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Travel Time Modelling using Gamma Ray and Resistivity Log in Sand Shale Sequence of Gandhar Field

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ABSTRACT : In the absence of recorded sonic log, many software packages available in the industry for reservoir characterisation using 3D seismic data cannot be used to their full potential. To solve this problem in Gandhar field of Cambay basin, an attempt has been made to synthesise the Sonic log using available GR and Resistivity logs. A formula is developed which predicts the sonic log in shale sand sequence reliably. The predicted sonic log has been tested in Gandhar field . The results are highly encouraging.

INTRODUCTION

Cambay basin, located in the Western India is predominantly a clastic basin. There are numerous Oil and Gas fields out of which Gandhar is a prolific Oil and Gas producer . It is producing from multi layered vertically stacked sands of Hazad member of Ankleshwar formation of middle to late Eocene age. The Sands are deposited in a deltaic environment with thickness of the order of 1-20m. They are separated by shales having thickness of the same order. 3D seismic data has been acquired in twelve different phases for the whole Gandhar field. However, 3D seismic data alone is not sufficient to map these individual sands . Therefore, Stratigraphic inversion and multiattribute analysis has been carried out on the seismic data to delineate the sands. More than 500 wells have been drilled so far and well log data has been acquired in all the wells. However, only about eighty well are having sonic log. Sonic log is needed for caliberating the seismic mapped horizons with well marker. Inspite of having eighty wells with sonic log, finally only few could be used for Seismic inversion and Synthetic seismogram generation, because of the following reasons,

1. Cycle skipping is observed on sonic log in many wells due to bad hole condition.
2. In most of the wells sonic log has been recorded up to only Hazad section. So, it is not available for the layers above Hazad member.

In order to solve the problem of non availability of sonic(DT) log some method was needed to predict the sonic log reliably in wells where it has not been recorded.

Prediction of Sonic log using other logs has been attempted in the past by several authors. Faust(1951, 1953), Smith(1968) and Gardener (1974) correlated the formation parameters like density and resistivity with velocity and arrived at different formaulae.

Faust(1951) showed that resistivity is a function of lithology if geological time is kept constant. He emperically arrived at a formula.

DT= 513.3*(Depth *RT)**1/6

where ,
DT = Transit time
RT=Resistivity of the Fromation

Similarly, Gardner (1974) in his historic paper " The diagonastic basics for stratigraphic Traps" proposed a relationship between formation density and velocity as

RHOB=0.23*V**0.35.
RHOB=Bulk density of the formation
V= Velocity of the formation

Similarly, Smith (1968) arrived at an emperical relationship between DT and Resistivity as

DT= C*(RT)**n

where C and n are constants,
C= 91.0
n= -0.15
RT=Resistivity of the Fromation

Recently, host of methods have come up which employ neural network for predicting any curve from other curves and large numbers of software packages are also available. These software packages are easy to use but the results are not very reliable as they lack fundamental principle of log interpretation. Secondly, these packages are like black box , where exact method for arriving at solution is hidden.

METHODOLOGY

In this paper we have used the principle of log interpretation for calculating DT curve using GR and Resistivity logs.

For calculating the value of Travel time at each depth point we used Willie's famous " Time averaging equation".

$DTlog = V_{shale} * DT_{shale} + V_{sand} * DT_{sand} + PHIE * DT_{water}$ (1)

Where,
V_{shale} = Volume of shale
PHIE = Effective porosity

In Gandhar region ,Gamma Ray (GR) log is fairly representative of V_{shale}. So, V_{shale} was computed from GR log by using the well known equation -

$V_{shale} = (GR_{log} - GR_{min})/(GR_{max} - GR_{min})$ (2)

We have,

$Vsand=(1-V_{shale} - PHIE)$ (3)

Substituting (3) in eqn(1) and rearranging it we get,

$DTlog = V_{shale} * (DT_{shale} - DT_{sand}) + PHIE * (DT_{water} - DT_{sand}) + DT_{sand}$ (4)

PHIE and DT_{shale} are two unknown parameters in the eqn(1). For finding DT_{shale} a cross plot of the DT_{shale} for the various wells against Depth is prepared and it is observed that within a given range of depth i.e, from 1000m to 4000m DTshale is linearly varying with Depth as shown in Fig-1.The regression equation for best fit line is

$DT_{shale} = 158.97-0.0241*Depth(m)$ (5)

To determine PHIE we made following assumptions which are valid for Gandhar field only.

