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A quantitative study of the seismic time-amplitude reflection characteristics in an oil field

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Abstract: The seismic time-amplitude reflection characteristics of selected sandstone horizons in a recently developed oil field are examined for effects of thicknesses, continuity and bed quality. This study uses an integrated approach of well data calibration, forward seismic modelling and 3D seismic data set for interpretation. In this area, wireline logs indicate velocity to be a poor lithologic descriptor. The acoustic impedance at sand-shale interfaces could be accounted for by changes in the density instead. Gassmann's equation confirms the minor effect of velocity perturbation with gas. Forward amplitude modelling 1D for sandstone encased in shale in the selected stratigraphic horizons permits values of tuning thicknesses to be ascertained for each lithologic units. This learning phase quantities subsequent reflection parameters and aids 3D seismic interpretation. Preliminary results suggest an east-west trending sandstone reservoir with thicker and better developed sandstone horizons towards the flanks of the anticlinal structure.

INTRODUCTION

The study area is located in Block PM-6, offshore Terengganu which is about 130 kms from the Terengganu coast (Fig. 1), Thirteen (13) exploration wells have been drilled in this oil field.

The objectives of this study are (i) to measure the changes in the waveshape of seismic reflection data associated with the reservoir and (ii) to interpret this trace-to-trace change with changes in their thicknesses and porosity extent.

An integrated approach of using well data, forward seismic modeling, and, a 3D seismic data set, are used in this study. A sandstone horizon have been selected to study its corresponding time-amplitude characteristics for effects of thicknesses and reservoir quality.

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WELL DATA

There are three (3) main lithologies identified namely coal, shale and sandstone. The sandstone is further classified into two different facies, namely flaser bedding sandstone (sf) and wavy bedding sandstone (sw) together with three (3) fluid types; gas, oil and water. The sonic and density data for the three lithologies, from all exploration wells, were extensively plotted to demonstrate differentiation of the various lithologies and to determine their trend and effects on the acoustic impedance. Two common geologic parameters, porosity and presence of gas in the sand have also been examined to determine their influence on the seismic amplitudes measured.

Velocity trend

Velocity data are found scattered over a wide range of values as shown in Figure 2. Coal has the lowest velocity range, between 2,000 m/s to 2,350 m/s, but sand and shale have higher velocities which overlap with each other. This indicates velocity as a weak parameter for differentiating various lithologices, except for coal in this instance. There is only a minor lowering of velocities due to presence of gas in the reservoir.

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Density trend

Density data are well separated for different lithologies and shows good trend patterns as seen in Figure 3. Coal has the lowest density range of 1.2 g/cm^3 to 1.8 g/cm^3 followed by sandstone with density range between 2.1 g/cm^3 to 2.4 g/cm^3. Shale has the highest density range between 2.4 g/cm^3 to 2.6 g/cm^3. This indicated density can be used to differentiate lithology types.

Acoustic impedance trend

Acoustic impedance data for all lithologic type are quite well separated which is similar to the density trend (Fig. 4). This implies acoustic impedance is mainly influenced by the density of the rock type and emphasizes the importance of density as a major contributing factor that affects seismic reflection amplitudes. In the study area the sandstone reservoirs have a lower acoustic impedance compared to shale.

Gassmann model

A study carried out by Ng and Leong (1990) on reservoir characterization using the Gassmann model showed that the presence of gas in sandstone has only a minor effect on seismic amplitudes.

In Figure 5, computed velocities from Gassmann's equation assuming a clean sandstone (quartz) with bulk modulus of 35 x 10^{10} dyne/cm^2, indicate a large velocity drop as due to the initial presence of 2.5 percent gas. The large lowering of velocity due to gas is generally associated with anomalous high amplitude reflector on the seismic section and are commonly use as a direct hydrocarbon indicator by seismic interpretator. Subsequent calibration of the Gassmann model from

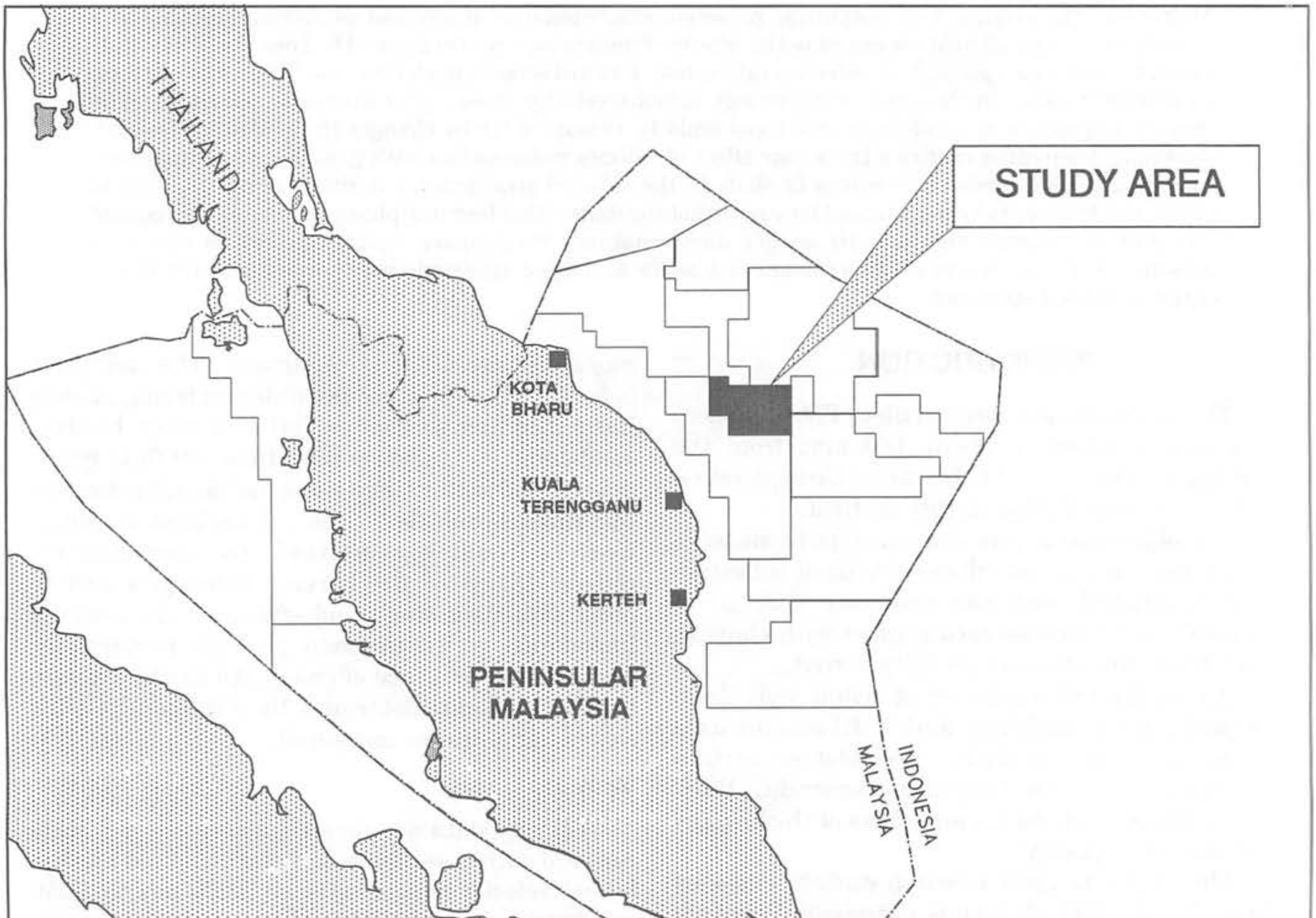

Figure 1. Location map of the study area.

