Implications of Neogene structural development on hydrocarbon prospectivity of the Tui-Maui area, offshore Taranaki, New Zealand

E R Matthews

Exploration Manager, New Zealand Oil & Gas Limited, 3rd Floor, Compaq House, 76 Berry Street, North Sydney 2060, Australia. Telephone 0061-2- 9925 8220, Email ericm@nzog.net

Abstract

Coastal sand bodies within the Palaeocene-Eocene Kapuni Group are a prime target for exploration in Taranaki. At Tui, stacked barrier island sand bodies within the Kapuni 'D' interval are present within a 4-way dip closure extending over some 50 km^2.

In order to understand the charge history of the Tui-Maui area, the structural development has been investigated. Four phases of deformation have been identified:

1) Early Miocene drape, modified by slight relaxation of Eocene extensional faulting

2) Mid-Late Miocene compression and eversion along normal faults

3) Late Pliocene flexing and uplift

4) Late Pliocene-Recent trans-tensional faulting

The main phase of hydrocarbon expulsion and migration, from the kitchen areas adjoining the Tui-Maui area, was in the Late Miocene-Early Pliocene. At this time, the D Sands in Tui and Maui A formed a large closure with two culminations. It appears that there was an extensive oil pool within this closure, which partly re-migrated southwards into the combined Maui A/Maui B closure that formed as a result of tilting and uplift over Maui in the Late Pliocene to Pleistocene. Since then, most of this large accumulation (more than a billion barrels of recoverable oil) was lost through breaching by active faulting at Maui. A residual oil column of some 150 m remained at Maui B, within which several small stacked accumulations have been exploited by the Maui Joint Venture.

The dip closure at Tui is a remnant of the original much bigger Tui-Maui closure. Unlike Maui, though, Tui was not affected by late faulting, and we do not expect the original oil accumulations here to have been breached. Instead, there may be multiple stacked pools, each having potential for recovery of 100-300 million barrels of oil.

Introduction

As part of the evaluation of the Tui Prospect, depth mapping has been extended over the adjacent Maui Field (Figure 1). In the course of this work it became apparent that the primary cause of lateral velocity variation in this area is late uplift. In the Taranaki Basin, the Miocene and Pliocene section compacts in a regular fashion, to a large degree independent of age or lithology. When a normally compacted sequence is uplifted, the slowest sediments are eroded, and velocities to a given depth are faster where uplift has occurred.

This led us to consider the changes to the structural configuration of the over Tui-Maui area, and their relationship to both live and residual columns known within Maui, particularly within the D Interval. This paper presents Top D Sand reconstructions for Early Miocene and the Early Pliocene and considers the implications for the charge history of the Tui-Maui area.

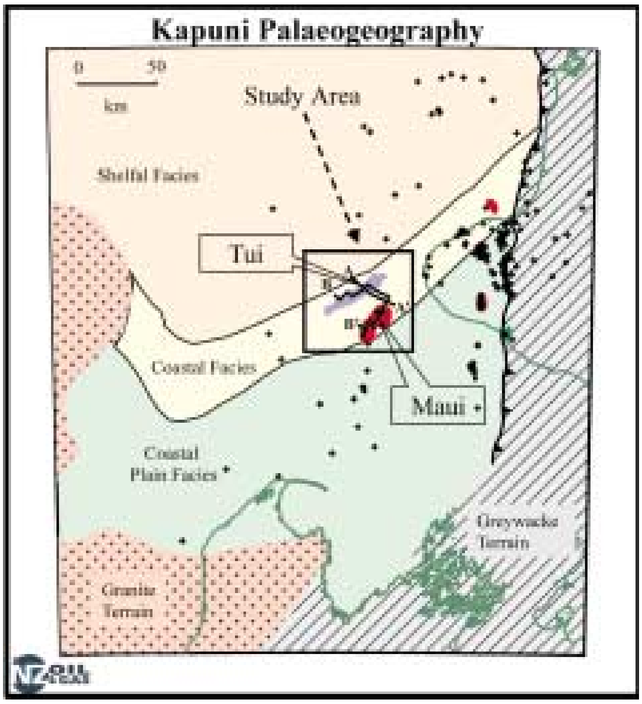

Figure 1: Location Map showing Tui-Maui mapping area.

Oligocene-Early Miocene

During the Oligocene, the Tikorangi Limestone (Figure 2) was deposited in an outer shelf depositional environment over a wide area of the western Taranaki Basin, including the area of interest in this paper. The base of this unit thus provides a good reference surface upon which to datum structural reconstructions, as it was probably close to horizontal at the time of deposition. Figure 3 is a seismic traverse across Tui and Maui that has been flattened on the base of the Tikorangi Limestone. This shows a high area at the termination of the D Sands, with dip to the east across Maui. The time interval map for Base Tikorangi to Top D Sand in Figure 4 shows the form of structure during the Oligocene and into the Early Miocene.

It appears that the Tui area was the focus of D Sand closure at this time, even though the area of shallowest basement was at Maui A. This northwesterly displacement of closure relative to the underlying basement high has been observed in other structures in the Western Platform including Tahuroa, Pukeko, Hector and Hochstetter.

It is postulated that this displacement occurred due to slight relaxation of Eocene normal faulting on the southeast side of the basement high blocks. In addition, at Maui, the Whitiki Fault at this time was downthrown to the east, which would have lowered the Maui B area relative to the Tui area to the west.

