TARIKI SANDSTONE EARLY OLIGOCENE HYDROCARBON RESERVOIR EASTERN TARANAKI, NEW ZEALAND

J F De Bock, J A Palmer and R G Lock
Petrocorp Exploration Ltd

In eastern Taranaki, New Zealand, wells drilled in the area of the Tariki-Ahuroa overthrust complex, encountered hydrocarbon bearing sandstone reservoirs of Oligocene age. This sandstone facies, the Tariki Sandstone, extends almost 50 km from Urenui-1 in the north, to Waihapa-1 in the south. Good reservoir properties are restricted to a few wells only, as the sand becomes increasingly silty and interbedded towards the south and west. The Tariki Sandstone is interpreted as a series of turbidite deposits, with characteristics of a submarine fan system.

INTRODUCTION

The Tariki-Ahuroa gas/condensate field was discovered in 1986. The hydrocarbons are trapped in a thick sandstone sequence that exhibits good reservoir quality. Subsequent drilling to the south found sandstone belonging to the same facies, but failed to yield significant hydrocarbons.

This sandstone dominated sequence, named the Tariki Sandstone, is of Oligocene age and consists of turbidites, channel, crevasse channel and levee deposits. The lack of well control, especially to the east of Ahuroa and Tariki, hampers the reconstruction of the exact environment of deposition. However, the available data support a possible outer shelf to mid-bathyal depth of deposition, the facies possessing characteristics of some form of submarine fan system. The fan is a departure from the simple pattern of radial growth, probably because of structural constraints of sediment dispersal and deposition.

DEFINITION OF TARIKI SANDSTONE MEMBER

The Tariki Sandstone is confined to the eastern part of the Taranaki Graben (Fig. 1). It is named after the Tariki-1A discovery well in northeast Taranaki and consists of a sequence of sandstones with siltstones and mudstones, interpreted as a sequence of turbidites. The Tariki Sandstone is a member of the lower part of the Otaraoa Formation (Fig. 2), which is thickest in the eastern part of the Taranaki Graben (Palmer, 1985).

Well developed sandstone beds occur at Tariki and Ahuroa; thin, discontinuous sandstone beds, pebble bands and beds containing carbonaceous fragments extend north to the McKee area. The sandstones are continuous to the south to Wharehuia, Piakau, Toko and Waihapa, where they become increasingly more interbedded and finer grained with thick intervals of claystone (Fig. 3). A fine-grained Tariki Sandstone equivalent occurs as very thin interbeds as far west as the Stratford and Kapuni wells (Figs. 4 and 5).

The top of the Tariki Sandstone is characteristically well defined on wireline logs. It is marked by the onset of a sandy interval below a mudstone dominated sequence. The base of the Tariki sandstone is commonly less clear, as it grades into a mudstone dominated Otaraoa sequence between the Tariki Sandstone and the Matapo Sandstone.

Faunal assemblages in the mudstone intervals of the Tariki Sandstone Member, give an Early Oligocene to Mid Oligocene age (Whaingaroan).

LITHOLOGY

The Tariki Sandstone is an interbedded sequence consisting of thin to thick, sometimes graded, sandstone, calcareous mudstone and limestone. The calcareous zones are variable and occur as marls, cemented fault zones, and veins. The sandstones are composed of white to light grey, well consolidated, generally clean, fine- to medium-grained quartz and feldspar grains, with minor lithic grains, and ubiquitous calcareous cement. Detrital coal fragments, up to 3 cm across, are common locally (Fig. 6).

The sandstones are of subfeldspathic or sublithic composition and usually contain marine fossils or glauconite. The majority are bimodal, between fine and medium or fine and coarse sand grade, and moderately sorted; better sorted unimodal sandstones also occur. Detrital mud is largely restricted to thin interbeds.

The Tariki Sandstone differs from the McKee sandstone (McKee Formation, Fig. 2) in various aspects. The McKee sandstone is slightly coarser and more angular and contains more feldspar. The Tariki Sandstone contains allochthonous coal fragments and claystone lithoclasts. The sandstones of the McKee Formation are interbedded with coalbeds and carbonaceous, silty, mudstones. The reservoir quality of both sandstones deteriorates rapidly from north to south. The McKee Formation becomes very silty south of Toetoe; the Tariki sandstone becomes increasingly interbedded,