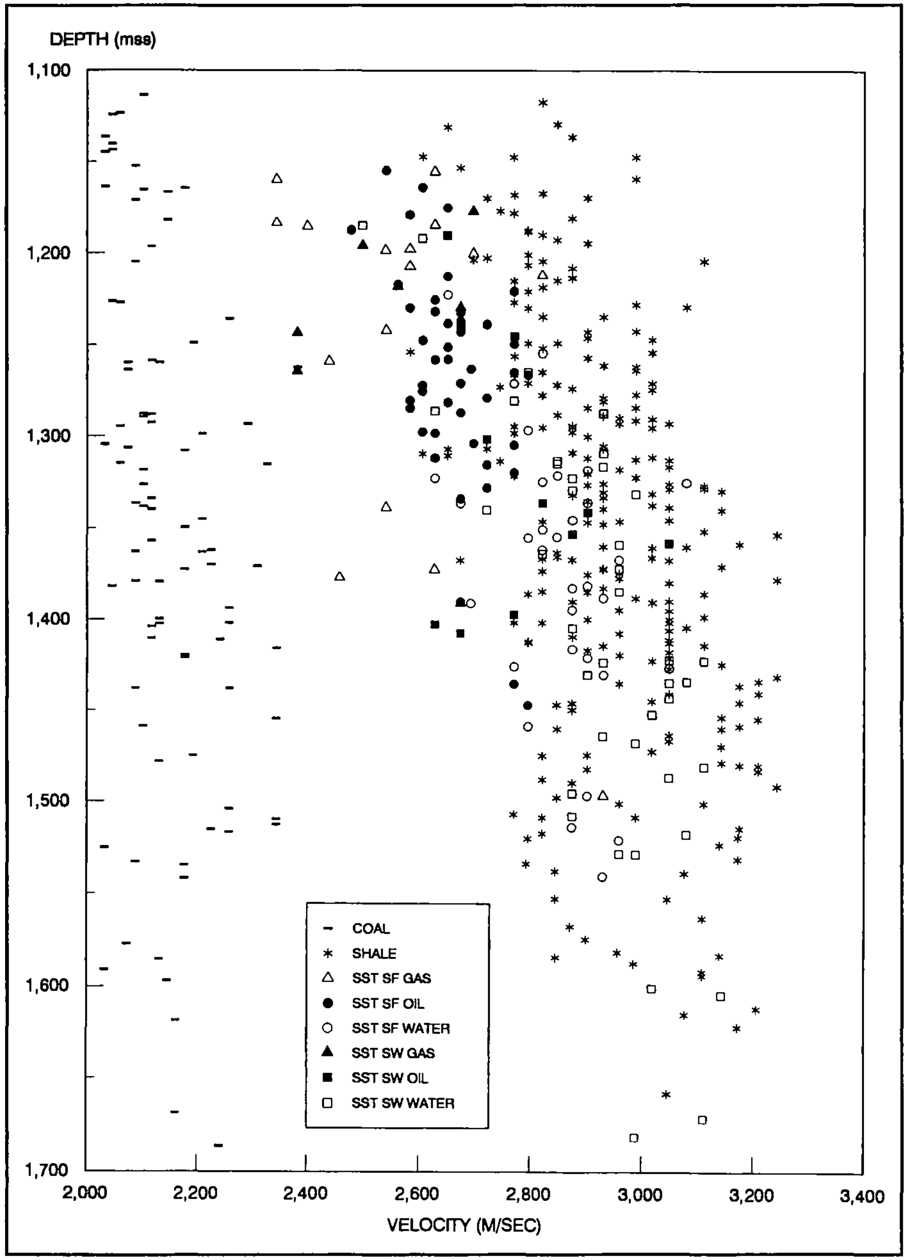

Figure 2. Velocity trend plot of the coal, shale and sandstone.

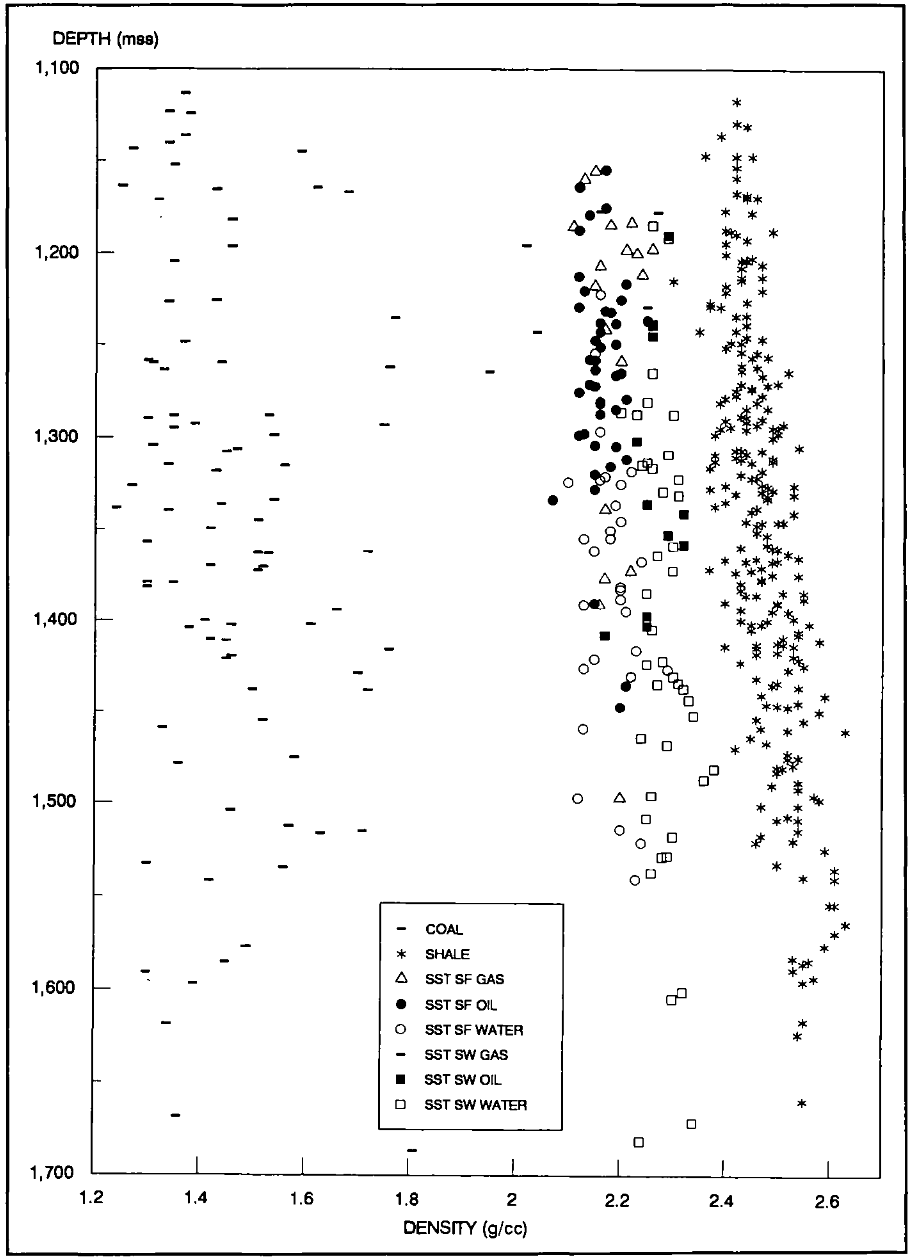

Figure 3. Density trend plot of coal, shale and sandstone. There is a wide separation between the three main lithologies.