Early Pliocene

The Early Pliocene Unconformity over Maui is evident on seismic an angular truncation, and this surface can be traced south to Moki/Maari and over a wide area of the South

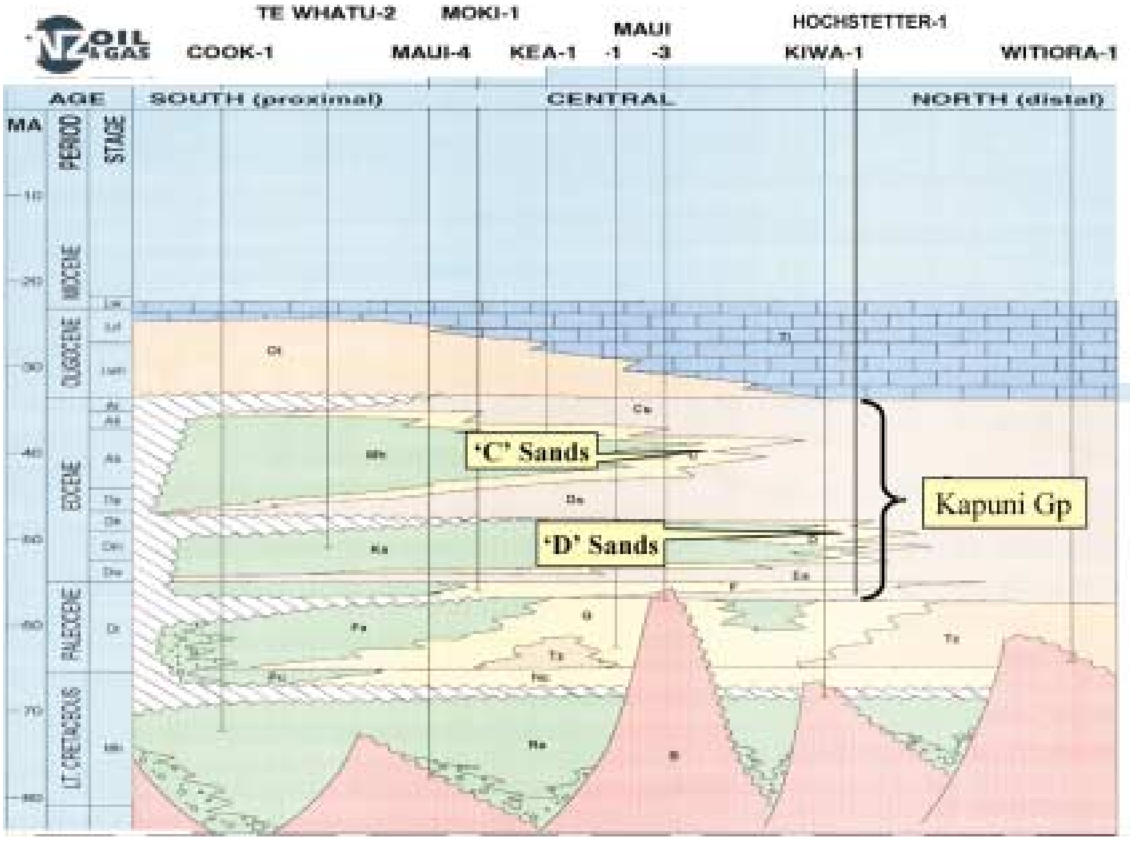

Figure 2: Taranaki Basin stratigraphy.

Taranaki Basin. However at the northern end of Maui, the angular unconformity becomes a conformable offlapping sequence, where no erosion has occurred (Figure 5). This means that reconstructions for this time, over the Tui-Maui area, are necessarily a little more complicated than using isopachs.

We used the following method:

1. Map the angular Early Pliocene Unconformity in time.
2. Derive an average velocity map to this surface from stacking velocities.
3. Calculate the depth of the Early Pliocene Unconformity.
4. By assuming that the deepest point on this depth map has undergone no post Pliocene uplift, calculate the amount of uplift implied by the deformation of the originally horizontal wave-cut unconformity surface (Figure 6).
5. Add the estimated uplift to the present-day depth structure map to create an estimate of D Sand structure in the Early Pliocene. (Figure 7). The seismic traverse in Figure 8 illustrates the nature of the closure.

During the Miocene there was eversion along previously normal faults. This occurred along the Whitiki Fault, creating a south-plunging compressional anticline at Maui B and a broad high over the Maui A area. Due to southward plunge, Maui B was at the limit of closure, but there was a large closure over the combined area of Tui and Maui A.

Present day

The Top D Sand depth map for the present day configuration (Figure 9) was made by the following method:

1. Map Base Tikorangi and Top D Sand horizons in time.
2. Derive a 'Best Estimate' velocity map to Base Tikorangi, using vintage stacking velocities, adjusted for misties and contoured using kriging controlled by Maui wells.
3. Calculate the depth map to Top D Sand assuming 3800 m/sec interval velocity between Base Tikorangi and Top D Sand.

The Present day Top D Sand depth map shows the effect of tilting and uplift at Maui, leaving a remnant dip closure at Tui.

