Identification of Low Resistivity Hydrocarbon Bearing Gs-11 Sand Through Acoustic Impedance Property

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Summary

GS-11 sand of Gandhar which is oil producer in North eastern and North western part of the field is having varying electrical property. The electrical resistivity range of hydrocarbon producing interval of this sand varies from 3 ohmm to 300 ohmm., while the range of water producing interval varies from 2 -9 ohmm. Due to its low resistivity it becomes difficult to identify it's hydrocarbon bearing potential on normal suit of log. A method has been devised which takes into account of acoustic impedance characteristic of this sand. Theoretical acoustic impedance of the sand is calculated using linear volumetric average formula. This is compared with the actual observed acoustic impedance on the log on a cross plot. As theoretically calculated acoustic impedance assumes the rock as water bearing only, hence in case of hydrocarbon bearing rock it is more than the actual acoustic impedance value. This difference in case of hydrocarbon bearing rock stands out on the crossplot involving the above two impedance values. Hence, the hydrocarbon bearing sand is discriminated against water bearing sand irrespective of their resistivity values.

Introduction

Gandhar is a prolific oil producer field in Cambay basin of India. The field is producing from multi layered sand bodies deposited in deltaic environment of middle Eocene age. There are thirteen pack of sand body named as GS-0 to GS-13 from bottom to top. Gs-11 sand is oil producer in north eastern and north western part of the field. The sand is elusive in nature that it's electrical characteristic on log is deceptive. In some places its resistivity value is high when it is oil bearing , while in other places it's resistivity is lower than the water bearing layer and it still produces prolifically. While the same low resistivity is water bearing in other places. This has allowed this sand to escape the production testing. A large number of drilled wells which have encountered this sand are not tested and its hydrocarbon bearing potential remains unexploited.

The present study finds out the method for detection of hydrocarbon bearing GS-11 sand irrespective of its resistivity character. It exploit the acoustic impedance character of the sand , which changes due to presence of hydrocarbon. In this area the hydrocarbon density is 0.7 gm/cc and sand is also filled with gas,., So, there is a minimum contrast of 0.3 gm/cc between hydrocarbon bearing sand and water bearing formation , this will increase with the saturation of gas in the sand. Though this contrast is too low to be individually detected on the density and sonic log but when acoustic impedance log is calculated this contrast gets amplified and may be detected.

Background

Acoustic impedance is the resistance offered by the rock to the propagation of acoustic wave and is the product of velocity of acoustic wave in the rock and density of the rock. The acoustic impedance contrast governs the wave reflection law. The amplitude of the reflected wave is directly proportional to the contrast of impedances between two layers. The acoustic impedance for waves of ultrasound frequency is widely used in medical industry for diagnosis of various disease, such as ulcers in stomach stones in kidney . Now a days due to advancement of computer graphic and processing capabilities of computer this technique is also applied in determining the density of muscle ,blood and other body fluid . This has been possible by accurate determination of acoustic impedance.

The same principle is also used in oil industry for determination of presence oil, water gas and other geological facies present in the rock.

Approach

GS-11 sand of study area is oil and gas producer. Many wells have been drilled in this area and have encountered the sand, but in most of the wells the sand could not be tested due to its low resistivity. But, the other well produced oil and gas from the same sand at the same resistivity value while, some wells produced water. In order to analyse the hydrocarbon potential of GS-11 sand, the study of acoustic impedance of the sand was undertaken. Four wells A,B,C and D were considered for the study .Well A (Fig-3) is hydrocarbon producer from GS-11 and It's resistivity is high i.e., more than 20 ohmm , the hydrocarbon zone is easily identifiable on the log, while well B and C(Fig-4 ,Fig-5) are also oil and gas producer and has resistivity of the order of 3-7 ohmm (low resistivity) , which is equivalent to water bearing sand . In well D (Fig-6) GS-11 sand is of low resistivity of the order of 2-6 ohmm and produced water on testing. Hence, the hydrocarbon potentiality of the zone could not be ascertained by reisitivvity logs. In all the four wells acoustic impedance log was generated by using the formula (i)

AI= VEL*RHOB (i)

