East Coast drilling results

EJ Davies[1], JB Frederick[1], WL Leask[2] and TJ Williams[1]

[1] *Westech Energy New Zealand, 4643 South Ulster Street, Suite 1190, Denver, Colorado 80237, United States of America*

[2] *Ian R Brown Associates Ltd, P O Box 24-147, Wellington*

Abstract

The Westech-Orion Joint Venture has drilled six exploratory wells and five appraisal wells in the onshore East Coast Basin over a two year period. All wells encountered significant gas shows, with two wells discovering hydrocarbons in potentially commercial volumes.

Each well was drilled on the crest of a seismically mapped structure, characterised by asymmetric folding over a northwest dipping thrust fault.

Prior to this drilling programme, the reservoir potential of the Wairoa area was inferred to be dominated by turbidite sandstones of the Tunanui and Makaretu formations (Middle-Late Miocene). The new wells show that the Middle Miocene and parts of the Early and Late Miocene pinch out across the “Wairoa High”, which subsequently deepened as a Late Miocene-Pliocene basin.

One of the primary reservoirs is the Kauhauroa Limestone (Early Miocene), a bryozoan-dominated, tightly packed and cemented limestone with dominantly fracture porosity. The other primary reservoir is the Tunanui Sandstone (Middle Miocene), which in well intersections to date comprises medium-thickly bedded sandstone, with net sand typically 40%. The sands have high lithic content, and are moderately sorted and subangular-subrounded. Porous sandstones have 18-22% porosity and 10 mD permeability. The Makaretu sandstones (late Middle-early Late Miocene) are absent in the Wairoa area because of pinchout on the flanks of the Wairoa High.

Abnormally high formation pressures were encountered in all wells, ranging up to 3400 psi at 1000 m. Crestal pressure gradients commonly exceed 70% of the lithostatic pressure gradient, despite the relative proximity to outcrop. The overpressure may reflect relatively young uplift of fossil pressures, with insufficient time for pressure equilibration within a generally overpressured system.

Introduction

The Westech-Orion Joint Venture was awarded Petroleum Exploration Permit 38329 onshore northern Hawkes Bay in May 1996. The permit occupies 5550 km^2 in the central part of the East Coast Basin, New Zealand (Figure 1). At the New Zealand Petroleum Conference two years ago, the present authors discussed the results of new seismic acquisition in PEP 38329, and pre-drilling interpretations of structure, basin evolution and reservoir potential (Davies et al. 1998). The improvement in seismic quality over previous surveys was a major advance in assessing the basin prospectivity, leading to an early drilling programme.

In the two years since March 1998, Westech-Orion has drilled six exploratory wells and five appraisal wells in PEP 38329 (Figure 2). All six exploratory wells encountered significant gas shows, and two wells discovered hydrocarbons in potentially commercial volumes. This paper presents new insights into the basin stratigraphy, reservoir potential, abnormal pressure regimes, and the types of hydrocarbons encountered. We also discuss the onshore exploration strategy, which attempts to balance the value of data from high-cost seismic acquisition against the value of data from a continuous drilling programme.

Previous exploration

The northern Hawkes Bay region was first mapped by explorationists in the 1920s, and as early as 1928, two wells, Gisborne-1 and 2, were drilled by the Taranaki Oil Fields Company. In the 1930s, Vacuum Oil Company carried out extensive field mapping, resulting in the Morere-1 and Totangi-1B wells drilled by the New Zealand Petroleum Company in 1939-41. In the late 1950s and early 1960s, BP, with partners Shell and Todd, made a significant impact on East Coast geology with advances in micropaleontology, photogeological interpretation and structural interpretation.

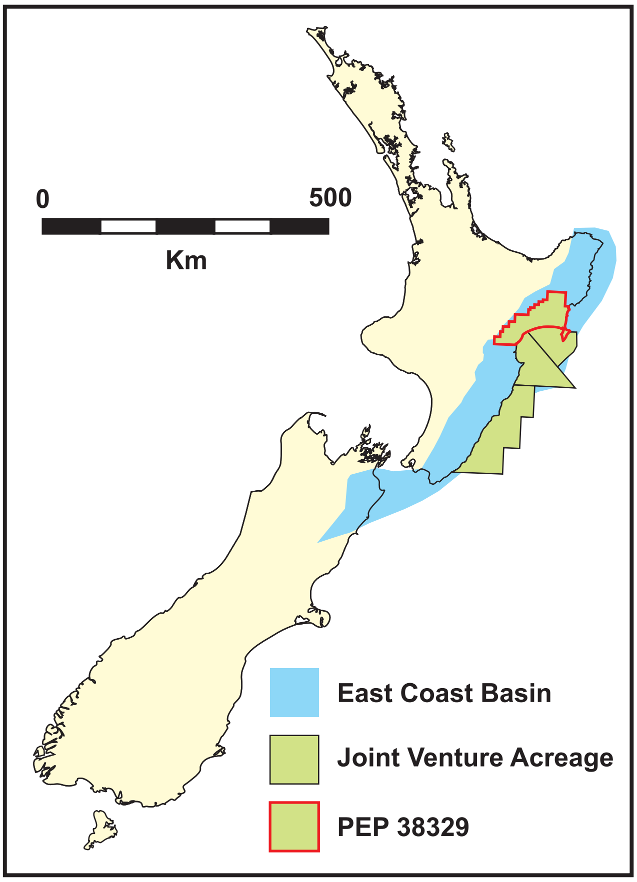

Figure 1: Location of the East Coast Basin in New Zealand, with Westech-Orion permit areas, including PEP 38329.

Their first well, Mangaone-1, was intended as a 3658 m Cretaceous test, but encountered major problems in the smectitic shales of the Eocene Wanstead Formation, and after penetrating a large reverse fault, was plugged and abandoned at 1550 m. The second well, Ruakituri-1, tested Middle Miocene sandstone formations to a depth of 2745 m, in part through steeply dipping strata. Aquitaine farmed into part of BP's licence in the mid 1960s, and drilled Opoutama-1, a 3658 m Cretaceous test, which achieved its stratigraphic objectives, but did not encounter significant hydrocarbons. Although seismic reflection surveys were carried out from 1960 onwards, the poor resolution led to these wells being sited primarily by surface geological mapping.

BP's later focus changed to targeting Pliocene limestone reservoirs, and these plus Miocene sandstones were among the primary targets of the offshore Hawke Bay-1 well drilled in 1976. Hawke Bay-1 took a large gas kick in a ?Middle Miocene limestone at 2255 m, but became stuck a short distance below at 2372 m in Oligocene claystone. The well was abandoned without having logged or tested the potential reservoir section.

