

Petroleum generation and implications for migration: a Maui Field charge study, Taranaki Basin

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Abstract

As production from the Maui gas/condensate field in the Taranaki Basin is in decline, some questions still exist about its complex petroleum system. While this field has dominated New Zealand's petroleum production figures for the last 25 years, the history of generation, migration and charge is poorly understood. This paper presents the results of a number of GNS studies into petroleum generation and possible charge scenarios for the Maui Field, and provides information on the petroleum systems that operate in the west and southwest of the Taranaki Basin.

Multi-1D or pseudo-3D models when combined with a map-based analysis reconstruct the distribution and timing of hydrocarbon generation and primary expulsion from Late Cretaceous coals, responsible for sourcing the Maui Field. Fluid inclusion data record a complex fill and column height history for the Maui area. The oils can be identified by their high pristane:phytane ratios, abundant hopanes and land-plant-derived triterpane distributions as being sourced from Late Cretaceous coals. The latest structural re-interpretation of the timing and movement on key fault segments is combined with volumetric assessment of hydrocarbon kitchens to predict the hydrocarbon volumes likely to be accessed by Maui through time.

Significant factors in the charge of the Maui Field include; complex structural development since the Late Miocene, charge from separate hydrocarbon kitchens, migration pathways interrupted by volcanic intrusions and active faulting, and sequential filling of stacked reservoir compartments. We discuss important implications from this work for the continued exploration for oil on the Western Stable Platform, Taranaki Basin.

Introduction

The oil and gas/condensate Maui Field in the Taranaki Basin (Bryant et al, 1994), with total estimated recoverable reserves of 3.68 TCF gas, 184 MMbbl oil and condensate and 3.3 million tonnes LPG is now expected to cease production around 2007 (MED 2003). The combination of the Maui Field's dominant role in gas production and the Maui gas contract has limited past interest by the industry in further gas exploration. Today, however, interest has been rekindled due in part to the impending demise of this major gas supply, but also by a perceived future energy short-fall.

The Maui Field is about four times larger than the next largest discovered field (Pohokura) and papers by Cohen et al. (1996), Matthews (2002) and Funnell et al. (2001) suggest that it may have been a significantly larger oil field in the past (e.g. several billion barrels of recoverable oil). Considering the significance of the Maui Field to New Zealand and the increased level of interest in exploring for similar Paleogene coastal margin plays in the offshore region, surprisingly little has been published on the overall Maui

petroleum system, or more specifically on petroleum migration and charge of the Maui Field.

A number of possible charge scenarios were suggested by Thrasher (1990), including charge of oil and gas from the Maui sub-basin in the east across the Cape Egmont Fault (CEF) (Figure 1). This scenario involves early oil charge across the CEF during Middle and Late Miocene contractional deformation followed by a later gas charge during re-activated normal movement on the fault. An alternative hypothesis was proposed by Haskell (1991) who argued that the Maui accumulations are dynamic and ongoing with southerly migration of hydrocarbons from the Northern Graben and spillage of oil from the A-area into the B-area (Figure 1), with migration based on present structural trends.

Funnell et al. (2001) presented initial results of a migration review around the Maui Field, including some fluid inclusion data. They indicated the existence of mature kitchen areas



Figure 1. a) Location diagram for Maui Field showing exploration and appraisal wells, development platforms, C-sand hydrocarbon-water contact, seismic lines used in re-interpretation and intersection of fault traces on the 3.7 Ma seismic interpreted horizon. b) Location of kitchen areas with respect to the Maui Field and likely migration pathways.

in the sub-basins surrounding the Maui Field and presented the case for charge from each of these sub-basins. In this paper we present the results of further structural interpretations and migration modelling to provide an update on the GNS Maui Field charge study.

