

An Engineering Analysis Of Taranaki Petroleum Systems: A 4-Dimensional Multi-Disciplinary Approach To Reduce Exploration Risk

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Abstract

A viable Petroleum System (Magoon 1988) consists of: mature source rock; migration path; reservoir; seal; and trap, all of which must be present within specific geographic, stratigraphic, and time limits, and which are (or have been) positioned in space and time such that a hydrocarbon accumulation results. It is not sufficient that the necessary petroleum system components are present. The entire system must work in accordance with physical and engineering principles.

It has been said that migration is the least understood aspect of Taranaki Basin petroleum geology. The complex geological history and tectonism has encouraged vertical migration and increased the number of trapping opportunities over time, but has also complicated the migration and trapping processes. In this paper, reservoir engineering principles are applied to petroleum migration and trapping processes by considering:

- the physical properties of the water and hydrocarbon phases involved;
- the driving forces of buoyancy, pressure and fluid-flow;
- the impediments of capillary entry pressure and critical saturation;
- the hydrocarbon losses along the migration path;
- the time available for migration to proceed.

In this scheme a hydrocarbon accumulation is considered to be a region where migrating hydrocarbons are presently (and temporarily) arrested.

This "Petroleum System Engineering" approach allows theories to be put forward as to why the Eastern Mobile Belt is gas-prone, and why only a small fraction of the theoretically generated hydrocarbons (particularly oil) can be accounted for in proven accumulations.

The approach employs a diverse skill set and requires geoscientists and engineers to work out integrated solutions. Field data collected to solve one problem has proven extremely useful in other contexts. A physically and mathematically correct analysis of each petroleum system component is the ultimate goal to reduce exploration risk, particularly as it only takes one component to be inoperative for the whole petroleum system to fail.

Introduction

In this paper we examine aspects of the petroleum system approach to exploring the Taranaki Basin. It is clear that considerable past effort has gone into defining the key components of petroleum systems, but relatively little study has gone into the processes that are necessary to

make the petroleum system viable. In particular, the processes of migration and entrapment are poorly understood despite being major exploration risks. These are the subject of this paper.

It has been said that, "The movement of hydrocarbons through rock is perhaps one of the least understood

aspects of petroleum geology, and nothing is known of the mechanisms controlling migration in the Taranaki Basin" (Bulte and Palmer 1991), and again more recently, "The movement of hydrocarbons within Taranaki Basin source-reservoir systems is poorly known" (King and Thrasher 1996). Many of the engineering principles that govern migration and trapping traditionally belong in the realms of reservoir- and petroleum-engineering. Such principles, routinely applied to understand the extraction of petroleum fluids from reservoirs, can also help solve the explorationist's questions on how petroleum might first migrate and accumulate in those reservoirs.

Petroleum system engineering

A viable petroleum system, as defined by Magoon (1988) consists of mature source rock; migration path; reservoir; seal; and trap, all of which must be present within specific geographic, stratigraphic and time limits, and which are (or have been) positioned in space and time such that a hydrocarbon accumulation results. The advantage of the petroleum systems approach is that it forces us to think of petroleum geology in terms of components (source rock, reservoir etc); timing (trap formation, critical moment, etc); and processes (fluid-flow, mass-transport, capillary retention etc). Recent examples of the petroleum systems approach in the Taranaki Basin (eg Cook 1994; Cook and Gregg 1996; and King and Thrasher 1996) consider the components and timing aspects of the petroleum system, but cover few of the essential processes that must also operate within a working petroleum system. An analysis of past exploration well results would suggest that migration and trapping are significant exploration risks in the Taranaki Basin.

We would suggest a comparison can be drawn between the petroleum system approach and some design processes used in civil engineering. For example, the components needed for a construction project, such as Auckland's "Skytower", are first assembled and arranged into a conceptual design. Thereafter, the processes that have to take place within the structure, such as heating, plumbing, and access have to be precisely engineered before the design can be considered functional. Interestingly, in the case of the "Skytower" it was the plumbing and engineering of the fire sprinkler system that provided one of the great engineering challenges (Schaffler 1997). We would argue that it is also the "plumbing" aspects of Taranaki petroleum systems that provide the great challenge for petroleum explorers.

The goal is to take the petroleum system approach beyond the conceptual design stage and through to a fully engineered solution. To do this we need to make numerous quantitative assessments of the properties of the rocks and fluids involved, some of which are listed under the following categories:

- Thermal Controls: heat-flow; thermal conductivities; specific heat.

- Fluid Properties: phase behaviour; densities; viscosities; solubilities; interfacial tension.
- Driving Forces: buoyancy; fluid-flow; hydraulic potentials.
- Impeding Forces: capillary entry pressures; critical saturations.
- Losses Along the way: residual saturations; fracture pressure limits.

This, together with consideration of the time necessary for these processes to operate, we term "Petroleum System Engineering".

In the remainder of this paper we consider two aspects of petroleum system engineering where our understanding is least, namely secondary-migration and petroleum-entrapment. We shall see that the processes governing migration and entrapment are the same as, or similar to, some reservoir engineering processes, though on a generally slower timescale. Quantitative methods can be used to gain better understanding of these processes, and how they operate in the Taranaki Basin.