Where AI= Acoustic Impedance
VEL= Velocity of Acoustic wave in rock = 1000000/ DT ft/sec
DT= Sonic travel time in ft/sec
RHOB= Density log value in gm/cc

The Acoustic impedance of a pure sandstone rock consisting of single mineral varies with the porosity and rock fluid as per equation (ii)

AI= VELOCITY*RHOB (ii)

Where

VELOCITY=(1-PHIE)*VELM+PHIE*VELW (iii)

RHOB=(1-PHIE)*RHOM+PHIE*RHOW (iv)

Where

PHIE = Effective Porosity of rock
VELM= Acoustic Velocity in Matrix
VELW= Acoustic velocity in water
RHOM= Matrix Density
RHOW=Density of water.
VELW= Acoustic Velocity in Water

Substituting eqn(iii) and eqn (iv) in eqn (ii) we get

AI= ((1-PHIE)*VELM+PHIE*VELW)*((1 PHIE)* RHOM + PHIE*RHOW)) (v)

This is a quadratic equation in terms of PHIE. The variation of impedance of sandstone with porosity is shown in Fig:1 for pure sand stone .

If oil and gas is present then equation-v further gets modified as

AI=((1-PHIE)*RHOM+PHIE*SW*RHOW+(1-SW)*PHIE*RHOH)*((1-PHIE)VELM+PHIE*SW* VELW+(1-SW)*PHIE*VELH) ....(iv)

Where

VELH= Acoustic velocity in hydrocarbon,
SW=Water Saturation .
RHOH= Density of hydrocarbon
PHIE= Effective Porosity
RHOM= Density of Matrix
VELM= Acoustic Velocity in Matrix
VELW= AcousticVelocity in Water

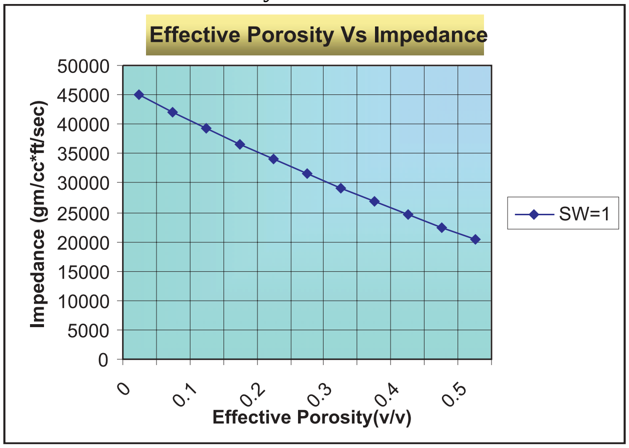

Fig. 1

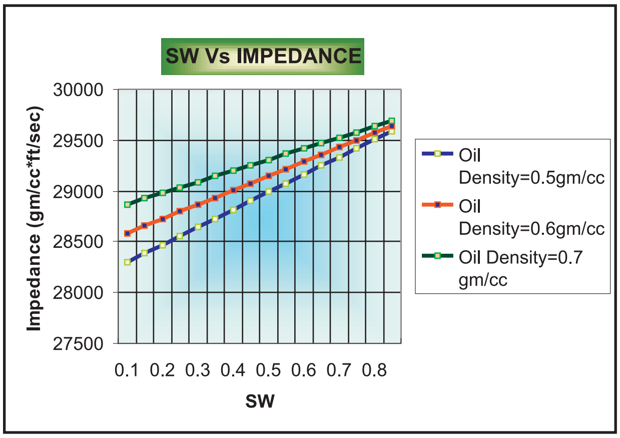

Fig. 2

Fig. 2: Variation of acoustic impedance for various value of SW and Oil density.

The above plots (Fig-1 & Fig-2) clearly demonstrate the influence of hydrocarbon on acoustic impedance in a rock.

Acoustic impedance of hydrocarbon producing well of GS-11 sand was found to be lower than the other producing sand in the same well.