Geology of the Maui Field

The Maui Field lies within a 3km thick Paleocene to Recent sedimentary succession overlying a fault-bounded basement horst of Median Tectonic Zone plutonic rocks (Mortimer et al. 1997). Structurally, the field consists of two broad

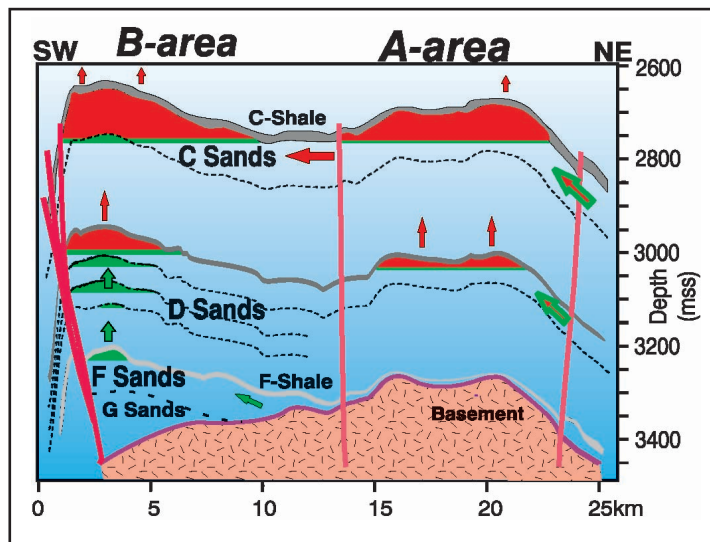


Figure 2. Cross-section through the Maui Field showing the distribution of hydrocarbon accumulations. Arrows indicate latest pre-production redistribution of oil (green) and gas (red). Position of cross-section shown in Figure 1a. (after Seybold et al. 1996)

anticlinal closures, bounded by normal faults to the southeast and a reverse fault to the southwest. Petroleum reservoirs consist of Paleocene to Miocene, stacked marginal marine-terrestrial and deep-water sandstones, usually subdivided into the F, D, C (Figure 2) and B sands. The entire succession represents deposition across a long-lived coastal plain and shoreline that shifted in response to sea level changes, superimposed upon regional passive margin tectonic subsidence (King & Thrasher 1996).

The Middle Miocene B sands (Moki Formation) consist of base of slope turbidite and basal floor sands. The Middle-Late Eocene C sands (Maui Formation or coastal facies of the Mangaheva Formation) comprise coastal plain, sandstones and lagoonal mudstones in the lower intervals, and shoreface and tidal channel sands and inner shelf shales in the upper intervals (Bryant et al. 1994). Seals are provided by intra-formational siltstones and shales, and the regionally transgressive overlying Turi Formation shale. The Early Eocene D sands (Kaimiro Formation) were deposited in a fluvial-estuarine environment (King & Thrasher 1996) consisting of stacked fining-upwards sequences of interbedded sands with thin coal-shale intervals acting as extensive intra-formation seals (Bryant et al. 1994). In contrast to the complex D sand architecture, the relatively simple layered Paleocene F sands (Farewell Formation) were deposited in paralic and near shore environments.

Petroleum reserves mostly consist of gas, with thin oil rims within the upper C sands in the Maui A-area, and more significant oil rims in both C and D sands in the Maui B-area. While the B sands contain oil, the level of saturation is low and oil is assumed to be either residual column or related to migration pathways. Generally the Maui B-area reservoirs contain a greater liquid component than the Maui A-area with oil produced from F, D and C sands in the Maui B-area (Seybold et al. 1996). The F sands and the lower D sands in the B-area contain under-saturated oils. The gas:oil ratios (GOR) in these intervals are significantly (100's scf/bbl) lower

than the GOR of the oils legs in the upper D and C sands, indicating that they have not exsolved and lost gas caps, but represent early expulsion products.

Similar to other oils in the south Taranaki Basin, the biomarker distributions in Maui oils are dominated by the gymnosperm-derived diterpane isopimarane and exhibit high pristane: phytane ratios, relatively low levels of cheilanthanes, abundant hopanes and higher-plant-derived terpanes, and relatively depleted steranes dominated by the C29 members (Killops et al. 1994). On this basis it appears that the oils from the Maui Field (Maui-1 and Maui-3 D sands, and Maui B-1 F sand) are related to Maui-4 and Moki-1 oils, suggesting a similar Late Cretaceous coaly source and, possibly kitchen, for all three fields (Killops et al. 1994). Compositional and isotopic data for gases from the Maui Field have been reported by Lyon et al. (1996), and Hulston et al. (2001).