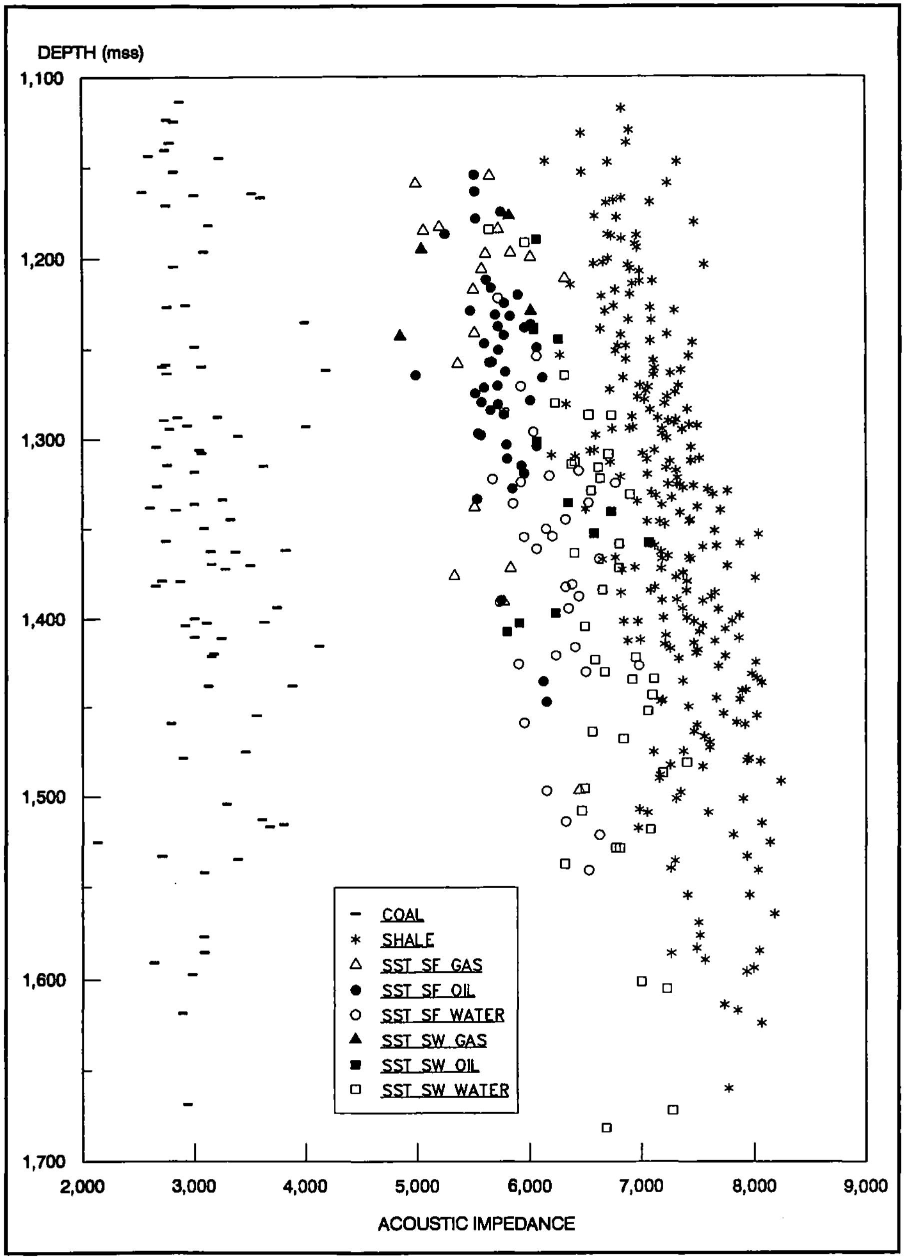

Figure 4. Acoustic impedance is the product of velocity and density.

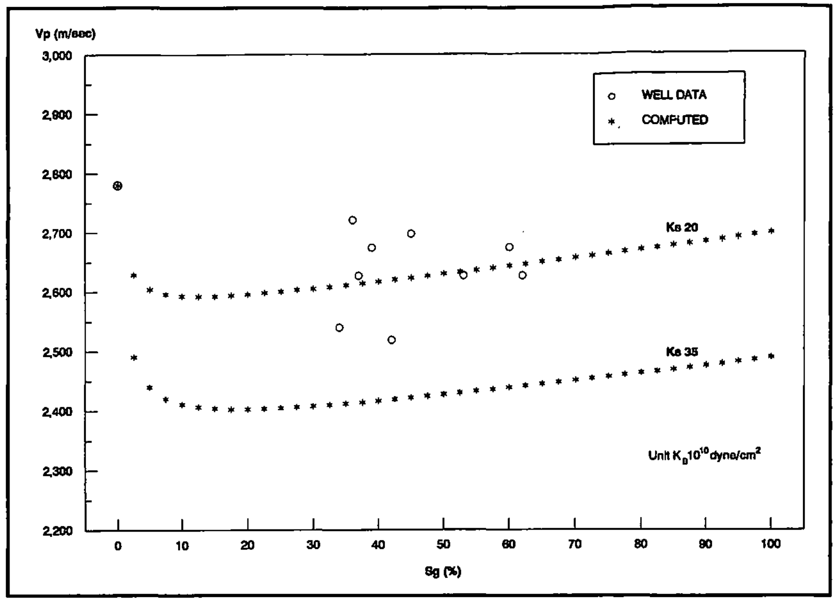

Figure 5. Calibration of the well data using Gassman model suggested the bulk modulus of sandstone is about 20 x 10^{10} dyne/cm^2.

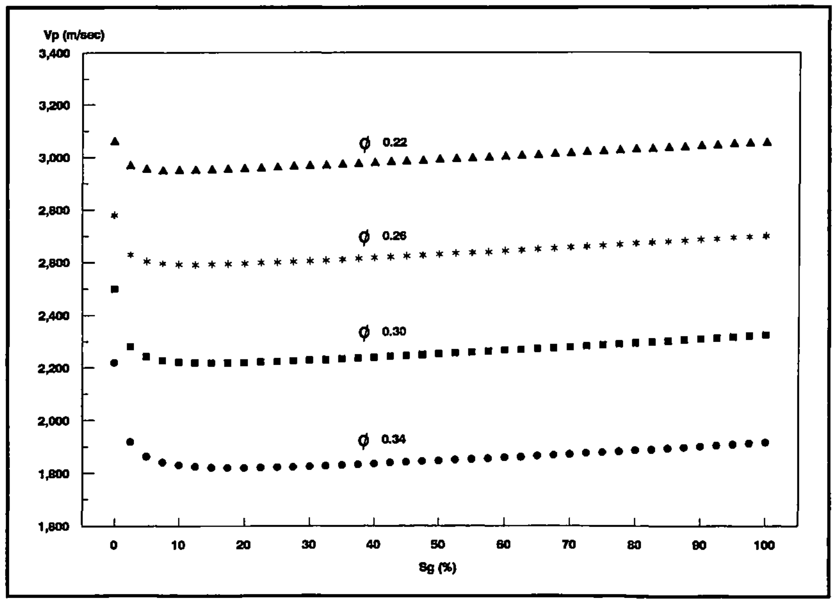

Figure 6. An increase of porosity from 30% to 34% will lower the velocity in the same magnitude as in the case of presence of gas.

well data in the area shows that the bulk modulus of sandstone is about 25 x 10^{10} dyne/cm^2. This suggests the presence of impurities in the sand. The corresponding drop in velocity is much less compared to the initial computation for clean sandstone.

An increase in porosity of 4 percent in the sandstone will lower the velocity in the same magnitude as in the case of presence of gas (Fig. 6). Thus a drop in velocity can be attributed either to the presence of gas or an increase in the porosity of the sandstone (Gardner *et al.*, 1974). Therefore it is concluded that, in the study area, the presence of high reflection amplitude in the seismic data is more likely due to an improvement of porosity.

FORWARD SEISMIC MODELLING

Seismic modelling was carried out to determine the change of bed thickness on the seismic response (Mecker and Nath, 1977). Information from well data and our results of studies from it are incorporated in constructing the geological model of the Lower D Sand reservoir.

Stratigraphically, Lower D Sand is bounded at the top and bottom by shale. The seismic responses have been generated by convolving the reflectivity series with a 10–60 Hz bandpass zero phase wavelet which is similar in frequency content with the acquired seismic data (Domenico, 1974). Density and velocity parameters for each lithology are the average values obtained from well wireline results.

Synthetic seismogram

A 10–60 Hz bandpass zero phase wavelet is used for generating the synthetic seismograms. Figure 7 is an example from a typical well. There is a good correlation between the synthetic seismograms and the seismic section as shown in Figure 8.

Synthetic seismograms from all wells have been generated and tied to each individual well location on the seismic section to ensure that the correct seismic reflectors corresponding to the top and bottom of the Lower D Sand reservoir have been correctly chosen.

Here peak and trough reflectors in the synthetic seismogram correspond to the black (peak) and white (trough) reflectors in the seismic data, respectively.

ID seismic modelling

This modelling experiment generates a sequence of synthetic seismic trace from a model of the Lower D Sands. Figure 9 shows the reflection geometries corresponding to a thickening of the sandstone (ρ = 2.11 g/cm^3, V = 2,418 m/s) surrounded by shale (ρ = 2.42 g/cm^3, V = 2,932.6 m/s). This is explained by accompanying quantitative plot Figure 10. This plot shows the variation of measured peak-to-trough thickness or apparent thickness (in msec) and relative amplitude as a function of the actual thickness (in meter).

The maximum amplitude occurs at 11 meters, which is called the tuning thickness of the sand, and corresponds to the location where the peak-to-trough separation time becomes invariant. Below this point, the actual thickness is linearly related to the relative amplitude whereas above it, the point is linearly related to the peak-to-trough separation time.

In summary, peak-to-trough separation can be used to estimate bed thickness for units thicker than the tuning thickness (thick bed), and, below turning thickness (thin bed), the amplitude response can be used to measure the thickness instead.

3D SEISMIC INTERPRETATION

The inferences and results derived from the learning phase of the first part of this study are used next to carry out the interpretation of the 3D seismic data. Seismic reflectors which correspond to the top and base of the Lower D Sand which have been confirmed by the simulated synthetic seismograms, are picked, and correlated, to generate time structure maps, isochron maps and amplitude maps at each level using seismic interpretation workstation.

Structure

The time structure maps at the top Lower D Sand is shown in Figure 11. Correlation and interpretation (tracking) of the seismic reflector was executed using the AUTO mode. This map indicates the Dulang structure as an elongated anticline plunging towards the west with complex faulting at the crestal area where most of the exploration wells have been drilled. The main fault trend is in the east-west direction while secondary fault trend is in the northwest-southeast direction. Wells results suggested that the main east-west fault trend to divided the hydrocarbon accumulations is a northern and southern system.