Petroleum Migration

Historical background

The concept of oil and gas in a water-saturated environment being impelled by the forces of buoyancy was formulated in the late nineteenth century and led to the establishment of the "anticlinal theory", which was amply supported by the numerous discoveries of hydrocarbons at structural crests. During the early twentieth century, the "hydraulic theory" was proposed in which the primary driver was water flow and that oil and gas migrated, except for an oblique upward drift, in the direction of water movement. During the 1940s and 1950s important contributions to the debate were made by Hubbert (1940, 1953) on hydrodynamic influences and Gussow (1954) on differential entrapment. By the 1960s the fundamental questions in petroleum migration had been identified.

These included:

- Factors affecting the quantitative estimation of generation and expulsion, including heat-flow; thermal conductivity; and specific heat.
- Mechanisms for expulsion from rocks subsequently acting as seals (primary migration).
- Migration losses and secondary migration efficiency.
- Quantitative understanding of subsurface phase behaviour.

- The role of capillary forces.
- The role of compaction; overpressure; and fluid potentials.
- Effects of lithological anisotropy.
- The role of faults as seals and conduits.
- Migration fronts versus discrete pathways.
- The time required for these processes to take place.

During the 1970s Berg (1975) presented practical approaches to the capillary phenomenon and linked the principles of capillary buoyancy pressure to the displacement pressure of reservoirs and seals. A landmark paper by Schowalter (1979) provided a synthesis of the physical mechanics of secondary hydrocarbon migration. Schowalter's paper examined the role of buoyancy, capillarity and hydrodynamics and provided a series of nomographs and "how tos" aimed at the petroleum explorationist. During 1970s and 1980s the roles of overpressuring, compaction, and fluid charge and recharge were examined by, for example, Tissot and Welte (1984), Magara (1987), Chapman (1987), England et al (1987), and Bredehoeft et al (1988). Concomitant with these studies, detailed investigations into large and small scale fluid flow were being carried out in research institutions using the increased availability of supercomputing facilities (eg Bethke et al 1988). The roles of faults as seals and conduits was discussed by Smith (1966), Downey (1984) and more recently by Knipe (1993). The issue of how petroleum migrates, whether in solution or as a separate phase has been the subject of much debate, but general consensus now favours migration as a discrete phase (McAuliffe 1979).

In the 1980s the advent of accessible computing facilities led to the development of practical tools for modelling hydrocarbon migration in the subsurface. These tools can be classified into two broad types; single-point or cross-sectional burial history, maturation and migration modelling packages; such as BASINMOD™, GENEX™, TEMISPACK™, and PETROMOD™, and 2D horizontal ray-tracing software which includes maturation modelling inputs and equations of state to accommodate phase behaviour changes. Sylta (1991) demonstrated the results of his "Basin of Domes" modelling conducted at the IKU with the now commercially-available SEMI™ programme. Other major oil companies have developed similar software in house, such as Amoco's FINESSE maturation, ray-tracing and hydrodynamics application.

Schowalter, in an abstract for The Geological Society's Petroleum Migration symposium in London (England and Fleet 1991), articulated the concerns that many in the commercial petroleum exploration world have by his comments that, although the physical principles of migration are well known, quantitative estimates of the

controlling phenomena on a basin scale are very difficult. As a consequence quantitative modelling on a basin scale is "complex to the point of being insolvable" Sylta acknowledges that incorporation of equations of state into modelling programmes requires considerable computer power. Burrus et al (1991) conclude that modelling cannot at present provide quantitative estimates of the volume of hydrocarbons in structures, but it can permit the analysis of various migration scenarios and their sensitivities to parameters which are poorly constrained.

Specific aspects of petroleum migration in the Taranaki Basin

In this paper we will follow the excellent approach of England et al (1987) and consider petroleum migration in terms of the movement and evolution of multi-phase fluids through a porous medium and through changing temperature and pressure conditions. We can envisage scenarios where the migrating hydrocarbons are variously acted upon by these parameters throughout geological time as they move towards their ultimate fate (which may be leakage to surface, or thermal or bacterial degradation). In this scenario a hydrocarbon accumulation is merely a point where hydrocarbons are presently and temporarily arrested along their migration route.

A schematic representation of petroleum migration and entrapment, and some of the important driving forces, controls, and impediments is shown in Figure 1. The buoyancy differences between the hydrocarbon and water phases provides the upwards driving force for migration (F_b). A lateral driving force (F_h) due to hydrodynamic flow of ground waters is a potentially important additional component that has mostly been neglected in studies of the Taranaki Basin. The net result of the buoyant forces and hydrodynamic forces can be a resultant migration vector (F_r) that is inclined with respect to the vertical.

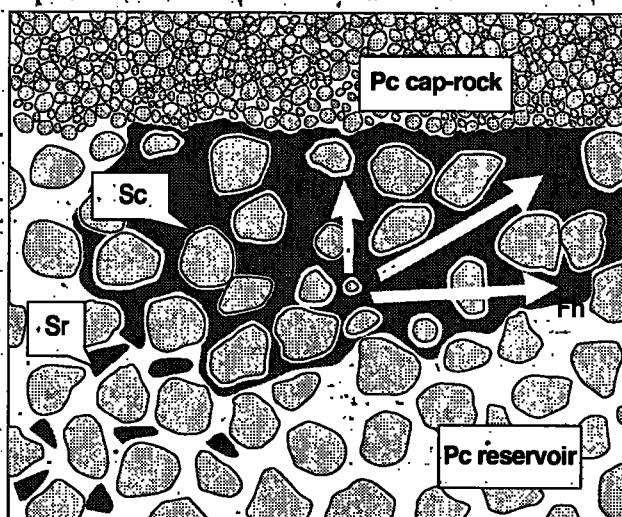


Figure 1. Schematic representation of migrating hydrocarbons through a water saturated porous medium.

