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Time-Depth Conversion- A Case Study of West Oil Field, UK

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ABSTRACT---- ***Time-Depth conversion analysis was carried out on the West Oil Field, to predict depth and velocity away from five existing well control points to predict hydrocarbon volumes in reservoirs and the feasibility of future well depths. Depending on the velocity characteristics of the layers, two velocity models have been applied in the time to depth conversion; constant interval velocity and the linear velocity (V_0, k). A justification of this velocity approach is that the constant velocity model accounts for layer thickening and thinning while the linear velocity (V_0, k) approach gives a rigorous description of velocity increasing with depth. Errors between well depths and formation tops for the Top Sherwood reservoir were found in the range -4 to 49, after the analysis of the final depth conversion, the errors were drastically reduced to between -0.11-1.57.***

Keywords--- Time-Depth Conversion, West Oil Field, constant interval velocity, linear velocity, Top Sherwood

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1. INTRODUCTION

The West oilfield is the largest of three producing oilfields in the Wessex Basin. The field is located beneath Poole Harbour (Figure 1) in Southeast Dorset; on the south coast of the UK .[1] The data provided for this study assumes the oilfield is in an early stage of development with five wells; four onshore wells (Well A1-A4) and one offshore well (Well A-5). Figure 2 outlines the location of the drilled appraisal wells. A 3D seismic survey was shot both onshore and offshore (See Figure 2 for onshore/offshore field extent). Land acquisition was carried out with both dynamite and vibroseis sources and has a very limited coverage due to environmental constraints. There were significant environmental constraints on data acquisition with much of the onshore portion of Poole Harbour being protected by legislation including; National Parks, Specific Sites of Scientific interest, area of Outstanding Natural Beauty and Heritage Coast. The offshore data has a higher resolution with bin spacing of 12.5 m but again was affected by the relative small size of the harbour and the active shipping lanes.

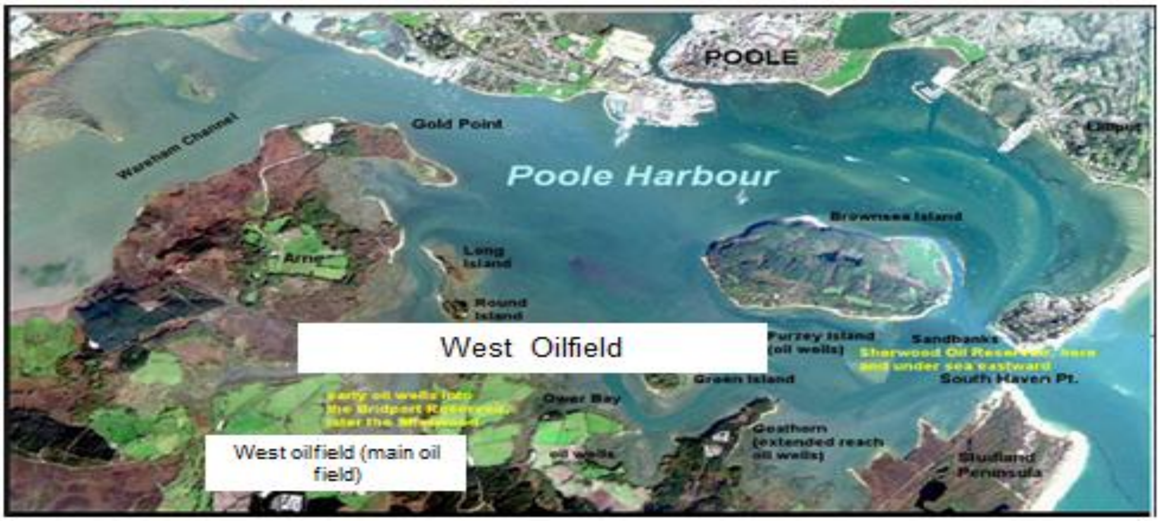

Figure 1: The location of the West Oil field relative to the Poole Harbour

Figure 2: Reservoir outline and location of wells at reservoir interval

1.1 Petroleum Systems Overview

The reservoir is the 150 m Permo-Triassic continental red bed succession of the Sherwood Sandstone Group. The net reservoir is sandstone bar deposits which may be stacked laterally and horizontally. Floodplain deposits also provide a small volume of sand in sheetflood sandstones but these are more important for their higher permeability and potential as a migration pathway.[2]