Formation evaluation of all the four wells were carried out and lithology fraction in terms of volume of shale, volume of sand and effective porosity was determined. The complete log analysis of the all the four wells has been shown in Fig-3, Fig-4 , Fig-5 and Fig-6 for Well A, B, C, and D

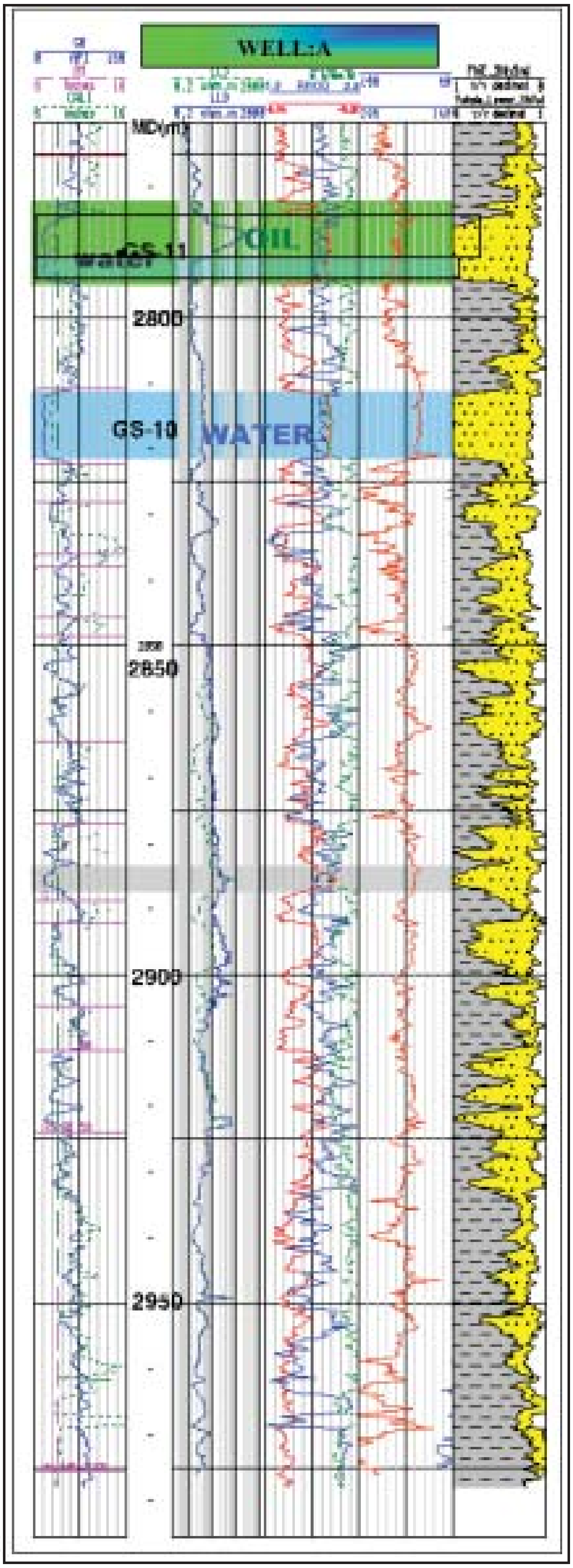
WELL:A
MD(m)
GS-11
OIL
water
2800
GS-10
WATER
2850
2900
2950