Errors and constraints

Depth Conversion using Stacking Velocities

The Present Day Top D Sand Depth map derived from seismic stacking velocities, ties to the Maui intersections reasonably well. The range of misties is +1 m to +23 m, with an average of +14 m and standard deviation of 9 m.

Uplift Estimates from well data

An alternative method of estimating uplift is to compare sonic logs from individual wells with a reference sonic compaction curve (Figure 10). By inspection of the seismic, the amount of section removed by the Early

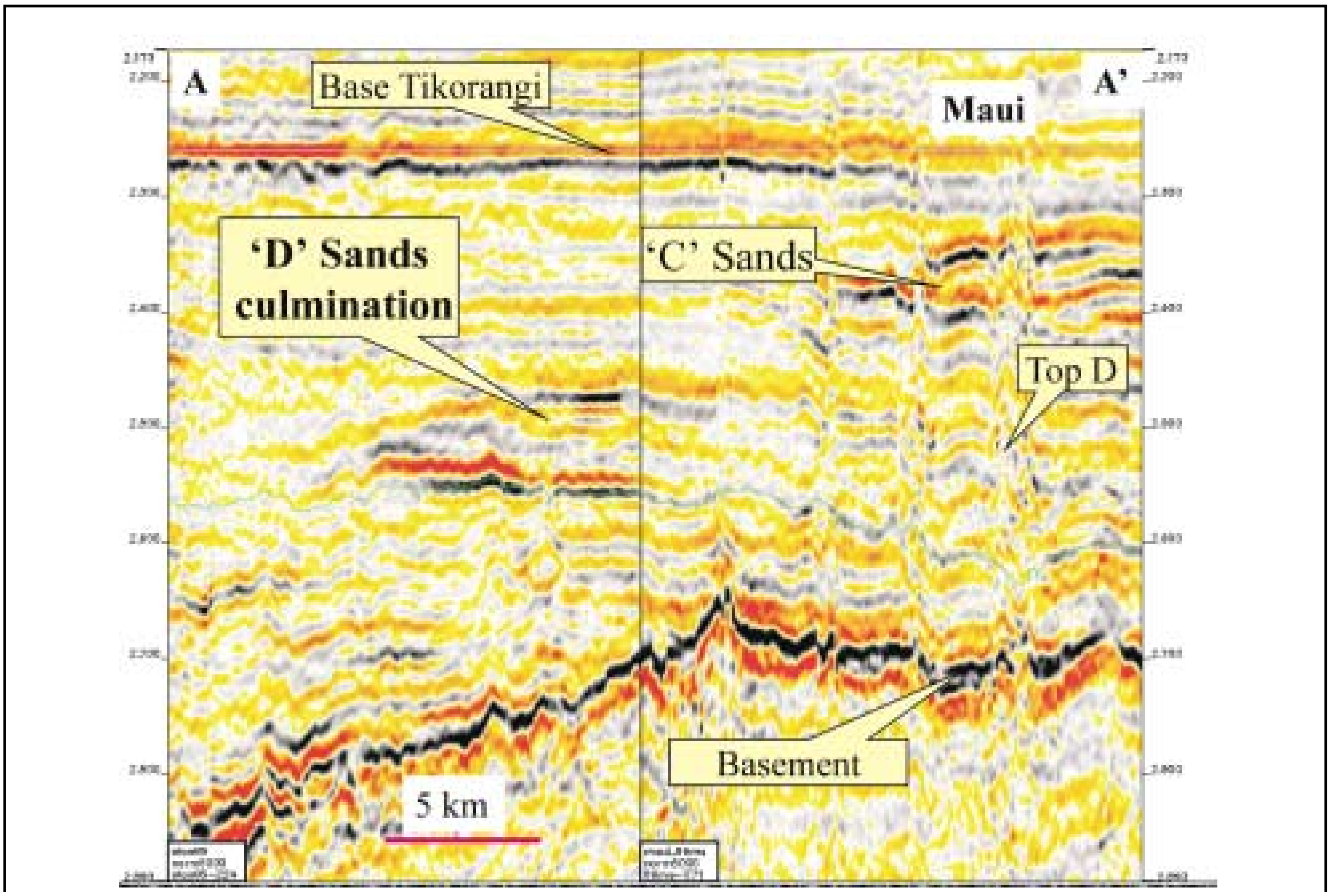

Figure 3: Tui-Maui seismic traverse flattened on Base Tikorangi, showing Palaeogene thinning over Tui.

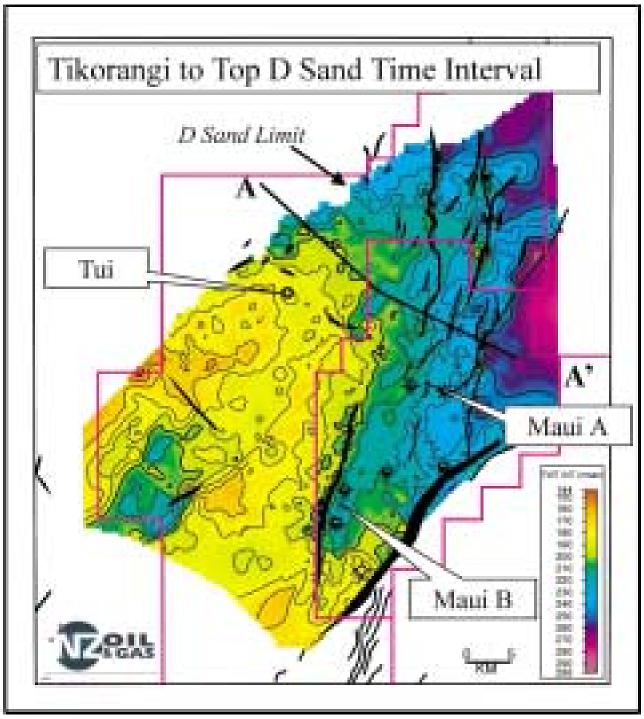

Figure 4: Base Tikorangi to Top D Sand time interval map, showing thinning over Tui.

