

THE STRUCTURAL SETTING AND DEPOSITIONAL HISTORY FOR THE KUPE SOUTH FIELD, TARANAKI BASIN

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Models depicting the structural and depositional evolution of the Kupe South Field have been developed to predict the distribution of reservoir sands and hydrocarbons. The Kupe South Field was discovered in December 1986 with the drilling of Kupe South-1, and is located in PPL 38116 within the South Taranaki Graben. The north-south trending Manaia Fault, which bounds the western margin of the field, has influenced tectonic development and sedimentation along the entire Manaia Trend.

Exploration and appraisal of the Kupe South Field has identified a complexly faulted, north-plunging anticlinal nose containing up to 140 m of hydrocarbons which may extend southwards beyond structural closure.

The Paleocene-Eocene terrestrial reservoir sediments subcrop beneath a regional Oligocene unconformity and extend from the large Kapuni gas-condensate field in the north, to beyond the licence boundary in the south.

The structural evolution and stratigraphy of the Kupe South area reflect a complex basin-wide history of extension, compression and wrenching from the Cretaceous to Recent. Synrift extension formed predominantly north-south half-grabens in the Late Cretaceous to Paleocene, with associated deposition of fluvial and lacustrine sediments providing the likely source and reservoir rocks in the Kupe South area. Postrift subsidence and passive margin shelf progradation through the Late Eocene and Oligocene have provided an excellent regional marine shale seal to these units.

Compression from the Late Oligocene to the Late Miocene has played a major role in the development of the Kupe South Structure. The compression, resulting from oblique collision along the Australia-Pacific plate boundary, induced rapid subsidence on the eastern margin of the Taranaki Basin. This *plate loading* subsidence overprinted the passive margin subsidence and marked the onset of deposition of a thick Oligo-Miocene progradational wedge across the basin. The combined effects of structuring and sediment loading resulted in a closed structure developing in the Kupe South area by the end of the Miocene.

Pliocene backarc extension and associated rapid subsidence and sedimentation in the North and South Taranaki Grabens, followed by Quaternary strike-slip movement along major faults, have further modified closure, and initiated favourable conditions for late migration of hydrocarbons and their accumulation in the Kupe South Field.

The Kupe South Field reservoir forms part of the Paleocene, graben-fill Farewell Formation which comprises upwards fining sandstone sequences in an overall coarsening-upwards interval. Sedimentary sequence boundaries have been seismically defined and correlated between wells, across much of the field. The uppermost ('A' and 'B') sands have core and log coverage and form the basis for development of a field-wide depositional model.

Sedimentological and wireline log interpretations have identified a high-energy, upper coastal plain (braided river and alluvial fan) setting for the 'A' Sands. These sands have a south to north paleocurrent trend with a component of west to east sediment control along the western margin. The 'B' and older sands exhibit a pronounced proximal to distal (south to north) relationship, and comprise low-energy, lower coastal plain (braided and meandering river) sediments.

The depositional model predicts that the textural characteristics of the 'A' Sands are likely to be maintained south of the known limits of the Kupe South Field, and that the northerly migration of the 'A' Sand depocentre, expressed as the upward coarsening of the sedimentary succession ('B' to 'A' Sands), is likely to provide a series of good quality sands beneath the regional unconformity. In contrast, the underlying 'B' and older sands are likely to improve southwards in a more proximal setting.

PART I: A STRUCTURAL MODEL

INTRODUCTION

The Kupe South Field is a gas/condensate accumulation in a Paleocene aged reservoir. A model depicting the structural evolution of the field relates three major plate-tectonic events to five successive phases of basin development since the Late Cretaceous. The model is presented as a series of time intervals in which the structural development of the Kupe South Field is assessed in the context of regional isopach maps and plate-tectonic reconstructions.

The field is located in the Late Cretaceous to Paleocene Manganui Graben (Fig. 1). Structural inversion of the graben has occurred from the Mid Oligocene to Late Miocene as a result of oblique convergence on the Australia-Pacific plate boundary. A closed structure had developed in the Kupe South area by the end of the Miocene. Subsidence associated with backarc extension, and Quaternary uplift as a result of continued convergence on the boundary subsequently modified the closure.

The structural evolution of the graben was a major factor controlling the distribution of source, seal and reservoir facies. Detailed field-wide correlations demonstrate local structural controls on reservoir development and suggest the timing of structural development.

THE MANGANUI GRABEN

The Kupe South Field is located in PPL 38116 in the South Taranaki Graben (Fig. 1). Pilaar and Wakefield (1978) identified the South Taranaki Graben as a major structural subdivision of the Taranaki Basin. The South Taranaki Graben is further subdivided by the Manaia Fault, which forms the western boundary of the Late Cretaceous-Paleo-

cene half-graben referred to by Haskell (1985) as the Manganui Graben. Licence PPL 38116 covers a large portion of the offshore extension of this graben, the present-day eastern boundary of which is the Taranaki Fault (Fig. 2).

