reservoir study and it plays a key role especially for lithology and fluid type prediction methods. Well C produced gas from AbuRawsh G formation and well D produced oil from Baharyia formation and Kharita is considered as water aquifer of the sandstone field under study.

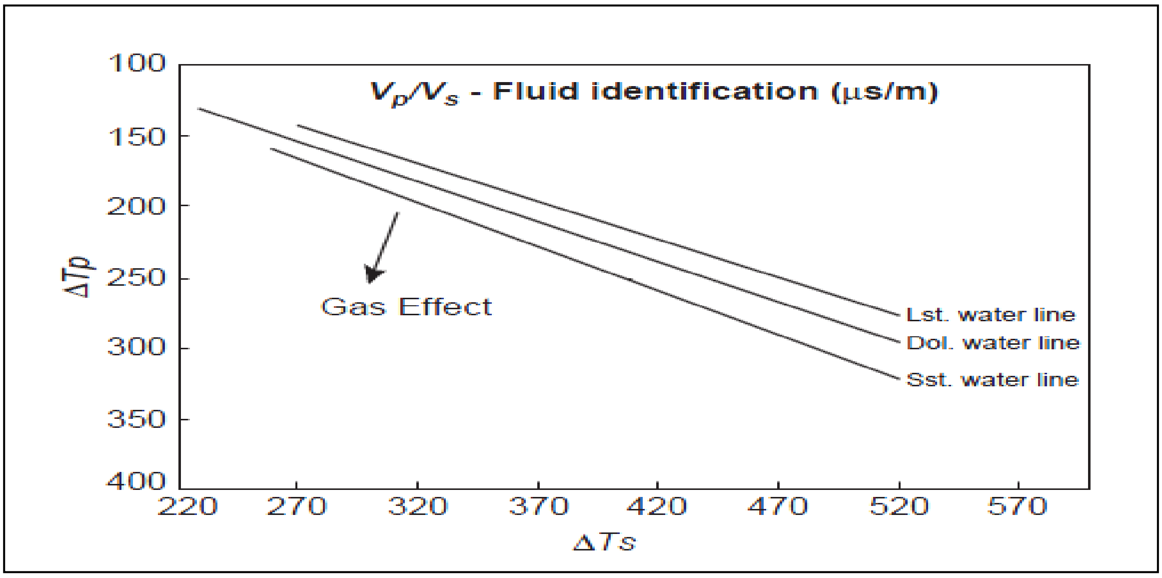

Fig. 7 ΔTp/ΔTs Crossplot- fluids identification for different reservoir rocks.

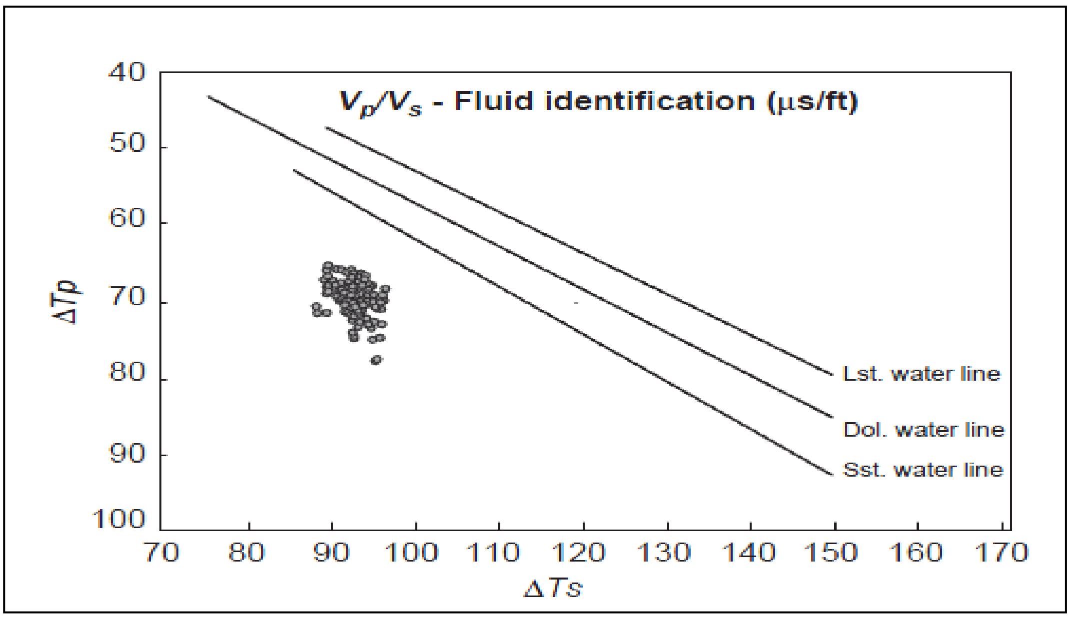

Fig. 8a Vp/Vs crossplot for unit 5-well C.