(1) Formation water resistivity (R_w) in Gandhar field varies from 0.15 to 0.25 ohmm. So, we took it 0.20 ohmm for our calculation.

(2) A generalised temperature gradient of 0.03 degree centigrade/m is estimated

The equation for calculating Water saturation in shaly sand was used with the above assumptions.

$1/\sqrt{(RT)}=[(V_{shale})^{(1-Vshale/2)}/\sqrt{R_{sh}} + (PHIE)^{m/2}/\sqrt{(a*R_w)}]S_w^{n/2}$. …(Indonesian Eqn) (6)

For water bearing sand S_w=1 and standard values of a, m and n parameters are 0.81, 2 and 2 respectively, so, after substituting these values in equation (6) we obtain

$PHIE=[1/\sqrt{(RT)}- V_{shale})^{(1-Vshale/2)}/ \sqrt{R_{sh}}]* \sqrt{(0.81*R_w)}$ (7)

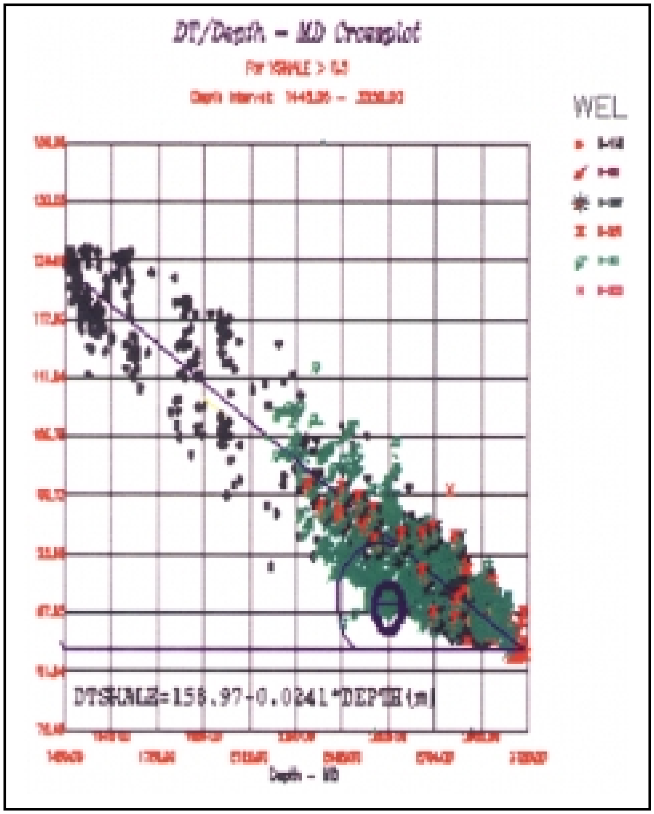


Figure 1

where, R_{sh} = Resistivity of shale
S_w = Water Saturation.

To compensate the variation of Rw with depth a generalised Temprtature gradient for Gandhar field .03 degree Centigrade/m was used

$R_w(T2)=R_w(T1)*(T1+26.5)/(T2+26.5)$ (8)
T1=Temprature at Bottom Depth
T2=32.5+0.031*Depth(m)

Where, $R_w(T2)$= Resistivity of Formation water at Temprature T2 (9)

Substituting DT_{shale} from eqn. 5 and PHIE from eqn.6 in equation (4) and rearranging it we obtain final result as

$DTlog=V_{shale}*(158.97-0.0241*Depth(m) - 55.55)+[(1/\sqrt{(RT)}-(V_{shale})^{(1-Vshale/2)}/\sqrt{(R_{sh})}*\sqrt{(0.81*R_w)}] * (190-55.5+55.5$ (10)

Where,
DTwater=190 microsec/ft
DTsand=55.5microsecond/ft

Using the above eqn(10) the DT value at each sample point of 0.1524m has been calculated for well A, B, C, D & E. The results are discussed as follows.

DISCUSSION OF RESULTS

The calculated DTlog was superimposed on DT recorded in each well. As shown in Fig. 2 ,Fig. 3, Fig. 4, Fig. 5 & Fig. 6 the recorded DT and calculated DT match very well. In wells where DT recorded is affected by bad hole as shown in Fig. 4 & Fig. 6 , the mismatch occurs. This is also verified by cross plotting the recorded DT vs calculated DT as shown in Fig. 9 Fig. 10, Fig. 11 Fig. 12 & Fig. 13. There is a clear trend at 45 degree straight line. The above formula was applied on other 10 wells located on different corners of the field. And we found a very good match between the recorded DT and calculated DT.