The Kupe South Field is located immediately east of the Manaia Fault, at the southern end of the Manaia Trend, in the Manganui Graben.

The generalised stratigraphy and structural timing of the Kupe South Field are shown in Fig. 3. Basement is considered to comprise the pre-rift Early Cretaceous and older metasediments, greywackes and volcanoclastics of the Mesozoic Rangitata Province. Over 5000 m of Late Cretaceous to Paleocene terrestrial fan to marginal marine sediments were deposited in the Manganui Graben which was bounded to the west by the Manaia Fault. The original eastern boundary of the graben is indistinct, but Cretaceous to Paleocene graben sediments are unknown east of the present-day Taranaki Fault.

The Paleocene sequence progressively thins to the south and ultimately subcrops beneath the Oligocene sequence near the southern licence boundary. To the north the Eocene sequence onlaps a latest Paleocene to earliest Eocene peneplain and thins southwards due primarily to non-deposition. Subsidence in the Early Eocene marked the onset of a marine transgression that culminated in the Early Miocene.

Structural inversion of the Manganui Graben commenced in the Early to Mid Oligocene and culminated in the Late Miocene. Line 1 (Fig. 4) is an east-west cross-section of the central graben. The Oligo-Miocene sequence comprises outer shelf to upper bathyal marine shales that vary in

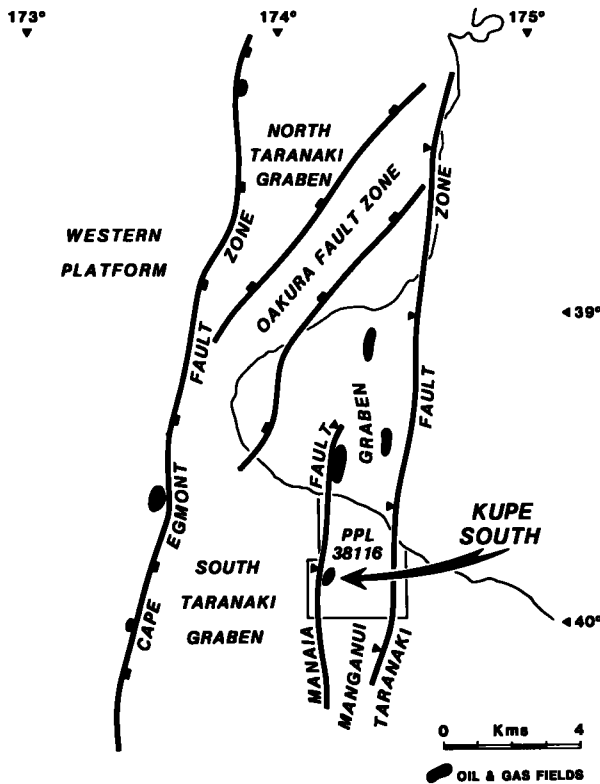


Fig. 1: Location map showing regional structural elements.

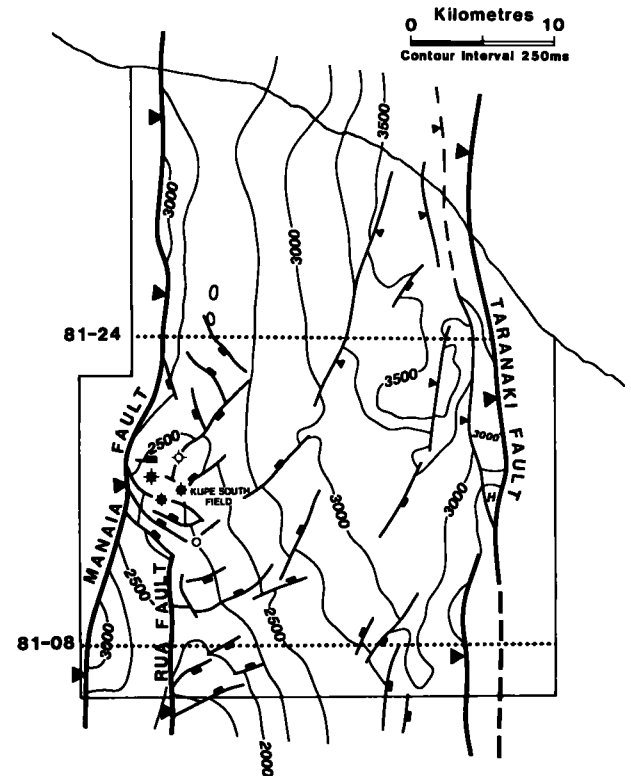


Fig. 2: Regional time map at the Base Oligocene Unconformity showing the locations of Lines P116-81-24/N16-85-003 and P116-81-08.