Pliocene unconformity over Maui is less than the amount of subsequent burial prior to the late uplift. Therefore, it can be assumed that the sonic logs reflect late uplift and not uplift associated with the Miocene eversion. This is supported by the fact that there is no step in the sonic curves at the unconformity.

When estimating uplift by this method three estimates – high, low and preferred – were made. For 33 wells in Taranaki, the average range between high and low estimates is 200 m. Thus the accuracy of this method is indicatively ± 100 m.

When the uplift estimates derived from six available wells over Maui are compared with those derived from deformation of the Early Pliocene Unconformity surface, the range of differences is +75 to –70 m, and the average is –44 m. It is considered that well-derived uplift estimates validate the assumptions inherent in the seismically-derived unconformity method.

Within the study area, the maximum uplift derived from the Early Pliocene Unconformity map is 450 m at the southern end of Maui.

Depth Conversion using PSDM

The Top D Sand depth map derived from stacking velocities reveals a closure of 30 km^2 and 15 m relief at Tui. However, given the accuracy of the map, as indicated by the well misties, the extent of the closure remained uncertain.

In order to address this, the grid of lines over the Tui dip closure were reprocessed to improve the quality of the gathers (in particular to remove multiples) and pre-stack depth migrated. This confirmed a closure at Top D Sand extending over 48 km^2 with 35 m relief. (Figure 11).

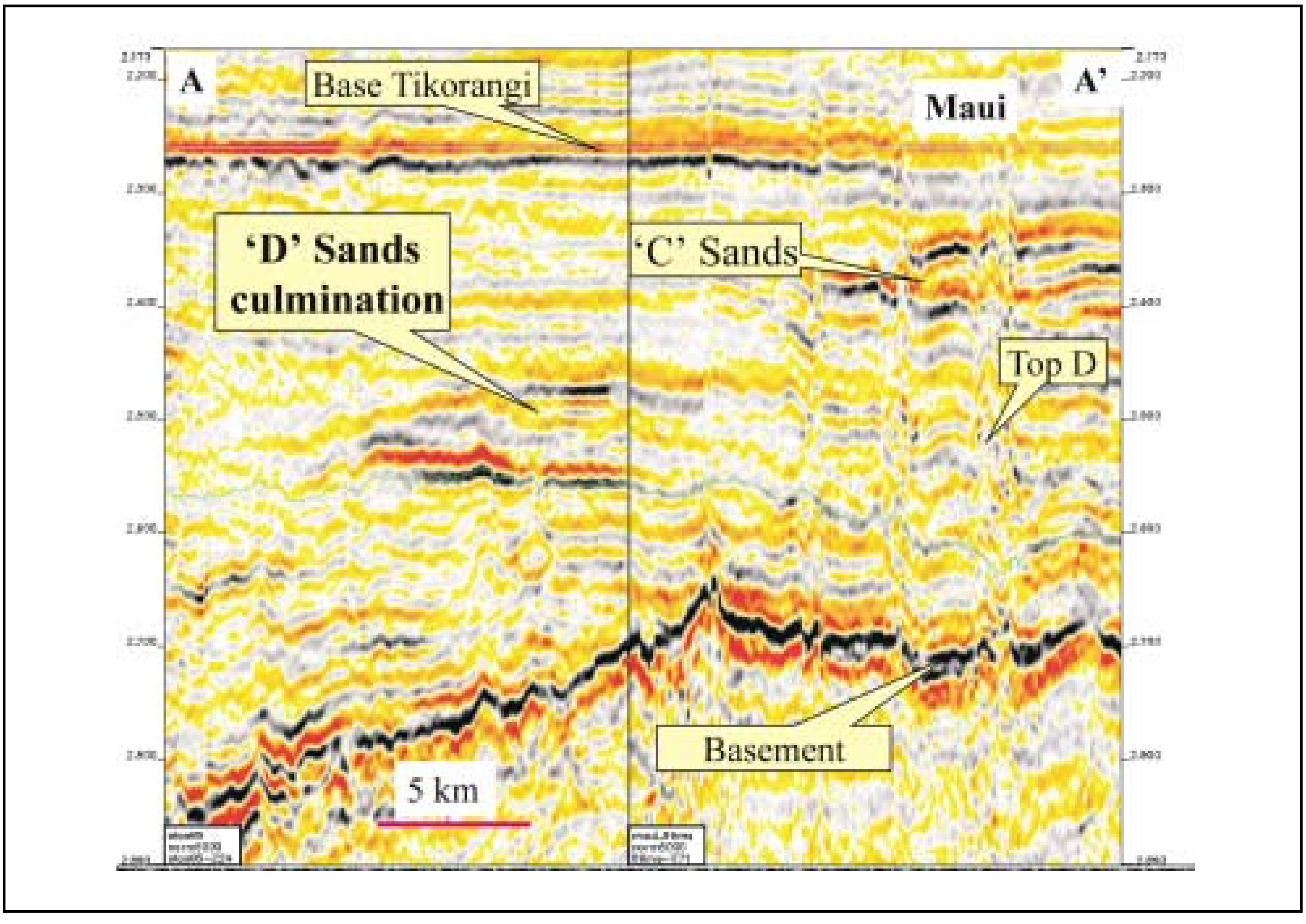

Figure 5: Seismic traverse over Tui-Maui showing extent of oil pool implied by residual column in Maui B.