Isochron

The isochron map as shown in Figure 12 is generated by subtracting the time structure map values of the base Lower D reflector from the top Lower D reflector. It indicate that thicker isochron is found especially on both of the two structural flanks, and, that the general sand geometry is trending in the east-west direction. Thin bed thickness are shown to exist in the southeastern

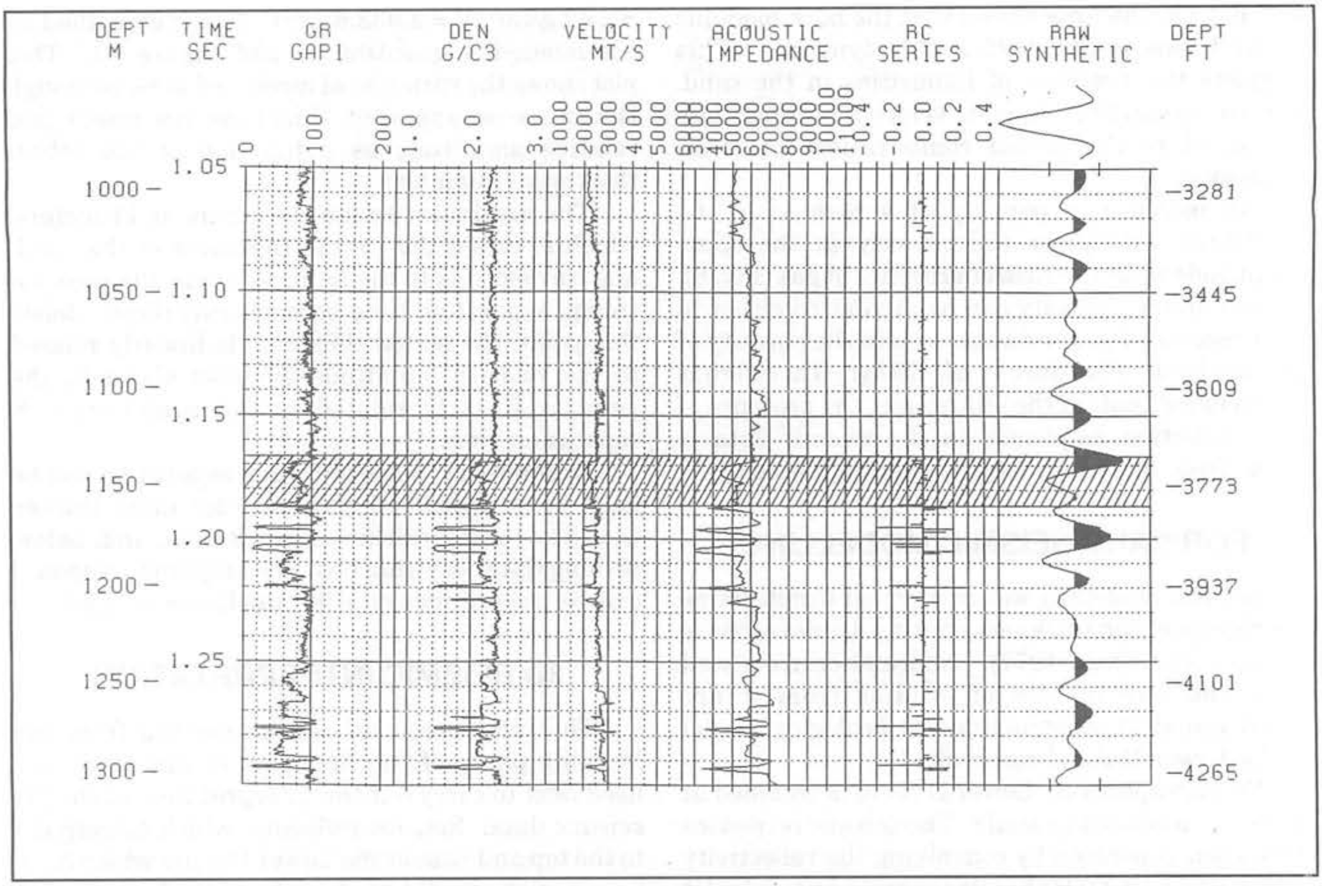

Figure 7. Synthetic seismogram of a typical well in the study area. The zone of interest is at 1.17 to 1.19 sec TWT.

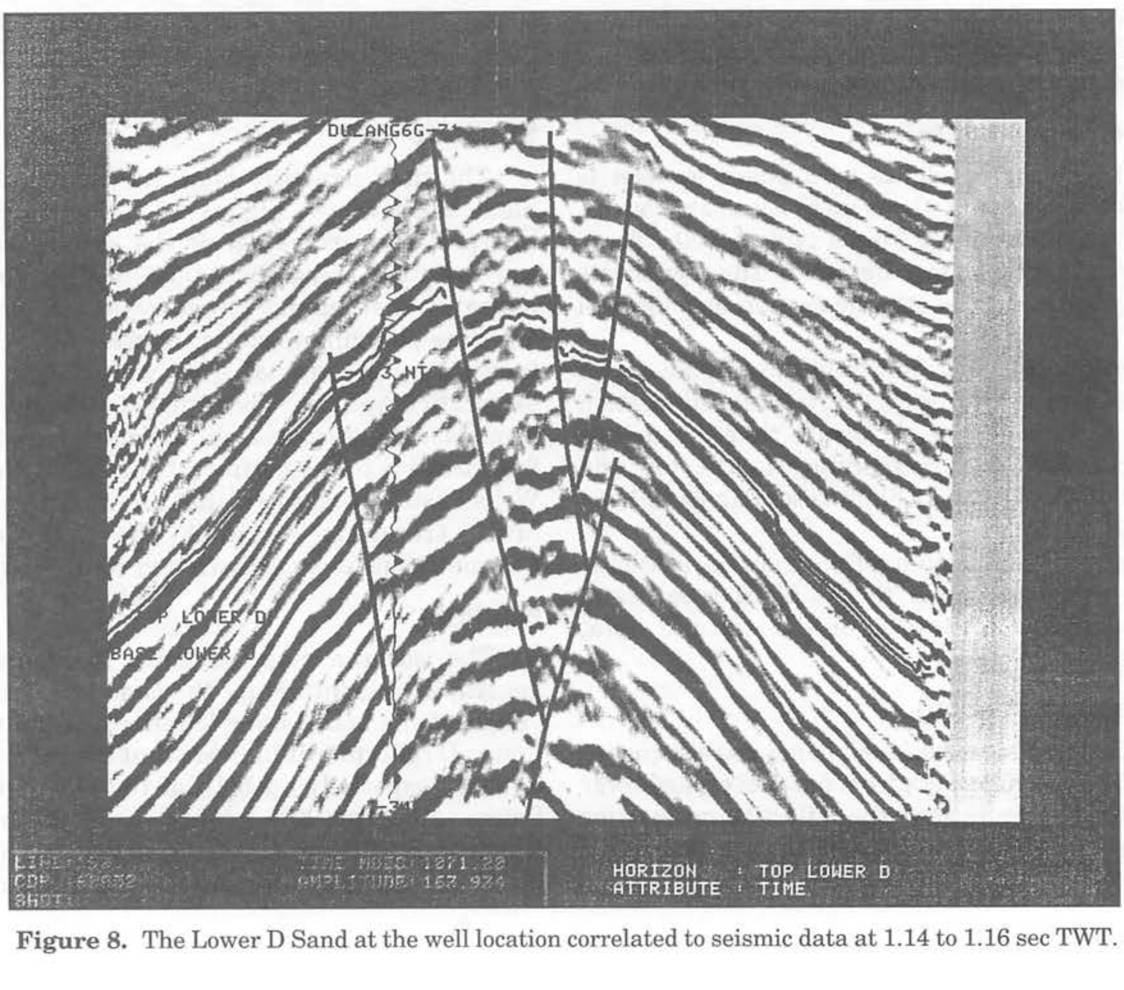

Figure 8. The Lower D Sand at the well location correlated to seismic data at 1.14 to 1.16 sec TWT.

