THE MOKI C SANDS: AN EXAMPLE OF MIO-PLIOCENE BATHYAL FANS IN THE NORTH TARANAKI GRABEN

S P Forder
New Zealand Oil & Gas Ltd
Wellington

B A Sissons
New Zealand Oil & Gas Ltd[1]
Wellington

Abstract

The Late Miocene to Early Pliocene bathyal fan sands in the North Taranaki Graben are considered to constitute a major exploration play in that region. This sand sequence, informally named the Moki C Formation, is best developed in the Mangaa-1 well where a gross 701 m sequence contained 586 m of nett sand within two main sand intervals, the Moki C1 and Moki C2 units.

The upper of the two main sand packages in Mangaa-1 has a gross thickness of 522 metres.[2] This package, referred to as the Moki C1 Sand, extends as a mappable sequence over a large percentage of the North Taranaki Basin. An isopach of the package determined from seismic interpretation defines a clastic depositional wedge elongated northeast-southwest along the axis of the North Taranaki Graben and being largely constrained to northwest and southeast by major syndepositional growth faults. This wedge was deposited as a bathyal fan sequence emplaced by turbidity currents flowing off the continental shelf from the south and east and is here called the 'Mangaa Fan'. Underlying the C1 Sand sequence, which includes members up to 80 m thick, is a massive 179 m thick unit referred to as the C2 Sand. A lower sand of Miocene Age underlies the C2 Sand and immediately overlies the volcanics in Mangaa-1.

The sands forming the Moki C1 and C2 units are petrographically distinct from those forming the third sand body as analysed from well data. The Moki C1 and C2 sands are of mixed metamorphic/igneous provenance. Current knowledge of sediment transport direction and occurrence of igneous and metamorphic basement indicates sediment supply from Murihiku Supergroup and northwest Nelson granitic sources.

This contrasts markedly with the third (lowermost) sand unit in Mangaa-1 which has a distinct volcanogenic element derived from Late Miocene andesitic volcanics. Volcanic bodies of this type have been penetrated by wells in the North Taranaki Graben, notably by Mangaa-1 and Kora-1 and are here referred to as the Mangaa Volcanics.

The two petrographically distinct sand sequences are effectively delineated by a change in the provenance coindicent with the Mio-Pliocene boundary which is marked by an unconformity in the eastern part of this area.

The bathyal-fan sand depositional model is used here to predict potential reservoir development within the Moki Sand sequence of the Mangaa Fan.

Introduction

The Late Miocene to Early Pliocene bathyal fan sands, collectively given the informal formation name Moki C have recently been considered principle reservoir objectives in the North Taranaki Graben (Figure 1). The term "Moki C" is used by New Zealand Oil & Gas to define a bathyal fan sand lithofacies of Tongaporutuan (New Plymouth-2, Turi-1) to Opoitian (Mangaa-1, Tangaroa-1) age and possibly as young as Nukumaruan in the Tangaroa-1 well.

The oldest sequence, thus defined, of the Moki C is equivalent to the mid- to upper-bathyal Mount Messenger Formation as described by King & Thrasher (in prep.). The youngest sequence comprising the bottomset units of the Giant Foresets Formation. This latter term was first used by Shell BP Todd in 1977, the formation being most recently described by Beggs (1990).

This paper focuses on the uppermost Moki C unit; the Moki C1 of Opoitian to Nukumaruan age.

The study area was the offshore North Taranaki Graben bound to the west by the Cape Egmont Fault zone and to the east by the compressionally overturned Taranaki Fault Zone. No northern limit is defined, the graben extending into offshore Northland, however, an arbitrary 'cut-off' at 38° south latitude has previously been applied.

[1] Formerly

[2] All depths quoted in this paper are in metres BKB (Below Kelly Bushing)

The North Taranaki Graben was formed as a distinct sub-basin of the Taranaki Basin by Neogene extensional tectonics. Late Oligocene transpression (King and Thrasher in prep) and Early Miocene compression modified the tectonic style of the region particularly along the eastern basin boundary where the normal Taranaki Fault was overturned and thrust structures developed along the eastern margin as at Te Ranga-1 (Shell BP Todd, 1986).

In the vicinity of the North Taranaki Graben a total of 16 petroleum exploration wells have been drilled, commencing in 1970 with Mangaa-1 drilled by Hematite Petroleum (N.Z.) Ltd. (Hematite, 1970; McSweeney, 1989). The initial pace of exploration was slow within what is, even now, regarded as a frontier region. Only one further well, Turi-1 (BP Shell Todd, 1975) was drilled during the 1970s. Between 1980 and 1985 a further three wells; Tangaroa-1, (Shell BP Todd, 1981) Awakino-1 and Te Ranga-1 were drilled. It was not until ARCO's sub-commercial oil discovery in a Neogene sequence in Kora-1 that the rate of drilling picked up, eleven wells having been drilled from 1988 to mid 1991.

Initial exploration in the region targeted the Paleocene-Eocene Turi Formation, the holomarine correlative of the Kapuni Group. This was to be expected as the Kapuni Group was the only known economically productive sequence in the basin at the time, containing the reservoir sequence for the Kapuni (Mangahewa Formation) and Maui (Maui Formation) fields. Additionally the Mangahewa coals and conceptually, lateral marine shale correlatives were considered to be the principle source beds within the basin.

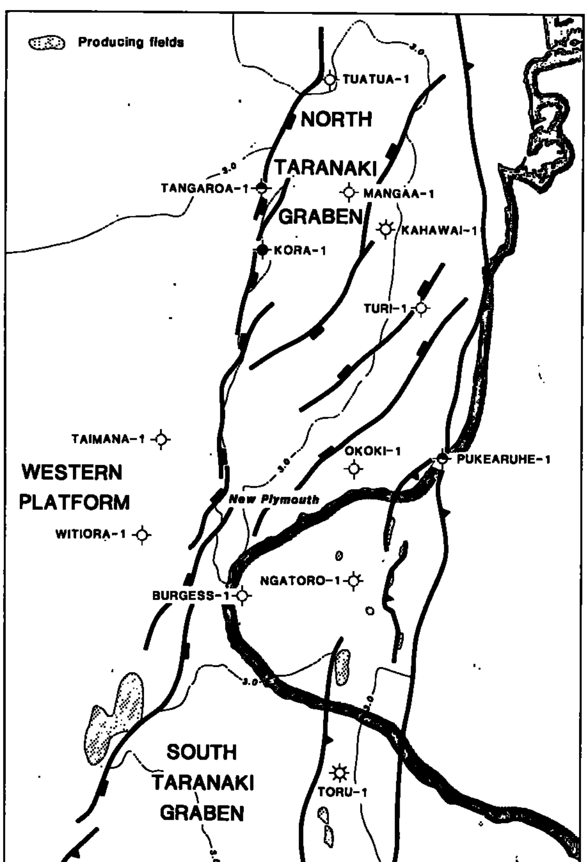


Figure 1: Location map of the North Taranaki Graben showing major structural features and selected wells.

The potential for hydrocarbon entrapment within the stratigraphically higher Moki Formation had been recognised since the sub-commercial oil discovery by Shell BP Todd in Maui-4 in 1970. However, it was not until the late 1980s that the Moki bathyal-fan sands which were by then known to have widespread occurrence throughout the basin, became a principle exploration objective.