By using the formula (10) , we predicted DT in wells F & G in which DT was not recorded . The calculated DT is shown in Fig. 7 and Fig. 8.

The calculated DTlog has been used to generate synthetic seismogram for the well F which was matched with

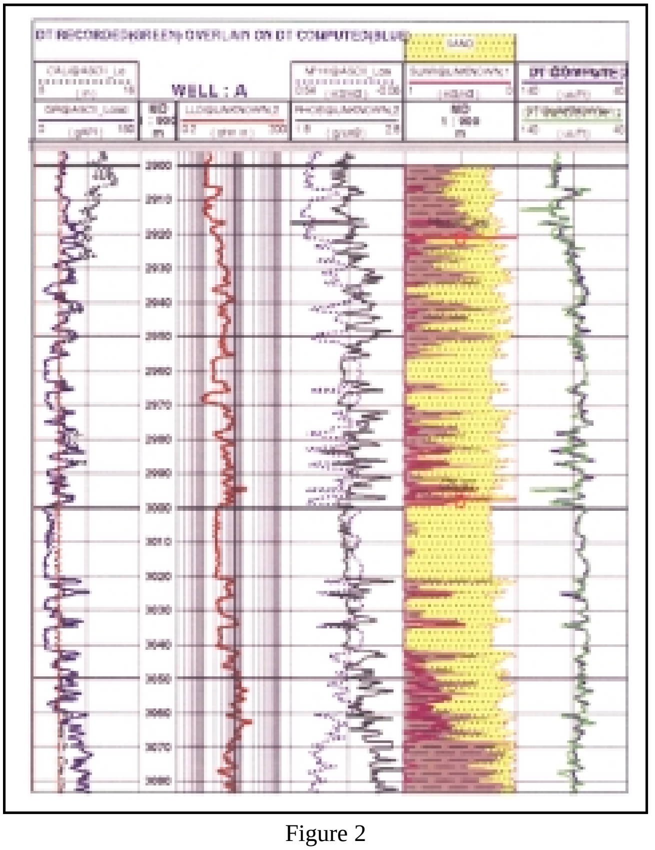


Figure 2

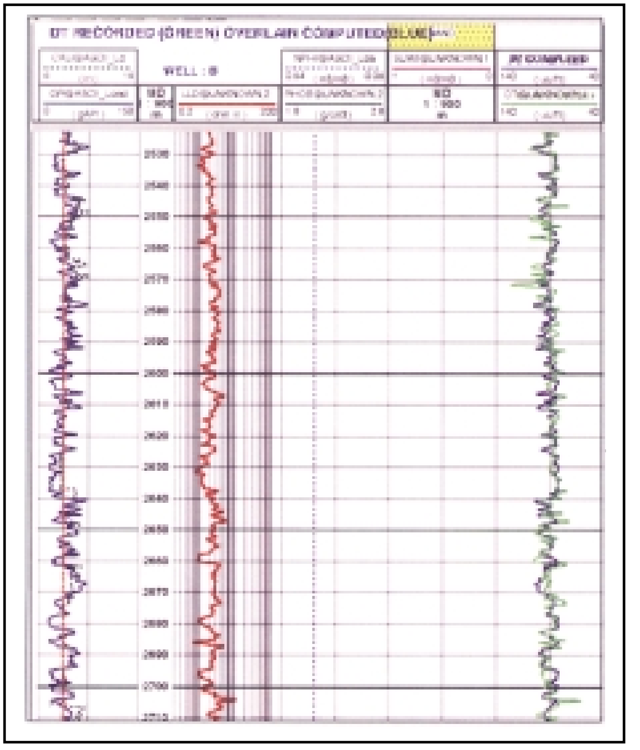


Figure 3

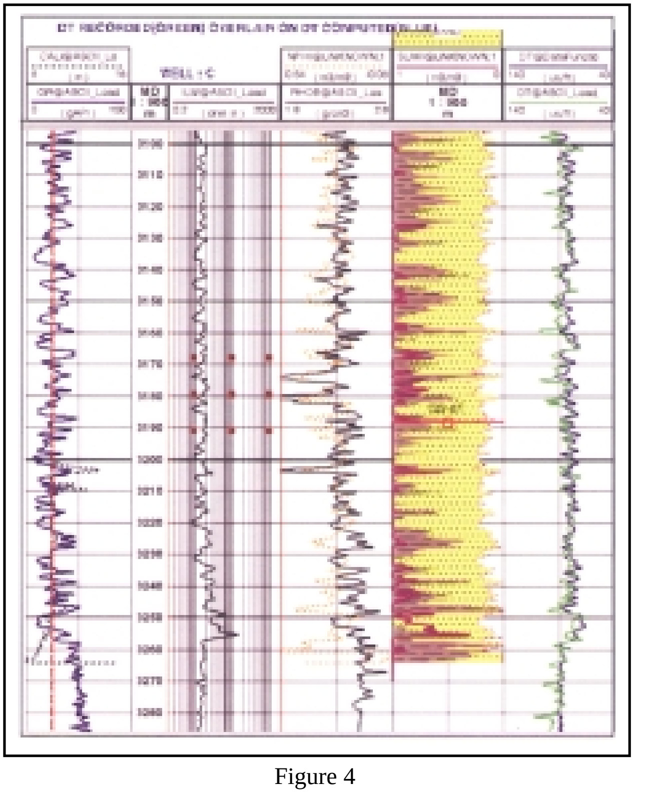


Figure 4

the seismic data. A very good match is found as shown in Fig. 14.

The equation (10) is valid for water bearing formation as Sw in equation (6) has been taken as 1. Accordingly, equation (10) will treat porous hydrocarbon bearing high resistivity zones as tight zones and mayl yield abnormally lower DT values resulting in spurious reflections in the seismogram. Nevertheless, this problem can be circumvented by substituting actual values of Sw rather than 1 in equation (6). The DT calculated is coming quite close to DT recorded against the oil bearing zone (3060 – 3070m) in well D even by taking S_w=1 (Figure 5). Thus, DT computed against hydrocarbon bearing zones can be expected to provide reliable seismogram.

The shaliness (V_{shale}) computed by GR alone may not be very accurate for all types of formations, and, thus, may affect the computed DT. So, it is suggested to check V_{shale} value from other logs as well before putting it in equation(6).

The effect of hydrocarbon saturation on DT and shaliness computation with other methods could not be covered in this paper. They will be taken up in the future study.