Fig. 3

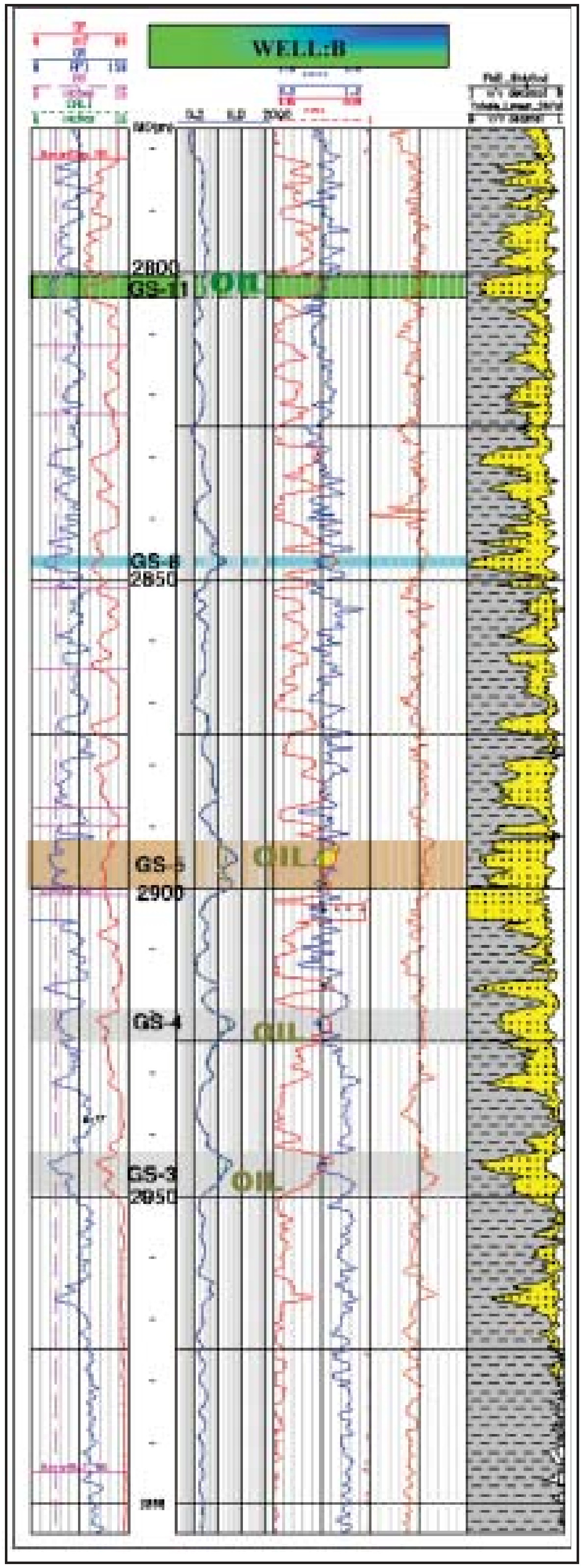
WELL:B
2800
GS-11
OIL
GS-8
2850
GS-5
OIL
2900
GS-4
OIL
GS-3
OIL
2950

Fig. 4

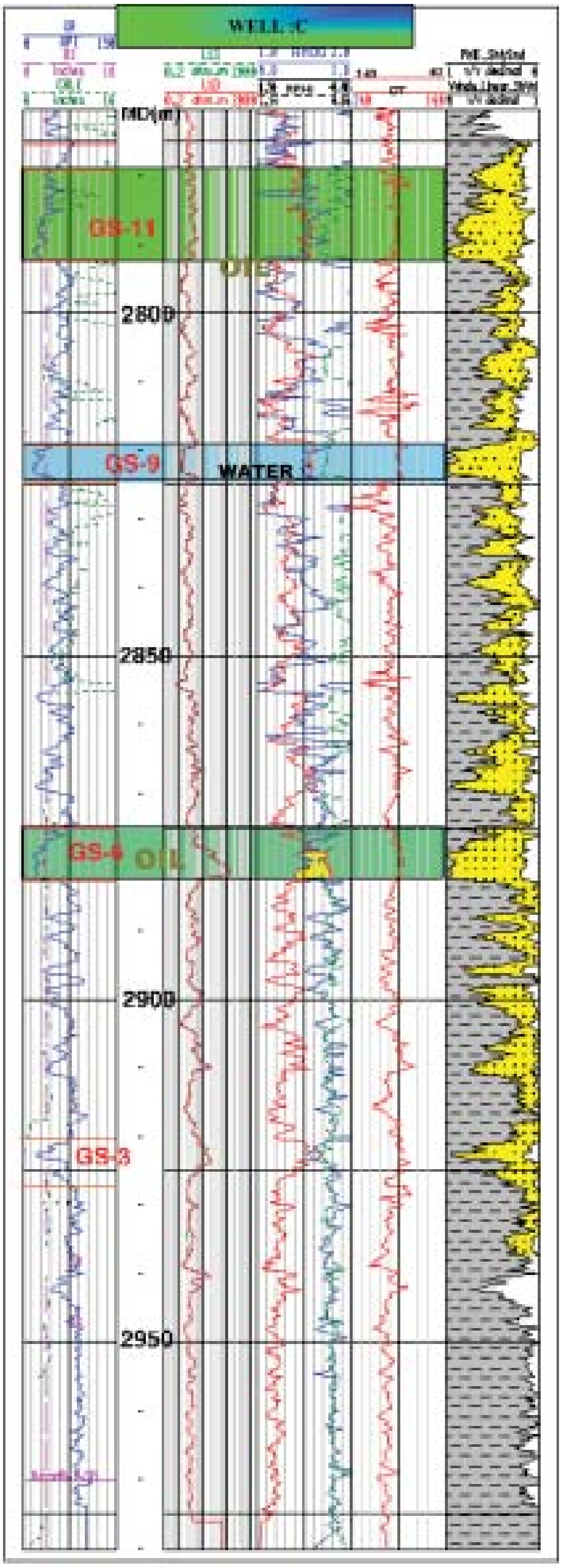
WELL :C
MD(m)
GS-11
OIL
2800
GS-9
WATER
2850
GS-4
OIL
2900
GS-3
2950