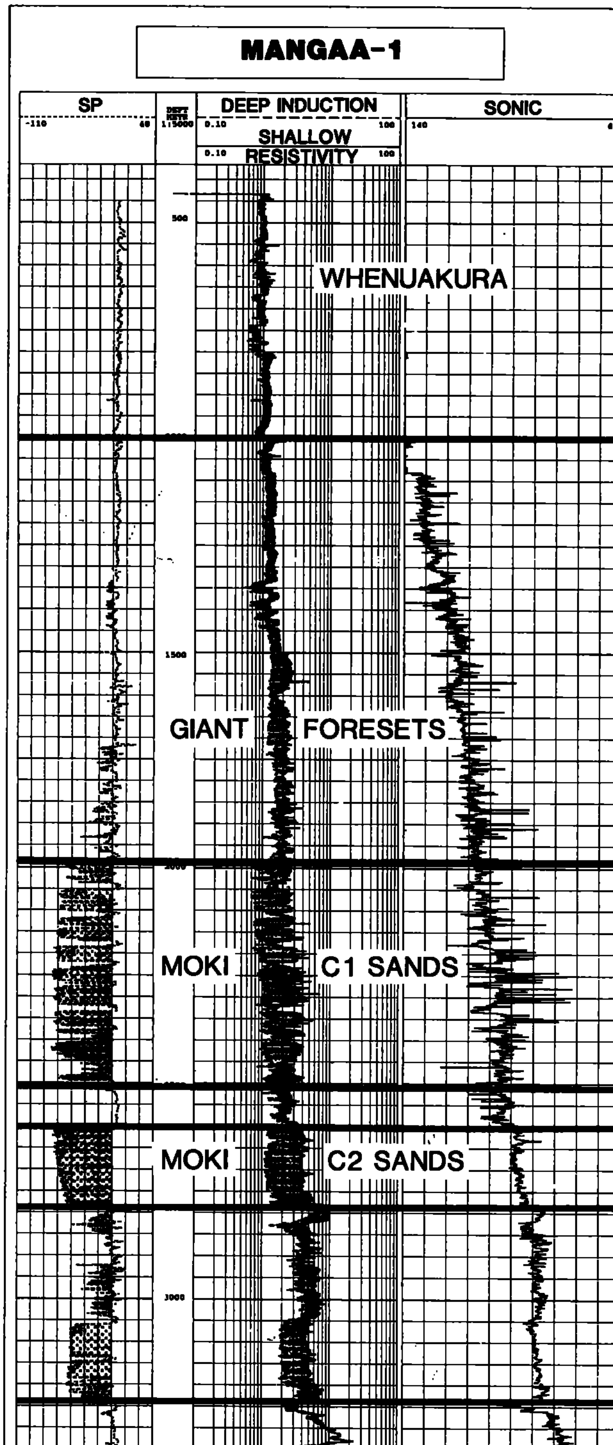


Figure 2: Mangaa-1 composite log, SP; Induction and Sonic logs over the entire logged interval to total depth. Porous sands show excellent SP expression and separation between deep and shallow induction logs.

Moki C Sand Development

In the Taranaki Basin it has often appeared that there is an abundance of units with excellent sealing potential and a relative paucity of reservoir units with suitable poroperm characteristics. It was, therefore, very encouraging to rediscover, upon re-evaluation of the Mangaa-1 electric logs a gross Moki Sand interval of 1250 m from 1991 m to 3241 m with three well-imaged sand units from 1991 m to 2512 m, 2605 m to 2784 m and 3060 m to 3241 m (Figure 2). The upper unit, here termed the Moki C1 Sand, has 422 m nett sand with effective porosity greater than 15 %. This sequence comprises the bottomset units of the Giant Foresets Formation the upper and lower interfaces forming regionally mappable seismic horizons in the study area.

A 92 m thick bathyal mudstone sequence separates the Moki C1 Sand from the C2 Sand which, in Mangaa is 179 m thick. A lower 181 m gross sand unit is separated from the Moki C2 Sand by a 276 m mudstone dominated unit.

In Mangaa-1 the Moki C1 Sand was initially dated by Hornibrook (1970) as wholly of Opoitian age. However, recent work by Hayward (1985) and Scott (1991) place the C1 Sand respectively as straddling the Opoitian/Waipipian boundary to wholly Waipipian in age. The age of the C2 Sand has, likewise, been re-evaluated and is now considered to be of Opoitian age (Hayward, 1985; Scott, 1991) where it had previously been considered to be Upper Miocene (Kapitean) (Hornibrook, 1970). Scott, however, places a stratigraphic hiatus at 2745 m in the well, considering the basal Opoitian and uppermost Kapitean to be absent. This hiatus may be placed at 2750 m where a 2.5 m mudstone separates the basal 31.5 m of sand from that above. However, there is little petrophysical evidence for such a hiatus and we are unable to resolve this matter by petrographic means as the deepest sample within the Moki C2 Sand submitted for petrophysical examination to date is from 2743 m.

The third and lowermost sand unit encountered in the well is distinguished from the overlying units on the basis of its age and petrographic character. The Tongaporutuan age adopted for this unit (Hornibrook, 1970; Scott, 1991) places it beneath the Mio-Pliocene hiatus; this boundary being a recognised unconformity over marginal areas of the graben (discussed below). Lithologically the sand below 3060 m depth is distinguishable from the Pliocene Moki Sands in containing volcaniclastic material, particularly apparent in tuffaceous siltstone bands between 3112 and 3173 m depth (Wodzicki, 1970). This contrasts with the Moki C1 and C2 Sands which provenance appears from petrographic analysis by Martin (1989, 1989b, 1990a and 1990b) to be dominantly metamorphic with secondary amounts of igneous and sedimentary material.

Petrophysics

The Moki C1 Sands in Mangaa-1 have an exceedingly clear log expression, particularly on the SP log. Individual units are typically 20 m thick and often up to 40 m thick. They are generally tabular in nature and alternate with distinct 10-20 m thick mudstone beds (Figures 2 and 3). These units are seen to be the bottomset facies of the Giant Foresets Formation

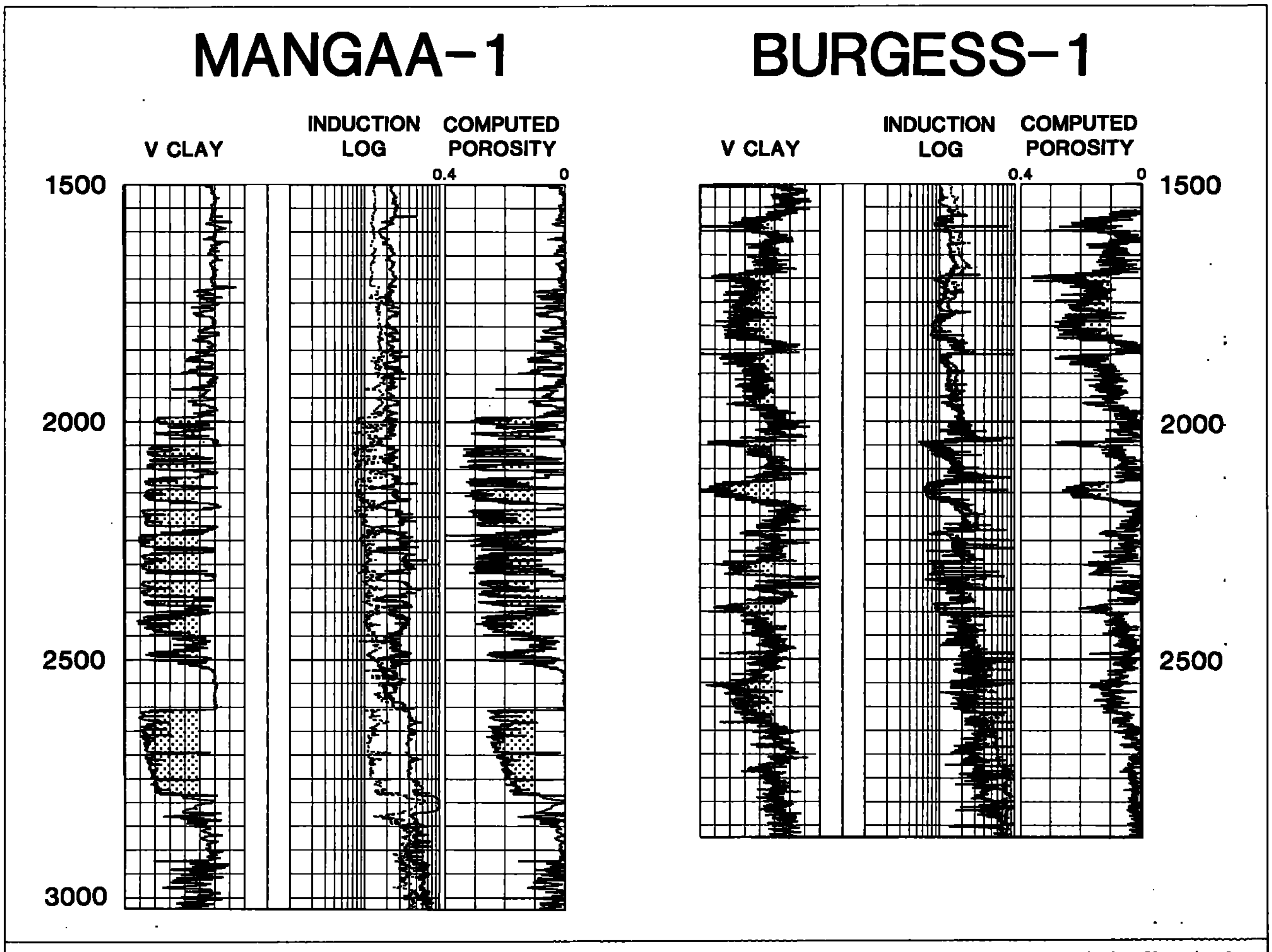


Figure 3: Electric log computation over the Moki C sand intervals in Mangaa-1 and Burgess-1. Reservoir quality sands are indicated by low Vclay and log porosity greater than 0.15.

(Beggs, 1990) being deposited in lower- to upper-bathyal environments and are mappable on seismic over tens of kilometres, as discussed below.