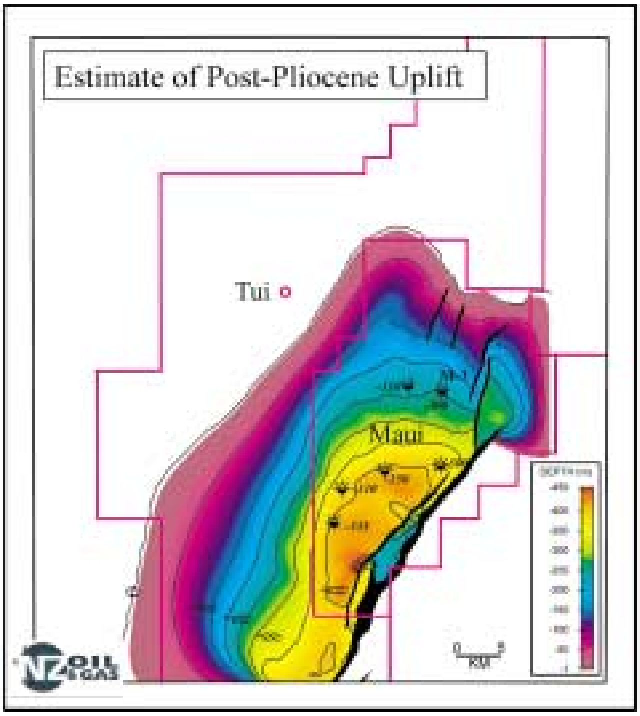

Figure 6: Estimate of Post-Pliocene uplift map.

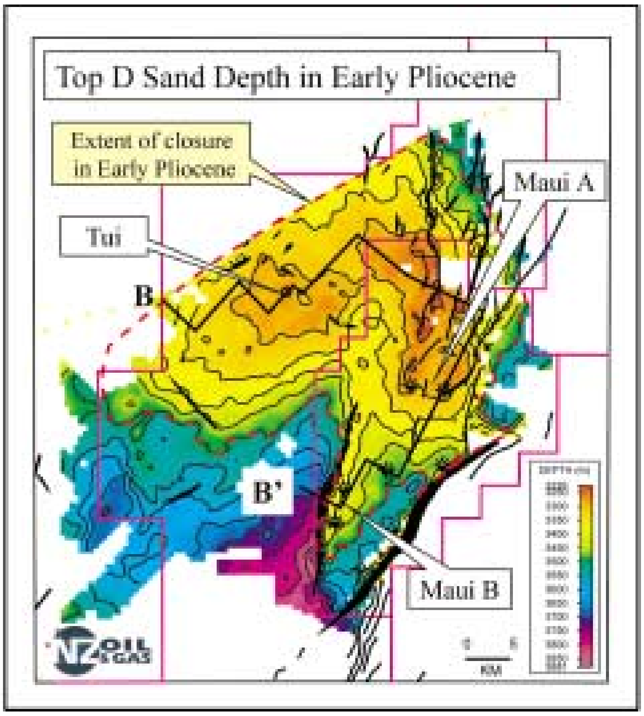

Figure 7: Top D Sand reconstruction at Early Pliocene time, showing combined Tui-Maui A closure.