The Sherwood Sandstone Group has a gradational boundary with silty mudstones of the Upper Triassic Mercia Mudstone above. This mudstone is about 700 m thick and forms a reservoir-seal pair, both in the Wessex Basin and elsewhere in NW Europe.

Geochemical work has identified the source rock as the 100 m thick organic shales of the Lower Lias (Lower Jurassic). Total organic carbon content up to 8% has been measured and is mostly algal material of Type II kerogen . [1-2]

Figure 3 shows the trapping structure is a tilted fault block which closes onto the net extensional West Field Fault. The trap requires the fault to be sealing. The Lower Lias shales are seen in outcrop at Charmouth but are only partially mature, although the presence of 'beef' (fibrous calcite) layers indicates burial to some depth prior to uplift to the surface. Published work indicates maturation occurred prior to the Tertiary inversion and is limited to a kitchen area south of the Purbeck-Isle of Wight disturbance. The Lower Lias has been identified as the source for the live oil seep in the Wealden beds in Mupe Bay. The reservoir and trap occurs to the north of the Isle of Wight-Purbeck disturbance so primary migration relied on leakage across the fault system to backfill the tilted fault block. This allows for the stratigrapically higher source to charge an older and lower reservoir.

Oil generation is reported to have begun in the Early Cretaceous with peak generation in the Middle to Late Cretaceous. The faults which acted as conduits for the backfilling of the reservoir must have then become sealing to allow for the accumulation of a thick oil column.

The majority of the deformation associated with the basin closure in the Tertiary is concentrated in the near vicinity of the Purbeck fault and in particular in the hanging wall to the south of the fault zone. Fault reactivation within the West oilfield does carry the risk of breaching the seal although all faults are still in net extension.[2-3]