Webster and Adams (1996) show a map with the areal distribution of overpressures in the Taranaki Basin and comment on their possible role in promoting vertical migration, but do not specifically address the implications for lateral migration. England et al (1987) state that in most rapidly subsiding sedimentary basins the major driving force controlling petroleum movement is compaction-related groundwater flow. The possible effects of this have yet to be determined in the Taranaki Basin.

Figure 1 also illustrates how the migrating stream of hydrocarbons needs to build up to a critical saturation (S_c) before bulk flow of hydrocarbons can occur. The value of this critical saturation is generally considered to be very low for finer grained (eg shale and siltstone) carrier beds, but could be higher for coarser (eg sandstone) carrier bed lithologies. Experimental data from Rudd and Pandey (1973), Schowater (1979) and England et al (1987) suggest reasonable critical saturation values to be:

Shales and Carbonates	3-10%
Siltstones	20-30%
Sandstones	around 50%.

Furthermore, the experiments of Rudd and Pandey (1973) in particular, suggest breakthrough of the non-wetting phase occurs along a focused, rather than diffuse, pathway through the carrier bed.

Also depicted in Figure 1 is the residual hydrocarbon saturation left behind the migrating hydrocarbons (S_r) this controls the amount of hydrocarbon lost along the migration pathway. Typical residual saturation values might be expected to be around 30% or less.

Finally, upon reaching a different rock type where the pore throats are smaller and the capillary entry pressure (P_c) exceeds the pressure exerted by the migrating string of hydrocarbons, the migration is arrested.

Estimates of the timing required for petroleum migration can be made by calculating the rate of supply of liquid hydrocarbons from the source rock, the pore volume of the rock involved in the migration pathway, the saturations required for the hydrocarbons to become mobile, and the Darcy flux equations for the migrating hydrocarbons. It is generally regarded that the secondary migration process is almost instantaneous compared with the rate of supply of liquid hydrocarbons from maturing source rock. Using typical rock and fluid properties suggests lateral flux in sandstone carrier beds of around $8 \times 10^{10} \text{ m}^3 \text{ m}^{-2} \text{ s}^{-1}$ (England et al 1987). In more practical units this equates to a flow of 160 MMb of oil per million years through a carrier bed 1 m thick and 1 km wide.

Dembicki and Anderson (1992) and Thomas and Clouse (1994) concluded from experimental studies that once a stringer of hydrocarbon has been formed which

overcomes the capillary entry pressure of the pore-throats, then the migration appears to take place in very discrete pathways along a line of least resistance. This is in sharp contrast with the common portrayal of migration taking place along generally broad migration fronts (eg Haskell 1991). The consequence of this is that migration losses could be smaller than previously assumed, because the zone of residual hydrocarbon saturation would be restricted to a more discrete pathway.

Hindle (1997), acknowledging that the physical mechanics of secondary migration are reasonably well known, noted that the prediction of 3D migration routes was not routinely undertaken. Using a simple ray-tracing tool known as PATHWAYS™, he analysed known petroleum occurrences in the Paris Basin (Figure 2). Using simple buoyancy drive, the ray-tracing method predicted 81% of discoveries and wells with oil shows (85% of discoveries) within 2000 m of the predicted pathways. Hindle stated his belief that using multiple sealing surfaces to account for remigration would result in a pre-drill prediction rate of 44% for hydrocarbon discoveries, compared to the overall success rate in the basin of 6%.

Clearly, an improvement of predictive risk of this kind represents a significant advance in exploration capability, and offers a great opportunity to loosen the constraints implicit in the practice of exploration using only historical statistics, to control risk/reward economics. Hindle also applied the technique effectively to the Madison Group in the Williston Basin, utilising potentiometric profiles to modify fluid flow for hydrodynamic effects. Hindle's paper also demonstrates the role of structure whereby anticlinal features, and structural noses tend to concentrate hydrocarbons whereas synclines tend to disperse them. This, together with Dembicki and Anderson's concept of migration along constricted pathways, exemplifies the need for the best possible mapping techniques. Once the pathway has been initiated it will follow the constraints of structure, buoyancy and hydrodynamics. The modelling technique

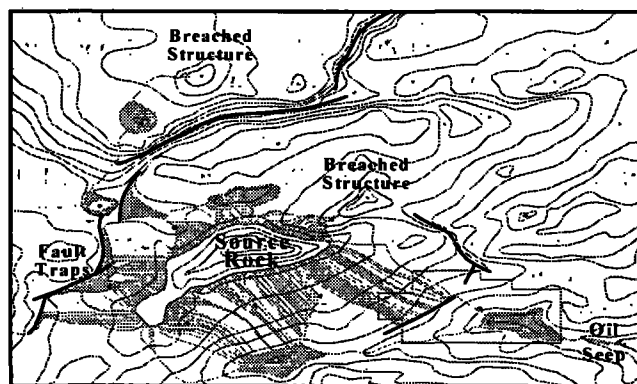


Figure 2. Example of modelled migration pathways generated by PATHWAYS™ programme (After Hindle 1997). Note the focussing and de-focussing that takes place along discrete "critical pathways".

also permits the backtracking of hydrocarbon pools and surface seeps to a source fetch area and the migration of hydrocarbons to a different reservoir level, thus permitting a gridded 3D approach. This may not be a perfect solution but these techniques of hypothesis-test, as exemplified by the approach used by Hindle, for which we consider the term "Critical Path 3D Modelling" appropriate, may provide the explorationist with a quick, cost-effective, fit-for-purpose methodology which has the potential to significantly decrease exploration risk.