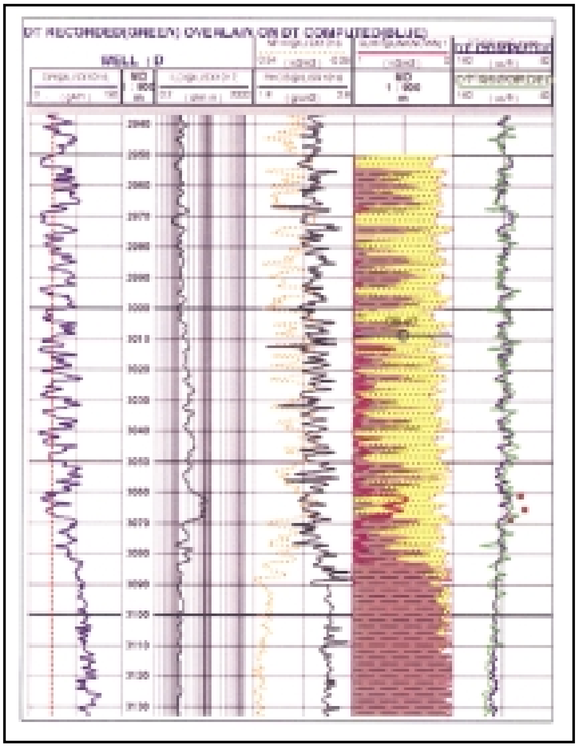


Figure 5

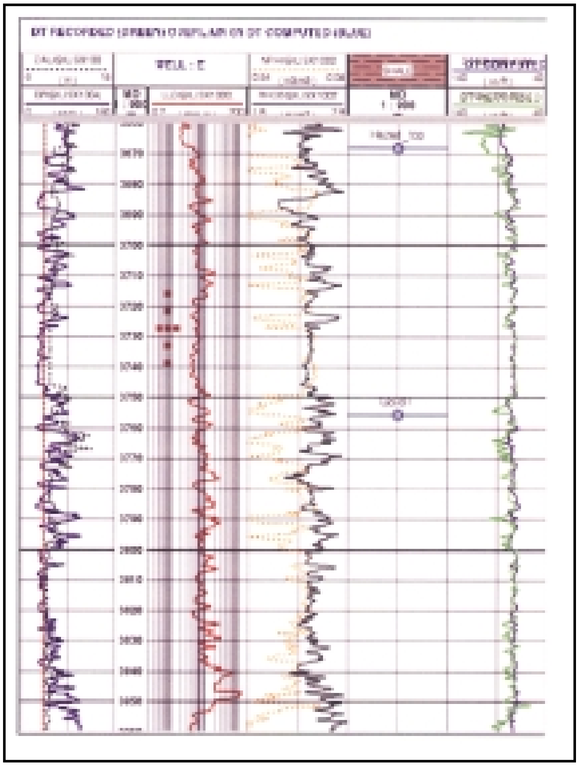


Figure 6