The next major phase of exploration was in the 1980s, by Petrocorp Exploration. A series of regional seismic lines was shot across the region, with a more detailed survey followed by the drilling of Rere-1, a 4351 m well on the northern edge of the current permit area. This well did not encounter significant hydrocarbons, but Petrocorp persevered with exploration of the northwest margin of the basin, targeting

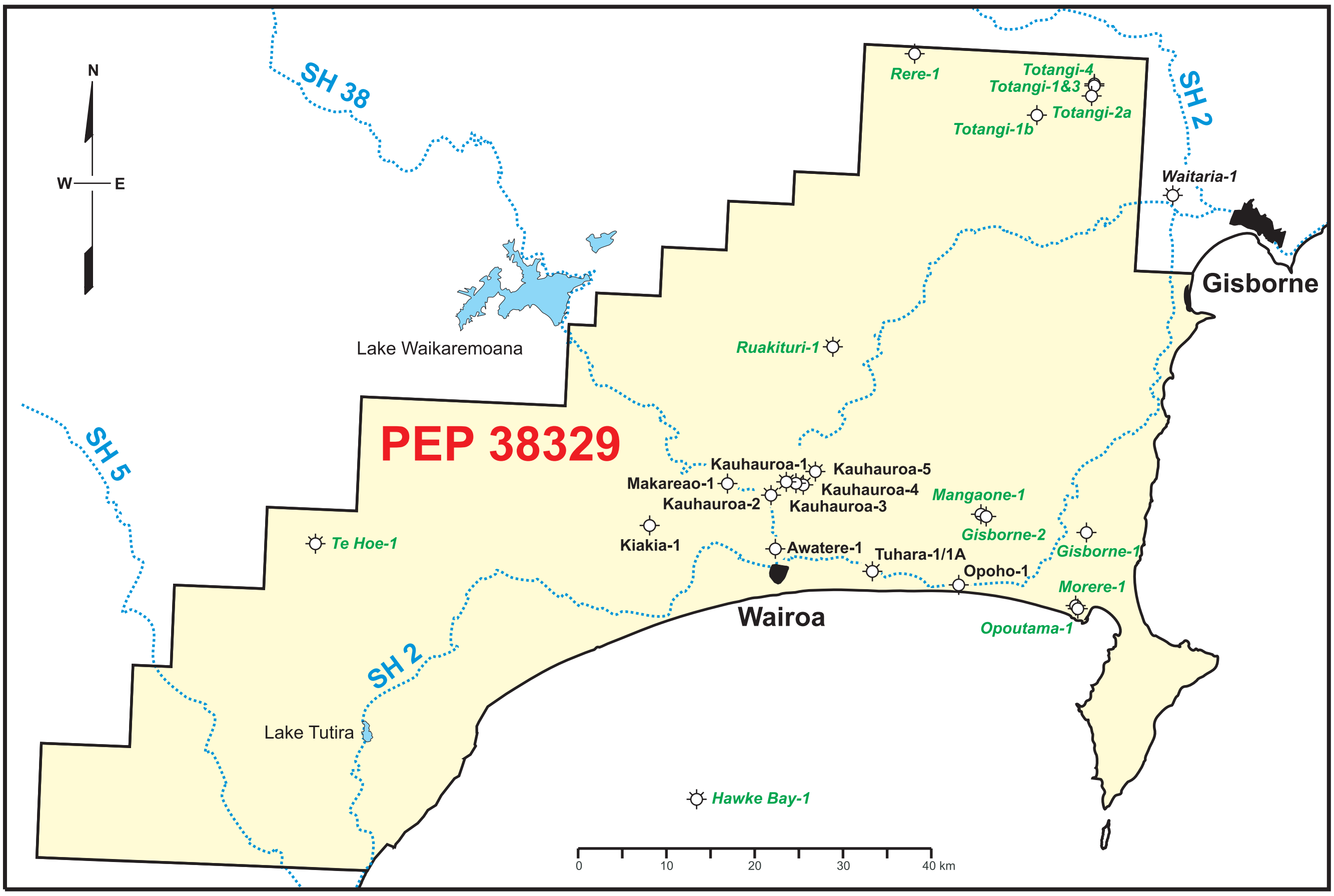

Figure 2: Petroleum wells in PEP 38329, East Coast Basin. Older wells shown with italicised names.

Cretaceous reservoirs in proximity to Cretaceous and Paleogene source rocks. The Te Hoe-1 well was drilled in 1990 to 627 m, and a small amount of gas was flared during testing. Petrocorp also carried out field mapping, soil gas and aeromagnetic studies in the Wairoa area, but in 1995 chose to drop their East Coast exploration in order to focus on Taranaki exploration.

Thus in 1996, when Westech Energy and Enerco (now Orion) acquired permits, there was a substantial body of surface mapping, seismic data of varying quality, and regional studies of reservoir and source rock potential. Westech reprocessed much of the older seismic, then carried out a reconnaissance seismic programme with vibroseis sources. Potential targets were detailed by dynamite-source seismic lines. Key points of this phase of the exploration were described by Davies et al. (1998):

1. a number of structural traps, some identified in surface mapping, and others previously unknown, were mapped from seismic lines;
2. a paleo-bathymetric high ("Wairoa High") was postulated across the Wairoa area in Early-Mid Miocene time;
3. the primary reservoir targets were the Makaretu and Tunanui sandstone formations, a series of Late-Mid Miocene, deep-water turbidite systems cropping out on the northwest and northeast flanks of the Wairoa Syncline;
4. an active petroleum system was indicated by oil and gas seeps in the region, and likely to be sourced from Paleogene-Late Cretaceous Waipawa Black Shale and Whangai Formation, and/or older Cretaceous formations.

Current exploration

From March 1998 to December 1999, Westech-Orion drilled six exploratory wells and five appraisal wells (Figure 2). Six previously undrilled structures were evaluated by the Kauhauroa-1, Awatere-1, Makareao-1, Kiakia-1, Tuhara-1 and Opoho-1 wells. These penetrated Pliocene to Early Miocene or Oligocene sections, with total depths ranging from 940 to 2320 m. Kauhauroa-2 to 5 and Tuhara-1A were subsequently drilled for reservoir appraisal. All the wells encountered significant gas shows, and two wells discovered hydrocarbons in potentially commercial volumes. Each well was drilled on the crest of a seismically mapped structure, characterised by asymmetric folding over a northwest-dipping thrust fault, with subordinate fore-thrust splays and back-thrusts.

Stratigraphy

Prognoses were based on outcrop sections to the northwest and northeast, and the Ruakituri-1 well. Potential reservoirs were identified as the Makaretu Sandstone of Waiauan to Early Tongaporutuan age (late Middle-early Late Miocene), and the older Tunanui Sandstone of Lillburnian age (Middle Miocene), with the Tahaenui Limestone (Pliocene) in Awatere-1 as a secondary target (Figure 3). Given the distance to comparable well and outcrop sections, the prognoses relied heavily on seismic interpretation, in later wells using pre-stack depth migration.

The stratigraphic nomenclature (Figure 3) is based on long-established but informal names erected by Vacuum Oil Company (Bremner et al 1934), used in part by BP (who mapped mainly in time-stratigraphic units), and resurrected by Hoolihan (1980) and Francis (1991, 1993). New formations and members have been defined during the drilling programme.