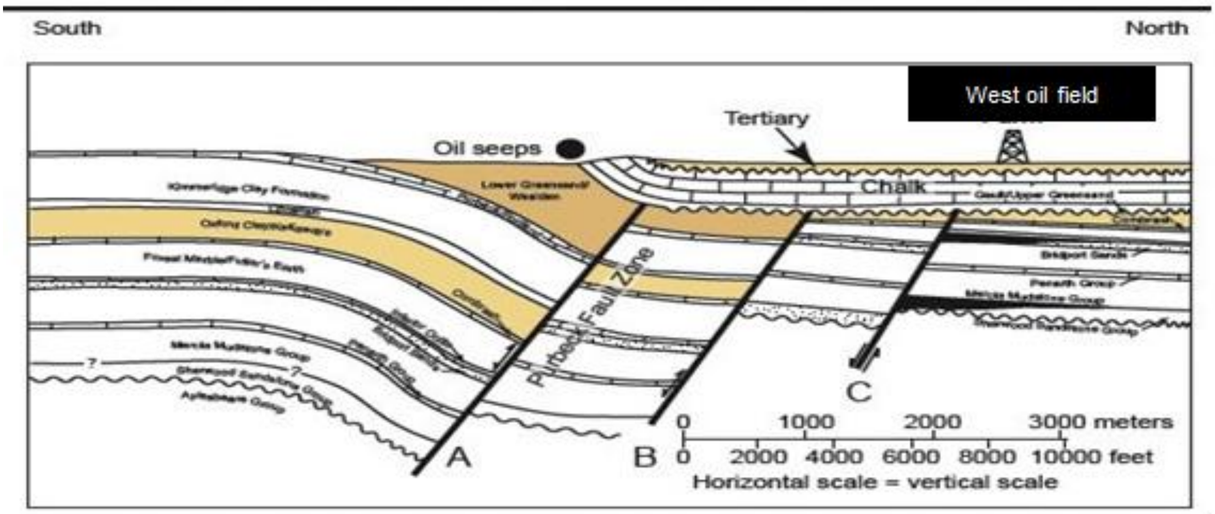

Figure 3: Structural deformities showing reservoir and seal pair

2. DEPTH CONVERSION METHODOLOGY

Depth Conversion is the process of taking time data derived from the seismic method and scaling it to depth.[4] The scale factor is the velocity of propagation of seismic energy through the earth, governed by the fundamental equation.

$$Z = V \times T \quad \text{----------------------------------- (1)}$$

Where
Z= depth (m)
V =velocity of propagating wave (m/s)
T= one way time (i.e. ½ two way time (s))

The success in predicting depths depends on: seismic interpretation, particularly in horizon and faults picking. The seismic line in Figure 4 shows the horizons picked to enable structural evaluation of the West oil field prospect.

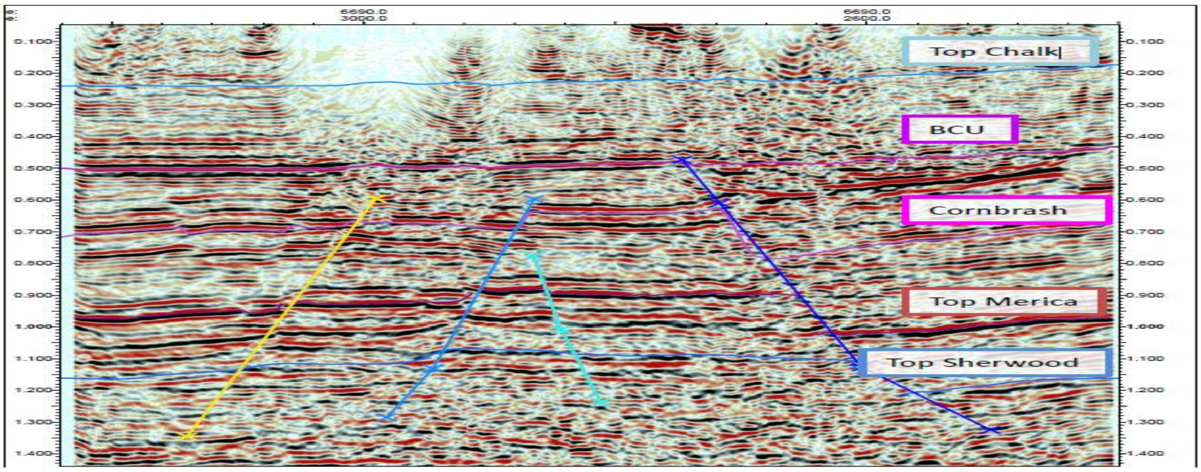

Figure 4: Inline 6690, running North-South through the West oil field.

The Top Mercia has a strong continuous reflector whereas the Top Sherwood is a very discontinuous reflector. Tops were picked from the 5 wells in the area. There are large uncertainties associated with picking the Top reservoir; Sherwood sandstone, because of its gradational contact with the over laying Mercia mudstone. It appears on the seismic section as a discontinuous reflector. The Mercia mudstone is laterally extensive and of uniform thickness across the field area and conformable with the younger Sherwood group, so an isopach method was used to image the Top reservoir. The difference in thickness of the Mercia across the reservoir was 30m. This assumption increase uncertainty in the seismic interpretation.