Examples of computed V clay and effective porosity for the Moki C1 Sand are given for the Mangaa-1 and Burgess-1 wells in Figure 3. Log porosity in the sands is typically 25% and often over 30 %. In Mangaa-1, however, this cannot be related to core porosity and permeability values since no cores were cut in this well. Relating log to core data is achieved in the Burgess-1 well, drilled in 1989 with the Moki C Sands as a primary target. In this well a core was cut over the interval 2149.6 m to 2158.56 m.

Permeability measured in the Burgess-1 core and also in core from Kapuni-1 is plotted with respect to core-derived porosity in Figure 4. Porosity versus permeability is a log linear relationship from 20 millidarcies at 20 % porosity to 1000 millidarcies at 30 % porosity. Permeability is here plotted on a 3-cycle log scale. It is evident from Figure 4 that the Moki C1 Sand, such as that in Mangaa-1 and Burgess-1, having porosity values in excess of 25 %, potentially constitutes an excellent reservoir.

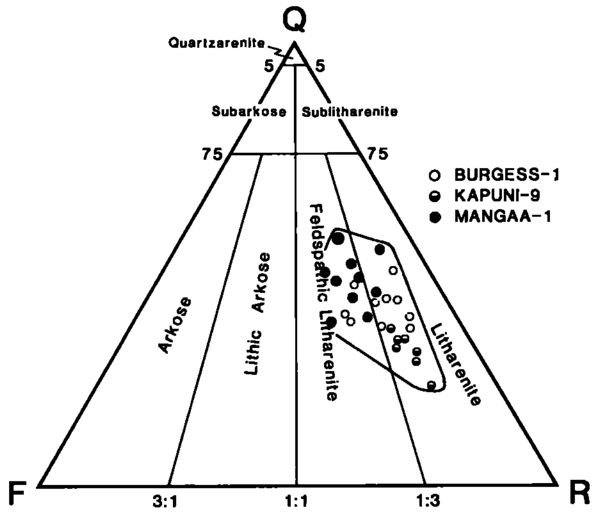


Figure 5: QFR diagram of Moki C1 and C2 sand samples showing close grouping of sample points within the Litharenite/Feldspathic Litharenite fields. Only data relating to non-confidential wells and NZOG Burgess-1 are shown (QFR diagram after Folk, 1974).

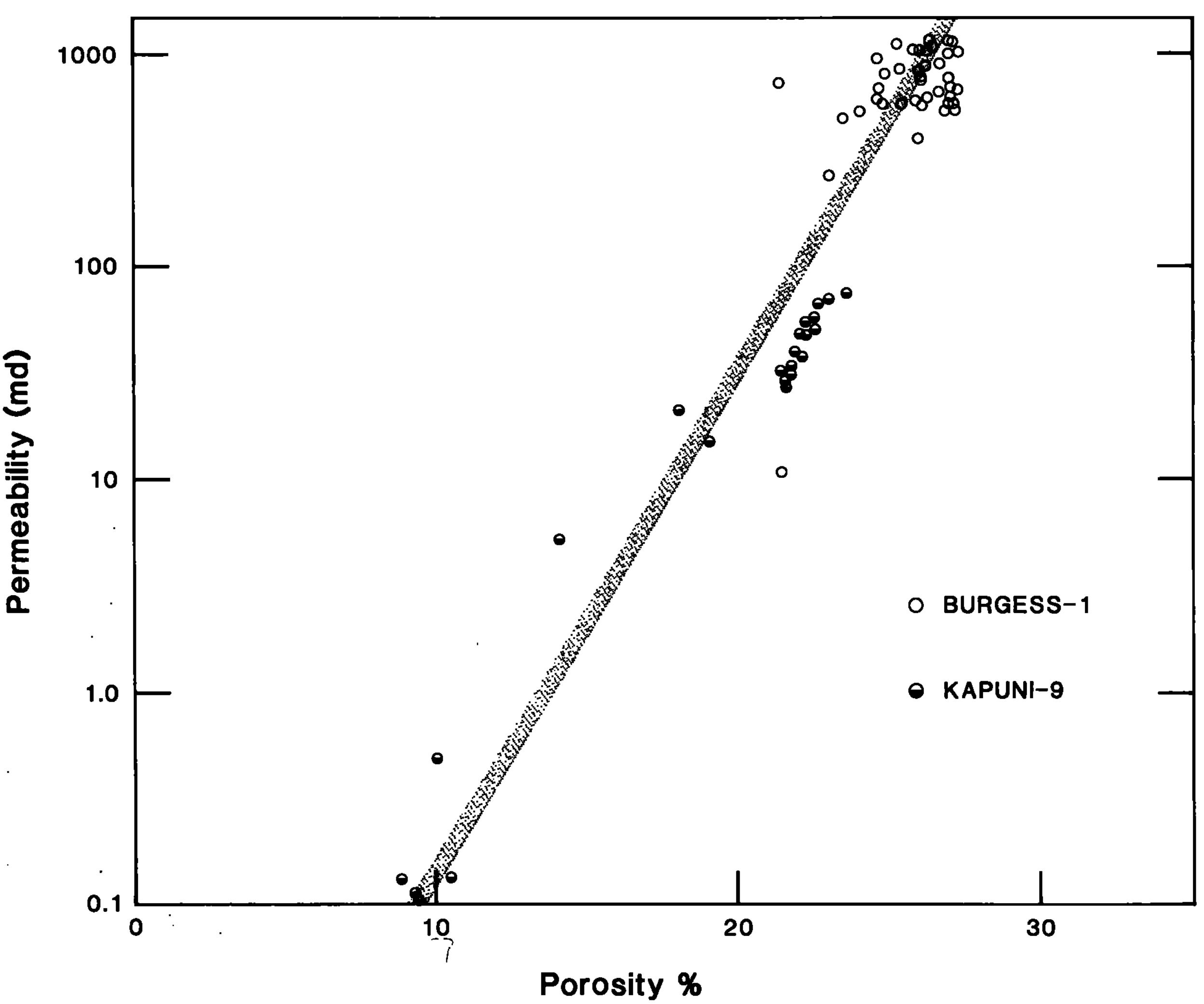


Figure 4: Porosity vs Permeability plot for Burgess-1 and Kapuni-9 exhibiting direct log-linear relationship; permeability increasing logarithmically with increase in porosity.

Petrology

Macroscopically, the Moki C Sands are fine- to very fine-grained friable sandstones. Microscopic description of cuttings and cores indicates that the composition of the Moki C1 and C2 Sands is relatively uniform throughout the study region.

Plotted on a QFR diagram (Figure 5) these Moki C1 and C2 sands form a distinct field within the Litharenite to Feldspathic Litharenite range. The modal analyses of cuttings and core samples, summarised here in Table 1A, are normalised to two 3-component systems (Table 1B) the range of QFR values being: 22-58 % quartz; 6-25 % feldspar and 27-65% rock fragments.

While there is no core-derived information for porosity and permeability in the Miocene volcanogenic sands, log-derived porosity is in the range of 10 % to 12 %, compared with an average of over 25 % in the Pliocene Moki C1 and C2 Sands. On the porosity/permeability cross-plot this porosity equates to a permeability of less than 10 millidarcies.

The petrology of the Moki C Sands indicates the potential for mixed provenance. The dominant metamorphic provenance is considered to be the metasedimentary Murihiku Supergroup due east of the main graben area while independent evidence is present in the seismic sections that would support a southern derivation for some of the clastic material. Base-Pliocene channels incised into the late Miocene sequence trending due north are present to the east