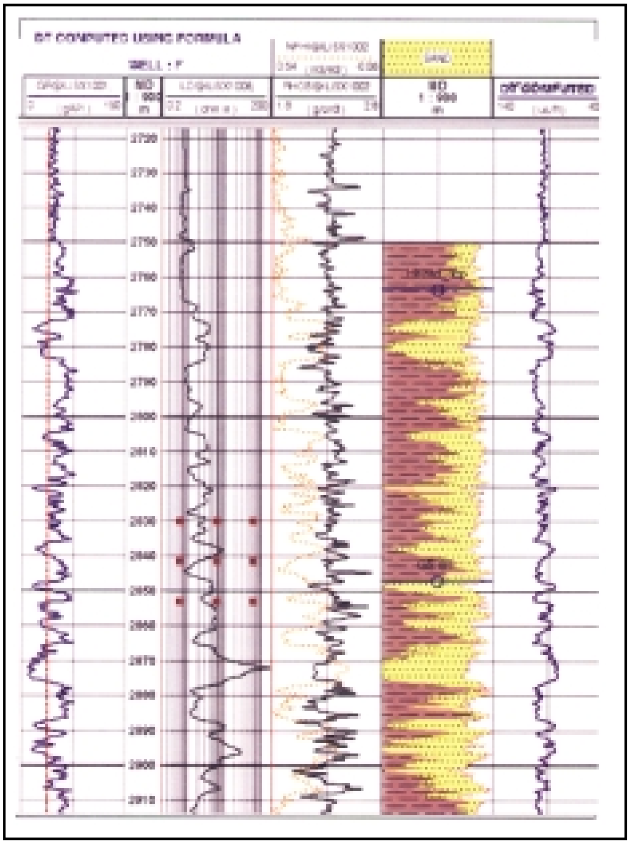


Figure 7

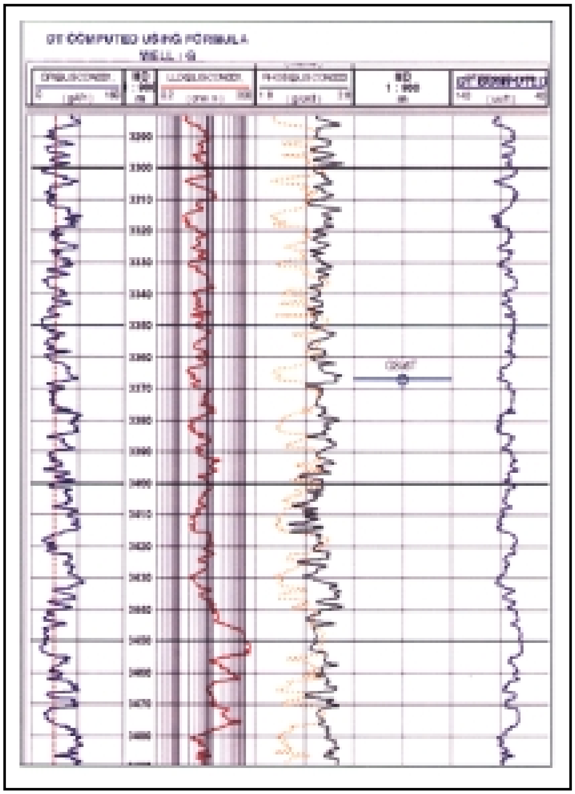


Figure 8

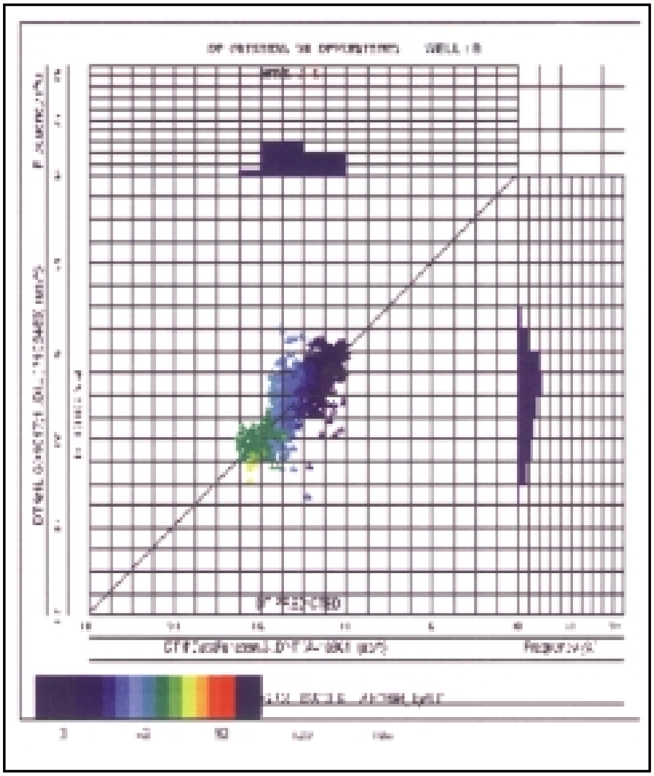