The new wells in the Wairoa area penetrated a largely complete stratigraphic succession from the latest Pliocene to the base of the Late Miocene. These strata are typically upper-mid bathyal, mudstone-dominated strata with a previously unrecognised unit of thinly interbedded sandstone and mudstone called the Makareao Sandstone Member in the lower Poha Formation. The Pindari Mudstone or Kiakia Limestone rests unconformably on an Early Miocene succession, and the Middle Miocene is almost entirely absent. The seismic reflectors prognosed as Makaretu Sandstone are now correlated with a previously unknown, tightly cemented, bryozoan limestone, named Kauhauroa Limestone, of mid-Altonian (Early Miocene) age. This is in places overlain by an interbedded sandstone and mudstone formation assigned to the Rere Sandstone (Early Miocene). The limestone unconformably overlies a mudstone-dominated formation assigned to the Wheao Formation (Early Miocene), which in turn overlies Weber Formation (Oligocene).

Wells to the east of Wairoa (Tuhara-1 and Opoho-1) encountered a succession similar to that in outcrop, with a major unconformity beneath the mid-Pliocene truncating a conformable latest Miocene to Oligocene succession. Although the Makaretu Sandstone was not encountered in this area, the Middle Miocene Tunanui Sandstone is developed. As in the older Mangaone-1 well, the Rere Sandstone is present as a series of units within the Waingaromia Mudstone, and a prominent sandstone unit is present in the Weber Formation.

Stratigraphic relationships from the Kauhauroa Anticline across the Wairoa Syncline and onto the Mangaone Anticline are demonstrated in Figure 4. Shelf limestones (Kauhauroa Limestone and Kiakia Limestone) pinch out north and eastwards down the nose of the Kauhauroa Anticline, and are not present on the Mangaone Anticline. Conversely, the deepwater turbidite formations (Rere Sandstone, Tunanui Sandstone and Makaretu Sandstone) are well developed in the east but pinch out on the flanks or crest of the Kauhauroa Anticline. Late Miocene and Pliocene formations are thickly developed in the Wairoa Syncline and also in the basin west of this cross section, but thin markedly across the Kauhauroa Anticline (with truncation of latest Miocene-early Pliocene strata).

Reservoirs

The main differences between prognoses and actual well results are firstly, the presence of the Kauhauroa Limestone, a formation unknown from adjacent outcrop, and secondly,

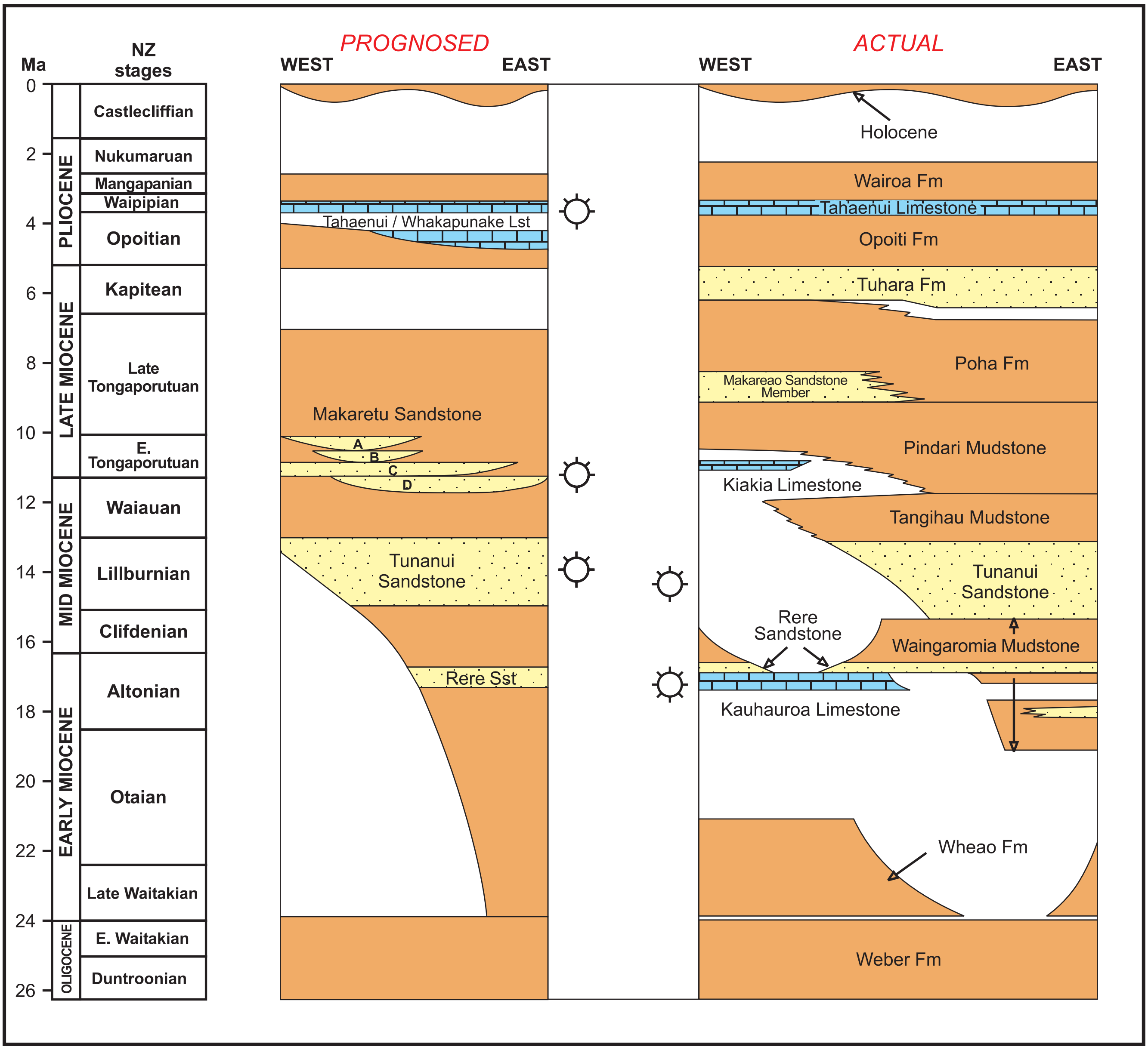

Figure 3: Chronostratigraphic column of Neogene strata in the Wairoa region, comparing pre-drilling prognosed reservoir formations (left) with current stratigraphic units (right). Most formation names are informal, and are derived from Bremner et al (1934), Francis (1993), or are new names adopted during the drilling programme.

the virtual absence of Makaretu sandstones. The two primary reservoirs in the region are the Kauhauroa Limestone and the Tunanui Sandstone. Other prospective reservoirs include a thick-bedded sandstone unit in the Weber Formation, thin-bedded sandstones in the Wheao Formation, the Rere Sandstone, Kiakia Limestone, and Makareao Sandstone Member of the Poha Formation.

Kauhauroa Limestone

The Kauhauroa Limestone (new name) is a cool-water, bryozoan-dominated, platform limestone of mid Altonian (Early Miocene) age. It is characterised on seismic by one or more high-amplitude reflectors, indicating that the limestone blankets the Wairoa High, ranging up to 130 m thick (Figure 5). The bulk of the formation is a tightly cemented, homogeneous grainstone or packstone, but in Kauhauroa-2, the upper part of the formation is interbedded with siltstone, and may represent syndepositional slumping off the Wairoa High.