Fig. 5

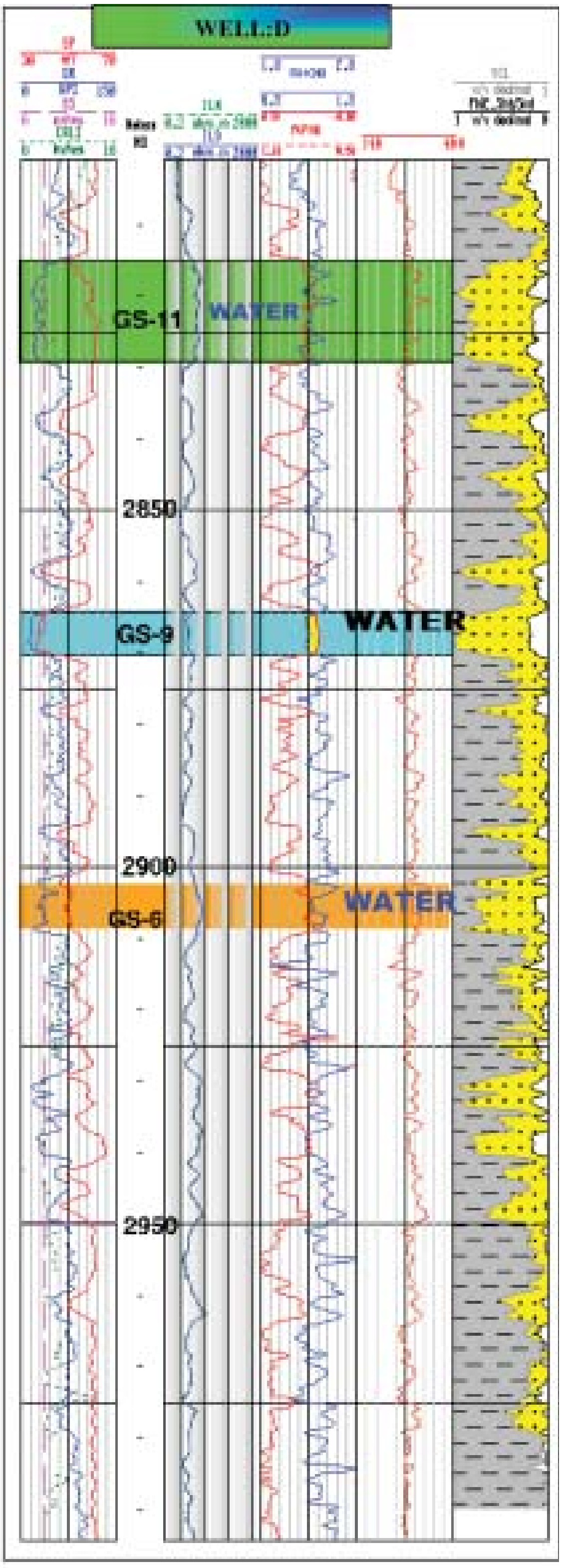
WELL:D
GS-11
WATER
2850
GS-9
WATER
2900
GS-6
WATER
2950

Fig. 6

respectively.