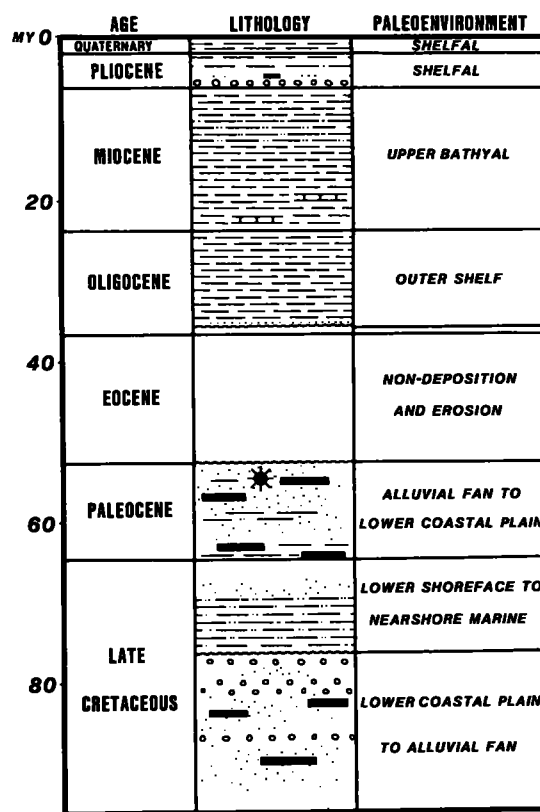
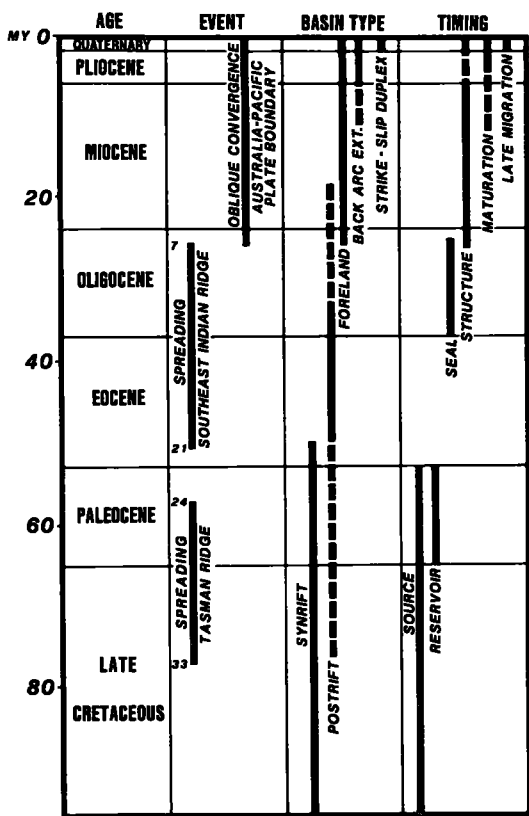


Fig. 3: Generalised stratigraphy and structural timing of the Kupe South Field.

thickness from over 4000 m west of the Manaia Fault to less than 1500 m on the Manaia Trend.

Uplift in the Late Miocene resulted in peneplanation and a return of terrestrial conditions in the Early Pliocene. Rapid subsidence throughout the Pliocene and Quaternary resulted in the deposition of some 2000 m of shelfal sands and shales. Late Quaternary uplift and erosion is evident to the east of Line 1 (Fig. 4). Associated Quaternary faulting occurs in an en-echelon pattern above the major basement faults.

The structural character of the western margin of the graben changes to the south of the Kupe South Field. Here the Rua Fault, illustrated on Line 2 (Fig. 5), is almost vertical and the Manaia Fault was non-existent through the Late Cretaceous to Paleocene.

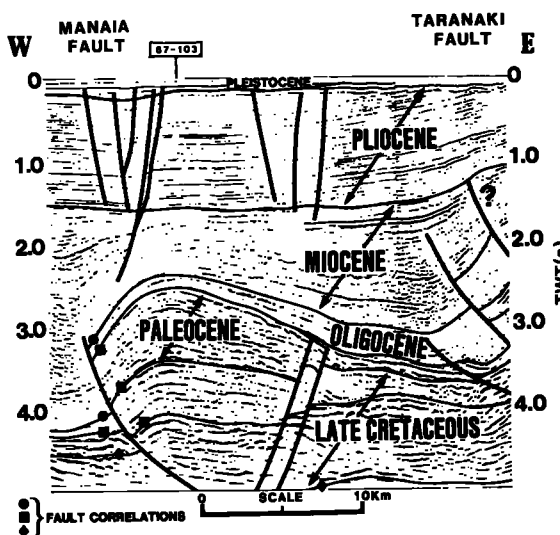


Fig. 4: Line 1 (Seismic Line P116-81-24/N16-85-003).