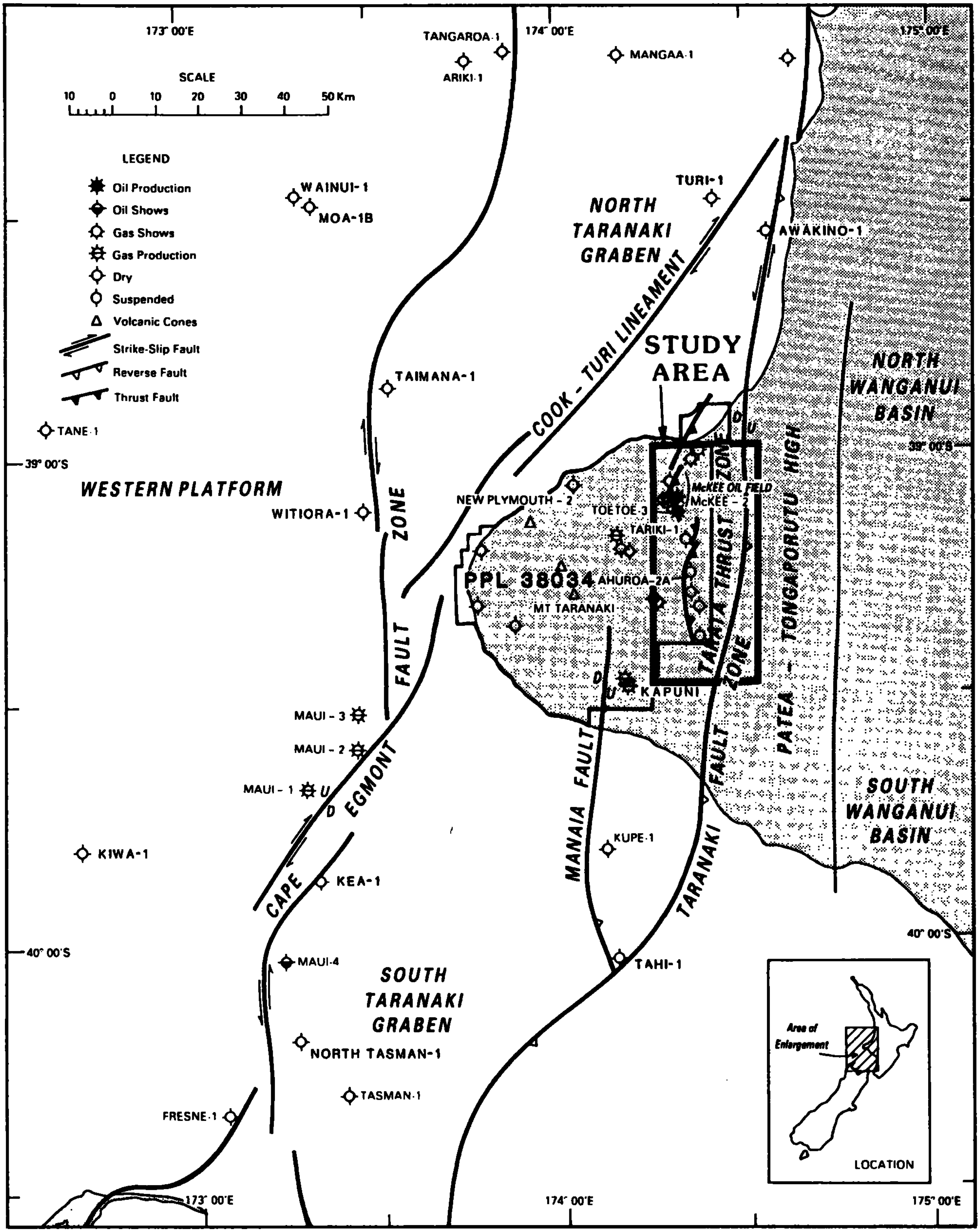

Fig. 1: Taranaki Basin major tertiary structural elements.

finer and silty at the Wharehuia, Toko, and Waihapa wells. The sandstone facies of the Tariki member is virtually absent at the Stratford and Kapuni wells. North of Toetoe-4, the Tariki Sandstone is represented by a few thin-bedded pebble and calcareous sandstone beds.

TECTONIC SETTING

The main structural features of the Taranaki Basin are shown in Fig. 1. The original structural framework was formed by Early Cretaceous block faulting of basement followed by Mid-Late Cretaceous rifting associated with the opening of the Tasman Sea. The emergent landmass consisted of north

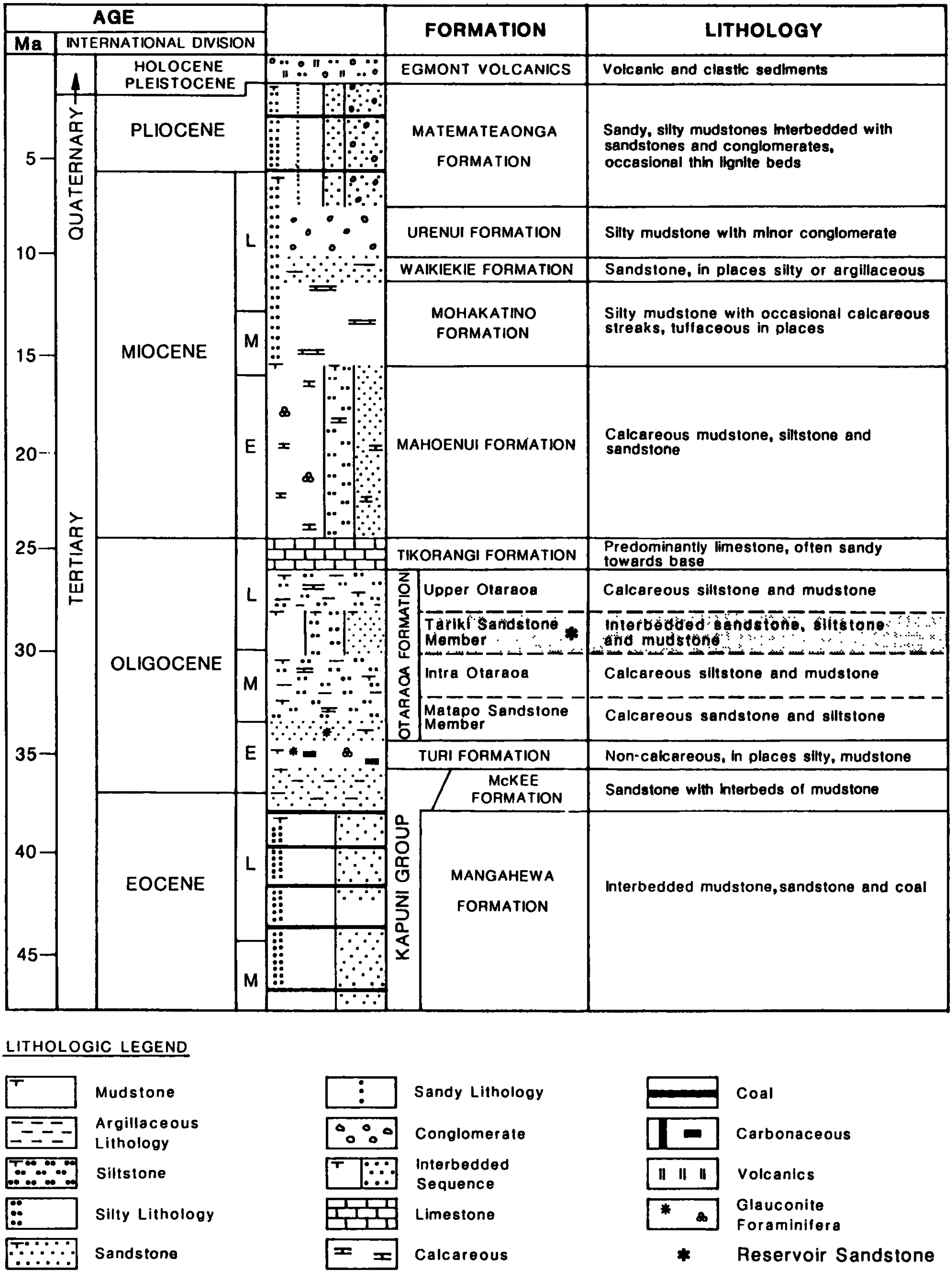

Fig. 2: Summary of the stratigraphy of Ahuroa/Tariki area.