The structural development of the Maui Field appears to have begun in response to convergent margin tectonics in the Late Miocene (King & Thrasher 1996).

Contraction and reverse movement of the Whitiki Fault (west of Maui) and the Cape Egmont Fault (CEF in Figure 1) resulted in the development of a broad anticline over, and to the east of, the Maui Field. In the Pliocene, the region became extensional and normal movement of the CEF enhanced the structural elevation of the Maui closure.

The Cape Egmont Fault

The geometry and movement on the Cape Egmont Fault (CEF) has been determined by re-interpreting 36 good quality multi-channel seismic lines over a region of the CEF, 80km long and up to 35km wide (Figure 1). Five Plio-Pleistocene horizons (1.6, 2.6, 3.2, 3.7 and 5.0 Ma), a mid Miocene, base Miocene, top C and D sands (reservoir units), base Paleocene and top basement were tied to the Maui-2, Maui-4, Kiwa-1, Te Kiri-1 and Tane-1 wells, with age determinations from biostratigraphy documented in unpublished well completion reports using modifications from M.Crundwell (pers comm., 2000), and velocity-depth functions from the Maui-2 and Maui-4 wells.

The CEF has been subjected to two phases of extension, during the late Cretaceous (ca. 65-80 Ma) and Pliocene-Recent (ca. 0-3.7 Ma), separated by contraction during the late Miocene (ca. 5.5-7.5 Ma). These phases of deformation are indicated by thickness changes of late Cretaceous, late Miocene and Pliocene-Pleistocene strata across the fault. Displacement profiles derived from 36 seismic dip lines crossing the fault also provide along-strike changes in maximum throws on the fault.

Generally, the shortening across the CEF in the Late Miocene (ca. 5.0-7.5 Ma) produced a hanging-wall high which was partially eroded. Little or no accumulation of displacement is indicated for the 5.0 and 3.7 Ma time interval. However, strata deposited during the period 3.7 to 3.2 Ma show substantial increases in the thickness from footwall to hanging-wall, consistent with up to about 1300 m of normal throw accruing