THE KUPE SOUTH FIELD

Exploration and appraisal of the Kupe South Field has identified a complexly faulted, north plunging anticlinal nose containing up to 140 m of hydrocarbons which may extend southwards beyond structural closure. The major structural features are identified in Fig. 6.

The Manaia and Rua Faults were active throughout the Late Cretaceous and Paleocene and were linked by a NW-SE trending basement fault beneath the southern edge of the Kupe South Field (Fig. 7). Reactivation of this basement fault in the Late Oligocene to Early Miocene produced the NW-SE faults that cut the Kupe South Field.

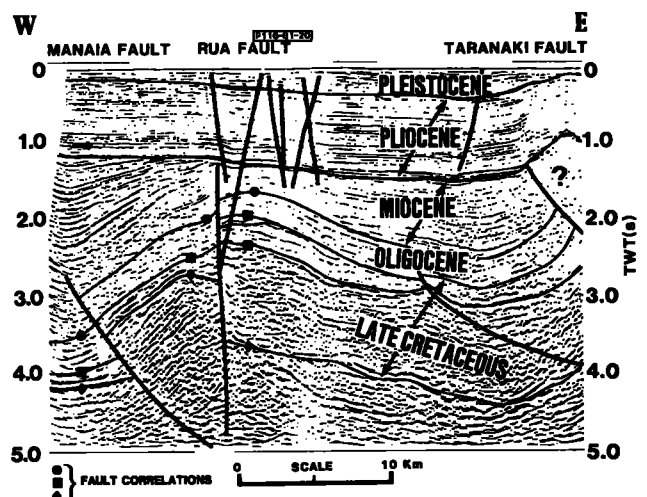


Fig. 5: Line 2 (Seismic Line P116-81-08).

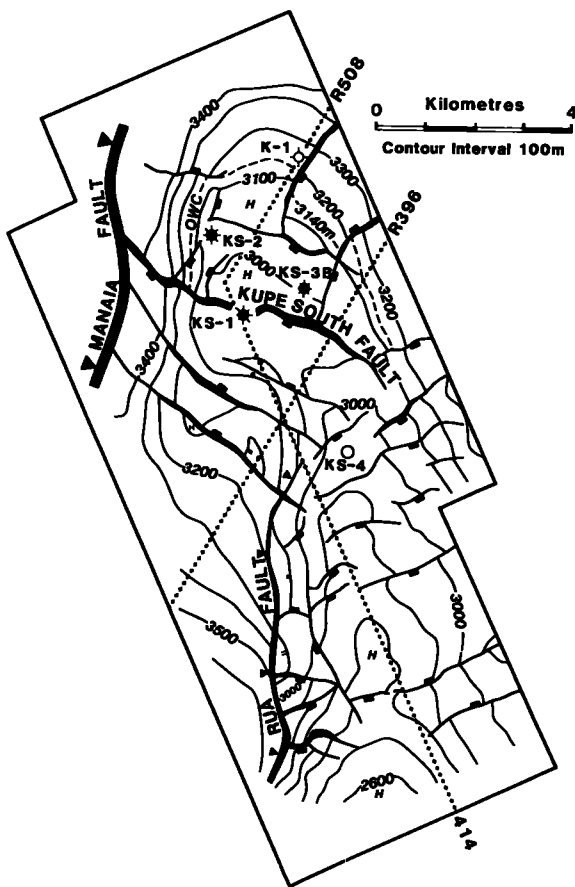


Fig. 6 Kupe South Field depth map at the base Oligocene unconformity showing the locations of Inlines 414/R508 and R396.

The Rua structure is cut by NE-SW trending normal faults that were active from the latest Cretaceous to the earliest Oligocene. Line 4 (Fig. 8) shows these faults situated above a major basement fault zone which forms an extension of the Rua Fault to the NNE.

Inversion along the Manaia and Rua Faults in the Oligo-Miocene resulted in a faulted anticlinal closure of the Kupe South structure by the end of the Miocene (Fig. 9). All the wells drilled to date are within the palaeoclosure, as are the observed flatspot anomalies (Figs. 7 and 8). The flatspot anomaly coincides with the hydrocarbon/water contact in the vicinity of the Kupe South Field. Quaternary uplift and folding tilted the palaeoclosure so that hydrocarbons migrated southwards, up-dip from the Kupe-1 area. The oil shows and staining encountered in this well are interpreted as residual. The closure was opened to the south (Fig. 6) implying the present accumulation in the Kupe South Field is stratigraphically sealed.