Using the calculated lithology fraction the impedance was calculated back using the formula (v)

CIMP= VSH*IMPSH+(1-VSH-PHIE)IMPSND+PHIE*IMPW (v)

Where ,

CIMP= Calculated Acoustic Impedance
VSH= Volume of Shale,
IMPSH= Impedance of Shale
IMPSND= Impedance of Sand,
IMPW= Impedance of Water
PHIE= Effective porosity,

Impedance of Shale is taken as the average actual impedance against 100% Shale zone from all the four wells

The average impedance of shale is 28000 gm/cc*ft/sec Similarly, the IMPSND i.e, impedance of sand is taken from the actual impedance against the water bearing shale free sand at each well using the formula given below.

IMP=(1-PHIE)*IMPSND+PHIE*IMPW (vi)
IMPSND = (IMP-PHIE*IMPW)/(1-PHIE) (vii)
Where
IMP= Actual impedance observed =1000000/DT *RHOB

For further analysis a cross plot between the calculated impedance (CIMP) and the actual observed impedance at each well for GS-11 sand was prepared.

Analysis of Cross Plot

The Fig-7, Fig-8, Fig-9 and Fig-10 shows the crossplot of calculated impedance on Y axis and Actual impedance on X axis. The range of two axes is same. A 45 degree line is also drawn , any point falling on this line is having the equal value for the calculated impedance and actual impedance.

The calculated impedance (CIMP) as shown in equation-v does not take into account of presence of hydrocarbon in rock . It consider the total pore space filled with water. Hence, it calculate the impedance of rock as if it's total pore spaces are filled with water only. In other words the CIMP represent the impedance of water bearing rock. This impedance should be greater than the actual impedance observed against the hydrocarbon bearing sand as, the calculated impedance ignores the effect of hydrocarbon on density and velocity of the rock.

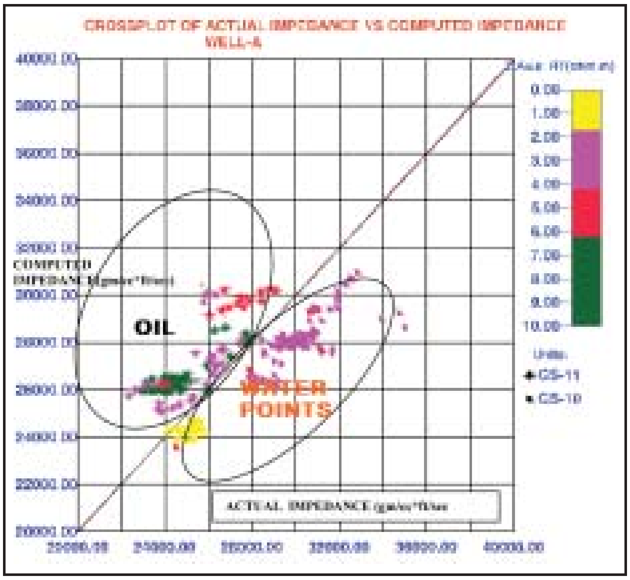

Fig. 7

Fig-7 is the crossplot for the well A, this hydrocarbon bearing in GS-11. The sand is having high resistivity against hydrocarbon zone and low against the water level in the same sand. There is a water bearing formation GS-10 below GS-11 in the well. We can see that most of the points fall above the 45 degree line , which suggest that calculated impedance is more than the actual impedance i.e, they are hydrocarbon bearing. The water bearing points of GS-10 and GS-11 (points in yellow color) fall below the 45 degree line. Hence, plot is able to separate oil bearing and water bearing zone.