SANDSTONE PETROLOGY - MODAL ANALYSIS
WELL: MANGAA - 1; KAPUNI 9; BURGESS 1
FORMATION: MOKI
NORMALISED COMPONENTS

Depth Interval (m)		Q.F.R.				R.F.			
Top	Base	Quartz	Feld.	Rock	TOTAL	Volc/Ig.	Meta.	Sed.	TOTAL
MANGAA 1									
2615.00	2624.00	50.00	20.59	29.41	100.00	10.00	50.00	40.00	100.00
2633.00	2643.00	43.33	18.33	38.33	100.00	13.04	56.52	30.43	100.00
2660.00	2670.00	58.82	13.73	27.45	100.00	7.14	64.29	28.57	100.00
2679.00	2688.00	52.38	14.29	33.33	100.00	19.05	52.38	28.57	100.00
2688.00	2697.00	49.06	13.21	37.74	100.00	25.00	55.00	20.00	100.00
2707.00	2716.00	37.93	25.86	36.21	100.00	9.52	57.14	33.33	100.00
2716.00	2734.00	47.44	19.23	33.33	100.00	11.54	61.54	26.92	100.00
2716.00	2734.00	43.33	11.67	45.00	100.00	18.52	62.96	18.52	100.00
2743.00	2752.00	55.10	6.12	38.78	100.00	5.26	68.42	26.32	100.00
2743.00	2752.00	39.44	16.90	43.66	100.00	3.23	54.84	41.94	100.00
KAPUNI 9									
1828.90		31.49	14.74	53.78	100.00	7.73	67.21	25.06	100.00
1829.20		28.72	12.14	59.14	100.00	13.91	53.64	32.45	100.00
1831.50		32.71	14.63	52.66	100.00	5.81	58.08	36.11	100.00
1832.36		33.39	12.87	53.75	100.00	13.94	60.91	25.15	100.00
1833.03		28.59	13.72	57.69	100.00	8.89	60.00	31.11	100.00
1833.90		33.42	13.99	52.58	100.00	10.34	66.41	23.26	100.00
1835.08		22.67	12.19	65.14	100.00	6.64	47.69	45.67	100.00
1836.59		30.00	11.48	58.52	100.00	9.92	60.55	29.54	100.00
1837.70		32.37	13.11	54.52	100.00	5.53	58.41	36.06	100.00
BURGESS 1									
2149.70		41.94	11.27	46.79	100.00	7.00	45.66	47.34	100.00
2150.70		37.46	10.00	52.54	100.00	4.02	60.32	35.66	100.00
2152.50		36.07	15.85	48.09	100.00	5.97	69.03	25.00	100.00
2152.30		42.20	10.75	47.04	100.00	5.14	62.29	32.57	100.00
2153.30		41.04	14.94	44.03	100.00	3.83	72.57	23.60	100.00
2155.10		37.99	8.58	53.43	100.00	6.91	51.11	41.98	100.00
2156.90		39.27	21.97	38.75	100.00	2.68	63.39	33.93	100.00
2157.50		49.40	7.61	42.99	100.00	0.93	61.80	37.27	100.00
2157.70		37.71	21.12	41.18	100.00	6.23	74.36	19.41	100.00
2158.10		44.88	15.85	39.27	100.00	0.00	81.07	18.93	100.00

Table 1b: The modal analyses from Table 1A are here normalised to two three-component systems: a) Quartz/Feldspar/Rock Fragments b) Volcanic Igneous/Metamorphic/Sedimentary Rock Fragments. The QFR data are plotted in Figure 5.

SANDSTONE PETROLOGY - MODAL ANALYSIS
WELL: MANGAA - 1; KAPUNI 9; BURGESS 1
FORMATION: MOKI

Depth Interval (m)					Rock Fragments									
Top	Base	Quartz	K-Feld.	Plag.	Volc/Ig.	Meta.	Sed.	Mica	Heavy	Opaque	Calc.	Clay	Vis Por.	TOTAL
MANGAA 1														
2615.00	2624.00	34.0	6.0	8.0	2.0	10.0	8.0	2.0		1.0		14.0	15.0	100.00
2633.00	2643.00	26.0	8.0	3.0	3.0	13.0	7.0	5.0			35.0			100.00
2660.00	2670.00	30.0	4.0	3.0	1.0	9.0	4.0	2.0	1.0	1.0	45.0			100.00
2679.00	2688.00	33.0	4.0	5.0	4.0	11.0	6.0	3.0		1.0	29.0	4.0		100.00
2688.00	2697.00	26.0	3.0	4.0	5.0	11.0	4.0	2.0		4.0	38.0	3.0		100.00
2707.00	2716.00	22.0	11.0	4.0	2.0	12.0	7.0	3.0		2.0	36.0	1.0		100.00
2716.00	2734.00	37.0	10.0	5.0	3.0	16.0	7.0	3.0	1.0	1.0		5.0	12.0	100.00
2716.00	2734.00	26.0	5.0	2.0	5.0	17.0	5.0	4.0		1.0	23.0	7.0	5.0	100.00
2743.00	2752.00	27.0	3.0		1.0	13.0	5.0	6.0			44.0		1.0	100.00
2743.00	2752.00	28.0	6.0	6.0	1.0	17.0	13.0	2.0	1.0	2.0	2.0	5.0	17.0	100.00
KAPUNI 9														
1828.90		25.0	2.7	9.0	3.3	28.7	10.7	2.3	0.3	2.0	3.7	9.7	2.7	100.10
1829.20		22.0	2.0	7.3	6.3	24.3	14.7	3.0	0.0	0.7	0.0	10.7	9.0	100.00
1831.50		24.6	2.7	8.3	2.3	23.0	14.3	3.7	1.0	1.7	0.0	14.0	4.3	99.90
1832.36		20.5	2.0	5.9	4.6	20.1	8.3	2.0	0.0	3.0	21.8	10.9	1.0	100.10
1833.03		22.3	2.7	8.0	4.0	27.0	14.0	2.0	1.0	1.3	0.0	15.3	2.3	99.90
1833.90		24.6	3.0	7.3	4.0	25.7	9.0	2.0	0.0	0.3	23.7	3.7	0.0	103.30
1835.08		17.3	2.0	7.3	3.3	23.7	22.7	2.7	0.0	2.0	0.0	12.3	6.7	100.00
1836.59		24.3	1.3	8.0	4.7	28.7	14.0	1.0	0.0	1.7	0.0	13.7	2.7	100.10
1837.70		24.7	2.0	8.0	2.3	24.3	15.0	2.3	0.0	0.7	0.3	17.7	2.7	100.00
BURGESS 1														
2149.70		32.0	4.6	4.0	2.5	16.3	16.9	1.5	0.0	0.3	0.0	4.6	17.2	99.90
2150.70		26.6	4.0	3.1	1.5	22.5	13.3	2.2	0.3	0.3	0.0	3.1	23.1	100.00
2152.50		26.4	4.6	7.0	2.1	24.3	8.8	0.9	0.3	0.3	0.0	3.0	22.2	99.90
2152.30		31.4	3.1	4.9	1.8	21.8	11.4	2.5	0.6	0.0	0.0	2.8	19.7	100.00
2153.30		31.6	5.4	6.1	1.3	24.6	8.0	2.6	0.0	0.0	0.0	7.3	13.1	100.00
2155.10		28.8	2.8	3.7	2.8	20.7	17.0	0.0	0.3	0.3	0.0	5.6	18.0	100.00
2156.90		22.7	4.8	7.9	0.6	14.2	7.6	3.0	0.3	0.6	37.9	0.3	0.0	99.90
2157.50		37.0	2.4	3.3	0.3	19.9	12.0	0.3	0.0	0.0	0.0	3.3	21.4	99.90
2157.70		25.0	6.0	8.0	1.7	20.3	5.3	7.7	0.7	0.3	0.0	7.0	18.0	100.00
2158.10		32.0	3.0	8.3	0.0	22.7	5.3	8.0	0.3	1.0	0.0	17.0	2.3	99.90

Note: Some of the above modal analyses do not add up to exactly 100 %. In most cases this is probably a rounding error.
However, the Kapuni sample from 1833.9 metres may contain an erroneous value.

Table 1a: A tabulation of K.R. Martin's modal analyses of Moki C1 and C2 sands in Mangaa-1, Kapuni-9 and Burgess-1. Analyses were conducted on cuttings samples for Mangaa-1 and core plugs for Kapuni-9 and Burgess-1. Further intervals await petrological analysis.

of PPL 38439 and are interpreted to be feeder channels for emplacement of the Moki C1 Sands in the North Taranaki Graben.

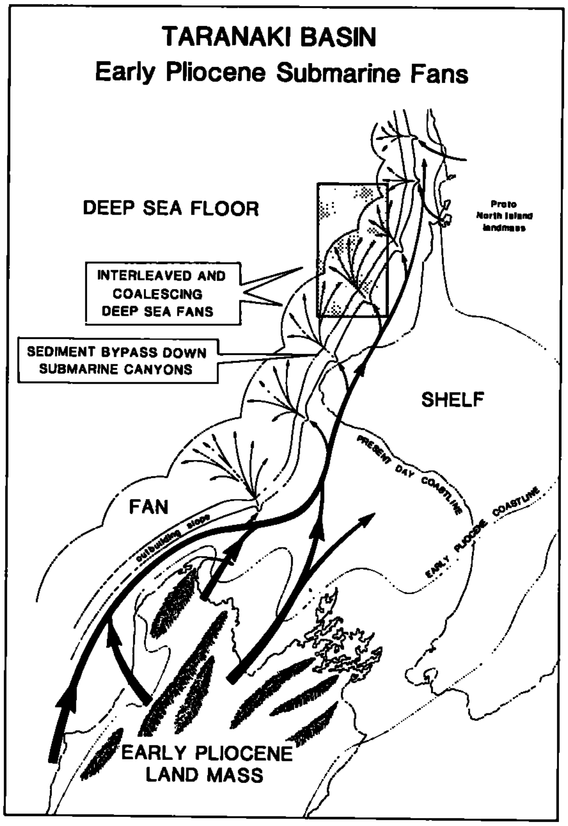


Figure 6: Taranaki Basin; diagrammatic representation of mode of emplacement of Early Pliocene 'Moki' submarine fans. Shaded box indicates study area.