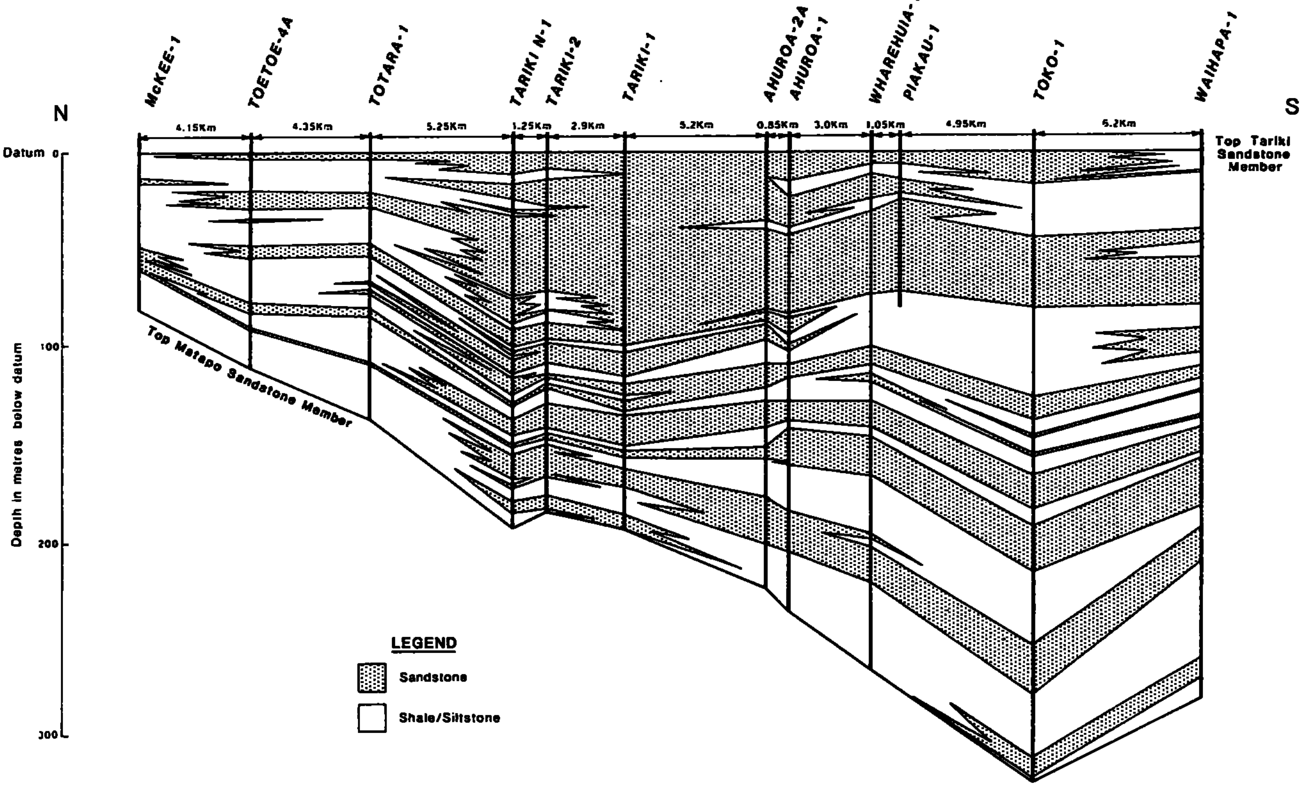

Fig. 3: North-south cross-section Tariki Sandstone Member.

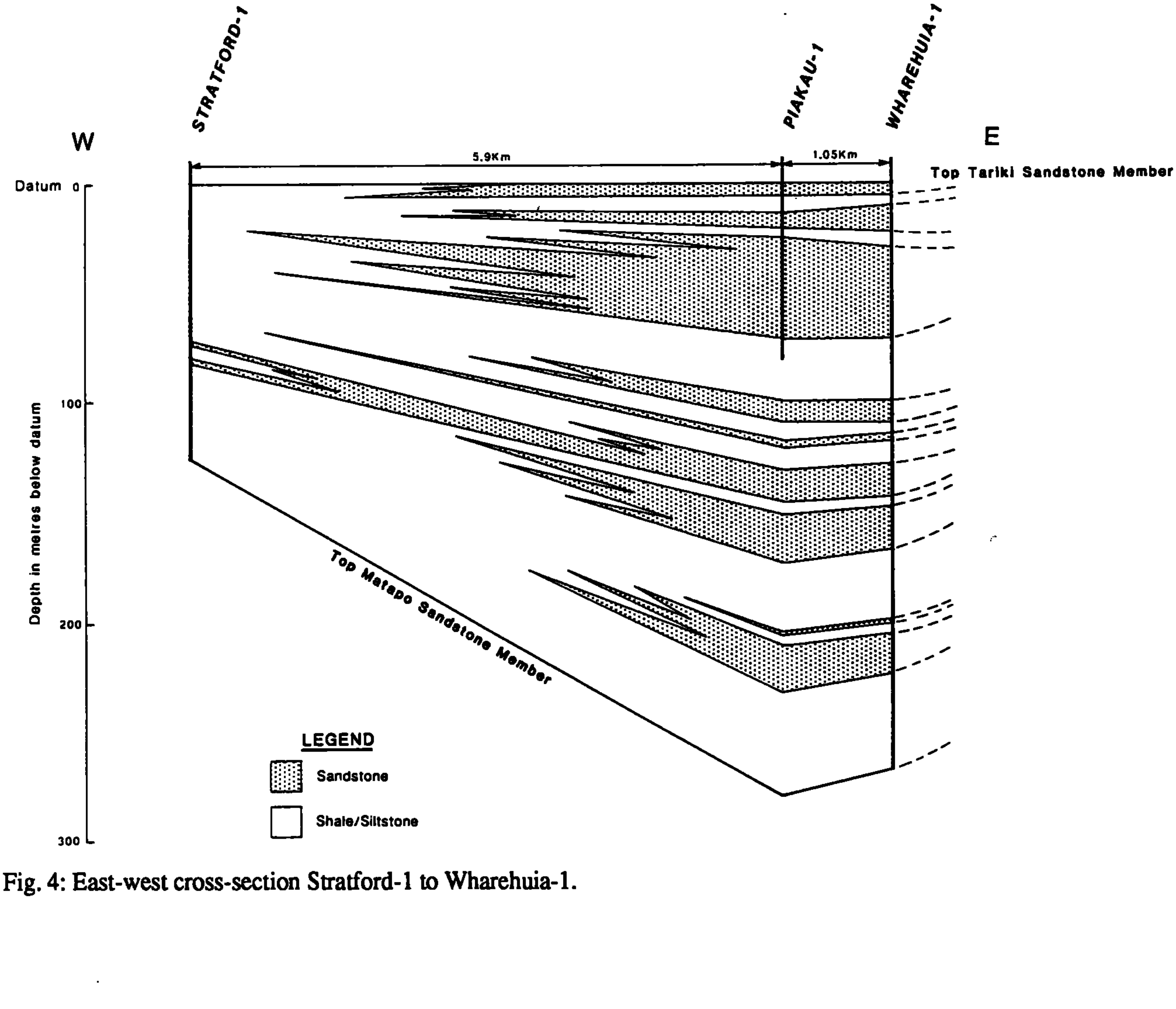

Fig. 4: East-west cross-section Stratford-1 to Wharehuia-1.

trending uplifted blocks and intervening grabens and half-grabens in which accumulated thick sequences of mainly continental sediments (Late Cretaceous coal measures and conglomerates, Fig. 2).

Seafloor spreading in the Tasman Sea ceased in the Paleocene (52 MYBP). Soon after, the Pacific and Austro-Indian plate boundary was propagated through the New Zealand microcontinent, changing the orientation of the principle horizontal stress and progressively modifying the structural regime of the Taranaki Basin.