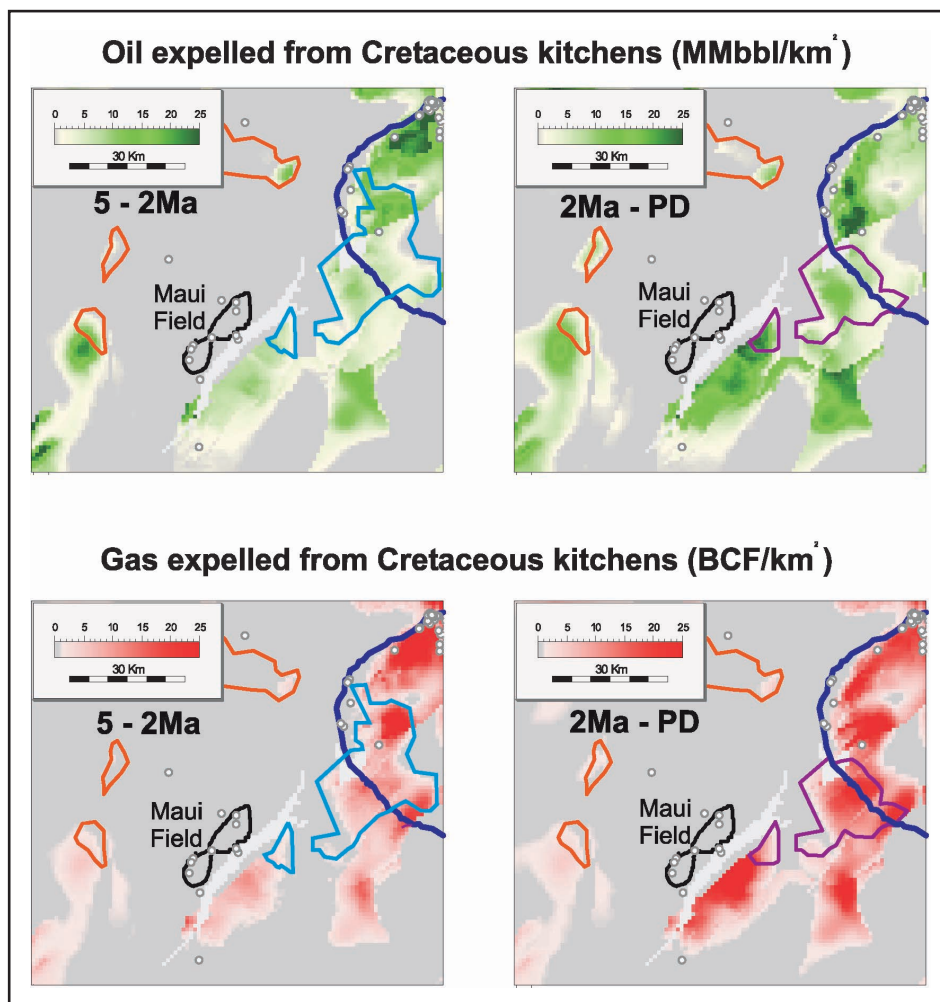


Figure 3. Maps of predicted expelled volumes of oil (MMbbl/km²) and gas (BCF/km²) from Late Cretaceous kitchen areas for two critical time periods. Note that Maui fetch areas are also indicated by polygons; orange for Western Platform fetch on top Cretaceous migration surface, blue for Pliocene fetch areas on Mid-Eocene migration surface and purple for Pleistocene fetch areas on Mid-Eocene migration surface for Pihama and Maui kitchens.

on the fault during this period. Following 3.2 Ma the fault accumulated up to 1000 m of normal displacement, with a maximum of 600 m accruing before 1.6 Ma and up to 85 m after 225 ka (Nodder 1993). Displacement rates therefore varied both in time and along the length of the fault. The footwall high that contains the Maui Field was largely formed since 3.7 Ma in response to normal movement on the CEF fault.

Fluid Inclusions

Fluid inclusions were analysed from C and D sand intervals in A-area (Maui A-1 Maui-3, Maui-2) and B-area wells (Maui B-8, Maui-7). Aqueous fluid inclusion homogenisation temperatures, coeval with oil filled inclusions, are similar to present day formation temperatures suggesting relatively recent charge of Maui. Based on thin section petrography, the following series of events are observed from the fluid inclusions (Funnell et al. 2001):

- initial fracturing of quartz grains and circulation of hot brine with high CO₂
- early oil influx associated with minor quantities of high CO₂ brine

- oil trapped in quartz overgrowths and siderite/calcite cement (Th ~105°C)
- late oil influx and gas-charged brine (Th 100-85°C)

In the A-area, the ratio of oil filled to aqueous inclusions (OFI) is very low in the C and upper D sands but increases to about 10% within the lower D sands of the Maui A-1 well samples. However, in the D sands in the Maui-3 well OFI results of greater than 20% suggest the presence of a paleo-oil column down to 3201mTVSS, but a similar depth range in Maui-2 contained fluid inclusions with very low OFI results. In the B-area, the presence of abundant oil filled inclusions within the water leg of the lower C sands in the Maui-7 well suggests a paleo-oil leg possibly existed in sands 80m below the present-day production zone.

Fluid system modelling

GNS typically utilises various combinations of software tools to predict the generation, expulsion, migration and ultimate entrapment and accumulation of hydrocarbon fluids associated with different petroleum systems. The approach

undertaken in this study was to use the multi-1D petroleum generation software BMID described by Wood et al. (1998) to delineate the hydrocarbon kitchens surrounding the Maui Field, to predict volumes of oil and gas expelled from various source rocks and to model the structure of migration surfaces for specific time periods (Funnell et al. 2001). The map based modelling package Trinity (Zetaware Inc.) was then used to identify migration pathways and determine the fetch areas for the Maui Field associated with each source rock kitchen, or the area of each kitchen that can potentially source the accumulation based on the determined paleo-structure and sand distribution maps. Both the Middle Eocene horizon (representing D sands) and top Cretaceous horizon (representing F sands) are treated as possible migration surfaces in the modelling. The phase and volumes of fluids trapped in, or leaking/spilling from, various accumulations are estimated using the Trinity flash calculator.