In addition to bryozoan fragments (typically erect, branching growth forms), the limestone is composed of a diverse fauna of echinoderms, bivalves and both benthic foraminifera (e.g. *Amphistegina*) and planktic foraminifera (M. Longman, unpublished 1999). Detrital quartz sand and glauconite are also common. Skeletal fragments are tightly packed (Figure 6), and cemented by calcite in syntaxial overgrowths on echinoderm fragments and as equant spar, with scattered dolomite present. Detrital clays are present in only trace amounts. Virtually all porosity is fracture porosity, in northeast-striking fracture systems related to anticlinal folding.

The predominance of bryozoa, the presence of planktic foraminifera, and the local association with debris flows

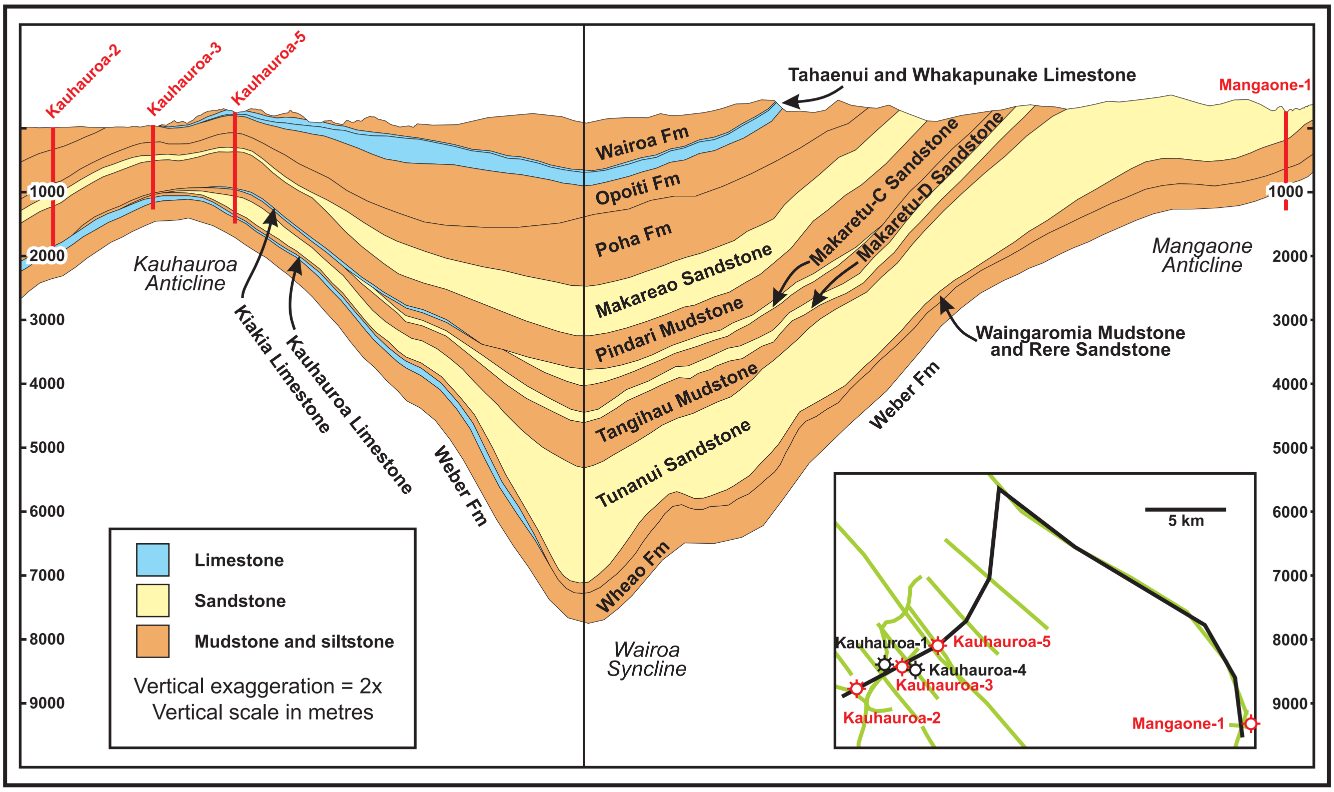

Figure 4: Geologic section along the strike of the Kauhauroa Anticline, which plunges northeastwards into the Wairoa Syncline. From the syncline axis, the section follows seismic line GW-2 southeastwards onto the crest of the Mangaone Anticline. The oldest horizon shown is the Miocene-Oligocene boundary. Inset shows line of section, with well and seismic control.

indicate a mid-outer shelf environment, comparable with present-day carbonate shelves off southern Australia (e.g. Boreen and James 1993) and New Zealand (Nelson et al. 1988).

The limestone is unknown from adjacent outcrop, but is a likely time-equivalent of the Moonlight Limestone, which crops out 80 km to the NNE (Mazengarb et al. 1991). Both limestones may occur within the same transgressive-early highstand systems tract (Field, Uruski et al. 1997). The Kauhauroa Limestone may be the equivalent age and shelf correlative of an intra-Waingaromia unconformity inferred in Opoho-1. The Waingaromia Mudstone and its Rere Sandstone members were deposited in a mid-lower bathyal environment, probably during lowstand periods. During an intervening highstand, sediment supply may have ceased to deepwater environments, while increased accommodation space allowed limestone deposition on the adjacent shelf.

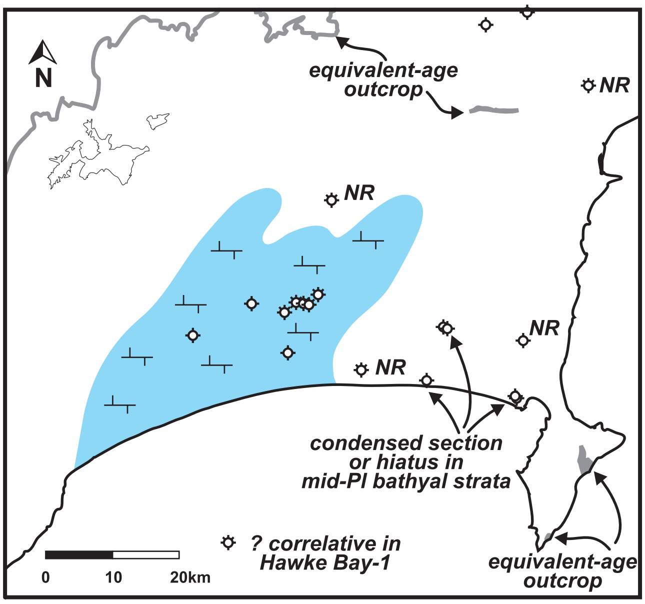

Figure 5: Subsurface distribution of the Kauhauroa Limestone (shaded), based on well and seismic control. Wells labelled NR did not reach the equivalent stratigraphic level.