The principle horizontal stress changed from parallel-to to oblique-to the pre-existing structural grain, causing faults to become reactivated as compressional wrench faults. A widespread Late Eocene-Early Oligocene unconformity is seen in the southern part of the basin. This appears to have been formed by uplift and tilting, probably in response to the changing orientation of the principle horizontal stress direction.

A half graben was formed between the Cape Egmont Fault Zone and the Taranaki Fault. Subsidence of the half graben was greatest immediately adjacent to the Taranaki Fault. A basin was thus formed, with the Patea-Tongaporutu High to the east and the Kapuni Stratford Mangahewa axial high to the west. A second tectonic phase, which resulted in fault reversal, occurred in the Early Miocene, when crustal stresses were being propagated into the basin via the Taranaki Fault. This caused wrenching and compression along several of its splay faults. The McKee, Tariki and Ahuroa structures formed in onshore Taranaki and the Awakino and Te Ranga structures in northeastern offshore Taranaki. Fig. 7 shows a cross section through the Ahuroa Structure.

FACIES DESCRIPTION AND DISTRIBUTION

Continuous and very thick sandstones occur at Tariki North-1A, Tariki-1, -2, Ahuroa-1, -1A and Ahuroa-2, -2A. Cores show that the sandstones are relatively clean, with varying amounts of calcite cement, and some argillaceous matter often incorporated by bioturbation. The base of the core at Tariki-1 is essentially claystone, but contains slumped blocks of pseudonodules of sandstone. In Tariki North-1A the core shows claystone rip-up clasts, thin claystone laminae and bioturbation. The sandstone contains clasts and flecks of angular to rounded lithic fragments, 0.5 cm diameter, well-rounded, turquoise green clasts, and randomly scattered sandy mudstone clasts 0.5 to 1.0 cm across. The sandstone sometimes contains 5 to 50% coal fragments (Fig. 6). In Ahuroa-1 core the sandstone is cross bedded and contains sparsely distributed clay clasts. The claystone interbeds are less than 10 cm thick and occur at various spacings up to a metre or more. Thin bioturbated siltstone intervals occur in the core, and skeletal components include agglutinated Foraminifera, Rotalids and fragments of Echinoderms and mollusc. Calcite cement occurs in bands less than a metre thick. Carbonate rich zones of 2.5 to 7.5 m thick are recorded consisting of dolomite and dolomitic limestone.

Electric logs show coarsening and/or finding upwards sequences, with only thin interbeds of claystone. These facies are interpreted to be a series of stacked channel flows and progradation deposits. The thick sandstone sequence at Tariki and Ahuroa is the result of channel erosion, filling, abandonment or rejuvenation. The base of the sandstone units appear to be load deformed. Immediately south of Tariki-Ahuroa area sandstone quality deteriorates rapidly; the beds become thinner, finer and silty. Logs in the Wharehuia and Waihapa wells show channel fill, levees and graded turbiditic sandstones. Although logs allow correlation of the Tariki Member to the Stratford, and Kapuni wells, these wells are virtually devoid of sandstone (Figs. 4 and 5). Log correlation is also possible north of Tariki North-1A, as far north as Urenui-1. Here, the Tariki Member equivalent includes a few sandy, calcareous intervals containing distinctive pebble horizons. The pebbles consist mainly of metaquartzites.

ENVIRONMENT OF DEPOSITION

General

Close examination of the tectonic setting, sediment source and supply, mode of sediment transport and regional setting, show facies characteristics resembling those of a submarine fan system near an active margin. Channels are represented by sequences of clean sandstone with thin claystone interbeds showing thinning and fining upward cycles. The thin sandstones interbedded with claystones are more probably crevasse channels and intralobe/overbank deposits. The sand sequences are thick near Tariki and Ahuroa, and thin to the south, north and west. The distal parts of the turbidites are represented by thin continuous sand and clay sequences at Waihapa, the sands showing mainly fining upwards characteristics. These are thought to be in a distal lobe position. The source of the clastic influx is from the east, probably near Ahuroa-1 and -2, running down slope and becoming southward directed, parallel to the Taranaki Fault (Fig. 8).

Depth of deposition

Mudstone of the Otaraoa Formation, immediately overlying the Tariki Sandstone, possesses Foraminiferal assemblages indicative of mid bathyal to bathyal depth. The Tariki Member itself, contains a mixed shallow and outer shelf fauna, which is consistent with rejuvenation.

Basin subsidence was greater to the south and near the Taranaki Fault (see Tectonic setting). Rip-up clasts at the base of subsequent channel deposits suggest seafloor gradients were steep and sediment was transported by high energy gravity flows. All these observations suggest the Tariki Sandstone was deposited in outer shelf to mid bathyal water depths.

Input point

Stacked channel sequences, composed of sandstone with claystone and fine sandstone rip-up clasts, with erosional contacts, occur in the Tariki and Ahuroa wells. Angular coal fragments indicate proximity to a coal rich source. Electric logs show both fining and coarsening upwards, indicating channel, crevasse channel and levee deposits. Only sparse channel deposits are recognised in the area from Wharehuia to Waihapa; thin sandstones interbedded with thick claystone intervals, representative of distal turbidites, are characteristic. In fan terminology, the Tariki Sandstone Member is more proximal at Ahuroa-1, -2 than at Tariki-1, Tariki North and other wells. A single input point may have existed near the Ahuroa wells, where meandering channels form thick sandstone dominated sequences in a middle to upper fan position (Fig. 8).