Initial input data to the models include regional maps of basin-wide structure, paleogeography, heat flow and geochemical data. BMID accounts for lateral variations in sediment type and time-transgressive formations, significant erosional events in the Late Miocene and in the Late

Pliocene-Pleistocene, and uses GNS-derived properties for the coaly source rocks (Sykes et al. in press, Funnell et al. 2001). Oil and gas generation is based on kinetic parameters using organofacies DE kerogen (Pepper & Corvi 1995a). Oil is assumed to expel from source rocks only after 23% of the potential oil yield has been generated, equivalent to an oil saturation threshold (or maximum S1) of 60 kg/tCorg. The oil and gas kitchen distribution (Figure 1) is primarily influenced by the available mapped Late Cretaceous source-rock distribution (Thrasher 1991, Thrasher et al. 1995). Additional smaller Western Platform kitchens based on the work of McAlpine (1999) using seismic facies analysis of 2D seismic data are also included. Kitchen areas overlain by sand fairways encircle the Maui field (Figures 1 and 3), but numerical modelling suggests that the Maui sub-basin to the southeast, and the Pihama sub-basin further to the east and northeast of the field (Thrasher 1992) are the more significant kitchen areas for Maui charge. Nevertheless, smaller and less mature kitchens on the Western Platform to the west of Maui Field must be considered as potential contributors to late oil charge, as has previously been suggested by a number of authors.

Volumetric estimates of oil and gas expelled from Late Cretaceous kitchens are based on the approach of Funnell et al. (2001) using a hydrogen index (HI) determined from Rock-Eval analysis of ca. 340 kg/tCorg (Sykes et al. in press), TOC of 4-8% depending on depositional environment, gas-oil generation index (GOGI) of 0.34 (King & Thrasher 1996) and an expulsion threshold of 60 kg/tCorg (*sensu* Pepper & Corvi 1995b). Use of these data suggest a potential oil productivity of 0.14 bbl/m³ (174 bbl/acre-ft) and gas productivity of 329 scf/m³ (0.41 MCF/acre-ft) for a 4% TOC source rock.

Calculated volumes of oil and gas able to be accessed by the Maui Field through valid sand fairway-based migration pathways, from the Late Cretaceous Pihama, Maui, Kahurangi and Western Platform kitchens (including Kahurangi) are presented for specific age periods in Table 1. Figure 3 illustrates the oil and gas productive regions of each Late

Cretaceous kitchen for two critical time periods in the recent charge history of the Maui Field. Appropriate Maui fetch areas accessible by valid migration pathways are also indicated in Figure 3.

Kitchens

The closest kitchen to the Maui Field is the easterly Maui sub-basin (Figure 1) requiring migration across or around the CEF. Detailed seismic interpretation indicates that reservoir units (available as migration pathways) may be continuous across the CEF prior to initiation of reverse movement in the Late Miocene (~7.5 Ma); however, later migration of hydrocarbons across the CEF into the Maui reservoirs requires a number of special conditions to be met. Thrasher (1990) speculated that during the Late Miocene and Early Pliocene following reverse displacement on the fault, the juxtaposition of reservoir and source rocks allowed the Maui reservoirs to be charged by cross-fault flow. Construction of Allen diagrams and calculation of shale gouge ratios led Funnell et al. (2001) to conclude that the CEF is likely to have formed a barrier to hydrocarbon flow at the time of juxtaposition of reservoir and source rocks (i.e. ~ 6 - 5Ma). However, because the seismic data used in this study are 2D (average line spacing 2-3 km) we cannot discount the possibility that unbreached, sub-seismic resolution relay zones allowed cross-fault leakage prior to the development of large normal displacements in the Middle Pliocene (ca. 3.7 Ma). Following the onset of Pliocene/Pleistocene normal faulting intact relays capable of transmitting fluids across the fault are most likely to have occurred approaching the fault tips where relatively low displacements are recorded (e.g., the northern region of plays, Figure 1).