Tunanui Sandstone

The Tunanui Sandstone is a turbidite complex of Lillburnian (Middle Miocene) age, which crops out extensively over inland northern Hawkes Bay and the west side of Poverty Bay. Isopachs of gross thickness (Figure 7), based on well and outcrop sections, show the formation to be over 1000 m thick over much of its extent, reaching 2000 m in a southeastwards-directed tongue which extends into offshore Poverty Bay and Hawke Bay. Paleocurrents determined from flute casts and groove marks show dominantly southeastwards transport directions.

The equivalent shelf succession to the northwest has been uplifted and eroded. A possible equivalent exposed in the western part of the permit is the Poamoko Formation (Cutten 1994) which comprises shell-rich sandstone of uppermost bathyal to outer shelf paleoenvironments. Although the same age as, or older than, Tunanui Sandstone, the transition between the formations occurs in remote terrain, and is poorly understood.

Figure 6: Thin section of typical Kauhauroa Limestone, showing a tight skeletal lime grainstone with common quartz and glauconite grains. Fossil debris includes bryozoa, echinoderms and molluscs. Almost all porosity between grains has been filled with equant calcite cement. Photo by M. Longman.

The northwesternmost strata of the Tunanui Sandstone, exposed at Lake Waikaremoana and upper Ruakituri River, comprise interbedded sandstone and mudstone punctuated by thick-bedded sandstone channel-fills. Foraminifera indicate a mid-bathyal paleoenvironment with water depths in excess of 600 m (B. Field, IGNS, unpublished data).

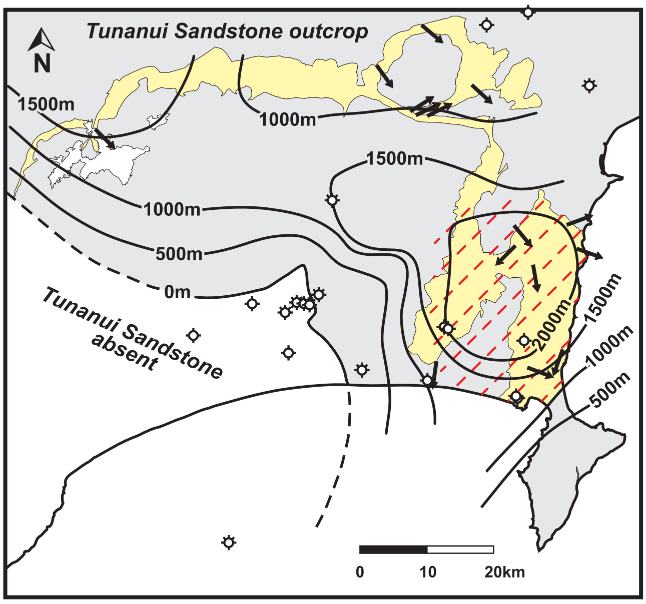

Figure 7: Distribution of Tunanui Sandstone (Middle Miocene), showing isopachs of gross thickness and inferred subsurface extent. The area with over 80% net sand is identified by diagonal dashed pattern. Black arrows are measured paleocurrents. Data from wells, seismic control and new field studies plus Haw (1959a,b), Phizackerley (1962), Francis (1993), and B. Field (IGNS, unpublished data).

Farther down-dip, turbidite facies are commonly mud-dominated, with low net thicknesses of thin-bedded, tight, very fine-grained sandstone. This facies suggests a slope environment bypassed by the bulk of the redeposited sand. This was mapped in the past as Taumatapoupou Formation (Bremner et al. 1934), but with no clear distinction from the Tunanui Formation.

In southeastern coastal areas, the Tunanui Sandstone represents more significant sand deposition in a basin-floor fan, with net sand commonly over 80%. Sandstone beds are typically 1-4 m thick (Figure 8), locally amalgamated up to 15 m thick. Large spheroid calcareous concretions are common in the middle part of thick sandstone beds. The sandstone is typically fine to very fine-grained sublitharenite, ranging from clean but calcite-cemented, well sorted sandstone to friable moderately sorted silty sandstone with appreciable clay matrix. Between these extremes there are sandstones with fair to good porosity and good permeability. Outcrop samples yield porosities up to 26% and permeabilities up to 128 mD (Francis 1991, 1993; unpublished Westech data).

The Tunanui Sandstone was penetrated by Westech wells Kauhauroa-5, Tuhara-1 and Opoho-1, and is absent in wells farther west. The gross thickness of 1000 m in Opoho-1 drops to 260 m in Tuhara-1 and 140 m (dip-corrected) in Kauhauroa-5, confirming the seismic interpretation of westwards pinchout onto the Wairoa High. Foraminifera indicate a lower bathyal paleoenvironment with water depths down to 1200 m, supporting a deep basin-floor fan deposit.

The well sections are characterised by medium-thickly bedded, fine to very fine-grained sandstone and mudstone, with net sand typically about 40%. The sands are feldspathic litharenites, moderately sorted and subangular-subrounded. They are slightly-well consolidated, locally tightly cemented, with moderate-common clay cement (J. C. Webb, unpublished data). Porous sandstones have 18-22% porosity and 10 mD permeability. Log trends indicate generally uniform successions, with locally thicker claystone beds up to 2 m. Tight streaks on logs may correspond to the concretions seen in outcrop, but whereas the latter form up to 10% of the sandstone, their equivalents at depth form 40-50% of the sandstone.

Makaretu Sandstone

The Makaretu Sandstone encompasses a series of turbidite systems, of which the A, B, and C sandstones are of Early Tongaporutuan age (Late Miocene) and dominantly occur to the northwest of Wairoa. The D sandstone is Waiauan in age (Middle Miocene) and occurs mainly on the east flank of the Wairoa Syncline. A revised map to that presented in 1998 (Figure 9) shows the sandstones ponded or deflected by the Wairoa High. Although less widely distributed than prognosed, the Makaretu sandstones may have reservoir potential in stratigraphic pinchout traps on the flanks of the Kauhauroa and Makareao structures.