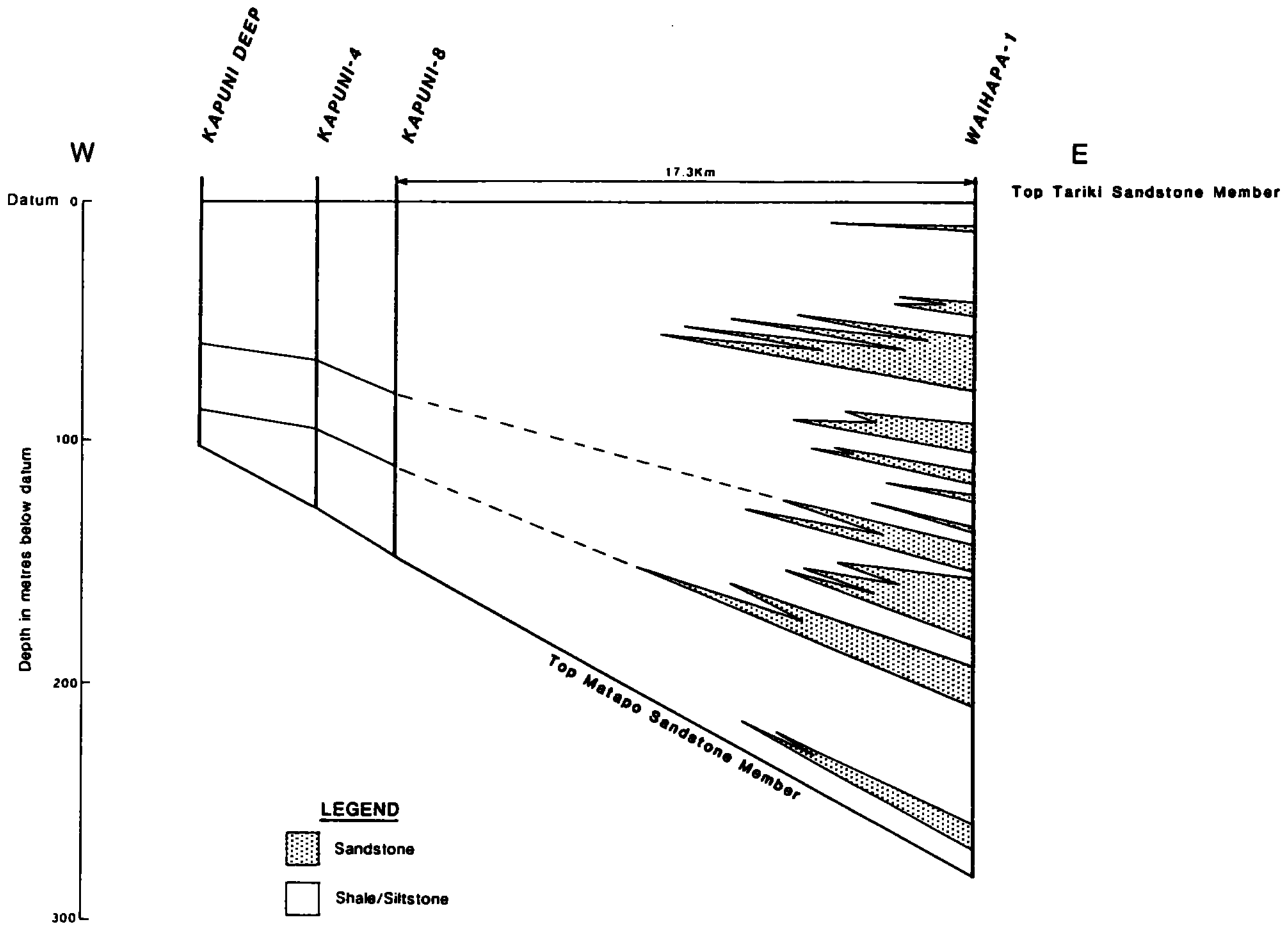

Fig. 5: West-east cross-section Kapuni Deep to Waihapa-1.

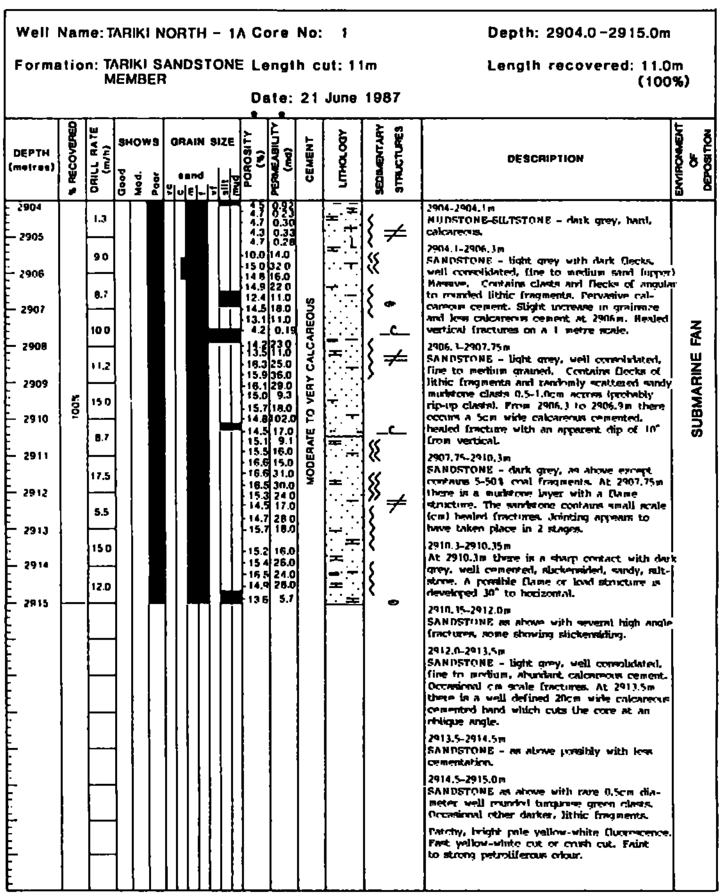

Fig. 6: Core description Tariki North-1A.