Development of reservoir

Rifting and subsidence during the Late Cretaceous and Paleocene introduced a marine influence on sedimentation patterns in the Manganui Graben. The Kupe South reservoir comprises a stacked succession of at least four depositional sequences that may have developed in response to eustatic sea level changes. Haq *et al.* (1987) recorded four major cycles of approximately 2 Ma duration each and several

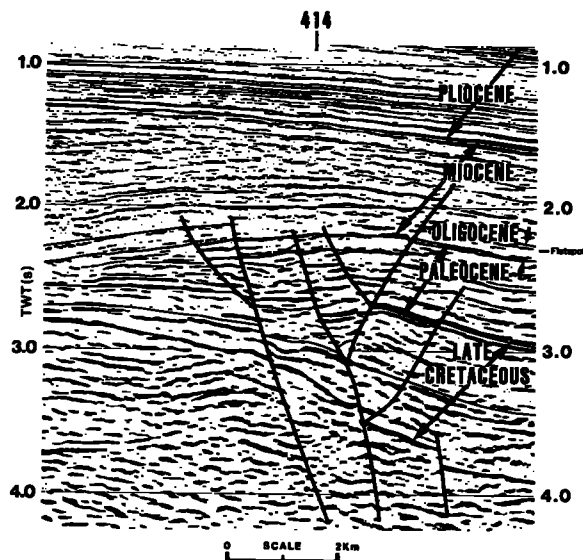


Fig. 7: Line 3 (Seismic Line-Regridged Inline R396).

shorter lived (0.5 Ma) in the Paleocene. The distribution of reservoir facies in the Kupe South area is believed to be controlled by the changes of relative sea level in conjunction with contemporaneous activity on the Manaia Fault.

Sequence stratigraphy

Paleocene aged sediments occur immediately beneath the Oligocene unconformity in the Kupe South area. The cyclic nature of the fluvial sand-shale packages is evident on the gamma and sonic logs (see Fig. 10 and Part II: Depositional Model). Each cycle has a sharp base, is approximately 150 m thick, and exhibits fining and thinning upwards sand beds. Lithologies within a cycle typically vary up-section from gravels and sands to coals and carbonaceous shales. The cycles are interpreted as stacked depositional sequences. Four cycles have been penetrated by drilling, but more probably exist within the Paleocene section. The four identified are informally annotated as 'A', 'B', 'C' and 'D' sands in descending order. The mappable sequence boundary beneath each sand package is denoted as the 'A', 'B', 'C' and 'D' horizon, respectively.

Field correlation

Fig. 10 shows the correlation from Kupe-1 to Kupe South-1. Kupe-1 is interpreted to have encountered the 'A' and 'B' sequence boundaries whereas Kupe South-1 intersected the 'B' and 'C' sequence boundaries. The 'A' sand is absent at the Kupe South-1 location due to faulting.

The correlation between Kupe South-2 and Kupe South-3 is shown in Fig. 11. The 'A' sequence boundary forms the base of an erosional trough controlled by faulting in the west. The fault trends north, parallel to the Manaia Fault. Erosion of the upthrown block suggests that the fault was active during the deposition of the 'A' Sand.

The correlation in Fig. 10 indicates that the Kupe South Fault and others of a similar trend (NW-SE) were not active during the deposition of the reservoir units. The correlations into the Rua area (Fig. 8), however, indicate syndepositional faulting.