Regional up-dip migration of hydrocarbons from the Pihama sub-basin (Figure 1) is consistent with proposed charge directions by Haskell (1991) and STOS (1994). Haskell's scenario, of an additional Northern Graben source, is supported by the similar compositional and helium isotopic values for the gases from Maui and Motumahanga, near New Plymouth,

Kitchen		11.5-5.0 Ma	5.0-3.7 Ma	3.7-2.0 Ma	2.0 Ma-PD
Pihama	oil (Bbbl)	26.8	1.2	2.6	2.3
	gas (TCF)	15.4	1.4	3.3	4.2
Maui	oil (Bbbl)	11.1	0.03	0.14	0.65
	gas (TCF)	4.4	0.01	0.04	0.30
Kahurangi	oil (Bbbl)	0.0	0.08	0.23	0.34
	gas (TCF)	0.0	0.03	0.05	0.07
Western Platform	oil (Bbbl)	0.0	0.07	0.14	0.38
	gas (TCF)	0.0	0.02	0.04	0.13

Table 1. Volumes of oil (billion bbl) and gas (TCF) expelled from Late Cretaceous kitchens and within Maui fetch areas for specific time periods. Volumes are based on migration at D sand level for Pihama and Maui kitchens and F sand level for the Western Platform kitchens. (Note that the Western Platform kitchens data in the table exclude the Kahurangi kitchen data).

(Giggenbach et al. 1993) although it has been suggested the light helium signature of the Maui gases could also be the result of magmatic-sourced gas leaking up the CEF (King & Thrasher 1996). Migration from the northern sector of the Pihama sub-basin is complicated by the existence of onshore Late Pliocene block faulting and offshore Pliocene volcanics which may be responsible for the development of structural traps and termination of specific migration pathways. Alternative migration routes for the Pihama sub-basin include migration through the Maui Terraces (i.e. the region of splays at the northern end of the fault), and around the northern extent of the CEF fault trace separating the Central Graben from the Maui Field (Figure 1).

Recent oil charge from small kitchens on the Western Platform (including the Kahurangi sub-basin), as predicted by McAlpine (2000), is possible; however, the modelled volumes are estimated to be small in relation to other kitchens to the east and north. While Western Platform kitchens are not the dominant source for the Maui Field they do source valid migration pathways and are predicted to contribute to the present day Maui Field hydrocarbon distribution in F and lower D sands.

Discussion

Significant quantities of both oil and gas were produced from Late Cretaceous kitchens surrounding the Maui Field, but only a very small percentage of the expelled hydrocarbons is expected to be accessed by the Maui Field. This is due to a number of factors including; the many alternative migration pathways from kitchens (such as the southwards path from the Maui sub-basin into the area of the Moki-Maari-Field), the late development of the Maui structure compared to historical expulsion from kitchens, and the effect of migration losses and losses through ineffectual seals. Hydrocarbon expulsion began as early as the Paleocene in the Maui sub-basin and in the latest Eocene in the Pihama sub-basin (Funnell et al. 2001), whereas formation of the Maui structure did not occur until the Late Miocene starting with reverse movement on the Whitiki Fault. Hence most of the volumes expelled prior to about 7.5 Ma, amounting to approximately 62% of total oil and 45% of the total gas from all kitchens, are predicted to bypass the proto-Maui high heading southwest along the Eocene sand fairway.

Uncertainties in the degree of structural development of the Maui trap and the extent of cross-fault leakage during the period of contraction and uplift, from 7.5 to about 5 Ma, cause difficulties in determining exactly which fetch area may have been active for Maui charge. Hence, for the purposes of this paper we will use the down-side volume, which assumes no hydrocarbons were charging the structure from the Maui sub-basin during this period. While most of the Pihama sub-basin is similarly affected, the northern sector is within the Maui fetch for migration around the CEF (expelling 1.77 B bbl oil and 1.23 TCF gas -Table 1). Such large volumes are unlikely to get to any proto-Maui structure that has developed at this time, but importantly they may accumulate on small structures along the migration path. In

particular, decompaction modelling identifies trapping structures close to the present western tip of Cape Egmont which may accumulate volumes important in contributing to later Pliocene charge.