It can be postulated, through there is little open-file information available at present to add weight to this interpretation, that the igneous rock fragments may have been derived from the Northwest Nelson region. The model proposed for transport of the sands being shown diagrammatically in Figure 6. The mixed provenance of the Moki C1 and C2 Sands can thus be appreciated.

Seismic Expression

As Figure 6 illustrates, the shelf-edge slope itself is largely a bypass zone and as such is an area of slow accumulation of fine-grained material which forms the regional seal. The slope deposits from a very prominent seismic facies 400 milliseconds to 600 milliseconds thick exhibiting large scale cross-bedding. This interval is referred to as the Giant Foresets Formation. The direction of progradation of the slope being evident on seismic.

On line ES89-003 the lower Foresets sequence (Figure 7) progrades from left to right. As this line strikes north, the direction of progradation is approximately northwards. Overlying this a later series of foresets appears to be more parallel-bedded and is being viewed in this section approximately normal to the direction of sediment transport. This latter sequence shows considerable evidence of channelling; these channels striking approximately normal to the line of section.

At the base of the northward-prograding foresetting sequence the Moki C Sand forms a package of strong parallel reflectors evident on Line ES89-003 (Figure 7). The correlation of the sands with reflectors is shown by the Mangaa-1 synthetic seismogram inset to seismic on Line ES89-032, as shown in Figure 8. The Moki C1 Sand interval has been mapped as a seismic isopach varying in thickness from zero to 400 milliseconds, the greatest thickness being in the south of PPL 38451 and immediately west of the Kahawai Horst on the downthrown side of the Kahawai Fault.

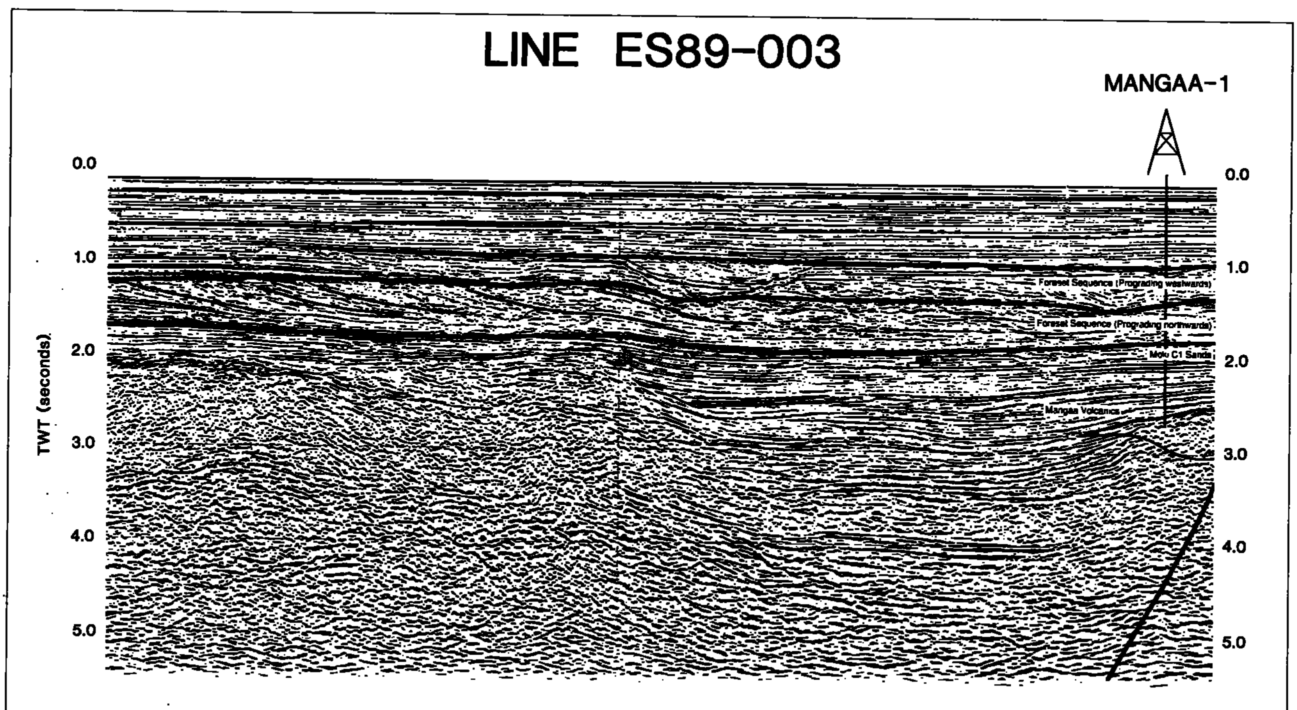


Figure 7: Seismic line ES 89-003; a SW-NE transect through the Mangaa-1 location. The Moki C1 sands; northward-prograding lower foresetting sequence and westward-prograding upper foresetting sequence are outlined.

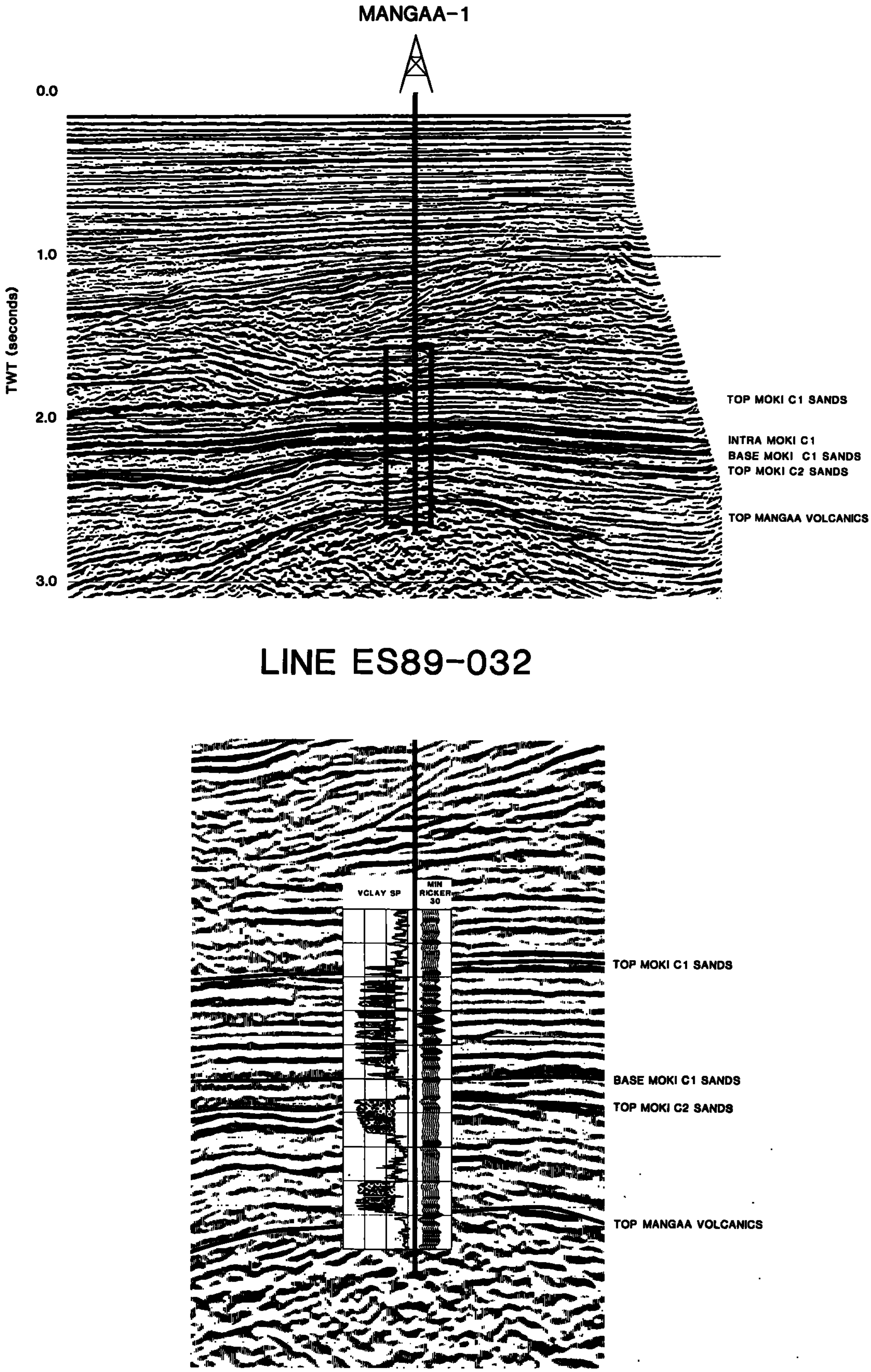


Figure 8: A segment of seismic line ES89-032 trending east-west through Mangaa-1 and enlargement over the Moki sand interval with Vclay and synthetic seismogram inserted to illustrate relationship between seismic events and sand development. The 'banded' nature of the seismic is attributable to the alternating sandstone and mudstone beds of sufficient thickness to be individually imaged on the section.