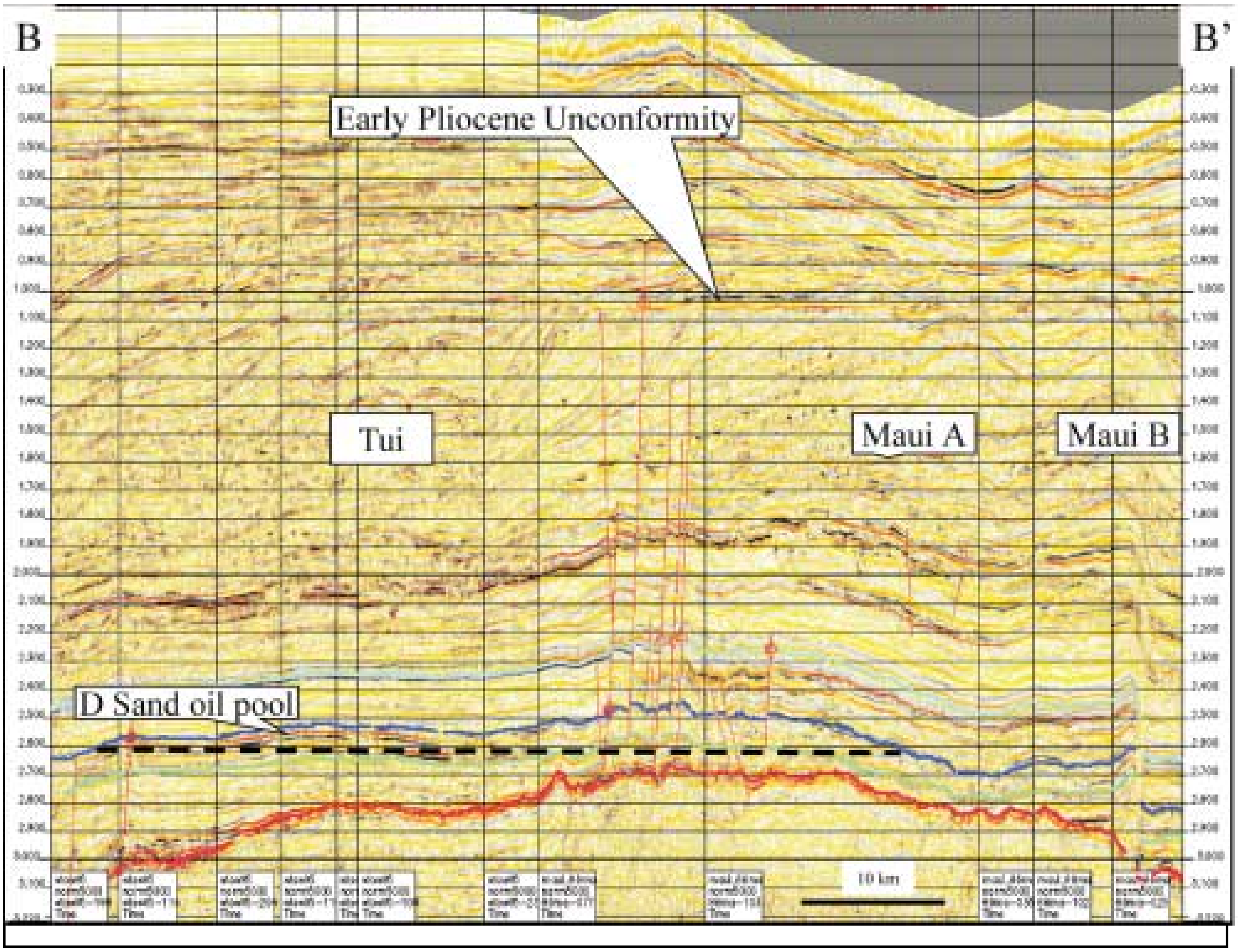

Figure 8: Seismic traverse over Tui-Maui flattened on Early Pliocene unconformity, showing the extent of inferred Early Pliocene oil pool.

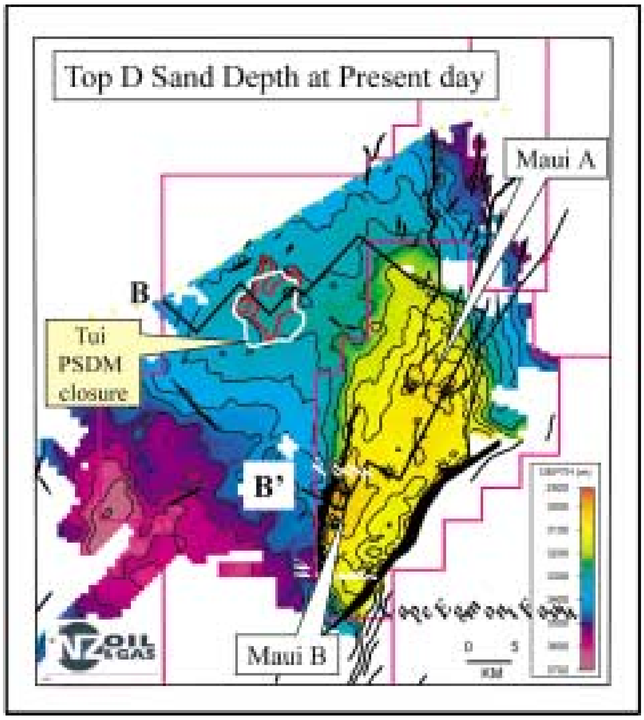

Figure 9: Top D Sand structure at Present, showing outline of dip closure at Tui.

Sensitivity tests were carried out to determine the resolution inherent in the data. Model velocities were changed by the amount needed to remove closure. This caused individual gathers to become clearly non-flat. The consulting group Oil Hunters, who conducted the study on behalf of the Joint Venture, considered that based on this work, relative accuracy for this data set at target depths was around ±10 m. This confirmed the validity of the Tui Top D Sand closure.

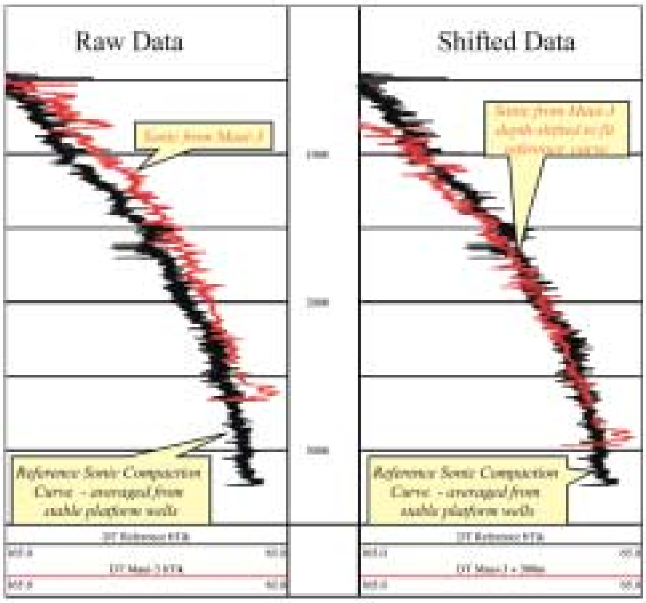

Figure 10: Reference sonic compaction curve compared with Maui-3, illustrating method of estimating uplift from well data.