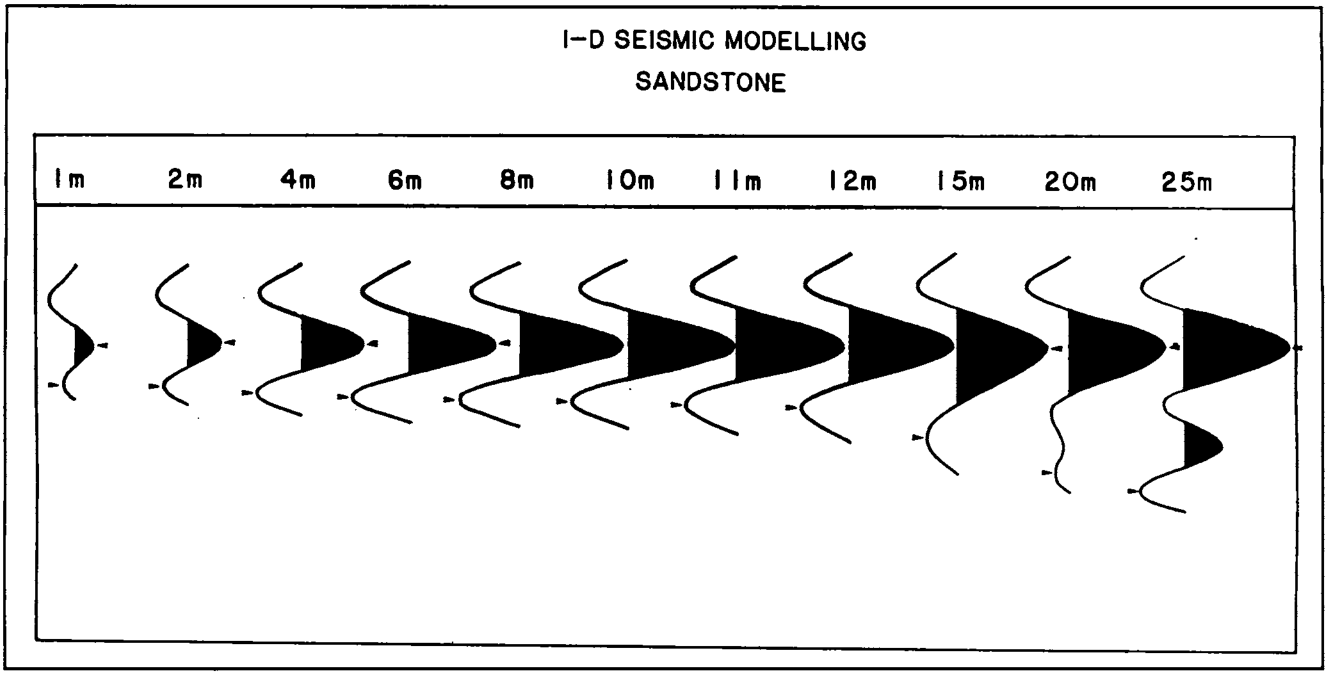

Figure 9. I-D seismic modelling of a sand encased in shale.

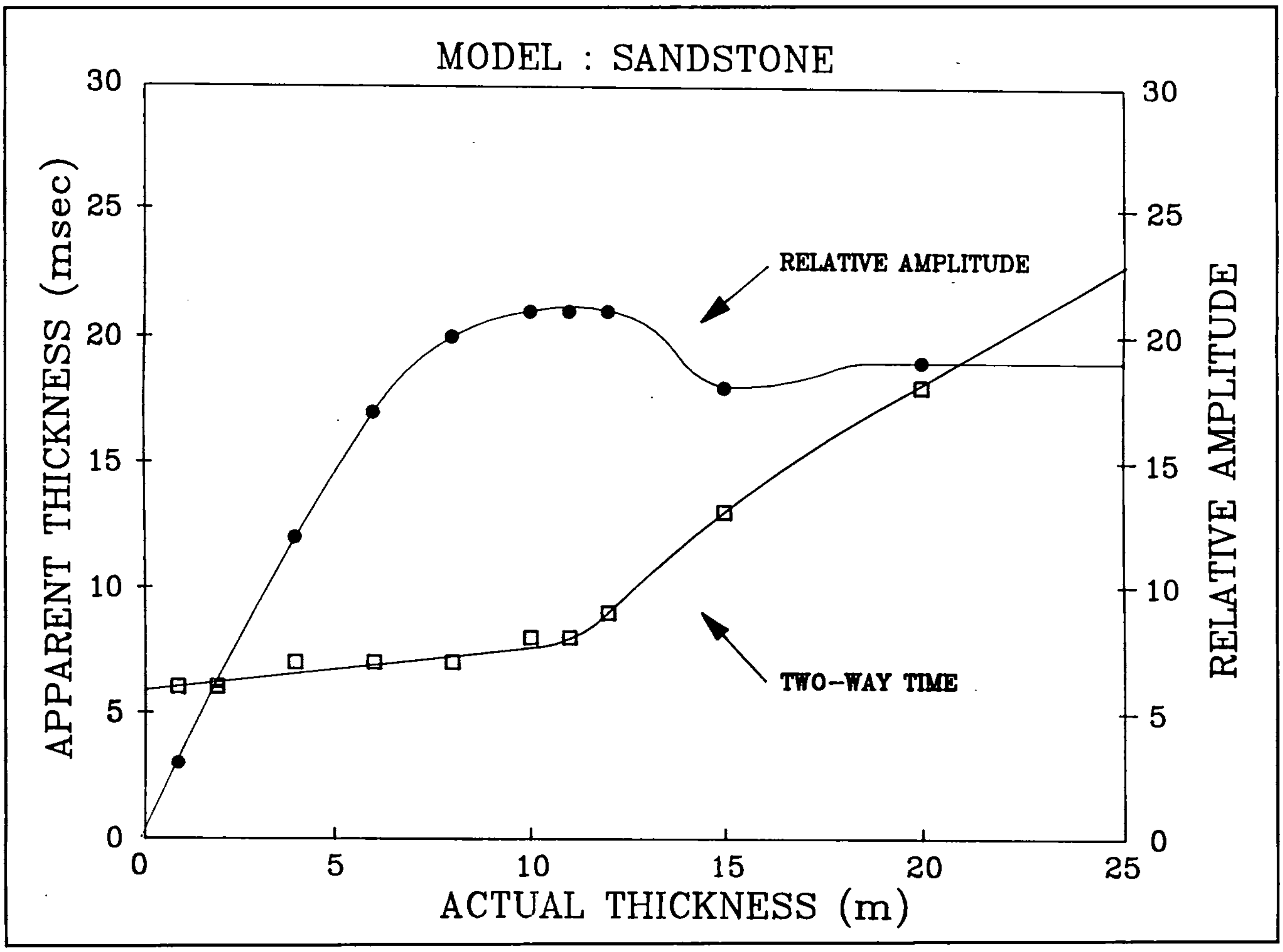

Figure 10. The 'tuning' thickness occur at eleven meters.

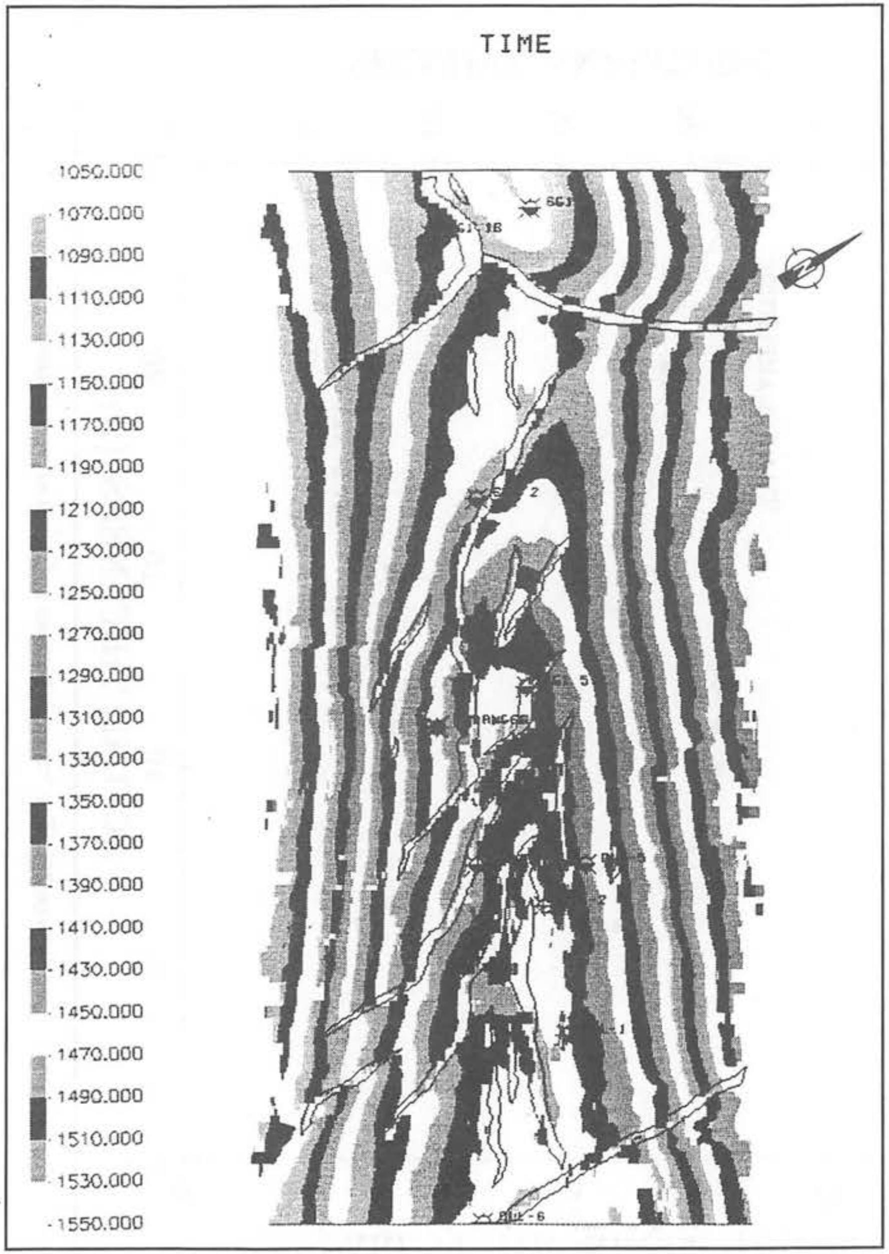

Figure 11. Time structure map of the top Lower D reflector.