Petroleum Entrapment

In some Taranaki petroleum assessments, the mere presence of a widespread fine-grained lithology has been considered sufficient to provide a seal. Event charts typically show the seal component to be satisfied as soon as the fine-grained cap rock has been deposited above the reservoir. However, our studies show a number of instances where a more cautious approach is necessary. Some of these are discussed in the following sections.

Cap-rock lithology insufficiently fine-grained to form an effective seal

Not all Taranaki Basin cap-rocks are sufficiently fine-grained to be effective seals. Grainsize data collected in wells and outcrops (for example: Browne, et al 1996; and Lindsay 1996) commonly show Miocene deep-marine sediments to have relatively little contrast in grainsize between the reservoir (mostly very-fine grained sandstone) and the cap-rock (mostly fine-siltstone). Using the approach of Berg (1975) to estimate sealing potential suggests this combination of reservoir/cap-rock lithologies could withhold oil columns no greater than approximately 30 m (Figure 3). An example using actual capillary pressure data from a Miocene reservoir and cap-rock shows an expected maximum trapped column of c 80 m (based on the common assumption that the seal limit is reached at around 10% non-wetting phase saturation) - and also that a significant capillary transition zone would be expected within the trapped column itself (Figure 4).

Examples of other formations in the Taranaki Basin where capillary pressure data indicate some element of seal quality risk are the Pliocene "Giant Foresets" Formation (Bergman, et al 1992) and the Palaeocene Tane Siltstone (Taylor 1986). It is therefore concluded that capillary entry pressure analysis, based on grainsize considerations of the cap-rock are an essential part of petroleum system analysis.

Cap-rock not sufficiently compacted to form an effective seal

The drawback of Berg's method (Figure 3) is that it does not consider the effects of compaction, which serves to

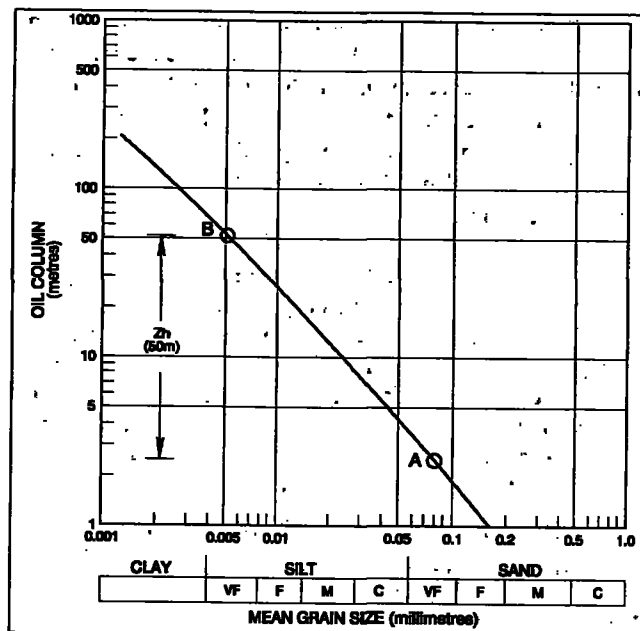


Figure 3. Nomogram for estimating oil column that might be trapped by different reservoir/cap-rock grainsize combinations (Modified after Berg 1975). The nomogram assumes perfectly sorted sediments with 26% porosity and rhombohedral grain packing. Other implicit parameters are: Water Density = 1.0 g/cc; Oil Density = 0.63 g/cc; Oil/Water Interfacial Tension = 35 dyne/cm.

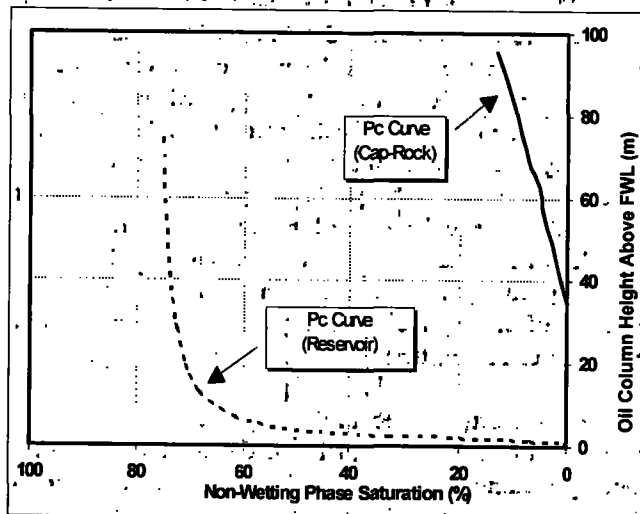


Figure 4. Cap-rock seal quality and expected reservoir transition zone saturation profile based on actual mercury/air capillary pressure injection data (Miocene example from Taranaki Basin). In this case the cap-rock is expected to retain a maximum oil column height of 80 m (ie seal limit reached at 10% non-wetting phase saturation).

close up the pore throats and increase capillary entry pressures, thereby improving seal quality. Berg's theoretical calculations are valid only for a porous medium with perfect rhombohedral grain packing and 26% porosity. Sediments with a greater or lesser degree of grain packing can be expected to exhibit correspondingly better or poorer seal characteristics.