2.1 Velocity Analysis

Generally, velocity increases with depth as illustrated by equation (1). This reasoning has its shortcomings when dealing with complex structural geology like the West oil field. The goal here is to combine well data with seismic and geological understanding to constrain velocity models (i.e. predict velocity and hence depth between wells).
From checkshots it was observed that on-shore wells depicted scattered but similar velocity trends since they contain similar geology across the area. However, the A-4 well showed very disruptive anomalies in velocity trend because of its deviated nature and so has been ignored in velocity modelling.
For well A-3, the plot in Figure 5(b) shows True vertical depth (TVDss) against time. Compare this to Figure 5(a) which shows a plot of depth against velocity where velocity variations occur. Scattered velocity trend at different depths down the layers explains the difficulty in data acquisition on land. The plots for the off-shore well A-5 (Figure 6) shows a better velocity trend with uplift around the chalk and Cornbrash layer. This smoother velocity trend accounts for why checkshots data acquisition is better onshore

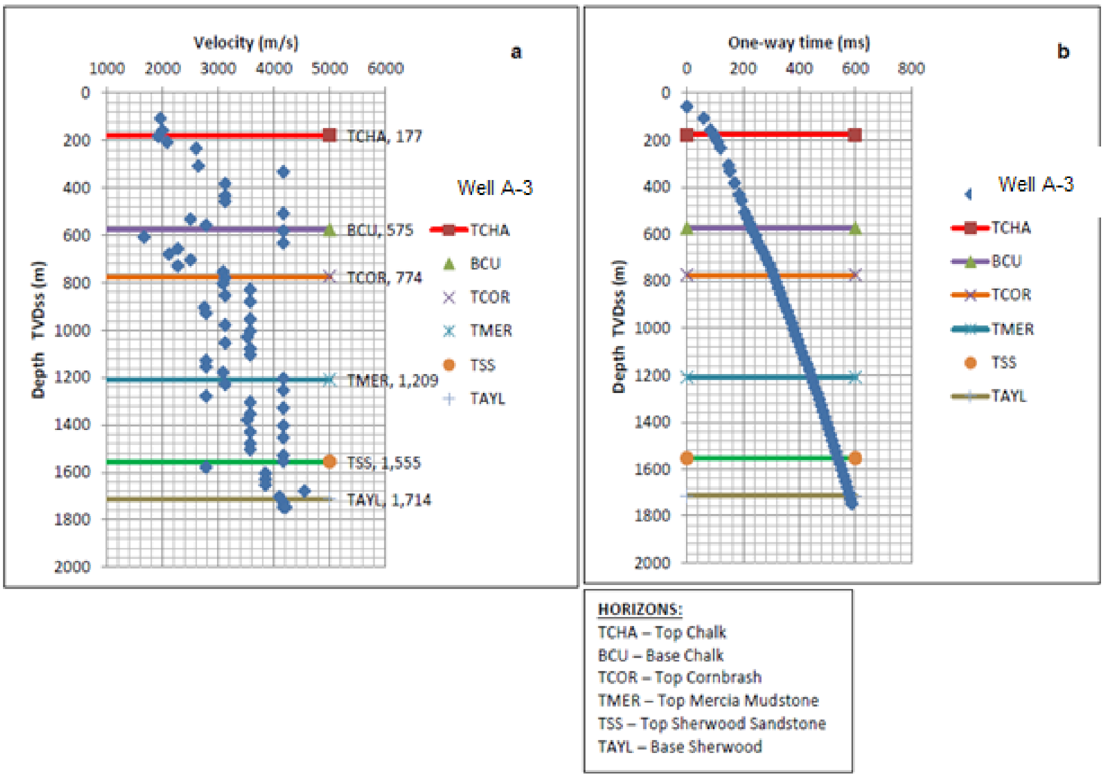

Figure 5 (a) TVDss vs Velocity (b) TVDss vs. time.