Charge history

Fluid inclusions indicate that there has been an extensive oil accumulation in the D Sands at Maui A and at Maui B (Funnell et al, 2001). Cohen et al (1996) postulate that the complete D Sand section at Maui B may once have been substantially filled with oil, most of which has escaped. The D Sand interval is about 200 m thick, and allowing for some 50 m of gas which is present today, this would imply that an oil column of some 150 m was present. This oil column would have been continuous across to Maui A, over an area of about 500 km^2 and would have contained several billion barrels of recoverable oil. Maturity modelling of source rocks in the two sub basins east of Maui (Funnell et al, 2001) indicate that over 150 billion barrels of oil has been expelled. The generative potential is therefore adequate to create an oil accumulation of this size (Figure12).

This modelling work also shows that the main phase of hydrocarbon expulsion began about 10 m.y. BP in the Late Miocene (Funnell 2001). The structural configuration at this time would have approximated the pre-tilt structure at Early Pliocene, and the combined closure over Tui and Maui A would have been in place to receive charge. We postulate that there was a large oil accumulation over this area at this time.

This is supported by seismic amplitude mapping of the D interval (Figure13). This map reveals the three gross facies belts in the D interval – seismically bland marine shales to the north, high reflectivity associated with coals and fluvial sands in the south, and intermediate reflectivity associated with coastal sands. There is also higher amplitude associated with hydrocarbons in the Maui Field, and over the Tui area. It is postulated that this amplitude relates to hydrocarbon saturation.

Modelling studies (Matthews et al, 2001) show that oil and gas cannot be discriminated using seismic amplitude due to the gassy nature of the oil. However, there would have been remigration of this accumulation when the late tilting (in the last million years or so) affected Maui and brought Maui B up into closure. It is therefore considered likely that the original Late Miocene/Early Pliocene accumulation was oil rather than gas. It should be noted that migration pathways from the east into the Tui area have since been disrupted or cut off by the uplift of Maui and by late faulting east of Tui, which would probably prevent late gas charge from reaching Tui from this direction.

For these reasons, Tui is viewed as an oil prospect, with the dip closure a remnant of a much bigger oil accumulation. The dip closure at Tui has not been uplifted or affected by late faulting, so may reasonably be expected to be intact, in contrast to the widespread breaching evident at Maui.

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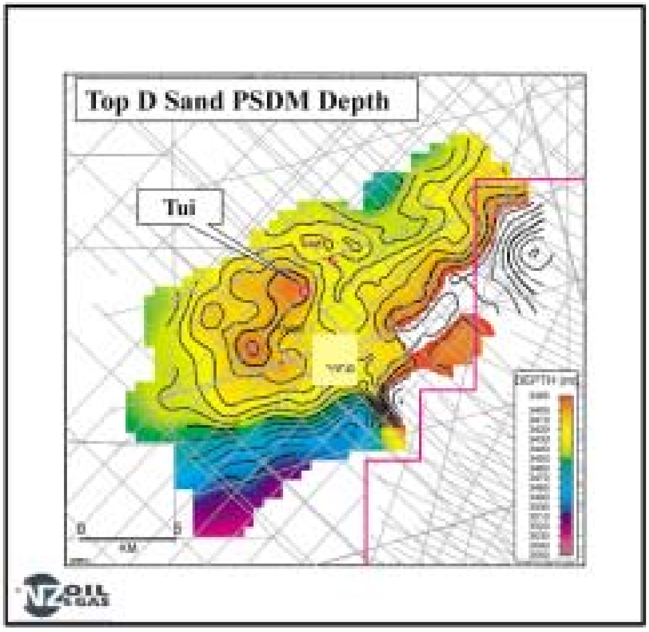

Figure 11: Top D Sand depth map from PSDM showing Tui dip closure.