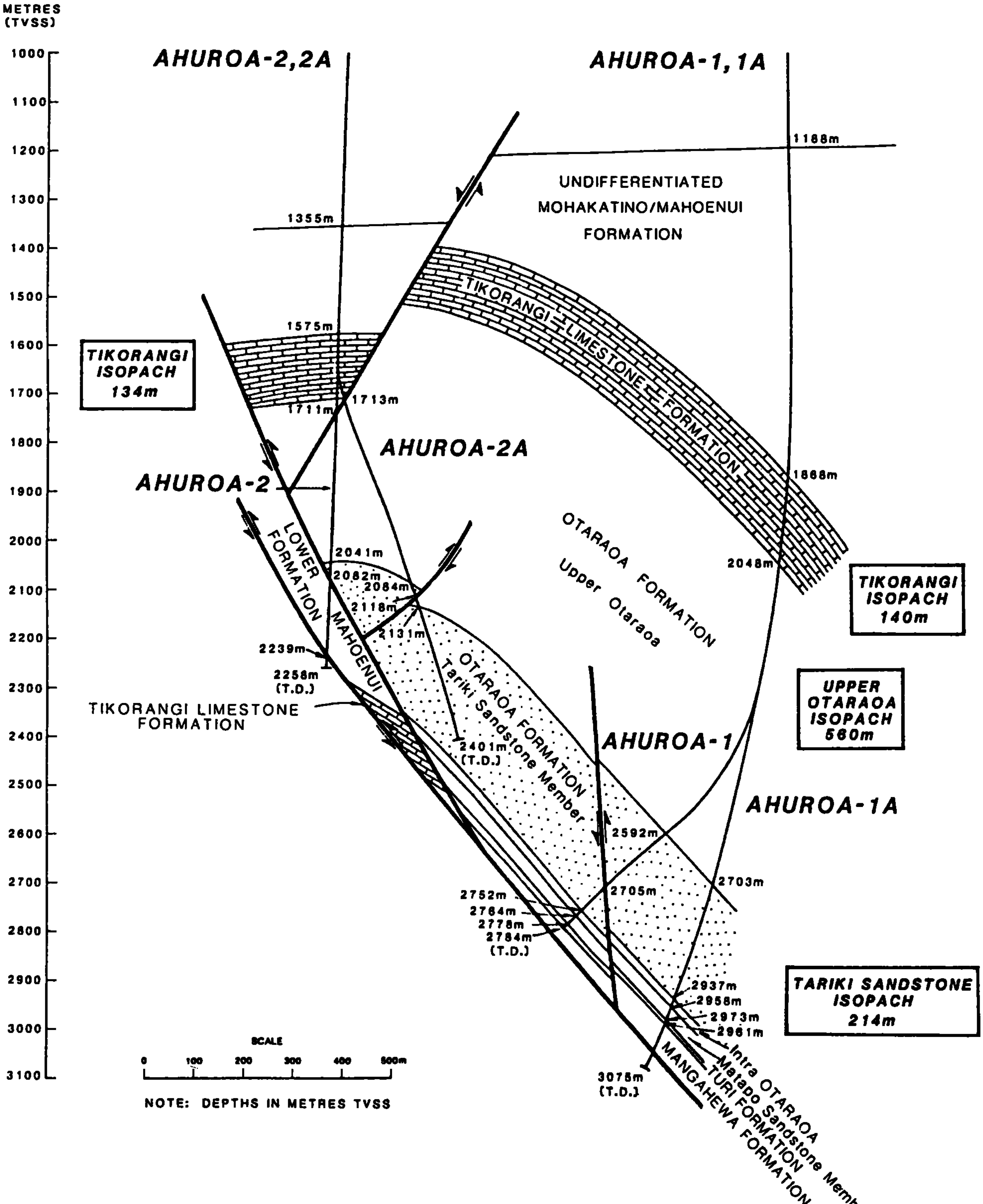

Fig. 7: Cross-section through Ahuroa structure.

Source

Sandstone distribution and current and channel direction plots suggest that the origin of the Tariki Sandstone lies to the east (Figs. 9 and 10). Exposed Kapuni Group rock is the most likely candidate for source. The Kapuni Group consists mainly of cylothems of sandstone/siltstone/coal, of terrestrial origin. Coal fragments in the Tariki Sandstone of Toko-1, were dated as Arnold Series (Kapuni Group) age. The Kapuni Group source is also supported by the low percentage of moderately sorted and moderately to well-rounded feldspar grains, indicative of a second cycle, reworked sediment.

No Kapuni Group sediments are known to exist east of the Taranaki Fault. Vertical movement, up to 7000 m along the Taranaki Fault, and subsequent erosion, are possibly responsible for its apparent absence.

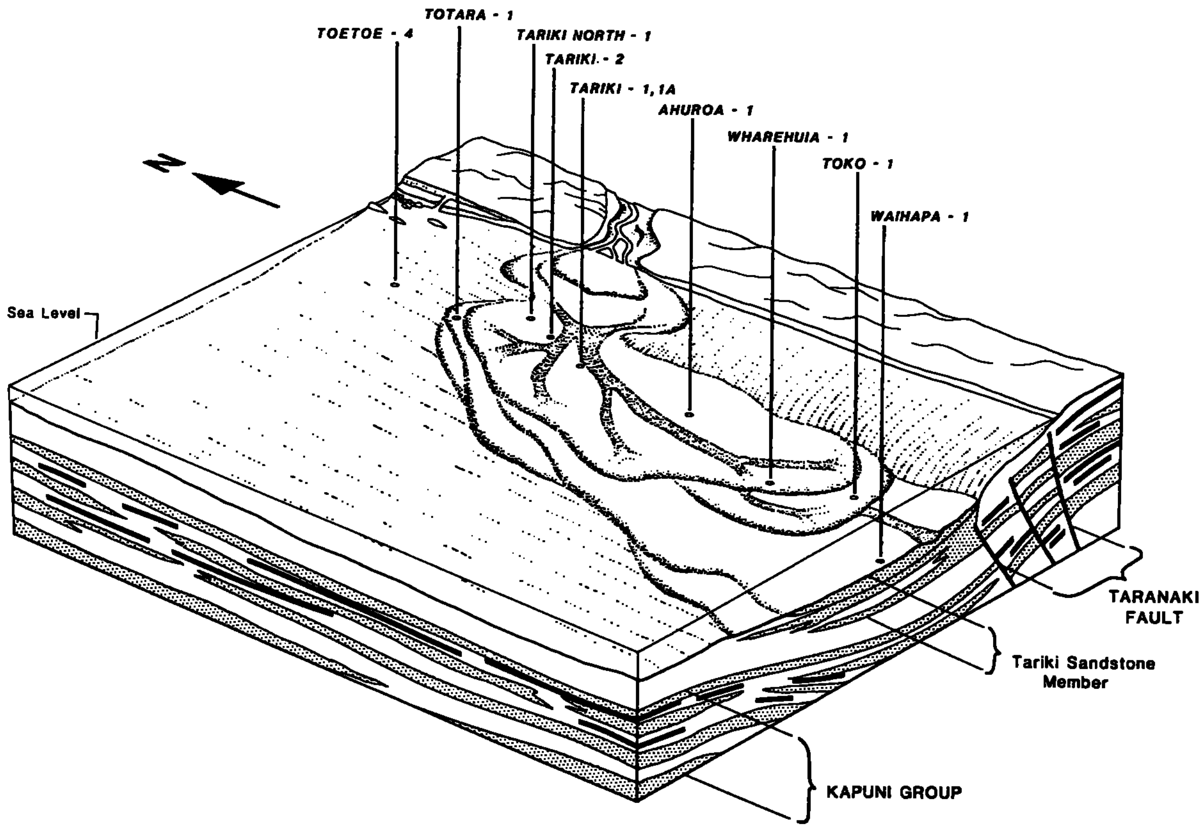

Fig. 8: Schematic Block diagram of the submarine fan system of the Tariki Sandstone Member.

The Taranaki Fault scarp in Early Oligocene times probably consisted of several levels of shallow, possibly narrow, terraces consisting of blocks of Kapuni Group rocks. The terrain was bordered by a steep, westerly directed, slope into the basin. The erosional products of the Kapuni Group sequences initially accumulated in a presumably coastal to deltaic setting. Intermittently these sand deposits slumped to form west and south flowing turbidity currents. The turbidity flows ran mainly parallel to the Taranaki Fault, depositing an elongated system of sandy sediments that extended from Tariki to Waihapa-1 (Fig. 8).