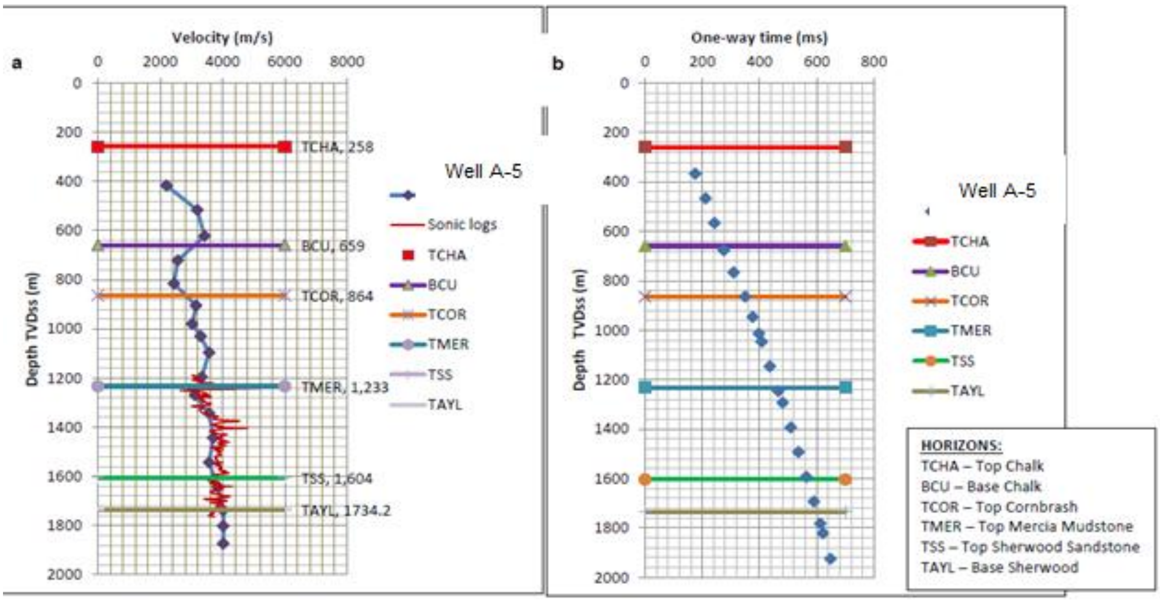

Figure 6 (a) TVDss vs Velocity (b) TVDss vs. time.

2.2 Velocity Modelling

The aim is to predict new velocity (and hence depth) values at another location based on values at known points (spatially and in depth). The layer-cake approach reflects the influence of structure on control of velocity. [5] This model is most suitable as it accounts for vertically variable velocity and spatially variable thickness as shown in Figure 7.

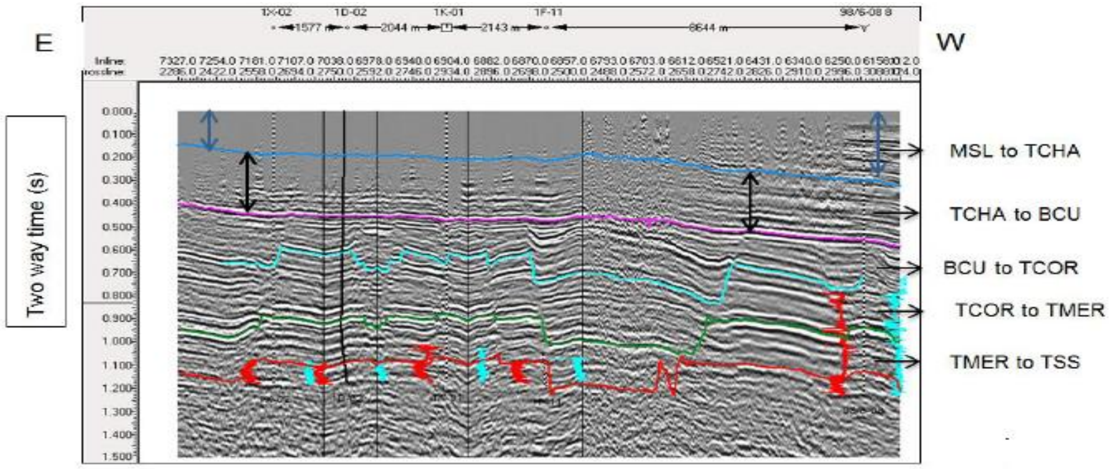

Figure 7: Seismogram showing spatially variable thickness

Depending on the velocity characteristics of the layers, two velocity models have been applied in the time to depth conversion:

(i) the constant interval velocity

$$V_{INT} = \frac{Isopach}{Isochron} = \frac{depth\ thickness}{time\ thickness} = constant\ ---------- (2)$$

(ii) the linear velocity

$$V_i = f(Z) = V_{oi} + k_i Z_{mid} \text{ ----------------------- (3)}$$

A justification of this velocity approach is that the constant velocity model accounts for layer thickening and thinning, while the linear velocity (V_0, *k*) approach gives a rigorous description of V_i increasing with depth. [6-7]. the latter is valid since the following assumptions holds for the chosen intervals:

a. Checkshots show a consistent gradient

b. This gradient reflects the compaction trend as compared to typical values see Figure 9

Equation (3) is analogous to the linear equation *y=mx+c*. Hence V_i is the predicted velocity of a given interval i, V_o is the intercept, k is the gradient and Z_{mid} is the mid-point depth of that particular interval; as illustrated in Figure 8.

$$Z_{mid} = \frac{Top\ layer\ depth + Bottom\ layer\ depth}{2}$$

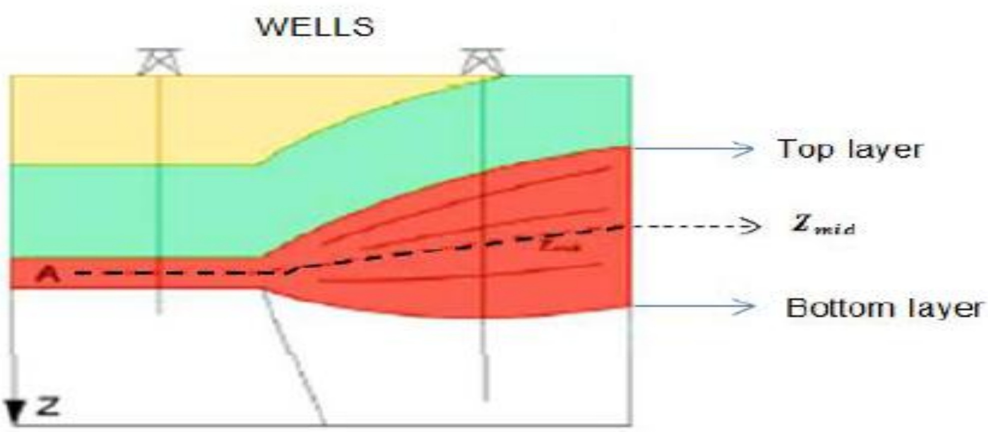

Figure 8: Concept of Mid-depth

3. RESULTS AND DISCUSSIONS

The linear velocity model requires a plot of interval velocities against the mid-point depth across each well between the different layers. The velocity values used for depth conversion are shown in Figure 9. For constant velocity model, the chosen V_{int} is the calculated mean of interval velocities across each well for a given interval.

INTERVAL	VELOCITY MODELS				
	Constant Velocity		Linear Velocity		
	Mean of V_{int} (m/s)		k	Typical compaction values	Predicted V_{int} (m/s)
MSL to Top Chalk	1819				
Top Chalk to Base Chalk			1.0764	$1 < k < 2$ (chalk)	2936
Base chalk to Top Cornbrash			0.4791	$k \leq 1$ (clastics)	2553
Top Cornbrash to Top Mercia	3253				
Top Mercia to Top Sherwood	3631				

Figure 9: Calculated Velocities for Time to Depth Conversion.