In order to investigate the possible effects of compaction on cap-rocks we have taken the published compaction trend data produced by the IGNS (Funnell et al 1996). These compaction trends are shown in Figure 5a. Using porosity/permeability relationships the IGNS have also derived theoretical trends of sediment permeability versus depth (Figure 5b).

Using theoretical considerations, Purcell (1949) proposed the simple relationship whereby capillary entry pressure (P_c) is proportional to the inverse square root of permeability. Later, and more sophisticated derivations of a P_c versus permeability relationship are summarised by Nelson (1988) but all are of a similar mathematical form and are derived either in spirit or rigour from the Kozeny-Carman relationship:

$$K = C_1 \times R^2 \quad (\text{Kozeny-Carman})$$

$$P_c = C_2 \times R^{-1} \quad (\text{Capillary Theory})$$

therefore:

$$P_c = C_3 \times K^{-0.5} \quad (\text{Purcell})$$

Where: K = permeability

R = pore throat radius

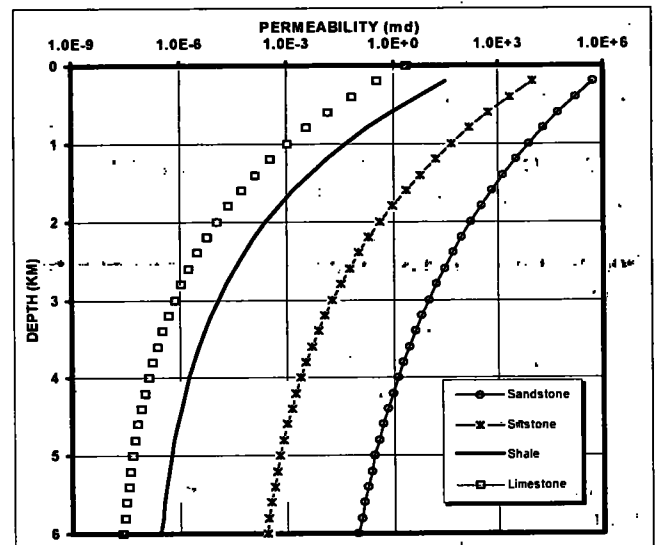
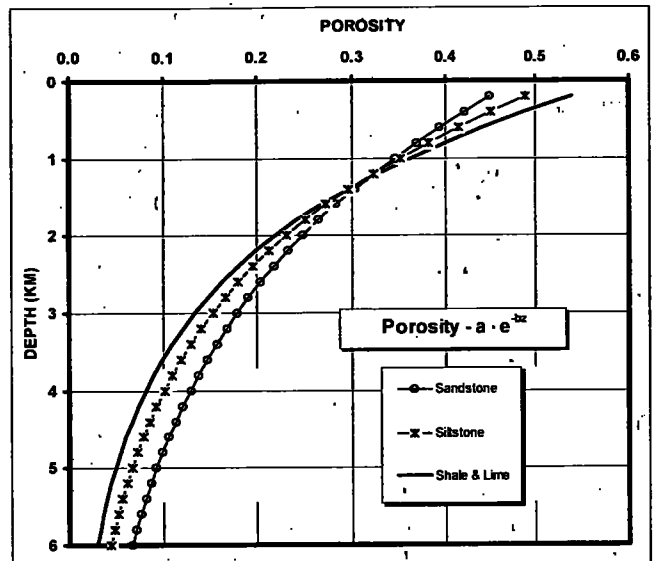
P_c = capillary entry pressure

$C_1, C_2,$ and C_3 are constants

Using Purcell's relationship, and calibrating the predicted P_c values to measurements determined in the laboratory, has resulted in the theoretical curves of P_c versus depth, shown in Figure 5c. Whilst this approach is somewhat simplistic, and is only calibrated to relatively few laboratory P_c measurements, the results nevertheless appear to have reasonable predictive power. Predictions of seal quality made before drilling have been reasonably reliable when matched to drilling results. All that is necessary to apply this approach to have some prior estimate of the cap rock lithology and maximum depth of burial (or effective stress).

Another interesting aspect of this approach is that it allows estimates of seal quality to be made through geological time by making use of the burial history. Figure 6 shows the prediction of seal development through geologic time for two Miocene prospects in the offshore Taranaki Basin. Different cap rock lithologies and burial histories result in different predicted seal qualities. Prospect "A" was subsequently drilled and the measured seal quality (determined in the laboratory) was close to the predicted value. Prospect "B" was not drilled, partly because of greater perceived seal risk resulting from shallower depth of burial.

Using this approach, we argue that the "critical moment" for sealing is not the time when the cap rock sediments are first deposited, but the time when sufficient burial has occurred such that the cap rock can retain a commercial column of hydrocarbons.



Figures 5a and 5b. Taranaki Basin Porosity/Depth and Permeability/Depth transforms (after Allis et al 1996).