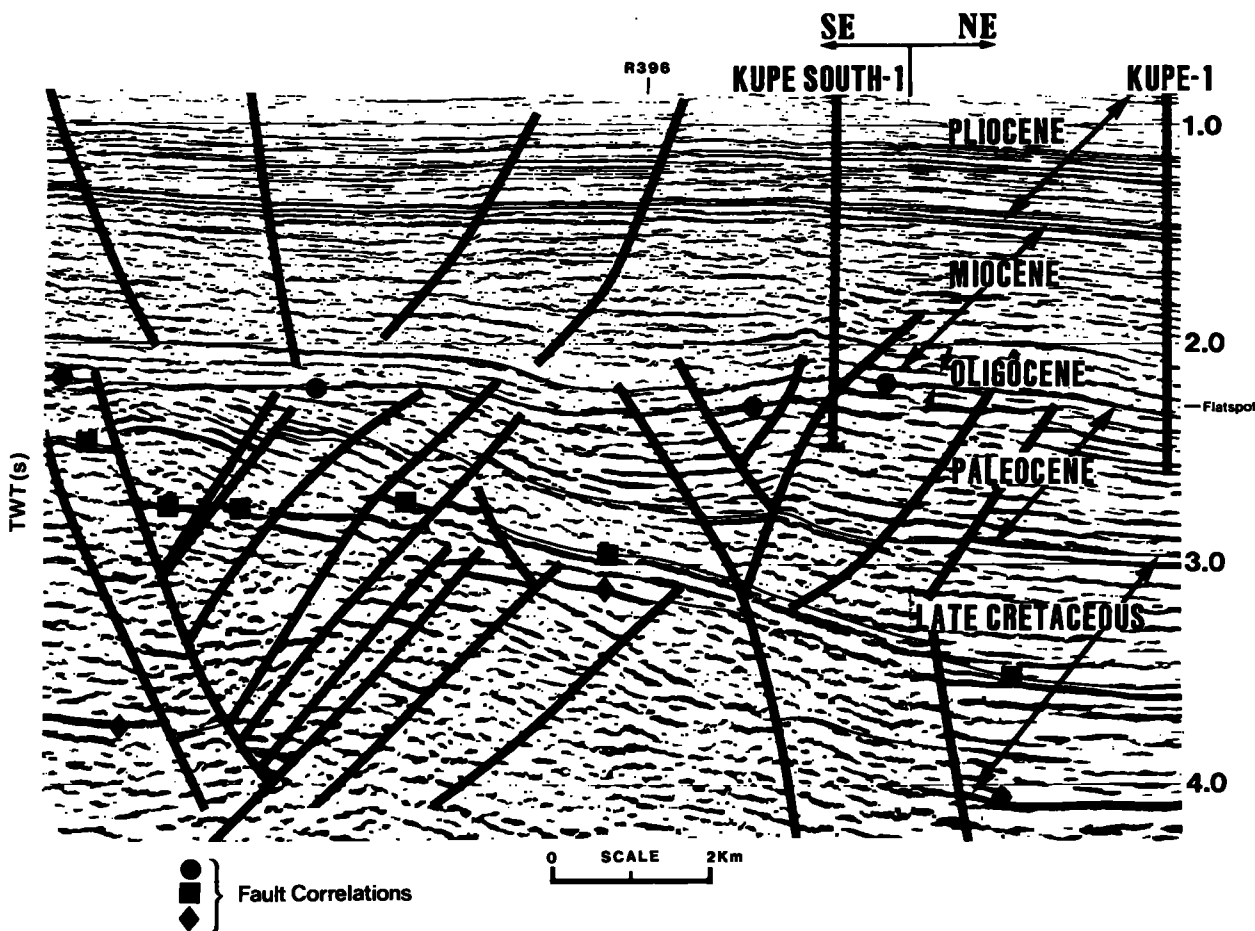


Fig. 8: Line 4 (Seismic Line-Inline 414/Regridded R508).

STRUCTURAL EVOLUTION OF THE KUPE SOUTH FIELD

Plate tectonic setting

The present-day plate tectonic map of the southwest Pacific Ocean (AAPG, 1981) locates the Taranaki Graben in relation to the present and past plate boundaries (Fig. 12).

Oceanic crust surrounding New Zealand is generally Late Cretaceous in age or older, except to the south in the Emerald Basin and to the north in the South Fiji Basin and Havre Trough. Eocene to Oligocene aged seafloor is interpreted in the Emerald Basin (Weissel *et al.*, 1977) and South Fiji Basin. The age of the seafloor in the Havre Trough is Pliocene to Quaternary.

A feature of the magnetic anomalies of the South Tasman Sea is the 90° change in the azimuths of anomalies 21 and 24. The Tasman Sea was opening from anomaly 33 (78 Ma) to anomaly 24 (57 Ma). Spreading on the Pacific-Antarctic Ridge commenced at anomaly 32 (72 Ma) and continues today. Spreading on the Southeast Indian Ridge had propagated eastwards into the Emerald Basin by anomaly 21 (51 Ma) and continued to anomaly 7 (26 Ma) as indicated in Fig. 12b. Spreading ceased at that time in the Emerald Basin. The resulting disparity in spreading rates across the Pacific-Antarctic and Southeast Indian Ridges is suggested by Kamp (1986) to have initiated the Australia-Pacific plate

boundary. Walcott (1987) suggested that parts of the boundary may have been active as early as the Late Eocene.

The proximity of the Taranaki Graben to the Australia-Pacific plate boundary is shown in Fig. 12c. Geodetic strain measurements record oblique convergence on the Hikurangi Margin (Walcott, 1987), which forms the southernmost part of the Kermadec-Hikurangi subduction zone. Relative plate motion further south is taken up by dextral transform movement on the Alpine Fault.

Tectonic styles associated with the developing Hikurangi Margin appear to change in time and space. Stern and Davey (1988) attribute this to maturity of the subduction zone. Backarc extension has occurred in the Havre Trough where subduction of the Pacific Plate has proceeded to depths of 300 km. Further south, where the subducting plate has not reached such depths (200 km), a broad extensional basin, the Wanganui Basin, has formed.