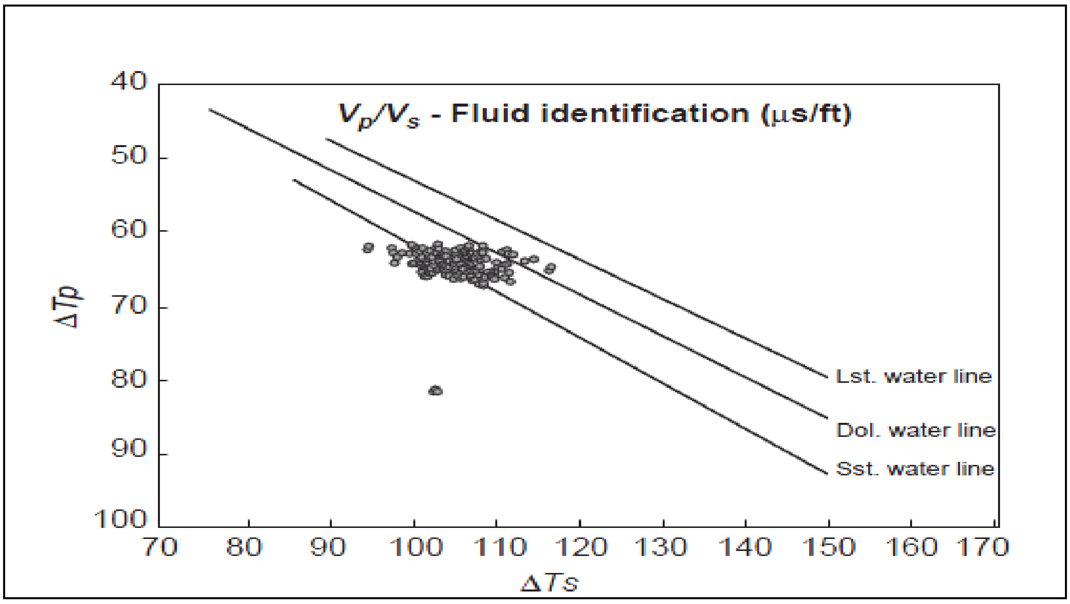

Fig. 8b Vp/Vs Crossplot for unit 1-well C.

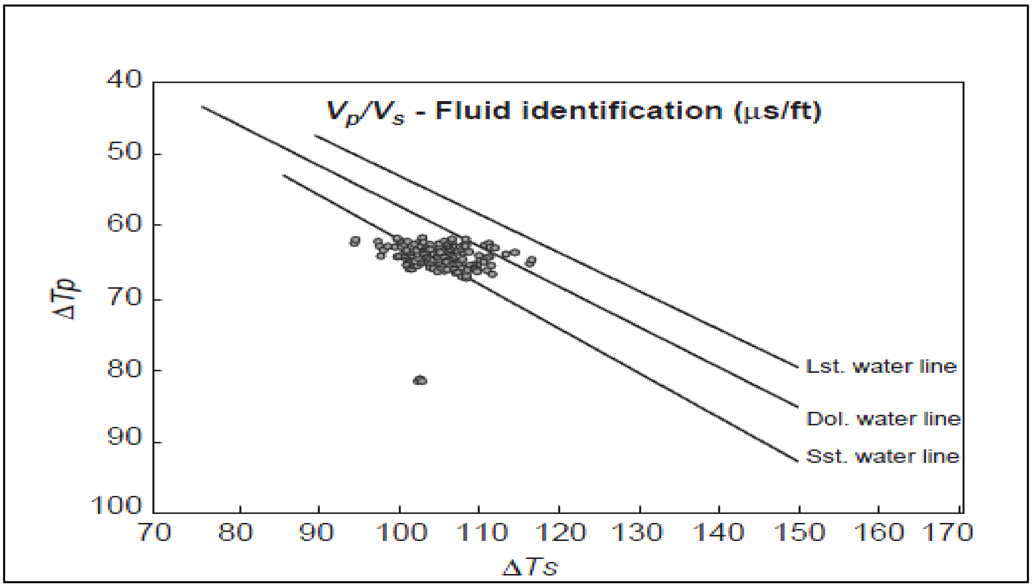

Fig. 9a Vp/Vs Crossplot for Kharitaformation, well D.