3.1 Creating Depth Isopach Maps (Calibrating to wells)

An initial isopach depth map for the top Sherwood is shown in Figure 10. Figure 11 indicates that the errors between well depths and formation tops for the reservoir were found in the range -4 to 49, which suggested the need to tie the depth surface to the well control using a residual grid. This is done by calculating the residual difference between the depth surface and the formation tops and applying the differences in order to tie the depth surface to the well control. Adding the residual grid depth surface (Figure 12) to the initial reservoir depth (Figure 10) map to create a final depth structural map (Figure 13)

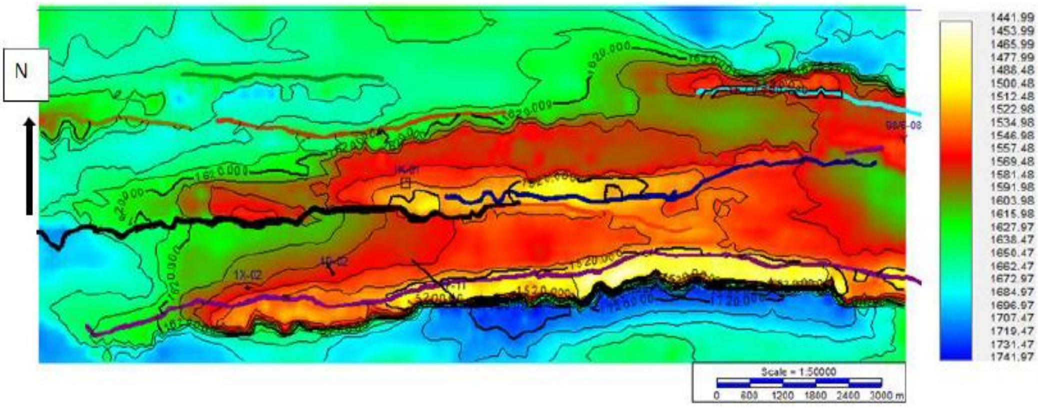

Figure 10: Initial reservoir depth map (contour interval= 20 m)

WELLS	Top Sherwood depth TVDss (m) comparison		
	Formation tops TVDss (m)	Isopach depth at wells TVDss (m)	Error in TVDss (m)
A-1	1570	1574	-4
A-2	1546	1577	-31
A-4	1565	1516	49
A-3	1554	1545	11
A-5	1584	1562	22

Figure 11: Errors (Residual) between well control and depths at wells of initial structural map.