Structural model

The model depicts the evolution of the Kupe South structure in a series of seven time slices from the Late Cretaceous to the Pleistocene. The model relates three key plate tectonic events to five successive phases of basin development. The process of reactivating pre-existing faults and zones of weakness is a feature of basin development since the Late Cretaceous (Nathan *et al.*, 1986; Walcott, 1987; Hobson,



Fig. 9: Kupe South Field Oligo-Miocene isochron map.

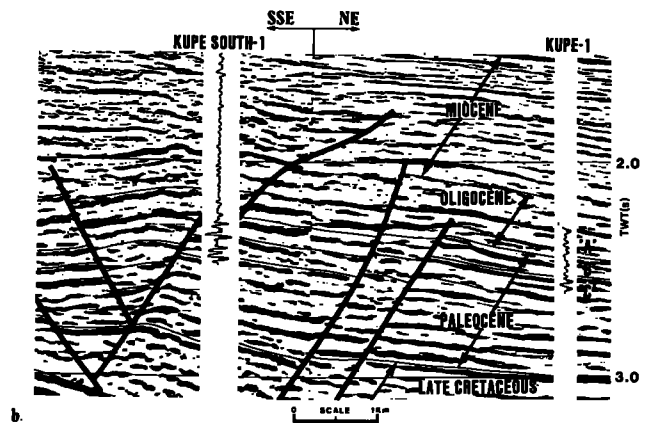
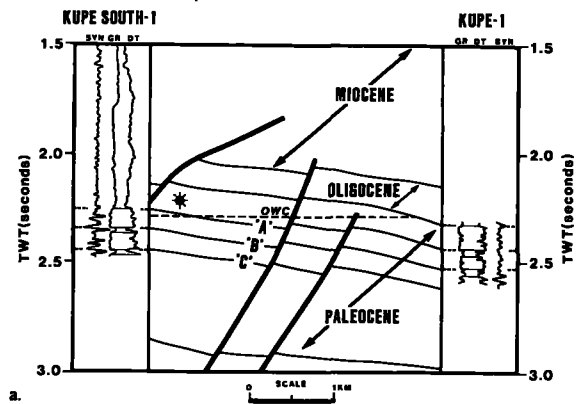


Fig. 10: Correlation of reservoir units between Kupe South-1 and Kupe-1 a: Correlation of reservoir b: Line 4 (Seismic Line-Inline 4145/Regridded R508).

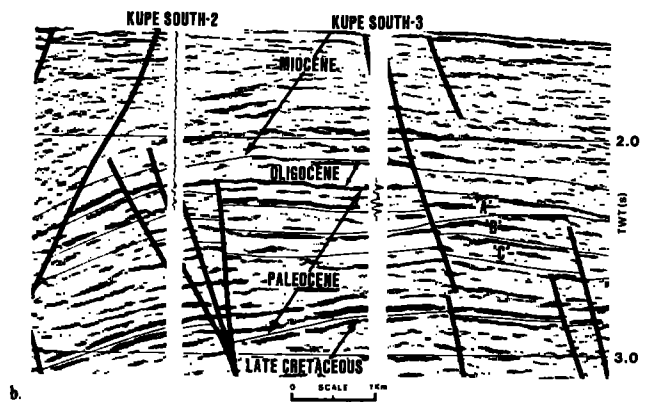
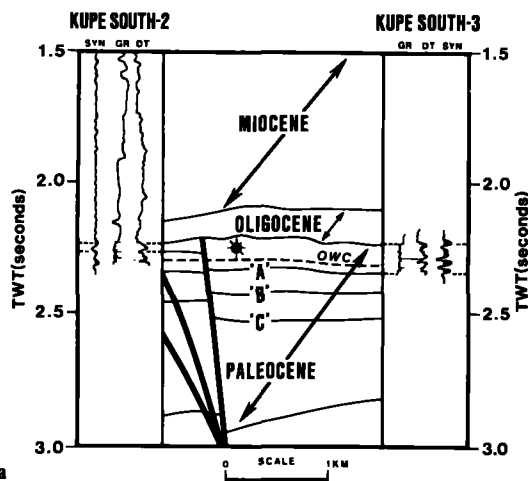


Fig. 11: Correlation of reservoir units between Kupe South-2 and Kupe South-3B a: Correlation of reservoir b: Line 5 (Seismic Line-Regridded Cross-line R1650).

1989) and has complicated the pattern of the resulting superimposed basins. The model is summarised in Fig. 3b.

Late Cretaceous Seafloor spreading commenced at anomaly 33 in the Tasman Sea and anomaly 32 in the Southern Ocean (Fig. 12a). Crustal stretching and associated rifting preceded this in the vicinity of the West Coast (South Island) and Taranaki Basins. In the Taranaki Basin the Late Cretaceous was a period of synrift basin development, during

which graben-fill sediments were deposited in N-NNE trending grabens across the Western Platform and, in particular, in the Manganui Graben. The dominant N-NNE structural grain appears to be older than Cretaceous and may have been imparted during the Paleozoic (Tuhua) Orogeny or even earlier (Nathan *et al.*, 1986).