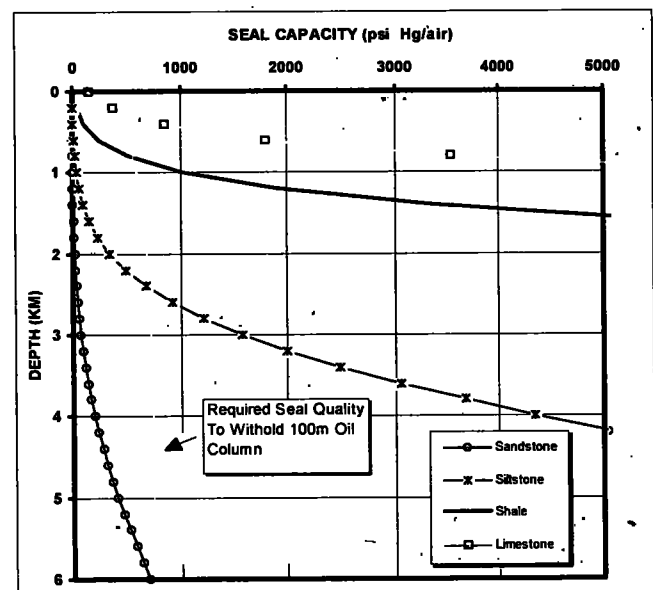


Figure 5c. Theoretical Seal Capacity/Depth relationships using: IGNS permeability transforms; Purcell's equation; and calibrations to laboratory mercury/air injection data.

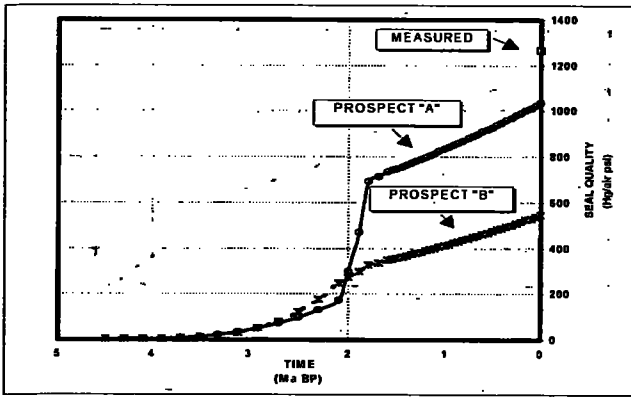


Figure 6. Predicted seal development through geologic time for two prospects in the Offshore Taranaki Basin.

Compaction related overpressures may have exceeded the fracture-limit of the cap-rock and destroyed the seal

It is well known that in some areas, the deeper parts of the Taranaki Basin are significantly overpressured. Present-day overpressures in the upper part of the Kapuni Group range from around 100 psi in near normally-pressured regions, to over 2,000 psi in parts of the Eastern Mobile Belt (Webster and Adams 1996). Preliminary modelling results by the IGNS indicate the observed overpressures might be explained by the relatively rapid sedimentation rates and low mudstone permeabilities (Funnell et al 1994; and Allis et al 1997). One dimensional fluid-flow modelling also indicates that overpressures may have been considerably higher in the past than observed at present, particularly in the Northern Onshore Taranaki, which has undergone 1 km or more tectonic uplift and denudation during the late Neogene (King and Thrasher 1996; and Funnell, in press).

Our fluid-flow modelling, which also combines thermal maturation modelling, allows the overpressure history to be easily displayed and suggests that compaction-related overpressures in some areas occasionally exceed the fracture strength limit of the overlying seals. This finding suggests that any previously generated hydrocarbons might be lost to shallower levels, or escape to the surface altogether. This could have important consequences for the overall hydrocarbon habitat of the Taranaki Basin.

Figure 7 shows an approximately East-West cross-section through the Taranaki Basin. It can be seen that the prograding Miocene to Pliocene clastic wedge produced high rates of sedimentation in the Eastern Mobile Belt during the Miocene. In the Western Stable Platform area, the maximum rates of sedimentation were experienced later during the Pliocene to Recent. Figures 8 and 9 show a graphical summary of results from fluid-flow and thermal modelling from two locations in the Taranaki Basin.

Figure 8 shows the modelling results from a pseudo-well location within a potential kitchen area in the Western