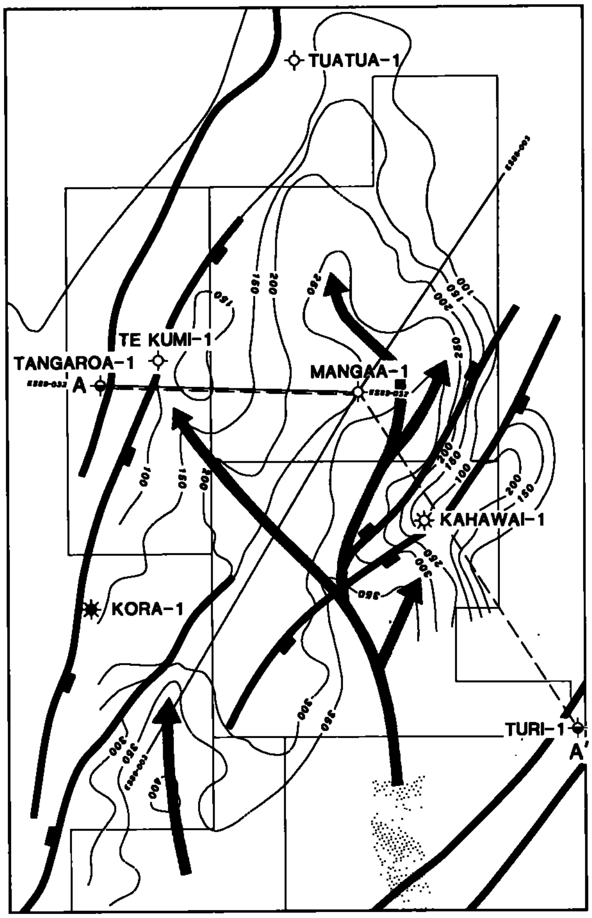


Figure 9: Isochron map of the Moki C1 unit in the North Taranaki Graben; termed the Mangaa Fan. The influence of dominant fault trends is discernible, the major locus of deposition being immediately west of the fault-bounded Kahawai horst. The Pliocene feeder channel is shown at bottom right.

Exploration Potential

The potential for the Moki C1 and C2 sands to form quality reservoir objectives has been discussed. However, the exploration perspective requires a defined 'play' to pursue; this being supplied by mapping the near-top and near-base Moki C1 and near-top Moki C2 reflectors. An isochore corresponding to the Moki C1 interval is shown in Figure 9.

Contours on Figure 9 are in 50 millisecond intervals, the outer contour limit being 100 milliseconds and the maximum 400 milliseconds. The isochore delineates a particular fan, which NZOG here terms the Mangaa Fan, emplaced from Pliocene channels identified on seismic and located at the south of the mapped area. The fan is about 70 km long and 35 km wide and its shape was controlled during deposition by a number of syndepositional normal faults. The dominant graben margin faults defined a primary depositional fairway with structural features such as the Kahawai Horst modifying this pattern.

These faults have influenced both depositional pattern and thickness variation of the Mangaa Fan unit; diverting the main clastic flows around structural highs. The Moki C1 unit being represented by a thin and dominantly fine grained sequence at both Tangaroa-1 and Turi-1 on opposing basin margins.

Line ES89-032 (Figure 10) extending from Mangaa-1 to Tangaroa-1 is a seismic section across the western half of the Mangaa Fan. The fan can be seen to thin dramatically across a fault at the western edge of the graben with a very thin sediment package continuing westwards to Tangaroa-1. The major graben-delineating fault trends have had a critical role to play on Moki C deposition.

The well correlation from Tangaroa-1 through Mangaa-1 to Turi-1 (Figure 11) demonstrates also that the Moki sands are primarily developed within the North Taranaki Graben and are thin to virtually absent on either side, as mentioned above. This correlation, on its left hand end, approximates a diagrammatic representation of line PR-89-032, with the line of section being shown on the Mangaa Fan map (Fig. 9).

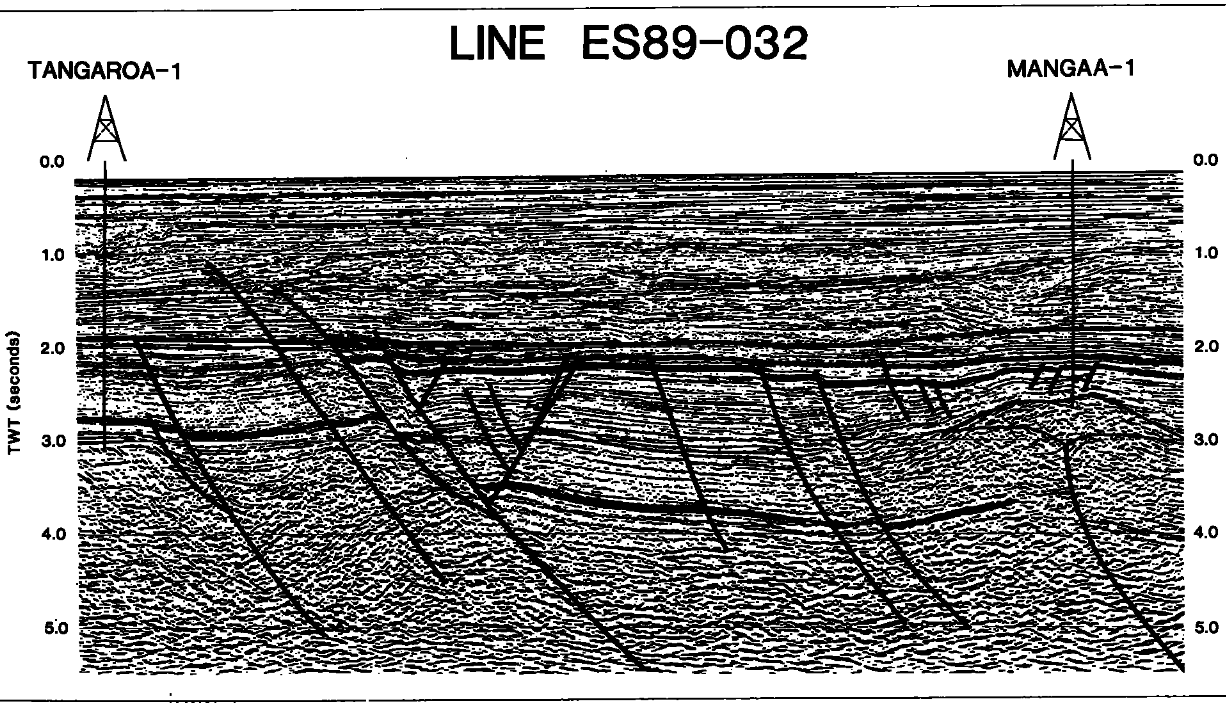


Figure 10: Seismic line ES89-032 linking Mangaa-1 to Tangaroa-1. The thickness variation in the highlighted Moki C1 sand unit demonstrates the effect of syndepositional fault movement.