Figure 10

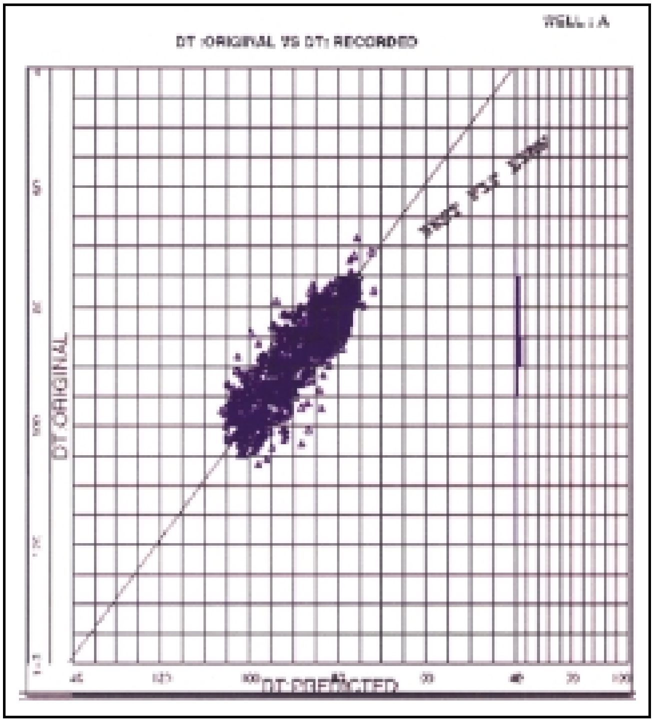
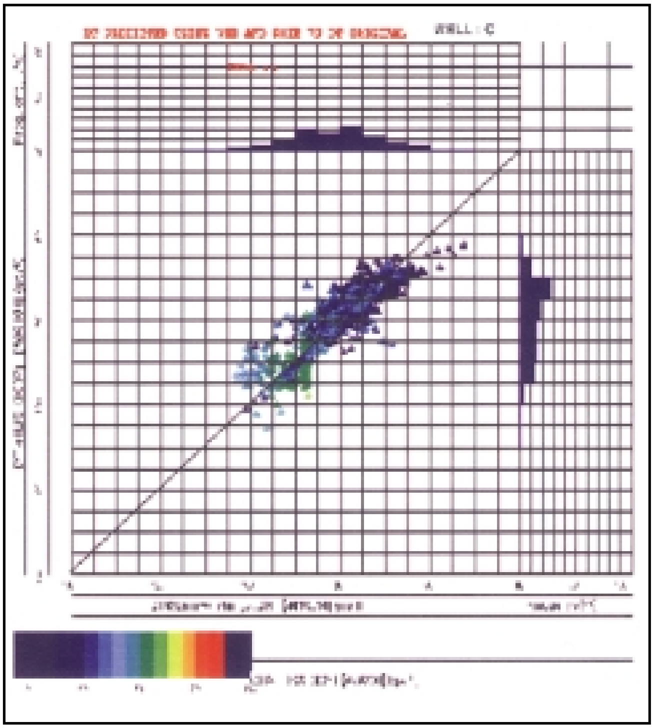