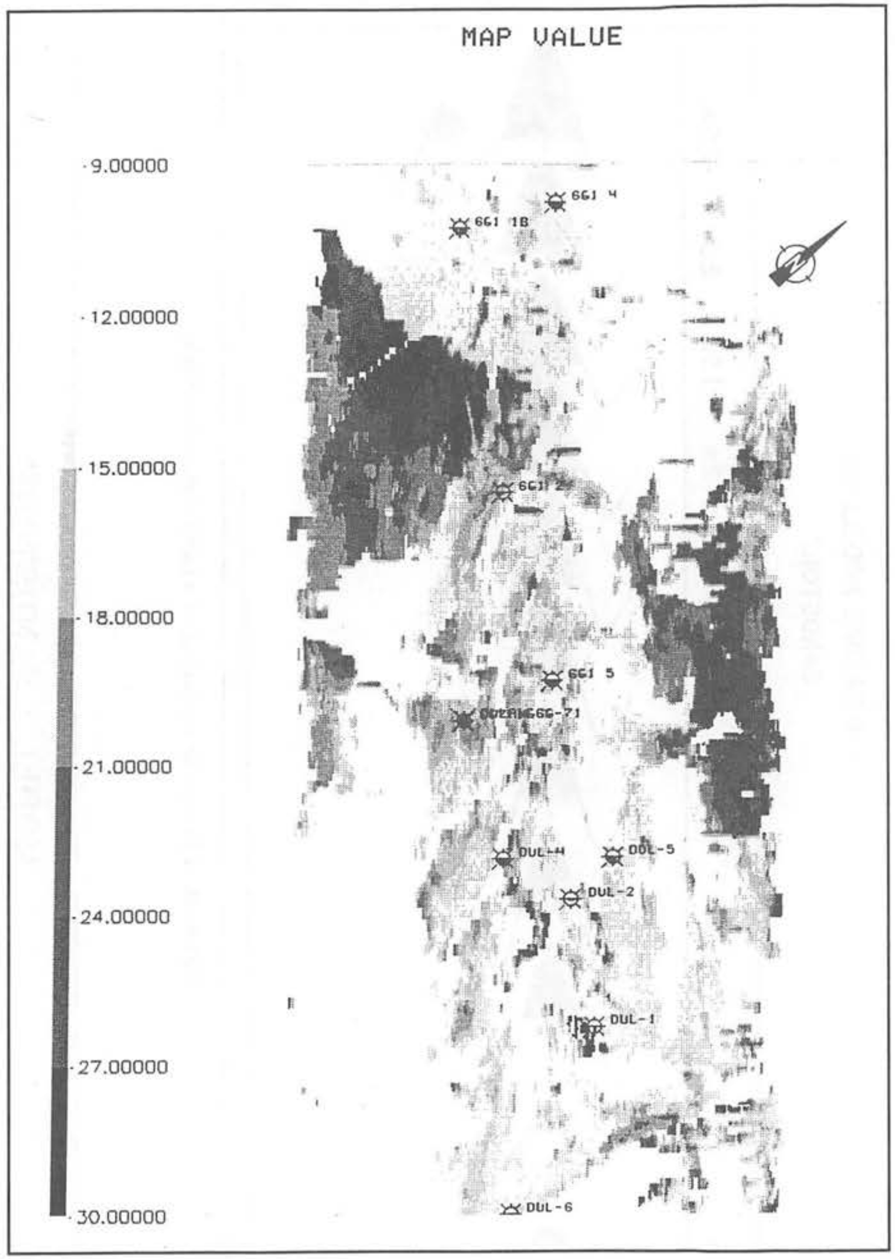

Figure 12. Seismic isochron map of the Lower D Sand.

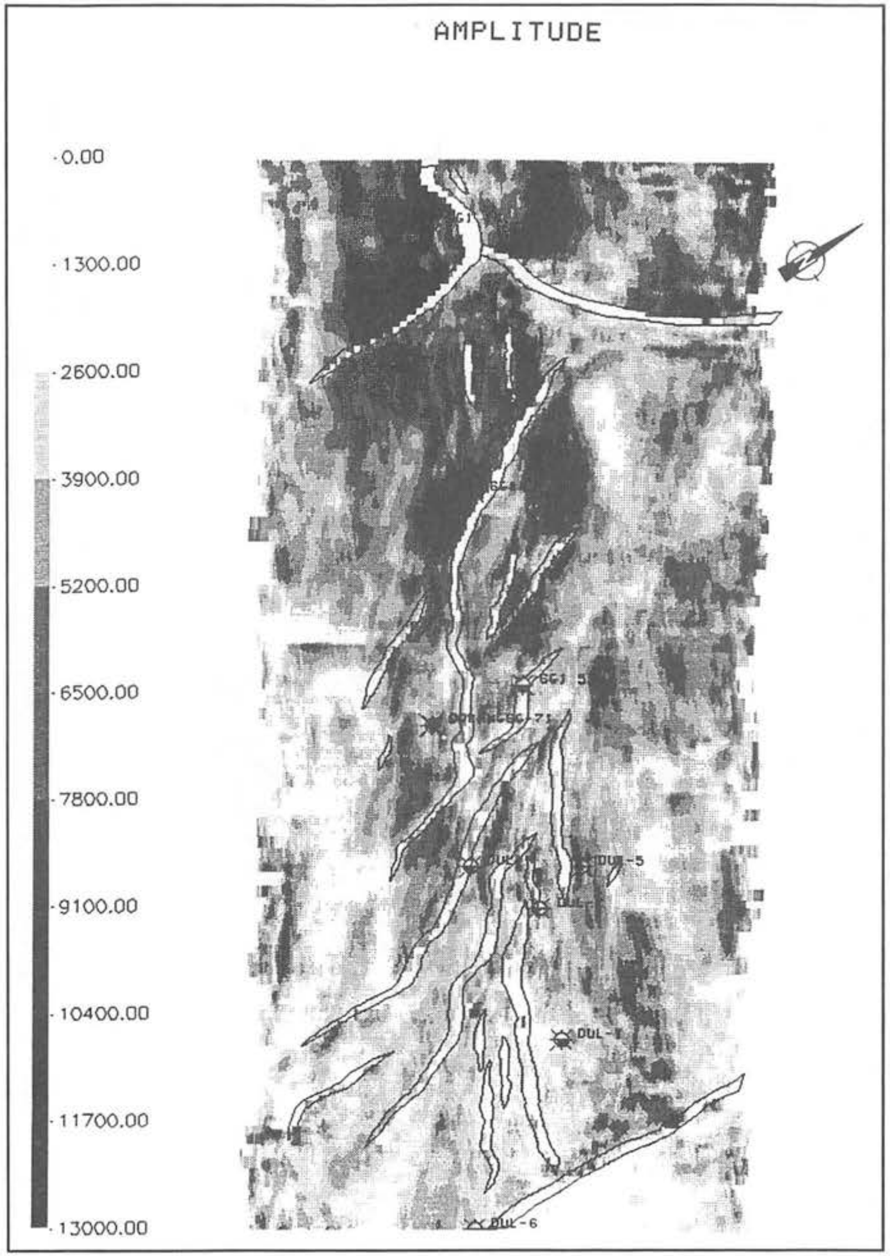

Figure 13. Seismic amplitude map of the top Lower D reflector.