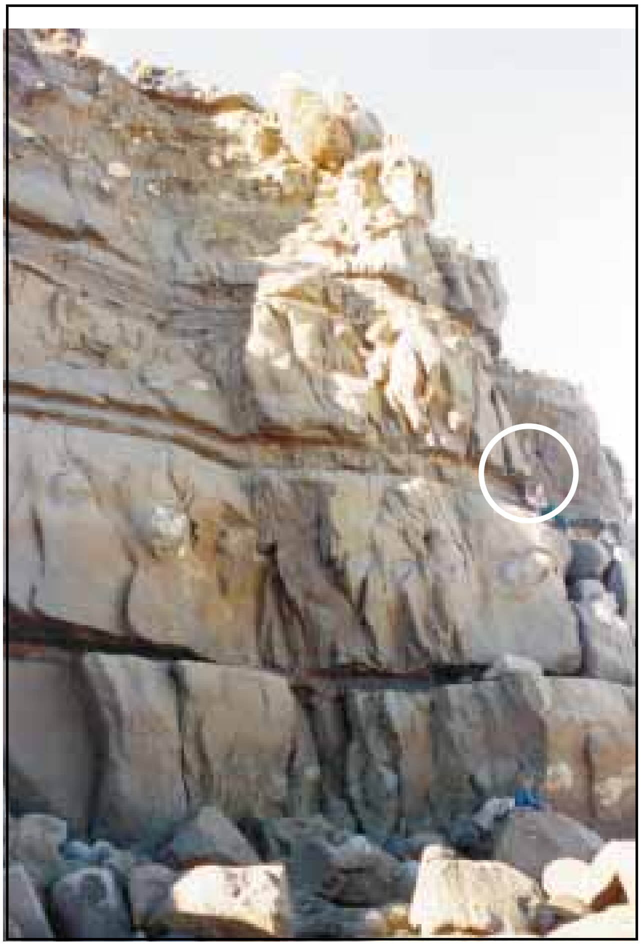

Figure 8: Very thickly bedded Tunanui Sandstone, comprising massive fine sandstone with calcareous concretions, alternating with thin beds of laminated sandstone and mudstone, near Opoutama, northern Hawkes Bay. Figure with 1.5 m staff for scale (circled).

Figure 9 also shows the extent of a shelf limestone correlative, the Kiakia Limestone. This limestone, up to 30 m thick, is similar to the Kauhauroa Limestone but is about 5 million years younger, and of basal Tongaporutuan (earliest Late Miocene) age. It was tested in Kiakia-1, but has not been encountered with fracture development comparable to the Kauhauroa Limestone.

Pliocene limestone

Previous workers speculated on the reservoir potential of the Pliocene coquina limestones, which are widespread in outcrop (Beu 1995), with permeabilities ranging into darcies (de Caen and Darley 1968; Francis 1993). The Awatere-1 well provided a significant test of such a play, with the Tahaenui Limestone thickly developed on a structural high, with apparent amplitude pinchout down-dip. However, drilling showed that the limestone was strongly cemented with no visible porosity, indicating that cementation took place at relatively shallow depths (600-700 m present depth plus about 500 m stripped off by erosion). Limestone outcrops on the basin flanks may not have been buried to such depths, or may have been modified by meteoric diagenesis.

Overpressures

Abnormally high formation pressures have been a characteristic of all the new wells. The Kauhauroa gas reservoir has a pressure of 3400 psi at 1000 m depth, equivalent to a formation pressure gradient of 0.9 psi/ft and a mud weight of 19.0 pounds per gallon (Figure 10). A review of the literature and worldwide file searches by mud companies has not found any comparable pressures in hydrocarbon reservoirs at this shallow depth anywhere in the world.

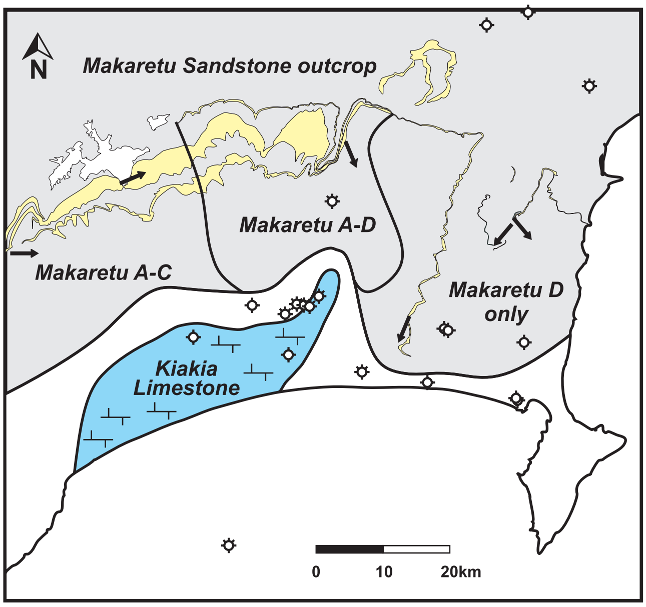

Figure 9: Distribution of Makaretu Sandstone units and Kiakia Limestone, showing inferred subsurface extent and paleocurrent data (black arrows). Makaretu outcrop shown by dark shading. Data from seismic control and new field studies plus Haw (1959b), Francis (1994).

Throughout the East Coast Basin, overpressured smectitic shales have caused considerable problems in many of the early wells, including Mangaone-1 (Brown 1961). Mud volcanoes associated with outcropping shale diapirs have exhibited spectacular activity during large earthquakes (e.g. Strong 1933; Ridd 1970). These smectite-rich shales are dominantly within the Eocene Wanstead Formation, and prior to drilling in the Wairoa area, it was less apparent that over-pressuring would be developed in Miocene strata. A probable mechanism is disequilibrium compaction, caused by basin-infilling of mud-dominated sediments, under high sedimentation rates and with few hiatuses.

Crestal pressure gradients at Middle-Early Miocene level are commonly over 70% of the lithostatic pressure gradient (Figure 11). The occurrence of such high pressure in the Kauhauroa structure is surprising given the proximity to outcrop of Middle Miocene reservoirs 20 km to the east. The only major structural separation from outcrop is the Wairoa Syncline, and the overall structural relief from the base of the syncline to the crest of the Kauhauroa Anticline is about 6000 m (Figure 4). Folding of anticlines in the Wairoa area, associated with underlying blind thrusting, is inferred to have commenced in the latest Miocene (5-6 Ma). The Kauhauroa Anticline has the steepest flanks of the structures resolved by seismic. We conclude therefore that the extreme overpressure at Kauhauroa reflects relatively young uplift of fossil pressures, with insufficient subsequent time for pressure equilibration within an overall overpressured system.

A major advantage of Kauhauroa-type overpressure is that it will concentrate 2.5 times the gas reserves of a normally pressured, comparable reservoir. However, drilling and reservoir evaluation can be difficult. Drilling costs are one third higher due primarily to barite mud costs, and heavy mud weights hamper thorough evaluation of the wells. The borehole itself is intrinsically unstable due to formation pressure, and this problem is often compounded by lost circulation due to differential overpressures. In most cases we were able to acquire the Schlumberger Platform Express suite, but many times we were reluctant to risk the static logging tools such as the repeat formation tester (or, later the modular dynamic tester) and sidewall core tool. We have obtained conventional cores, which have been very helpful even though core runs were shortened due to the barrel jamming in inferred fracture zones. The Formation Micro-Imaging log has also proved valuable for bedding and fracture attitude measurements and bed thickness analyses.

The main log interpretation evaluation problem relates to borehole corrections and to the effect of barite mud invasion of reservoirs. In consequence we have run production casing on most wells to confirm formation fluid content. Even here, there are some uncertainties due to cementing problems in heavy mud systems, and a propensity to cement channelling behind casing.