Figure 9



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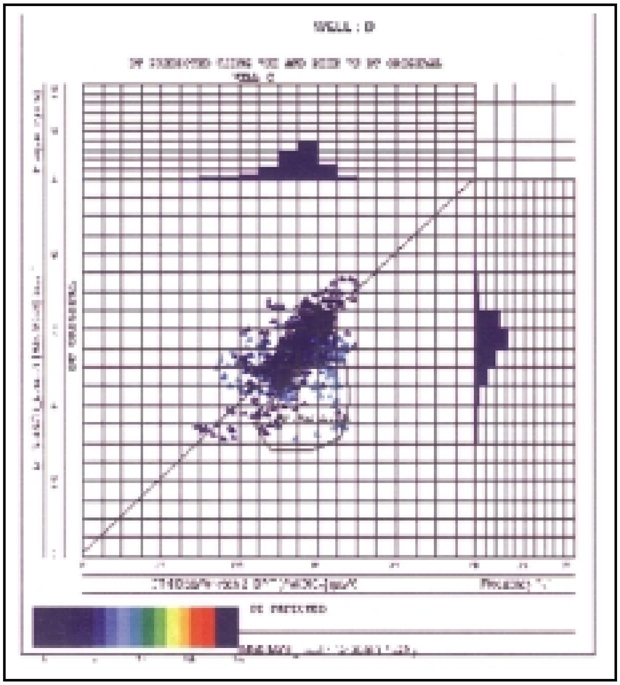

Figure 12

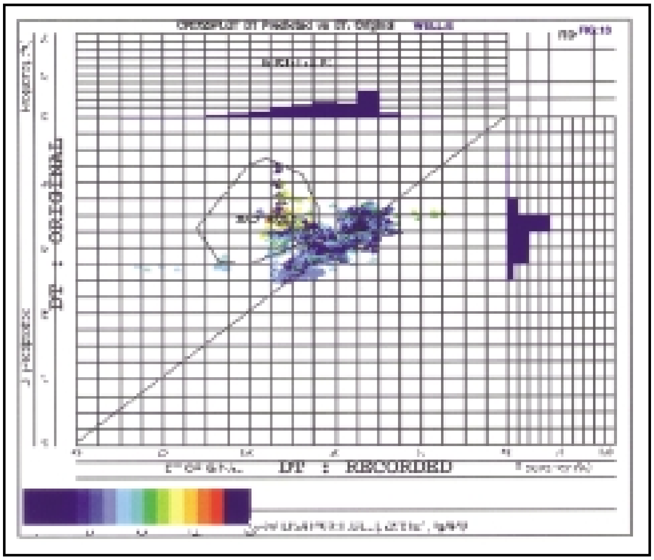

Figure 13

CONCLUSION

1. The predicted DT can be used for seismic to well caliberation , seismic inversion and formation evaluation.
2. All wells of Gandhar field can be used for seismic inversion and reservoir characterisation thus improving, the resolution and quality of inversion and estimation of water saturation.

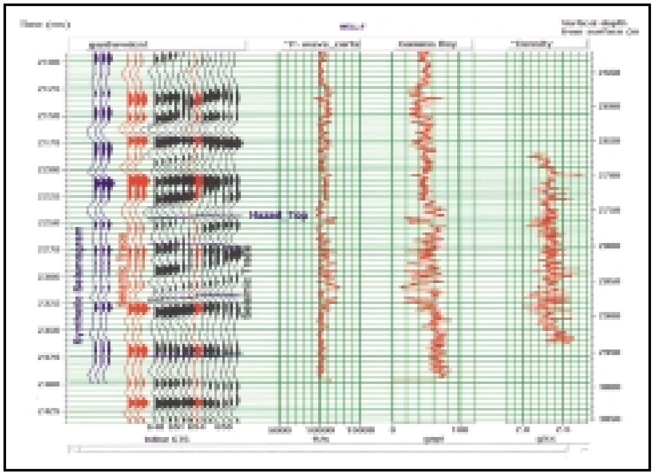

Figure 14

2. Hence,the above formula (10) can be used effectively and reliably in Gandhar field for prediction of DT log using GR and Resistivity log only, where DT log curve is not recorded.
4. This formula may also be used in any field by using the input parameters of that field.

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