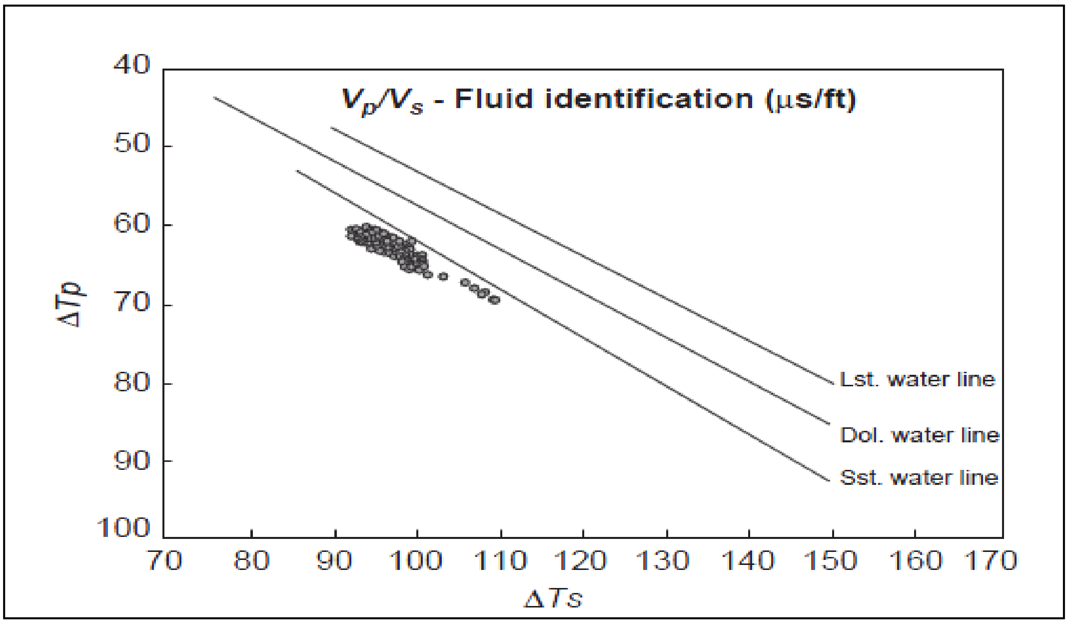

Fig.9b Vp/Vs Crossplot for Baharyiaformation, well D.

5. Conclusions

The HCM factor monitors the hydrocarbon movability. HCM factor can be used in identifying type of reservoir fluids. Also it is possible to predict hydrocarbon recovery factor from shallow and deep resistivity data. Predicted primary recovery factor from resistivity data shed good matching with material balance recovery factor specially in water drive reservoir.

Vp/Vs crsossplot has proved as a good tool to identify type of saturating reservoir fluids; water, oil and gas. This technique presumes formations have similar lithology and same porosity.

Results of well testing data for studied wells confirmed the conclusions of HCM factor and Vp/Vs crossplot technique in testing hydrocarbon movability and in identifying reservoir fluids.

References

[1] G.E. Archie, Electrical resistivity log as an aid in determining some reservoir characteristics, Trans. AIME 146 (1942) 54-62.

[2] P.N. Sen, Resistivity of partially saturated carbonate rocks with microporosity, Geophysics 62 (2) (1997) 456-465.

[3] G.M. Hamada, M.N. Al-Awad, A.A. AlSughayer, Water saturation computation from laboratory 3D regression, Rev. IFP 57 (2002) 637- 651.

[4] M. Fleury, M. Efinik, Z.M. Kalam, Evaluation of water saturation from resistivity in carbonate fields from laboratory to logs, SCA 2004-22, Intl. Conference of Society of Core analysis, Abu Dhabi, UAE, 5-9 October, 2004.

[5] S. Eshimokhai, E. Ashirevbulu, Reservoir Charaterization using Seismic and Well Logs Data (Case Study of Niger Delata), Journal of environmental Studies and Management 5 (4) (2012) 597-603.

[6] G.A. Brown, The formation porosity exponent; the key to improved estimates of water saturation in shaly sands, Transactions of the 29th Annual Logging Symposium of SPWLA, Colorado, June 10-12, 1988.

[7] J.W. Holloway, M. Holmes, Oil, gas and water saturations calculated as separate entities from density, neutron and resistivity logs, SPWLA-1990-MM, SPWLA 31st Annual Logging Symposium, Lafayette, Louisiana, 24-27 June, 1990.

[8] C.A. Garattoni, R.A. Dawe, Influence of Fluid Distribution upon Electrical Resistivity of Partially Saturated Media, SPWLA-1995-II, SPWLA 36th Annual Logging Symposium, Paris, France, 26-29 June, 1995.