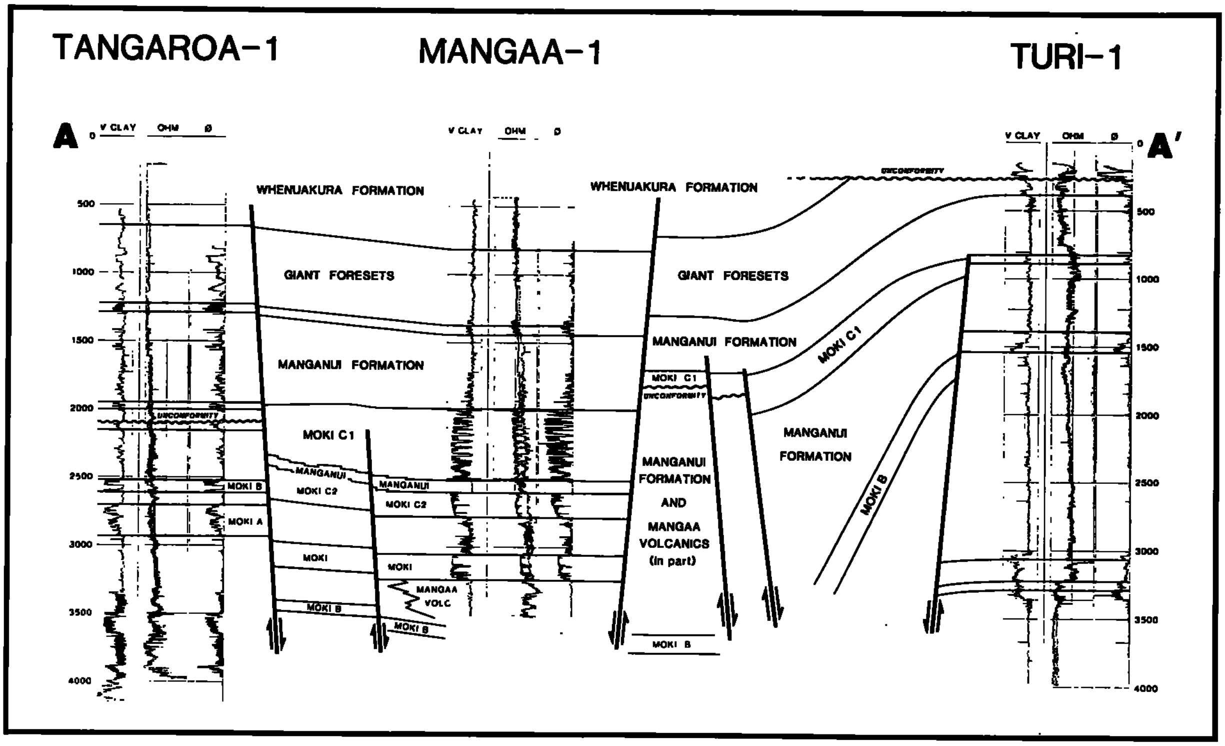


Figure 11: Diagrammatic cross-section through Tangaroa-1, Mangaa-1 and Turi-1 wells showing Moki sand correlation. The left half of this diagram effectively represents a simplified structural/stratigraphic picture of seismic line ES89-032. Once again, the dramatic thickness variation in the Moki C1 (and C2) interval across faults evidences the syntectonic nature of this unit. Coarse clastic deposition also is generally limited to the main graben, with very poor sand development on the Tangaroa and Turi blocks.

The Mangaa Fan is a bathyal fan much younger than and, consequently, emplaced much higher than hydrocarbon sources in the North Taranaki Graben and is thus representative of a play which has strong analogues in the North Sea, viz the Paleocene Fan fields such as Frigg and Forties.

The fan of the Frigg Field in the North Viking Graben is shown diagrammatically in Figure 12 to the same scale as the Mangaa Fan as an example.

When considering bathyal fans the classical image of a radially spreading depositional lobe tends to spring to mind. As discussed above, the Mangaa Fan does not have this form and has been dramatically influenced in its depositional pattern by syndepositional growth faulting along pre-existing major fault trends.

The Frigg Fan is a documented example of a lobate bathyal fan which has been heavily influenced in form by a pre-existing structural framework. It is located close to the deepest part of the Tertiary embayment on the Western Flank of the Viking Graben. Sediment of Paleocene to Lower Eocene age (somewhat older than the Moki C Sands)

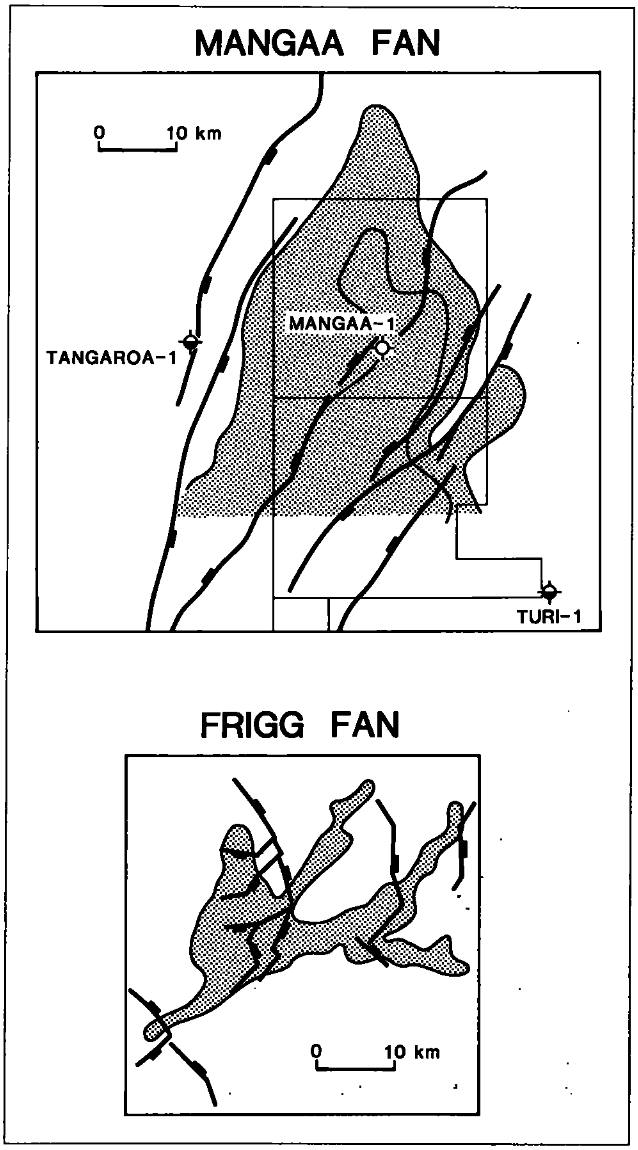


Figure 12: A comparison, to the same scale, of the Mangaa Fan with the Frigg Fan in the Viking Graben, North Sea. Both fans exhibit morphology determined to some degree by the syndepositional structure.