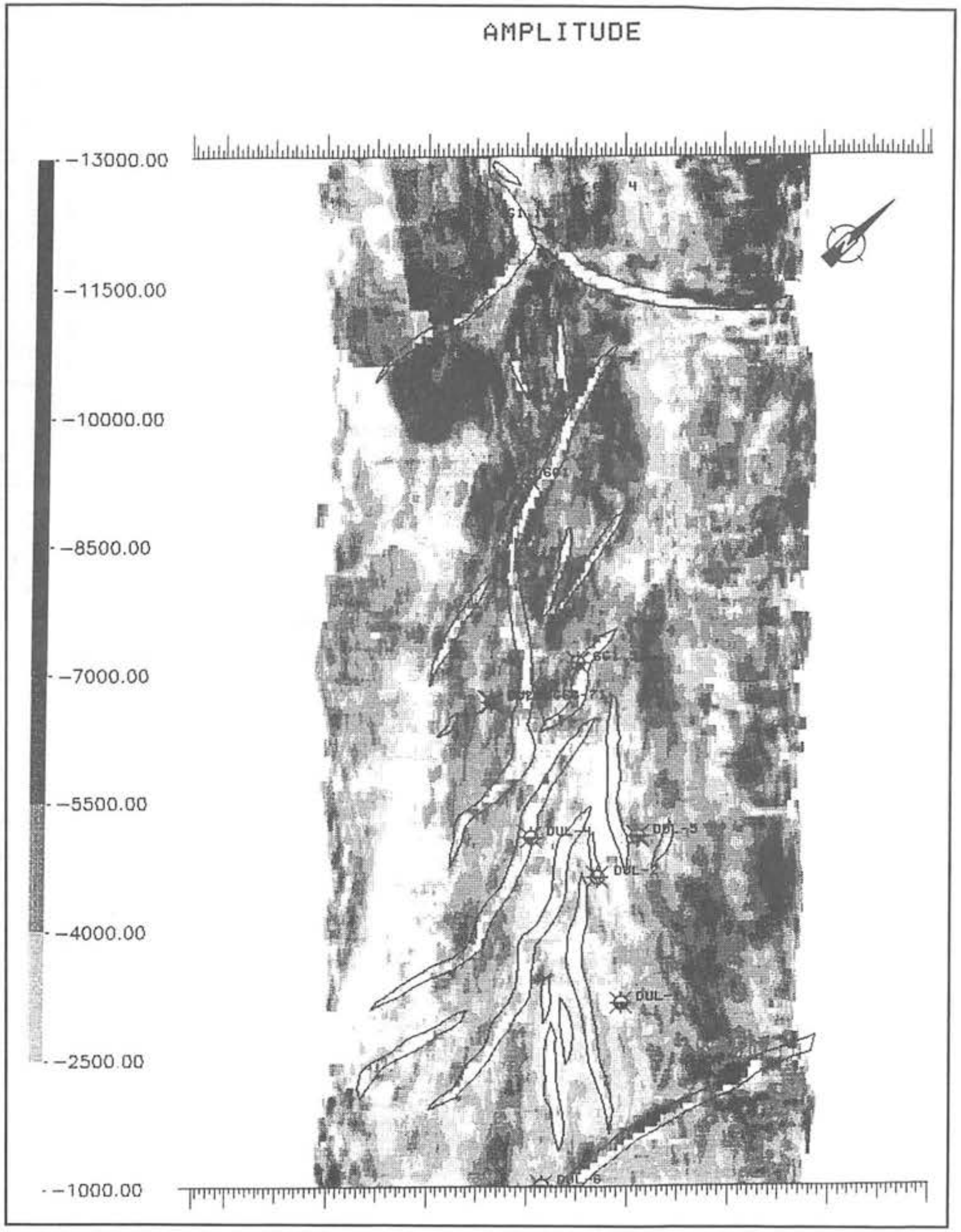

Figure 14. Seismic amplitude map of the base Lower D reflector.

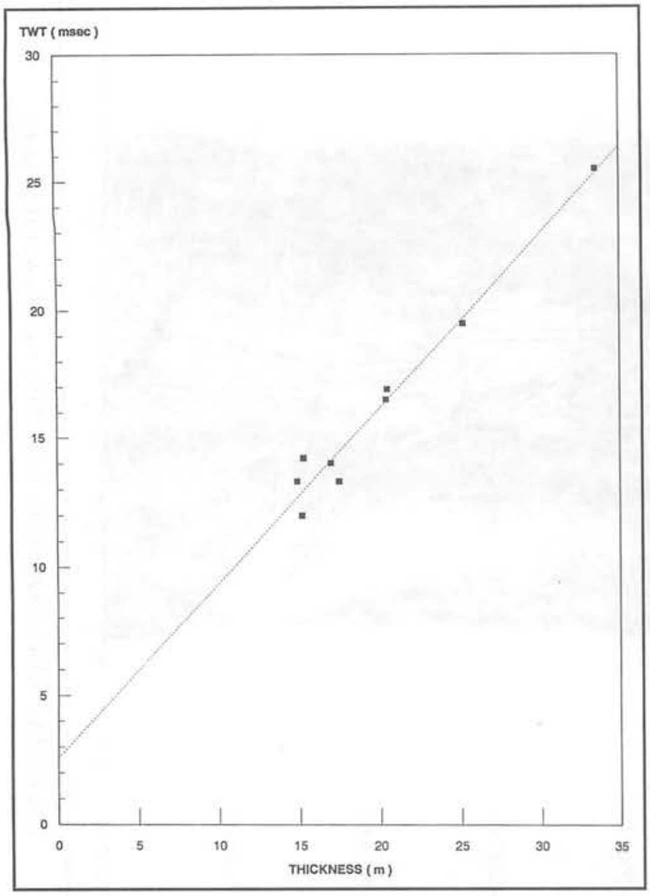

Figure 15. This plot established a linear relationship between seismic isochron and reservoir thickness.

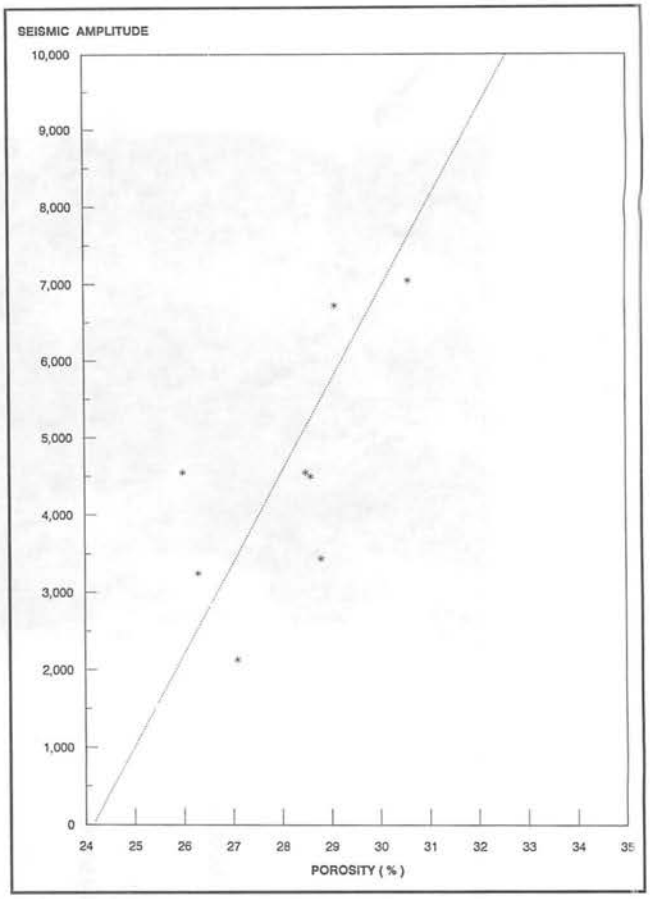

Figure 17. Assuming a linear relationship between seismic amplitude and reservoir porosity, the error could be ±2% porosity unit.