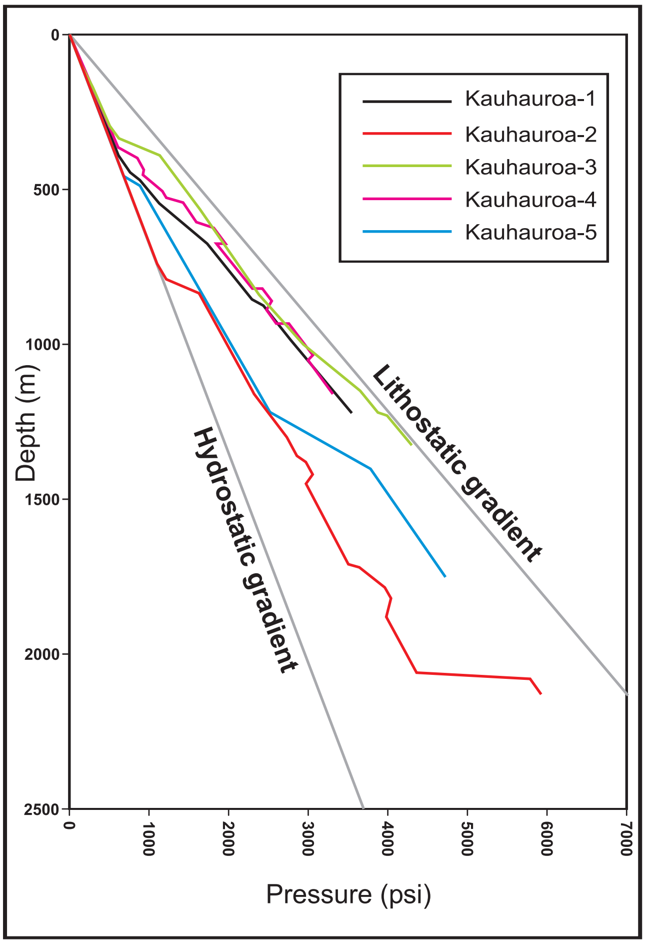

Figure 10: Formation pressure gradients of Kauhauroa wells.

Seals

Thick, clay-rich mudstone formations separate and overlie the reservoir formations. These are considered effective seals, to the extent that water analyses from reservoirs are consistent, with little indication of flushing. However we do observe that the methane gas and water phases have not always

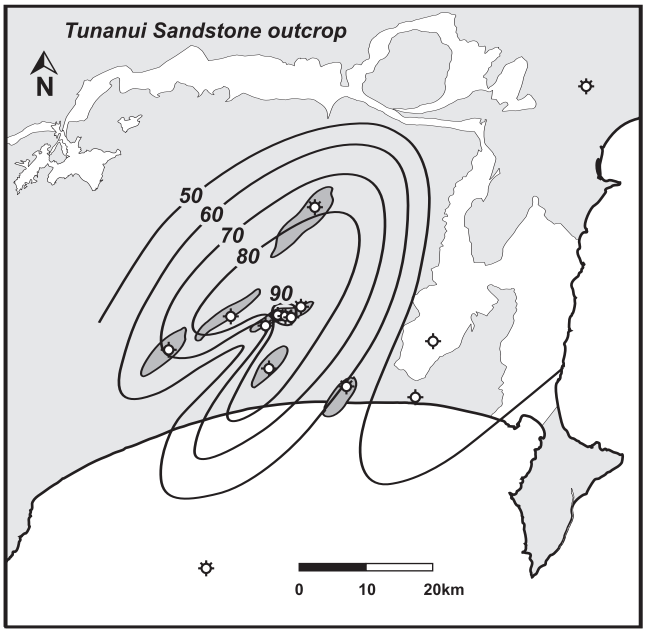

Figure 11: Crestal formation pressure gradients in the Wairoa region, expressed as a proportion of the lithostatic pressure gradient. Structural closures indicated by dark shading.

separated in the reservoir, particularly in Makareao-1 and Kiakia-1. The quantities of gas far exceed methane solubility limits, and we are thus looking to a combination of inadequate charge and seal fracturing as a possible explanation. In a few cases, we also suspect that the cement has failed to adequately isolate discrete gas and water zones behind casing.

Hydrocarbon occurrences

Significant gas shows were encountered in all wells, and typically comprised 98% methane, 0.2-0.4% ethane and negligible amounts of higher hydrocarbons. Nitrogen and carbon dioxide comprised 1.2-2.2% and 0.04-0.06% respectively. Higher hydrocarbons were encountered in Tuhara-1A, with up to 0.8% ethane, 0.07% propane and traces of C4-7 alkanes in the Tunanui Sandstone.

None of the Westech wells penetrated below the Oligocene Weber Formation. No significant organic horizons were encountered, and vitrinite reflectance data indicate that the well sections were too immature for hydrocarbon generation. Although Lowry et al. (1998) suggested that a biogenic methane source would explain many methane-rich gas accumulations in the East Coast, isotopic analyses of methane from Kauhauroa-1, Awatere-1 and Tuhara-1A indicate a thermogenic origin (Figure 12). We therefore continue to believe that the source rock is an older formation and probably the Waipawa Black Shale (Paleocene) or Whangai Formation (Late Cretaceous), or possibly an older Cretaceous formation.

Exploration strategy

A key issue in petroleum exploration of a large, structurally complex, onshore permit is the application of finite financial resources (the budget allocation) to maximise the probability of finding commercial hydrocarbons within a finite time frame (the permit term awarded by the Crown). From a strategic perspective, this issue resolved down to the optimum balance between seismic detailing and drilling. In an attempt to relate strategy to financial resources, we examined the cost of possible exploration activities relative to the cost of a dry hole (Table 1). This table highlights the different exploration strategies warranted by onshore and offshore.

Onshore, we acquired a regional vibroseis grid at the outset, which revealed a large number of structural reversals. The question then focused on the cost benefits of helicopter-dynamite 2D and 3D surveys, since the rugged topography ruled out vibroseis detailing. Further analysis evaluated the overhead and delay costs attributable to seismic detailing and intermittent drilling, as opposed to continuous drilling.

Offshore, the seismic versus drilling benefits are reversed. This supported the decision to acquire the very large, exploratory 3D survey described elsewhere in these Proceedings.

The onshore drilling programme has identified two structures with hydrocarbons in potentially commercial volumes, which will be the focus of ongoing exploration in the permit area.