Sediment supply

Well correlation (Wharehuia-Toko-Waihapa) shows three major cycles of sand deposition, each followed by a clay dominated sequence (Fig. 5). Thick clay intervals, as well as the minor interbeds of claystone, reflect periods of poor sediment supply. They may be related to relative sealevel rises rather than *sedimentary bypass zones*. High stands of sealevel coincide with relatively inactive phases in fans and turbidites (Stow *et al.*, 1985; Shanmugam *et al.*, 1988). Sediment transport across the shelf would have been at reduced levels, as more detritus is trapped in estuaries, lagoons and other nearshore environments. Cyclicity in vertical sequences may thus be related to repeated sea-level fluctuations as well as to normal channel abandonment. High stands of sea-level are often periods of relative fan dormancy, while low stands of sea-level commonly result in active fan growth. The periodicity of tectonic activity and sea-level changes are significant controlling factors in fan development.

The isopach maps for the Tariki Sandstone show a thickening from north to south, with the thickest deposits near Toko-1 and Waihapa-1 (Fig. 11). Log and core analyses indicate sequences in a proximal setting near Tariki and Ahuroa, becoming increasingly distal to the south and north. These, coupled with the observed current and channel direction (Figure 10), suggests either a paleo sea-floor sloping to the south and/or an increased rate of subsidence to the south, sub parallel to the Taranaki Fault.

RESERVOIR PROPERTIES

Porosity values were determined using density and neutron logs, and are in good agreement with measurements of in situ core porosity (overburden). There are, however, fundamental difficulties in estimating porosity from logs at Ahuroa and Tariki because of the extreme variation in lithology, the presence of gas and the possible existence of a dual porosity system. Table 1 shows the porosities for the hydrocarbon bearing intervals.

Porosity	Tariki	Ahuroa	Wharehuia
Average	14.3%	17.0%	14.8%
Range	6.5-21.7%	26.5-22.5%	5.0-23.0%

Table 1: Log porosities in hydrocarbon bearing sandstone intervals.

Secondary porosity and micro-porosity were identified during petrographic studies of the Tariki Sandstone.

Diagenetic evolution of the sandstones is similar in the Tariki and Ahuroa wells and is interpreted as leaching of feldspars to create secondary mouldic pores, followed by precipitation of carbonate cements and authigenic clays. Compaction and associated pressure solution led to the

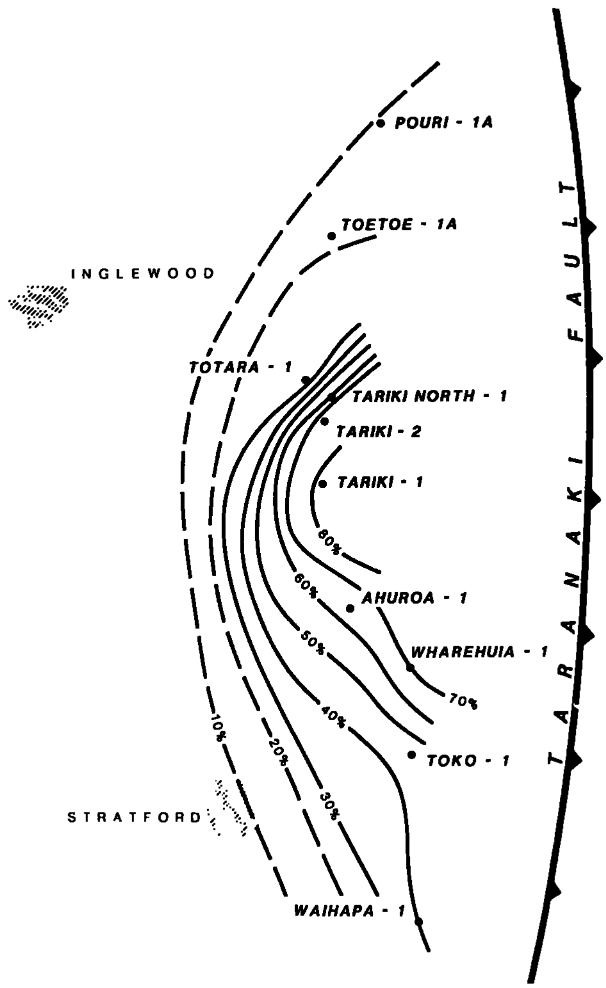

FIGURE 9 : % NETT SANDSTONE OF THE TARIKI SANDSTONE MEMBER

Fig. 9: Percentage nett sandstone of the Tariki Sandstone Member.

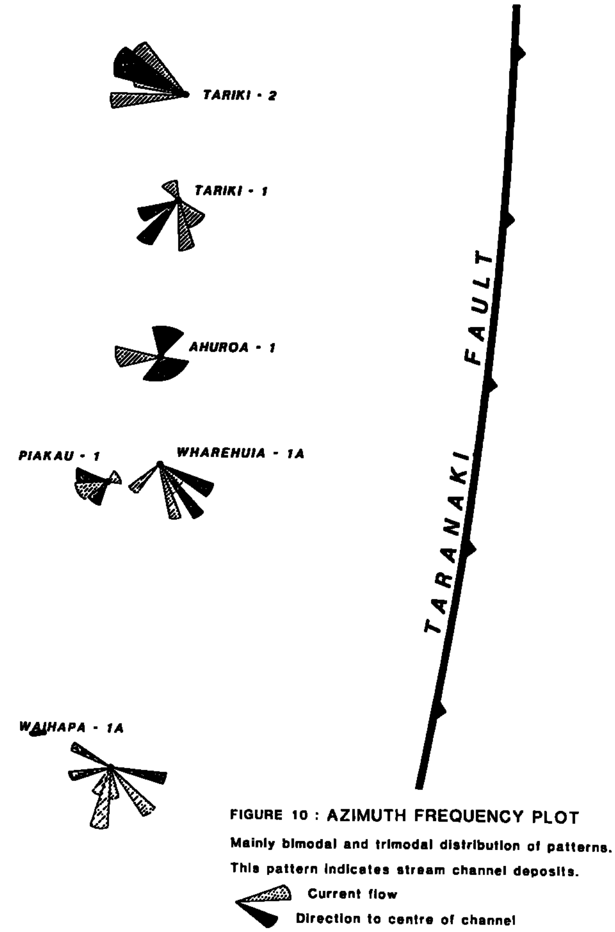

Fig. 10: Azimuth frequency plot.

suturing of grains and reduction of intergranular pore space. Sandstone porosity is provided by intergranular pores, secondary mouldic pores and micropores.

Permeability is more variable than porosity on account of the microporosity and is best developed at the Ahuroa and Tariki wells. The higher permeabilities are apparent where both primary and secondary pores are preserved. A general reduction in grain size, thinning of the beds and increase in clay content further reduces porosity and permeability to the south.