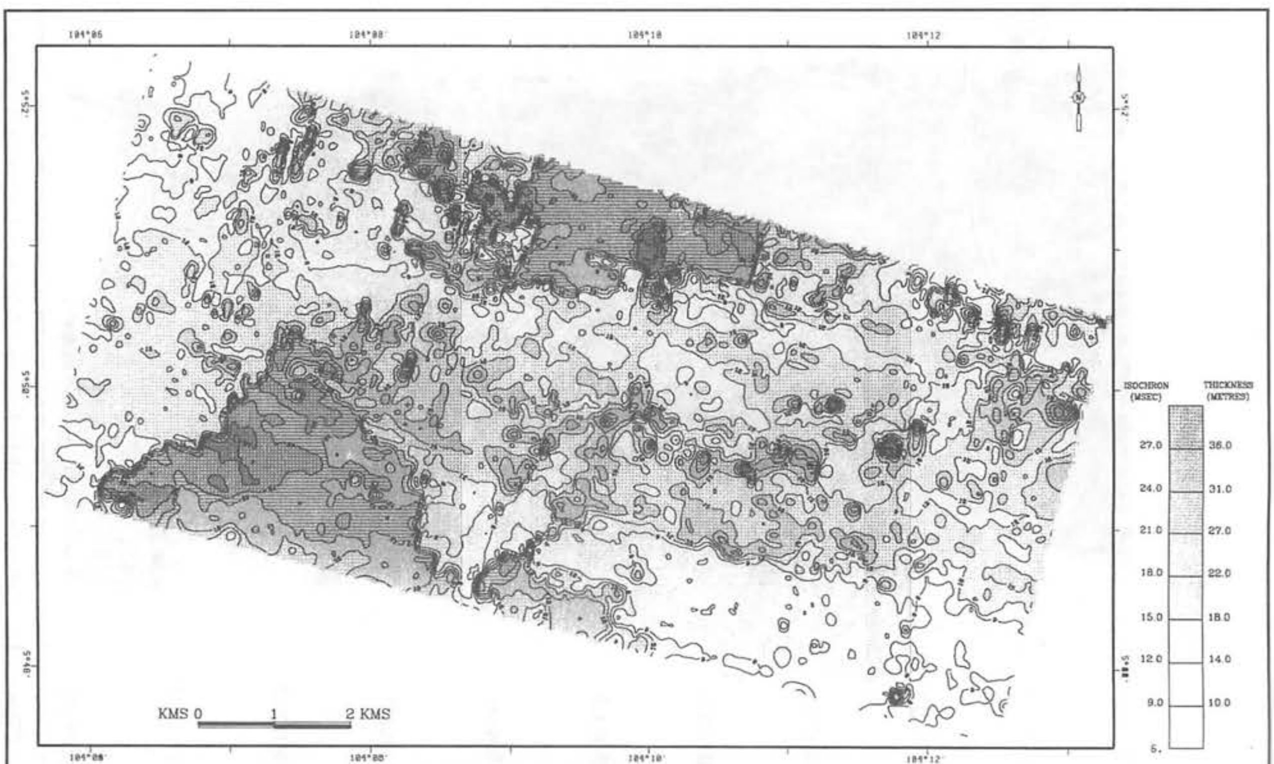

Figure 16. Thick reservoirs are found at the flank of the structure whereas thin reservoirs are mainly concentrated in the southern and northwestern corner.

and northwestern corner of the structure.

Amplitude map

Amplitude maps of the two reflectors corresponding to the top and base of Lower D Sand are shown in Figures 13 and 14. These maps are direct output from the seismic interpretation workstation. They indicate high amplitude towards the west and low amplitude toward the east of the anticlinal crest and is probably due to relative high and low porosity beds respectively. The amplitude maps highlighted a east-west trend. By comparing Figures 13 and 14, they indicated a similar trend even though they are extracted from two difference seismic reflectors.

In the most area, the amplitude map of the top Lower D reflector have a higher value compare to the amplitude map of the base Lower D reflector. This seismic attribute characteristics is consistence with the results we highlighted in the synthetic seismogram and 1D seismic modelling.

SAND THICKNESS PREDICTION

Seismic isochron values (workstation output) of the Lower D Sand, observed at the vicinity of the well location are plotted against the actual thickness which have been calibrated by the well results. The plot for the Lower D Sand are shown in Figure 15. It suggests a linear relationship between seismic isochron and reservoir thickness. Some of the well locations have to be shifted towards the south due to different navigation system used in well location and 3D seismic acquisition

Estimation and delineation of the thick beds (defined here as a unit thicker than the tuning thickness) are carried out by using the isochron maps and well calibration plot. Thick beds (Fig. 16) which are interpreted to have thicknesses of between 10 to 36 meters, are widely distributed all over the Dulang structure. The thin beds of the Lower D Sand was interpreted to have a thickness of less than 10 meters (corresponded to 9 msec TWT). These beds are generally located in the northwestern and southeastern corner of the structure. Two areas were interpreted to have reservoir thicker than 22 m but it had to be further proven by well results. Over the crestal area there are numerous pocket of thick and thin beds reservoirs.

RESERVOIR POROSITY PREDICTION

Seismic amplitude values (workstation output) correlated to the top of Lower D Sand observed at the vicinity of the well location are plotted against the average porosity of the sand reservoir (Fig. 17). Assuming a linear relationship between seismic amplitude and reservoir porosity, the error in predicting reservoir porosity from seismic amplitude

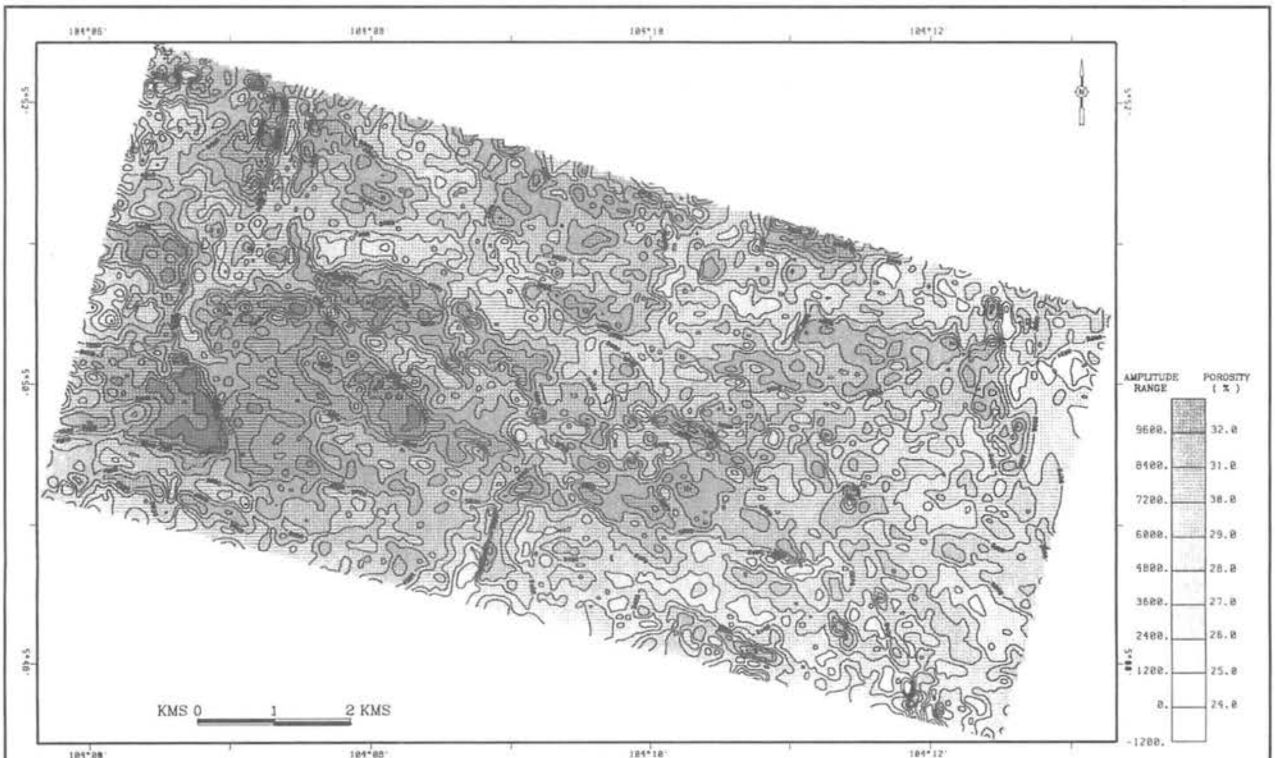

Figure 18. Porosity of the Lower D sandstone is predicted to range from 24% to 36%.

map is ±2% porosity unit. The error in estimation of the reservoir porosity is most probably due to the effect of scattering in the velocity data as discussed earlier. The result of this porosity prediction is shown in Figure 18. Relative high porosity is found in the west of the anticlinal crest. In the south eastern and north western corner of the map where low porosity (low amplitude) is compounded by thin bed (less than 9 msec isochron) it could imply a shale-out region of the Lower D Sand.

RECOMMENDATIONS

The following further work are recommended:

a. Recalibration of the seismic attributes to bed thickness and porosity incorporating the additional development drilling results and updated sedimentological model.
b. Further work on multi seismic attributes calibration through neural network analysis.

CONCLUSIONS

We conclude that:

a. Seismic attributes (time, amplitude etc.) can be used to predict bed thickness and porosity. An integrated approach of using well data, seismic modelling techniques and 3D seismic data interpretation can aid in the prediction of reservoir geometry with a higher degree of accuracy.
b. Seismic attributes study should provide geophysical constraints to sedimentological model.

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