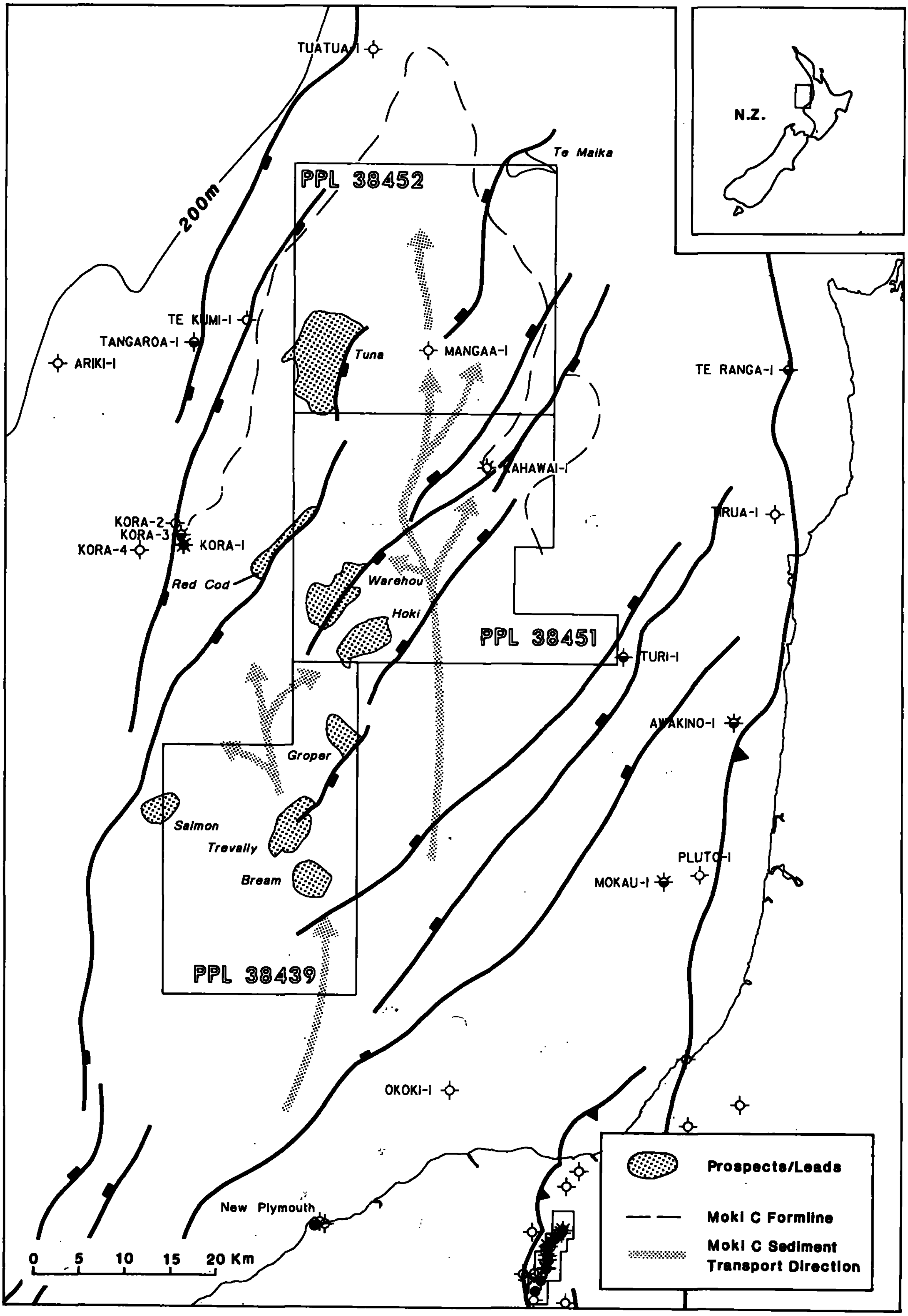
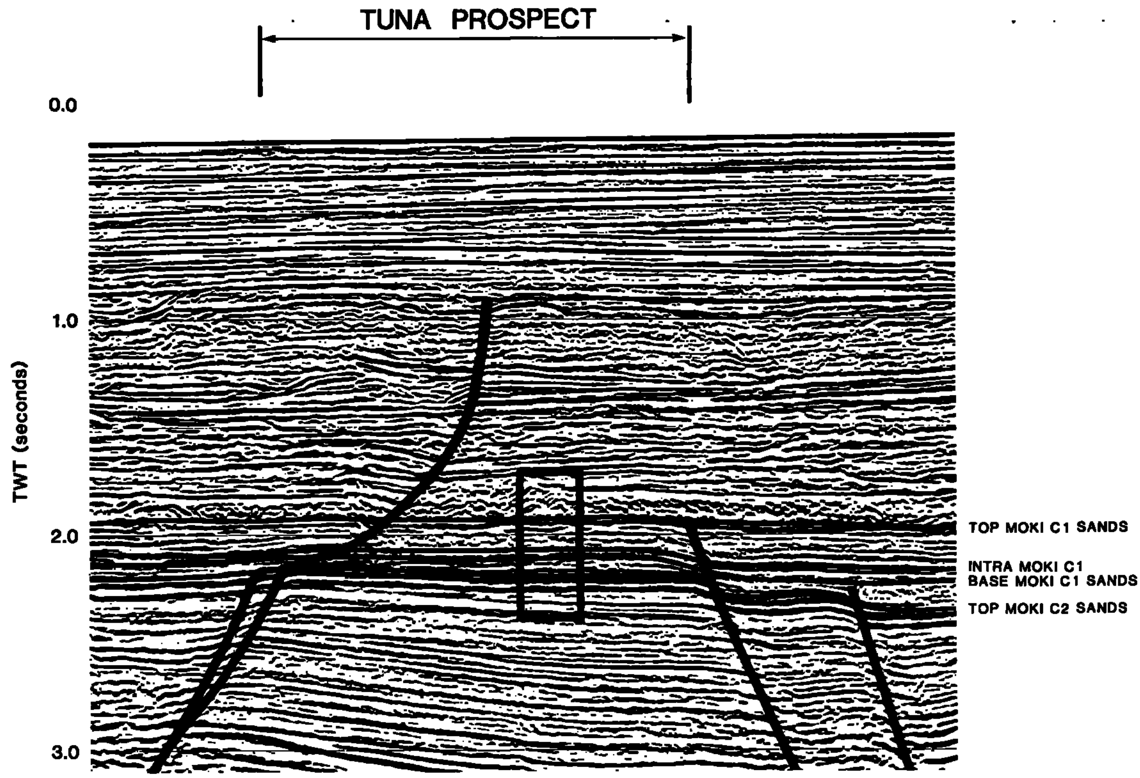


Figure 13: Location map of NZOG permits and major prospects in the North Taranaki Graben. The hatched line depicts the outline of the Mangaa Fan; all prospects shown having Moki sands as their primary objective.



LINE ES89-032

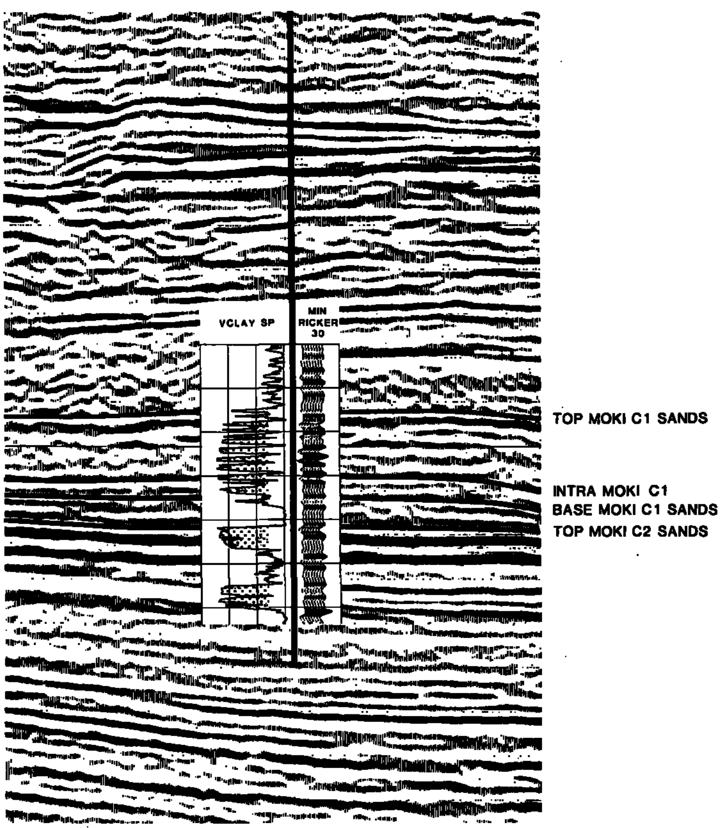


Figure 14: A segment of seismic line ES89-032 through the Tuna Prospect with enlargement and insert of lithologic model as expressed by the Vclay curve and derivative synthetic seismogram. Compared to Mangaa (Figure 8) the interbedded sandstone/mudstone nature of the sequence is still evident, though thinner individual beds at this location (proposed) are not as well imaged by seismic.

fed through the Beryl Embayment which acted as a feeder channel, with the sands being deposited on the Frigg and East Frigg Late Cretaceous anticlines.

The diagram of the Frigg Field in Figure 12 is after Heretier *et al.* (1981). This diagram indicates how sediment ponded and then debouched over the fault scarps.

Within the Mangaa Fan and an earlier fan immediately adjacent to the south, a number of prospects have been delineated by the exploration efforts of the last few years. The shaded closures shown in Figure 13 indicate the principal prospects mapped by NZOG in this region; most of which can be seen to be advantageously placed with respect to Moki C Sand development.

The prospects are generally formed by differential subsidence causing the fan to drape over various pre-existing structural and volcanic features, and have, in some cases, been influenced by post-depositional fault reactivation, as at Tuna-1 (Figure 14). While one hesitates to put into print estimated potential reserves figures for this play, the example of Tuna-1 can be called upon; this structure having a maximum area of closure of 86 sq km and a median potential reserves (C1 + C2 Sands) of 530 million stock tank barrels.

Summary

The Moki C Sands form a Mio-Pliocene bathyal-sand play with examples throughout the Taranaki Basin; as evidenced by Kapuni-1, Burgess-1, and Mangaa-1, for example. In the North Taranaki Graben the extensive Mangaa Fan is a particular example of this play extending over a region approximately 70 km long by 35 km wide. The Pliocene sands with porosity of order 20-30 % and permeabilities of up to one darcy (as at Burgess-1) would be expected to give very high productivity wells in the case of discovery. These sands are predicted to be present in structural features at shallow to moderate well depths in the study region.

This paper indicates a necessity for further paleostratigraphic and petrographic work to be conducted on samples from wells in the North Taranaki region to verify the distinction in lithologic character between the Upper Miocene and Lower Pliocene Sands and the extent and importance of the Mio-Pliocene Unconformity.

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While confidential data from Burgess-1 has been incorporated into this paper, data from other confidential wells which was incorporated into the Christchurch presentation was required to be omitted; necessitating a partial re-write. We hope that readers will understand the constraints that confidentiality places upon the release of such information.

Authors

STEVE FORDER graduated B.Sc. (Hons) from Victoria University in 1976. He then spent two years in mineral exploration in New Zealand and South Africa before working in petroleum exploration in New Zealand, the North Sea and Australia. He returned to New Zealand in 1986 working for New Zealand Oil and Gas Ltd. This paper was co-authored by BRIAN SISSONS.