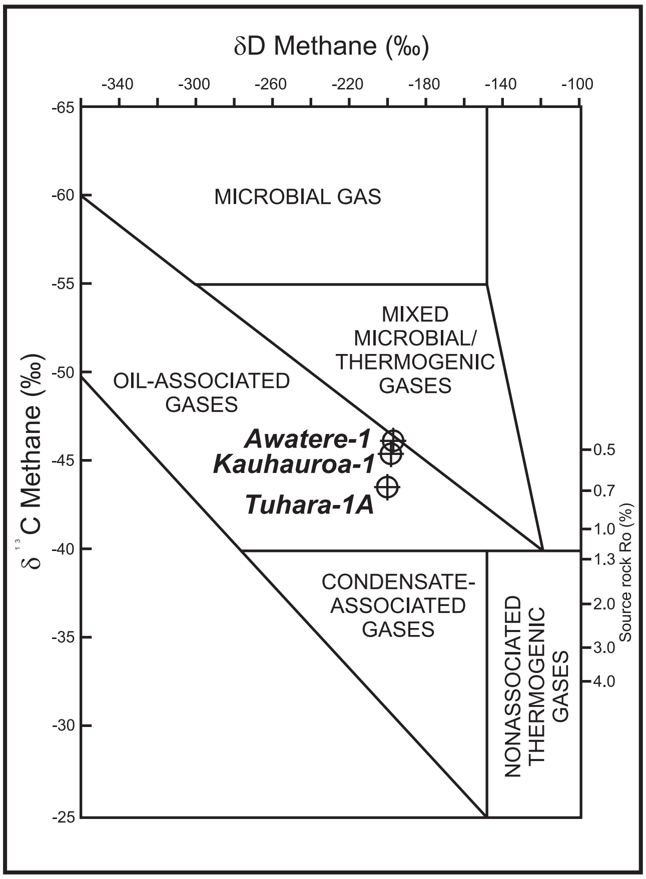

Figure 12: Plot of methane sigma 13C versus methane sigma D, Kauhauroa-1, Awatere-1 and Tuhara-1A. Genetic composition fields from Laughrey and Baldassare (1998). Analyses by G. Lyon (IGNS).

The onshore stratigraphy is now known in some detail, while valuable experience has been gained in drilling and evaluating overpressured formations. This wealth of data sets the stage for venturing into offshore Hawke Bay.

References

Beu, A. G. 1995. Pliocene limestones and their scallops. Lithostratigraphy, pectinid biostratigraphy and paleogeography of eastern North Island late Neogene limestone. Institute of Geological and Nuclear Sciences monograph 12.

Boreen, T. D.; James, N. P. 1993. Holocene sediment dynamics on a cool-water carbonate shelf, Otway, southeastern Australia. Journal of sedimentary petrology 63: 574-588.

Bremner, C. St. J. and others 1934. East Coast area: Geological maps, cross sections, stratigraphic columns and correlations. Vacuum Oil Co. report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 204.

Brown, B. R. 1961. Geological completion report for Mangaone-1. BP, Shell & Todd Petroleum Development Ltd. report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 320.

Cutten, H. N. C. 1994. Geology of the middle reaches of the Mohaka River. Scale 1:50 000. Institute of Geological & Nuclear Sciences geological map 6.

Davies, E. J.; Frederick, J. B.; Leask, W. L.; Williams, T. J. 1998. East Coast Basin exploration. 1998 New Zealand Petroleum Conference proceedings: 101-113.

ONSHORE	OFFSHORE
ONE WELL	ONE WELL
equals	equals
125 KM 2D VIBROSEIS	16,000 KM 2D SEISMIC
equals	equals
50 KM 2D HELI-DYNAMITE	
equals	
30 KM^2 3D HELI-DYNAMITE	2,500 KM^2 3D SEISMIC
equals	equals
1 YEAR OVERHEAD	13 YEARS OVERHEAD
equals	equals
1.5 WELLS CONTINUOUSLY DRILLED	1.3 WELLS CONTINUOUSLY DRILLED

Table 1: Comparison of onshore and offshore exploration costs.

De Caen, R. F. B.; Darley, J. H. 1968. An examination of Wanganui carbonates, Hawkes Bay, North Island, New Zealand. BP Shell Aquitaine and Todd Petroleum Development Ltd report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 382.

Field, B. D.; Uruski, C. I. and others 1997. Cretaceous - Cenozoic geology and petroleum systems of the East Coast region, New Zealand. Institute of Geological & Nuclear Sciences monograph 19.

Francis, D. A. 1991. Reservoir formations adjacent to offshore PPL 38315, Gisborne Region, East Coast, New Zealand. Client report to Pan Energy Resources Inc. Ministry of Commerce, New Zealand, unpublished Petroleum Report 1827.

Francis, D. A. 1993. The geology of the Mangaone - Opoutama area, Hawkes Bay, adjacent to PPL 38321. Client report for Conquest Exploration Ltd. and American Exploration Co. Ministry of Commerce, New Zealand, unpublished Petroleum Report 1927.

Francis, D. A. 1994: Reservoir formations in license area PPL 38316, northern Hawkes Bay, East Coast Basin, New Zealand. Client report for Petrocorp Exploration Ltd. Ministry of Commerce, New Zealand, unpublished Petroleum Report 2149.

Haw, D. 1959a. The geology of the Morere-Kopuwhara Uplift. BP, Shell & Todd Petroleum Development Ltd report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 312.

Haw, D. 1959b. Geological completion report on the Mangaone-Waingake Uplift (including the Waerangaokuri Culmination). BP, Shell & Todd Petroleum Development Ltd report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 315.

Hoolihan, K. 1980. Proposed study of source rock potential in the Gisborne region, East Coast Basin, North Island, New Zealand. Petroleum Corporation of New Zealand (Exploration) Ltd and BP (Oil Exploration) Company of New Zealand Ltd report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 835.

Laughrey, C. D.; Baldassare, F. J. 1998. Geochemistry and origin of some natural gases in the Plateau Province, Central Appalachian Basin, Pennsylvania and Ohio. American Association of Petroleum Geologists bulletin 82: 317-335.

Lowry, D. C.; Francis, D. A.; Bennett, D. J. 1998. Biogenic gas: a new play in the East Coast Basin of New Zealand. 1998 New Zealand Petroleum Conference proceedings: 207-221.

Mazengarb, C.; Francis, D. A.; Moore, P. R. 1991. Sheet Y16 Tauwhareparae. Geological map of New Zealand 1:50 000. New Zealand Geological Survey, Department of Scientific and Industrial Research, Wellington.

Nelson, C. S.; Keane, S. L.; Head, P. S. 1988. Non-tropical carbonate deposits on the modern New Zealand shelf. Sedimentary Geology 60: 71-94.

Phizackerley, P. H. 1962: Geology of the Ngatapa District including Otoko-Totangi area. BP, Shell and Todd Petroleum Development Ltd geological report. Ministry of Commerce, New Zealand, unpublished Petroleum Report 317.

Ridd, M. F. 1970. Mud volcanoes in New Zealand. American Association of Petroleum Geologists bulletin 54: 601-616.

Strong, S. W. S. 1933. The Sponge Bay uplift, Gisborne, and the Hangaroa mud blowout. New Zealand journal of science and technology 15: 76-78.

Authors

ED DAVIES holds BSc and PhD degrees in geology from the Universities of Wales and Alberta and a MSc in management from the Massachusetts Institute of Technology. Prior to being appointed President of Westech Energy, he worked for Shell and Conoco.

JOHN FREDERICK holds a BA degree in physics from the Colorado College. Prior to joining Westech Energy as Manager of Interpretation, he worked for Ampolex (USA), Inc. and McAdams, Roux and Associates.

BILL LEASK holds a MSc from Victoria University of Wellington. He is a geologist with Ian R. Brown Associates Ltd., a geological and engineering consulting firm based in Wellington.

TOM WILLIAMS holds a BA degree in geology from the University of Colorado and a MSc degree in geophysics from Stanford University. Prior to joining Westech Energy as Manager of Geophysics, he worked for Amoco and Rocky Mountain independent oil companies.