[9] M.H. Kamel, W.M. Mabrouk, An Equation for estimating water saturation clean formations utilizing resistivity and

sonic logs: Theory and applications, Journal of Petroleum Science and Engineering 36 (3-4) (2002) 159-168.

[10] F. Verga, V. Rocca, M.T. Galli, I. Gonfalin, The Impact of resistivity uncertainty on water Saturation, Offshore Mediterranean Conference and Exhibition, Ravenna, Italy, 26-28 March, 2003.

[11] O. Chardac, A. Brie, A.C. Chouker, Correlations of Shear vs. Compressional in Shaly Sands and Application to Quick Look Hydrocarbon, 2003.

[12] J. Khazanehdari, C. McCann, Acoustic and petrophysical relationships in low-shale sandstone, Geophysical Prospecting 53 (4) (2005) 447-462.

[13] P.A. Alao, A.I. Ata, C.E. Nwoke, Subsurface and Petrophysical Studies of Shaly-Sand Reservoir, ISRN Geophysics 2013, Article ID 102450, pp. 1-11.

[14] B.M. Ghawar, F.S. Elburas, Poisson's ratio, deep Resistivity and water saturation relationships for shalysand reservoir, SE Sirt, Murzuq and Gadames Basins, Libya (Case study), Journal of Geography and Geology, 7 (1) (2015) 20-26.

[15] J.D. Robertson, W.C. Pritchett, Direct hydrocarbon detection using comparative P-wave and S-wave seismic sections, Geophysics 50 (1985) 383-393.

[16] M.N. Toksoz, C.H. Cheng, A. Timer, Velocities of seismic waves in porous media, Geophysics 41 (1976) 621- 645.

[17] M. Gutierrez, J. Dvorkin, A. Nur, In-Situ Hydrocarbon Identification and Reservoir Monitoring Using Sonic Logs, La Cira-Infantas Oil Field (Colombia), paper RPB 2.6. Expanded Abstracts, 2000 Annual Meeting Technical Program, SEG, pp. 1727-1730.

[18] W.W. Soudra, Using Sonic Logs to Predict Fluid Type, Petrophysics Jr. 43 (2002) 412-419.

[19] G.M. Hamada, Vp/Vs Crossplots Identify Reservoir Fluids. Oil & Gas J. 102 (24) (2004) 41-44.

[20] P.K. Jain, C.V. Jamhekar, P.P. Pandey, Identification of Gas Using Vp/Vs vis-à-vis Poisson's Ratio, P-240 Presented at 9th Biennial Intl. Conference &Exposition on Petroleum Geophysics, Hyderabad, India, 2012.

[21] X.M. Tang, D. Patterson, Detecting thin gas beds in formations using Stoneley wave reflection and high-resolution slowness measurements, paper OO. Trans., 2001 Annual Logging Symposium, SPWLA, pp. 1-14.

[22] R. Mojtaba, B. Bohloli, Intelligent approaches for prediction of compressional, shear and Stoneley wave velocities from conventional well log data: A case study from the Sarvak carbonate reservoir in the Abadan Plain (Southwestern Iran), Journal of Computers & Geosciences 36 (5) (2010) 647-664.

[23] W.O. Raji, A. Taiye, Petrophysical sensitivity of elastic modulus and inverse quality factor (1/Q) analysis in well logs, The Pacific Journal of Science and Technology 15 (1) (2014) 404-413.

[24] M.A.A. Kashif, M. Hussain, J. Siddique, I. Aslam, Z. Ahmed, An Integrated analysis of petrophysics, cross-plots and Gassmann fluid substitution for characterization of Fimkassar Area, Pakistan: A case study, Arabian Journal for Science and Engineering 40 (1) (2015) 181-193.

[25] M.R. Wyllie, A.R. Georgy, L.W. Gardner, Elastic wave velocities in heterogeneous and porous media, Geophysics 21 (1956) 41-70.

[26] R. Woodhouse, Accurate reservoir water saturation from oil-mud cores questions and answers from Prudhoe Bay and behind, Log Anal. 39 (1996) 23-47.

[27] I. Aigbedion, Reservoir fluid differentiation case study from Oredo field in the Niger Delta—Nigeria, Intl. Journal of Physical Sciences 2 (6) (2007) 144-148.

[28] Md. AbdulHai, R. Islam, S.M. Abu Sayeem, Petro-Physical analysis of reservoir rock of Fenchuganj Gas Field (Well#03) using wireline log, American Journal of Engineering Research 3 (8) (2014) 37-48.