The Early Pliocene (5 to 3.7 Ma) is a period of relative hiatus on the CEF and hence we predict a similar pattern of hydrocarbon migration and accumulation as during the time of contraction (above). Similar volumes are expelled from the northern Pihama kitchen (1.2 B bbl oil and 1.4 TCF gas – Table 1) and in combination with the existing accumulations should charge the relatively low lying structures associated with the Maui Field that developed during inversion on the Whitiki and Cape Egmont faults. This period is modelled as the early Maui charge with a possible oil column accumulating within the primary migration pathway; presumably the Kapuni upper D sands (Kaimiro Formation) as recognized in fluid inclusion data.

Extension occurred in the Late Pliocene (3.7 to 2 Ma) and normal movement of the CEF significantly enhanced the structural elevation of the Maui closure. Thus additional migration routes were developed from the Maui sub-basin through the northern fault splay area (Maui Terraces) and allowed more significant hydrocarbon columns to accumulate. Renewed subsidence occurred in both main kitchens, but the Pihama sub-basin remained the major contributor to the Maui fetch during this time (2.6 B bbl oil and 3.3 TCF gas expelled – Table 1). At this stage a single upper D sand accumulation is predicted to have occurred extending across both the A- and B-areas. A small gas cap is also predicted to have exsolved resulting in gas leaking upwards through seals into the C-sands. Expulsion of oil with minor quantities of gas was initiated from the Kahurangi kitchen on the Western Platform (Figure 3) and during this period the Maui fetch area contributed 225 MMbbl (Table 1) to a northeasterly migration route to the north of the Whitiki Fault and into the Maui Field. Due to the regional scale, seismic-mapped surfaces it is not possible to accurately assess migration losses related to the relatively small volumes involved. One can predict however, that small accumulations such as in the Tui Prospect will be sequentially filled up-dip, culminating in the development of the F sands accumulation in the Maui B-area.

Near the start of the Pleistocene (~ 2 Ma) displacement rates on the CEF were an order of magnitude lower (0.2 mm/yr) than during the mid Pliocene (1.8 mm/yr). Hence, our models predict that deformation had isolated the A- and B-areas at D sands level by this time. While the B-area was cut off from primary migration pathways from the Pihama and Maui kitchens, the D sands in the A-area continued to be charged with gas saturated oil. The C sands accumulation is modelled to consist of oil and gas leaked from D sands and sufficient columns were then developed to leak primarily gas into the overlying Moki B sands. It is possible that the C sands also acted as a migration pathway from both kitchens (not included in the model). This scenario would have allowed seal leakage of oil into the overlying Moki sands prior to the development of the C sand gas column.

During the Pleistocene the northern migration pathways from the Pihama kitchen were compromised by complex faulting (presently onshore and offshore) and, in an area immediately offshore from Taranaki Peninsula, by the emplacement of volcanic intrusions. The age of these intrusions is difficult to estimate although they are assumed here to have a similar age to the Sugar Loaf Island volcanics of about 1.7Ma (King & Thrasher 1996). Hence, the calculated volumes indicated in Table 1 (2.3 B bbl oil and 4.2 TCF gas expelled) may not have been able to be accessed directly by Maui, but would have accumulated in small traps along the migration pathway. The development of such accumulations may cause separation of the hydrocarbon phases with gas columns leaking into overlying active migration pathways leading to Maui. Since all our models result in oil-rich accumulations in C and upper D sands, such a process is necessary to account for the present high GOR of the Maui Field hydrocarbon distribution (Figure 2).