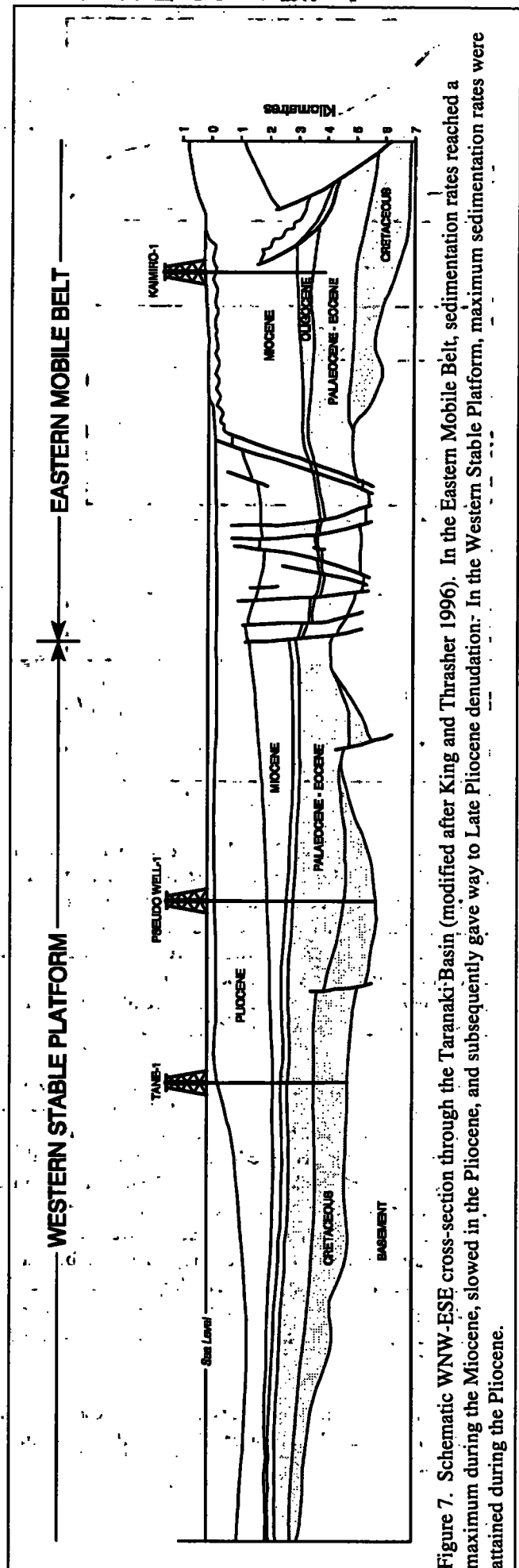


Figure 7. Schematic NW-ESE cross-section through the Taranaki Basin (modified after King and Thrasher 1996). In the Eastern Mobile Belt, sedimentation rates reached a maximum during the Miocene, slowed in the Pliocene, and subsequently gave way to Late Pliocene denudation. In the Western Stable Platform, maximum sedimentation rates were attained during the Pliocene.

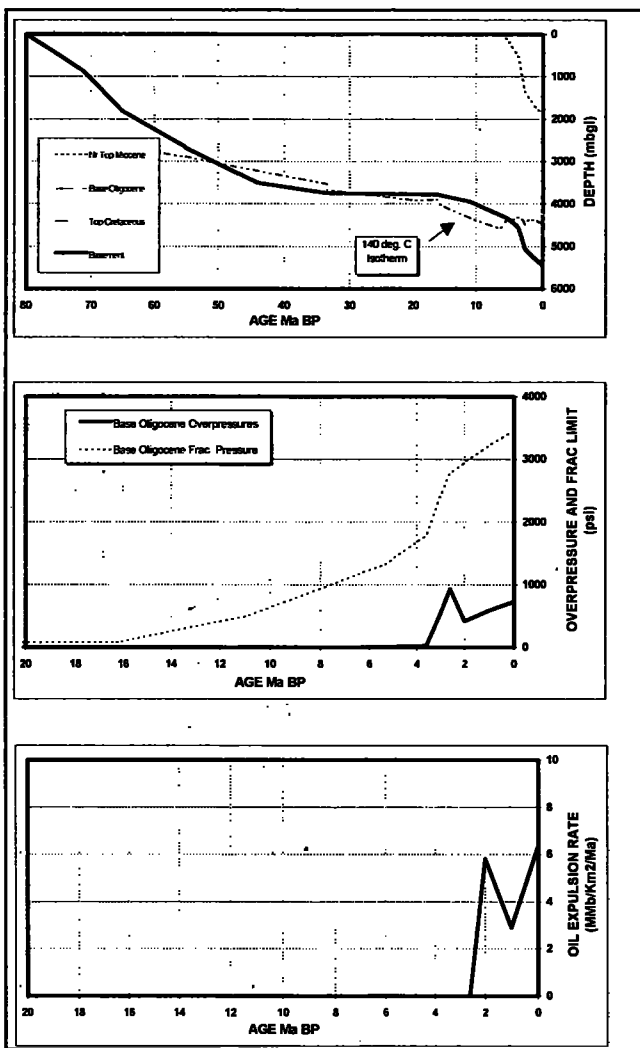


Figure 8. Results from fluid-flow and thermal modelling at Pseudo Well-1 Location on Western Stable Platform. Upper chart shows compaction corrected burial history. Middle chart shows overpressure development beneath regional Oligocene seal. Lower chart shown modelled rate of oil expulsion from Cretaceous source rocks. The modelling suggests late-expelled oils are likely to have remained beneath the regional Oligocene seal.

Stable Platform. Here basement is at a present day depth of 5.5 km (subsea) and the main period of sediment loading occurred during the Pliocene (4-2 MaBP). The sediment loading is predicted to have caused the Cretaceous source rock units to enter the oil-window in the late Pliocene (middle chart). Sediment loading appears not to have been rapid enough to generate overpressures that were large enough to take the regional seal beyond its fracture limit. One might reasonably conclude therefore that any hydrocarbons generated from this kitchen are more likely to have remained sealed within the petroleum system.

By contrast, Figure 9 presents modelling results from a location within the Eastern Mobile Belt (Kaimiro-1 location).