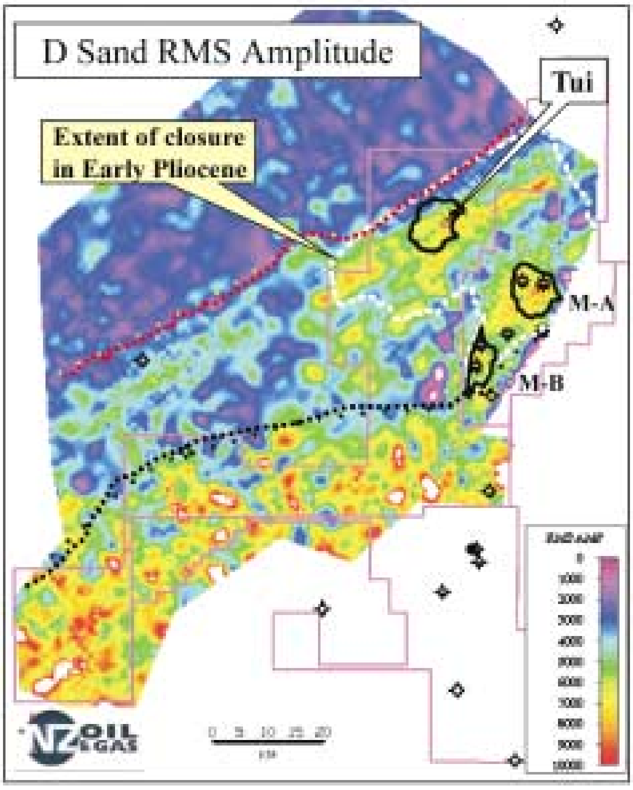

Figure 13: RMS Amplitude for a window from 10 msec above to 40 msec below the top D Sand seismic horizon. Anomalous amplitude over Tui and Maui lies substantially within the extent of closure in the Early Pliocene

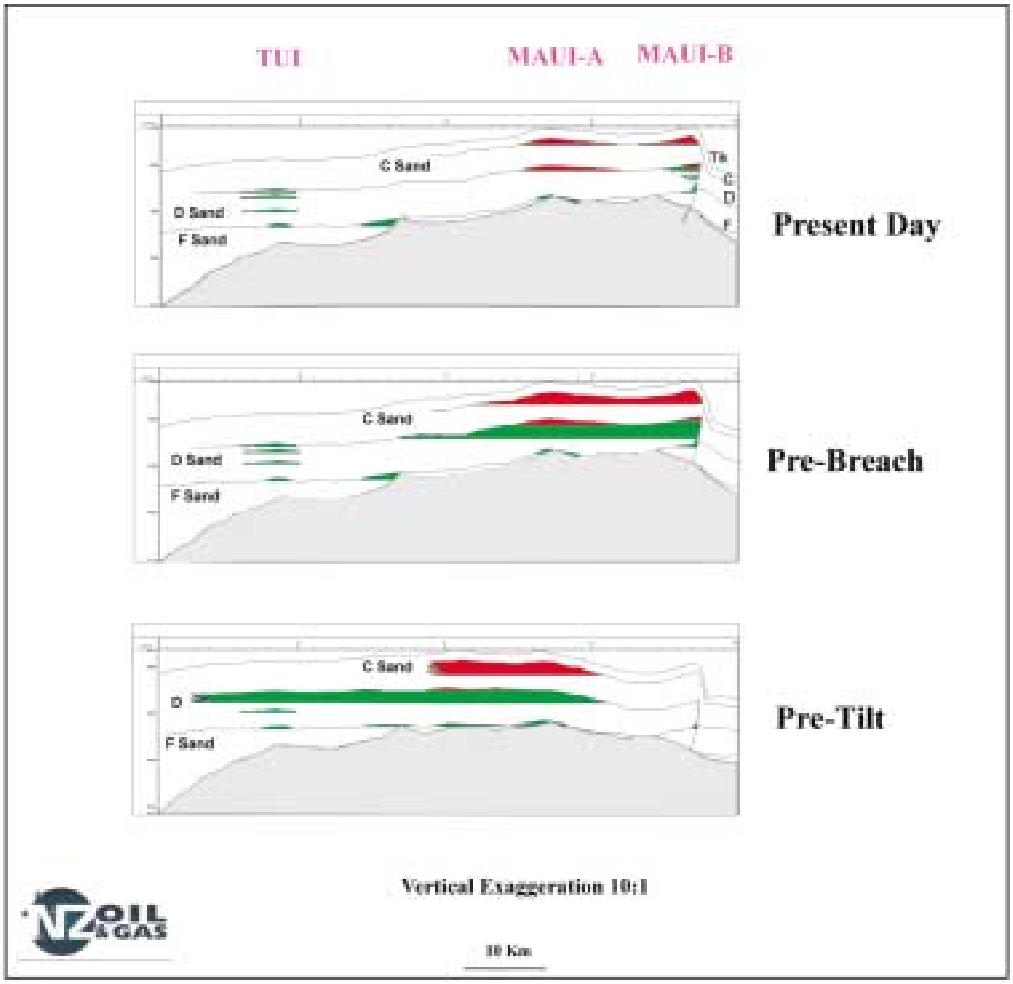

Figure 12: Charge history into Tui and Maui montage.

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Conclusions

1) The structural reconstructions presented here show that Tui was the early locus of closure over the Maui-Tui area.
2) Miocene compression then created a combined closure over Tui and Maui A which was charged with primarily oil in the late Miocene to Early Pliocene.
3) Late tilting caused remigration of some of this oil into a large pool extending over a combined Maui A and Maui B closure.
4) Most of this oil has been lost by breaching associated with active faulting at Maui, but oil remaining in the Tui dip closure has not been disturbed and presents an attractive target for exploration drilling.

Acknowledgments

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Author

ERIC R MATTHEWS PHD, MSC, BSC Dr Matthews has extensive experience in oil exploration in Australasia working primarily in the Taranaki and Carnarvon Basins over the last 20 years. He is currently Exploration Manager for New Zealand Oil and Gas Ltd, based in Sydney.