The D sands in the A-area are predicted to leak gas to overlying C sands and the C sand fluids to spill into the B-area via the saddle near the Maui-5 well (Figure 1). In addition to the predicted high GOR fluids migrating from the Pihama sub-basins, and to a lesser extent the Maui kitchen, low GOR oil has migrated through the Paleocene F sands from the Kahurangi kitchen and possibly other Western Platform kitchens (McAlpine 1999)(Figure 3). The F shale is modeled with seal capacities capable of retaining 25-30 m oil columns allowing leakage of low GOR oil into, and the sequential filling of, the overlying lower D sands (see Figure 2).

Conclusions

The relatively complex pattern of hydrocarbon distribution in the Maui Field and evidence for previous oil columns from fluid inclusions and petrophysical data necessitate an intricate charge model for Maui. Our approach, using a combination of source rock volumetrics, map-based migration models including hydrocarbon accumulation fill/spill/leakage, and structural re-interpretation for the CEF, has provided one such model.

Primary controls on the model include:

- recent charge supported by fluid inclusion homogenisation temperatures similar to present day formation temperatures,
- development of the Maui structural high in the Late Miocene with further structural enhancement related to extension in the Late Pliocene (3.7 - 2 Ma),
- shale gouge ratios and high fault throw on CEF suggesting a sealed fault to cross-fault flow following reverse movement at about 5Ma,
- primary charge from Pihama and Maui Cretaceous kitchens with generation, migration and accumulation models utilising regional-scale maps, and,
- a complex in-place distribution of oil and gas.

In association with Late Miocene to Middle Pliocene (7.5 to 3.7 Ma) charge of Maui we predict the development of small

oil accumulations related to migration pathway-sands east and northeast of the Maui high. Early Maui charge of inversion related structure created oil columns within upper D and possibly C sands.

In the Late Pliocene structural enhancement of the Maui high allowed greater column heights to accumulate in upper D sands with subsequent leakage through seals into overlying C sands. Continued development of structural relief isolated the upper D sands in the B-area, which no longer received charge, while charge of gas saturated oil continued to D sands in the A-area. Additionally, the relatively immature Western Platform kitchens were expelling oil by this time and low GOR oil was migrating towards the Maui high at F sand level.

During the Pleistocene (since 2 Ma) faulting in the northern Pihama kitchen and volcanic intrusions emplaced along migration routes increased the uncertainty associated with valid fetch areas and hence volumes available for Maui charge. However, the central Pihama and northernmost Maui kitchens were still viable hydrocarbon sources and we predict that subsidiary accumulations along migration pathways effectively fractionated the hydrocarbon phases allowing gas to leak into overlying C sands and then to continue migrating into the Maui high.

Latest pre-production redistribution of hydrocarbons includes gas leaking from upper D sands to A-area C sands, subsequent spilling of gas at C sands level from the A- to the B-area, and the low GOR oils of the B-area F sands accumulation leaking vertically into the overlying lower D sands. The more liquid-rich accumulations of the B-area are a direct result of the isolation from latest high GOR charge of the A-area at D sand level, and the continued charge of low GOR fluids via F sand migration pathways from the Western Platform kitchens.

Our charge model currently over-predicts the volume of oil relative to gas in the upper D and C sands in both areas. Refinements to the model such as the use of higher resolution seismic interpreted maps to predict subsidiary accumulation phase fractionation, the inclusion of greater sampling detail in the development of the fluid inclusion picture, further assessment of source rock properties, inclusion of in-source oil to gas cracking, and the use of more appropriate PVT correlations for understanding the phase behaviour of trapped fluids through time, should result in a significant increase in the GOR of the system, and accuracy of the model.

A relatively complicated model for Maui charge is presented which fits much of the available data and is based on a series of numerical generation, expulsion, migration and accumulation models. Although this is only one model that fits the data it is useful in developing an improved understanding of how hydrocarbons may have been redistributed within the circum-Maui region of the Taranaki Basin. Implications for the continued hunt for new oil and gas reserves include the confirmation that Western Platform kitchens can source additional oil accumulations, the likelihood of small subsidiary accumulations on migration

pathways and the importance of such accumulations in fractionating hydrocarbon phases.

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