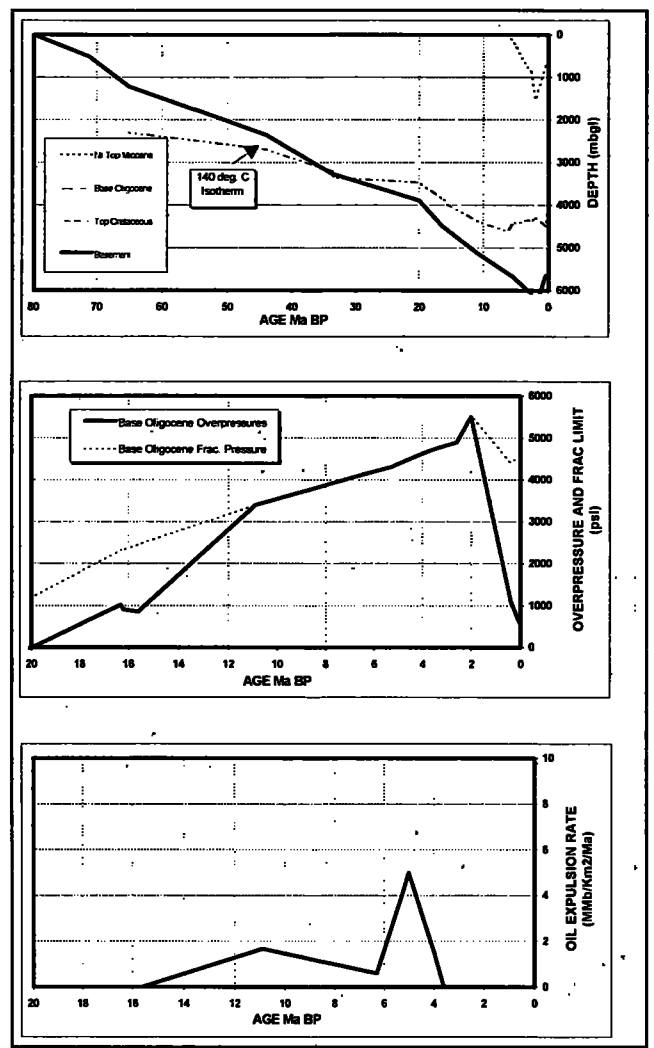


Figure 9. Modelling results at Kaimiro-1 Location. Middle chart shows that overpressures beneath the regional Oligocene seal reached the fracture limit of the seal from the late-Miocene until commencement of late-Pliocene uplift. Cretaceous source rocks were oil generative during the Miocene (lower chart) and then entered the gas window. The early-expelled oils are likely to have breached the regional Oligocene seal due to severe contemporaneous overpressuring.

The upper chart in Figure 9 shows the compaction-corrected burial history. Basement at this location is at a present day depth of 5.7 km, but has undergone c 900 m of uplift during the late Pliocene (Funnell and Allis, in prep). The Cretaceous source rocks are modelled to have generated oil during the period 16-4 MaBP and have subsequently passed into the gas window (lower chart). The middle chart shows the modelled development of overpressures at the base Oligocene regional seal. The increase in sedimentation rate at around 16 MaBP is predicted to have caused overpressures to develop in excess of the fracture limit for the seals. Much of the previously generated oil might therefore have been lost from the petroleum system at this time. Slowing rates of sedimentation and eventual uplift during the mid- to late-

Pliocene (2-0 MaBP) is predicted to have caused a reduction in overpressure, to levels lower than the fracture limit of the seals. The gas generated during this period is therefore more likely to have been retained within the deeper parts of the petroleum system.

The modelling results in the Eastern Mobile Belt might help explain the observation why so little of the theoretically generated hydrocarbons and particularly the early-generated (Cretaceous sourced) oil, can be accounted for by present discoveries. Our modelling suggests the main regional seals became breached by compaction-related overpressures after much of the early oil had been generated. Killops (1996) presents oil biomarker data for the Taranaki Basin that indicates Cretaceous sourced oils to be essentially restricted to the Eastern Mobile Belt.

Chapman et al (1996) also ponder this question of what happened to early-formed hydrocarbons? They concluded that whilst lack of structural traps might partly be responsible, the lack of hydrocarbon discoveries in stratigraphic traps suggests early-generated hydrocarbons have escaped from the petroleum system, either to the surface or to areas outside and probably to the west of the Eastern Mobile Belt. Their simple volumetric calculations, whilst subject to much uncertainty, suggests that even with significant migration losses; more than 95% of the oil potentially expelled from the Eastern Mobile Belt is unaccounted for.

Conclusions

For the tectonically active Taranaki Basin, the analysis of where, when and how hydrocarbons have migrated and become entrapped is a fundamental task. There is sufficient evidence to suggest compaction-generated overpressures are sufficient to have influenced both vertical and lateral migration of hydrocarbons in the Taranaki Basin. Furthermore, the seal integrity of some prospects might be jeopardised by original cap-rock lithology; lack of burial; or breaching by extreme overpressures. However, we live in a world of budget and manpower constraints and, in the case of many of the major oil companies, drastically shrinking research facilities. As Hinch et al (1994) have pointed out, petroleum explorationists must not only understand the geological, geothermal and geochemical framework of the basin, but they also must understand the spatial and temporal relationships of the framework. This requires the coming together of a considerable number of different skill sets; geochemistry, stratigraphy, fluid mechanics, petrophysics, and geophysics to name but a few generalised ones. Solutions may be sought under the 80:20 principle that, although not necessarily "state of the art", may be a long way down the road of continuous improvement.

Lastly we consider there is sufficient data available from the Taranaki Basin to allow a more quantitative approach to estimating migration paths; migration rates; migration

losses; and seal quality than has usually been done in the past.

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