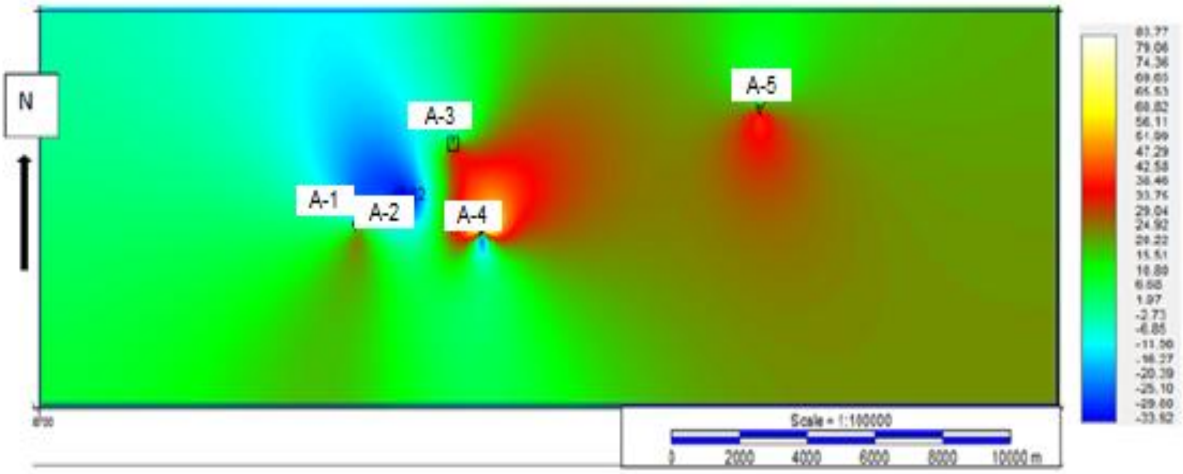

Figure 12: Residual Grid map

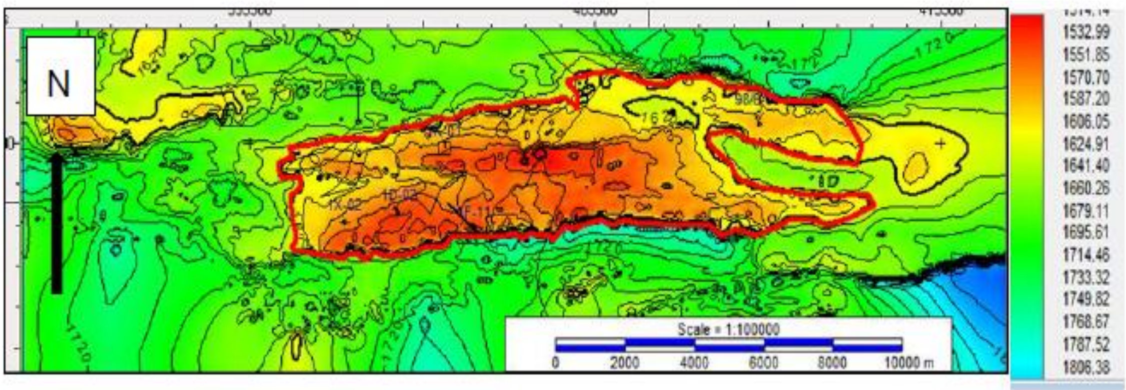

Figure 13: Structural Depth Map used for Reservoir Modelling (Contour interval = 20 m). Estimated GRV at 1622 m OWC $=1.893 \times 10^9$ m^3

To check for errors in the final depth map for the reservoir, Figure 14 compares the depth values at wells to formation tops (well control points).

WELLS	Top Sherwood depth TVDss (m) comparison		
	Formation tops TVDss (m)	Velocity analysis model (5 layers)	Error: Column (2 – 3)
A-1	1572	1572.11	-0.11
A-2	1546	1546.56	-0.56
A-4	1565	1563.43	1.57
A-3	1554	1552.93	1.07
A-5	1584	1584.64	0.64

Figure 14: Depth conversion values at wells compared to known well control points (formation tops).

The errors in the reservoir interval have been drastically reduced with the biggest contribution to error at the deviated A-4 well. The uncertainty in depth (Figure 15) can therefore be calculated.

$$uncertainity\ in\ depth\ (m) = (v_{max} - v_{min}) \times (t_{max} - t_{min}) - - - - - (4)$$

For a given interval layer where:

V_{max}=maximum interval velocity and t_{max} is the corresponding maximum one-way-time (s)
V_{min}=minimum interval velocity and t_{min} is the corresponding minimum one-way-time (s)

LAYERS	Interval Velocity (m/s)		One-way time (s)		Uncertainty in depth (m)
	V_{min}	V_{max}	t_{min}	t_{max}	
MSL to Top Chalk	1743	1839	0	0.148	$\pm$14
Top Chalk to Base Chalk	2882	3004	0.224	0.281	$\pm$7
Base Chalk to Top Cornbrash	2519	2594	0.305	0.361	$\pm$4
Top Cornbrash to Top Mercia	3215	3294	0.443	0.473	$\pm$2.4
Top Mercia to Top Sherwood	3360	3988	0.537	0.566	$\pm$18

Figure 15: Uncertainty calculation in depth conversion

4. CONCLUSION

This uncertainty in depth conversion is greatest in the top Sherwood because of large errors in horizon picking due to the gradational contact with the over laying Mercia mudstone, it appears on the seismic as a discontinuous reflector and quality of checkshots data. In conclusion, the methodology applied for depth conversion produced satisfactory results. The aim has been achieved, which is to minimise the uncertainty and predict successfully the depths away from well control.

5. ACKNOWLEGMENTS

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6. REFERENCES

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