RESERVES

The Tariki and Ahuroa gas/condensate discoveries are located in the eastern part of the former petroleum prospecting licence PPL 38034 (now PMLs 38138 and 38139) (Fig. 1). Both fields are small by comparison with Maui, Kapuni and McKee, but both are expected to be commercially viable. An integrated development using common production facilities is envisaged, but will be dependent upon identifying suitable gas markets. The Tariki-1A well was production tested at a maximum rate of 28 MMSCFD of gas and 1395B/d of condensate. Ahuroa-2A was tested at a maximum rate of 24.1 MMSCFD of gas and a 826B/d of condensate. Table 2 shows the reserve estimates for Tariki and Ahuroa fields.

	Tariki Discovery	Ahuroa Discovery
Hydrocarbon initially in place		
Oil/Condensate (MMstb)	6.35	2.20
Gas (BCF)	124.00	55.30
Ultimate recovery		
Oil/Condensate (MMstb)	2.38	0.94
Gas (BCF)	80.44	38.80
Cumulative production to 31 March 1987		
Oil/Condensate (MMstb)	0.009	0.0075
Gas (BCF)	0.166	0.1900
Reserves estimates as at 1 April 1987		
Oil/Condensate (MMstb)	2.82	0.93
Gas (BCF)	80.30	38.70

Table 2: Tariki and Ahuroa reserves estimates.

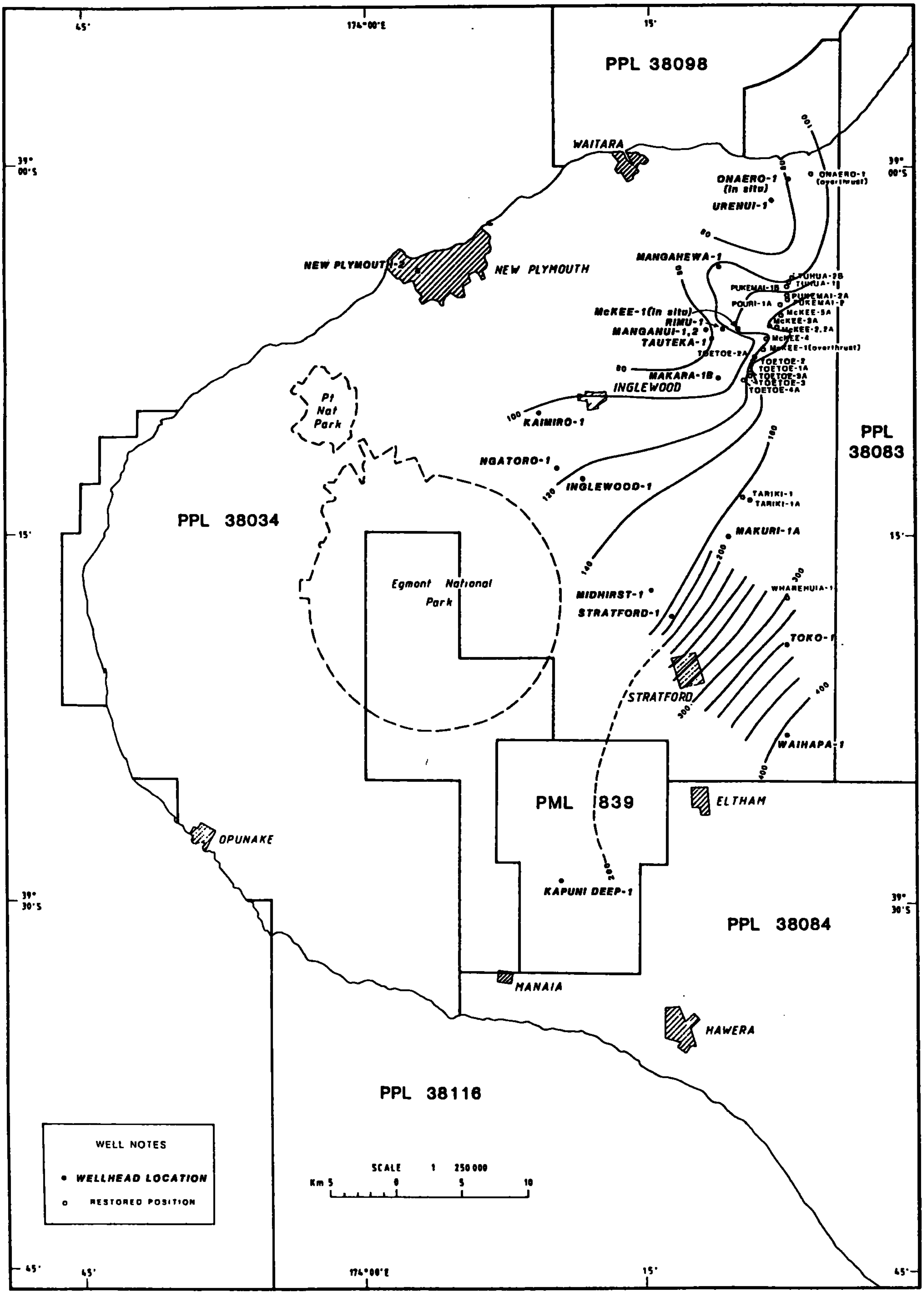

Fig. 11: Top Tariki Sandstone Member to Matapo Sandstone.

CONCLUSIONS

The Tariki Sandstone is an example of an ancient turbidite deposit forming a marine fan system, at middle to outer shelf depth, along an active basin margin. The channel and turbidite sequences show the typical contorted mudstone and siltstone of slump origin, pebbly mudstone of debris flow origin. Well correlation indicates the Ahuroa and Tariki wells are proximal and the Toko and Waihapa are more distal. Reservoir quality of the Tariki sandstone deteriorates to the west, south and north of Ahuroa and Tariki area. Exploration to date shows that the Tariki sandstone of reservoir quality appears to be limited to the Tariki-Waihapa area.

REFERENCES

BOUMAN, A.H., W.R. NORMARK AND N.E. BARNES, 1985: *Submarine Fans and Related Turbidite System*, Springer Verlag, New York.

PALMER, J.A., 1985: PreMiocene Lithostratigraphy of Taranaki Basin, New Zealand, *NZ Journal of Geology and Geophysics*, *28*:197-216, 1985.

SHANMUGAN, G. AND R.J. MOIOLA, 1985: Submarine Fan Models: Problems and Solutions, *In*: *Submarine Fans and Related Turbidite Systems*, A.H. Bouma, W.R. Normark and N.E. Barnes, Springer Verlag, New York.

SHANMUGAN, G. AND R.J. MOILOA, 1988: Submarine Fans: Characteristics, Model, Classification, and Reservoir Potential. *Earth Science Reviews*, *24*, pp 383-425, Elsevier Science Publishers B.V., Amsterdam.

STOW, D.A.V., D.G. HOWELL AND C.H. NELSON, 1985: Sedimentary, tectonic and Sea Level Controls *In*: *Submarine Fans and Related Turbidite Systems*, A.H. Bouma, W.R. Normark and N.E. Barnes, Springer Verlag, New York.