The cross plot shown by Fig-8 is a well B , which

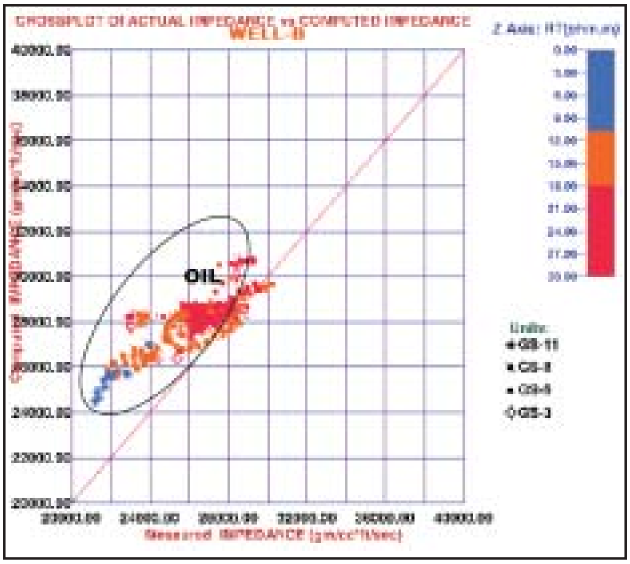

Fig. 8

H.C bearing in GS-11 (low resistivity), GS-8, GS-5 ,GS-4 and GS-3. While except GS-11 other hydrocarbon bearing layers are easily identifiable on log . On the cross plot in Fig-8 all the points fall above 45 degree line.

Similarly Fig-9 of well C which is oil producer from GS-11 and GS-6. While hydrocarbon potential of GS-6 is easily identifiable on log , but GS-11 due to low resistivity is unidentifiable . There is also a water bearing layer GS-9 whose resistivity is in the same range as of GS-11. But on cross plot shown in Fig-9 the GS-11 and GS-6 points fall above the 45 degree line and water bearing point of GS-9 fall below the line .

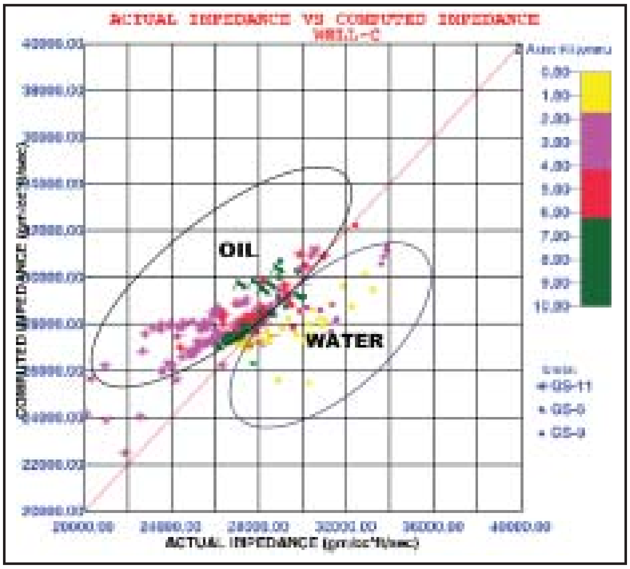

Fig. 9

Fig:10 is of well D which is having low resistivity and is water producer from GS-11 . The plot shows that all the points pertaining to the two water bearing sand GS-9 and GS-11 are falling below the line.

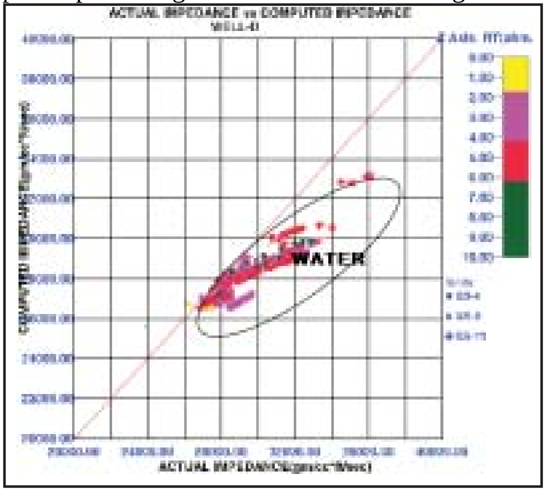

Fig. 10

Conclusions

Hence, it is evident that the crossplot between calculated impedance and actual impedance is able to discriminate between the hydrocarbon bearing zone and water bearing zone irrespective of their reisitivity value

Limitations

(1) The study includes only four wells due to limitation of recorded sonic log data. More wells are needed to be included in the study for establishing the result conclusively.
(2) The impedance of pure shale could not be determined for all the wells as, the density and sonic data in three out of four wells were highly affected by enlarged bore hole.
(3) The effect of other minerals on impedance log has not been considered. However, they have profound effect on impedance of rock.
(4) A small error in litho fraction determination will get amplified in calculated impedance, which will make the cross plot study irrelevant.

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