Early Late Cretaceous alluvial fan to lacustrine and lower coastal plain sediments are estimated to have accumulated to a thickness in excess of 2000 m in the Manganui Graben

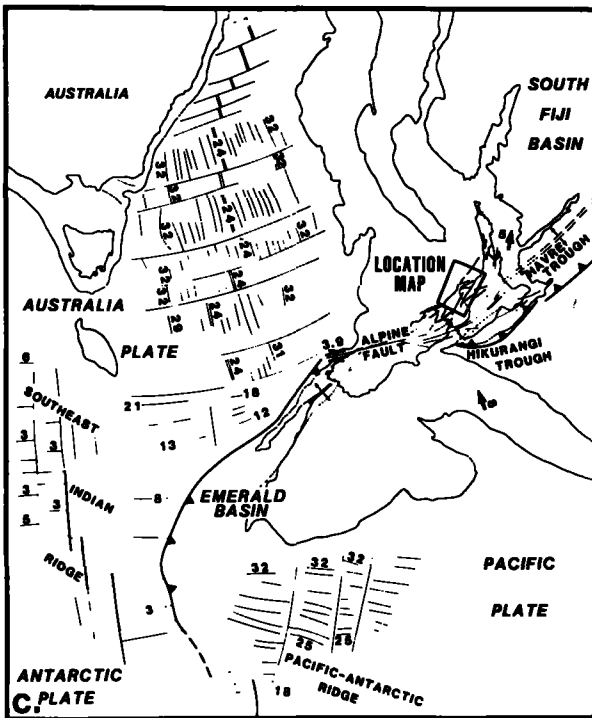
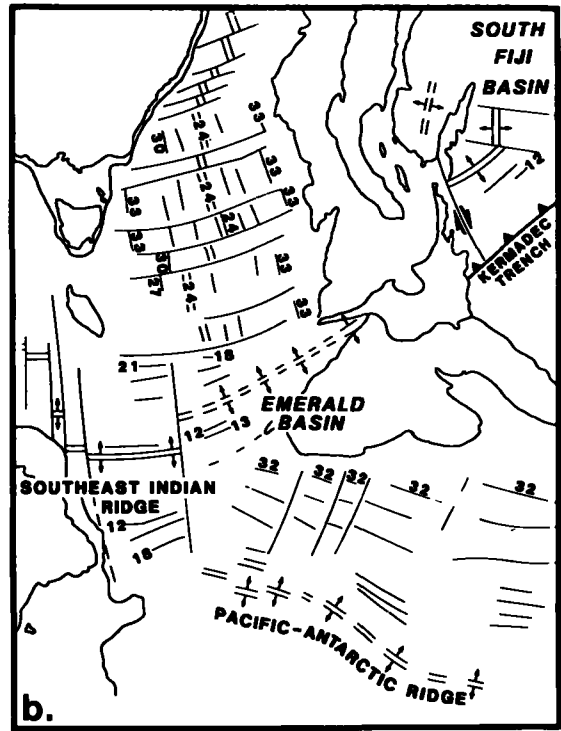
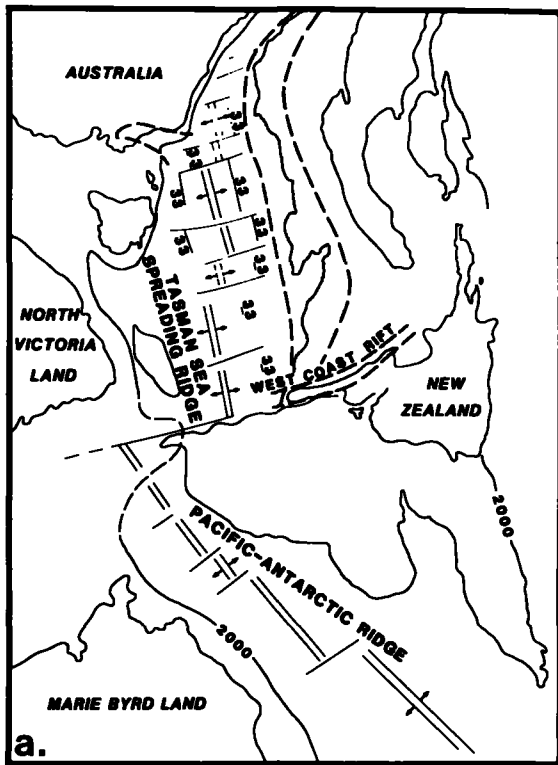


Fig. 12: Plate tectonic maps of the Southwest Pacific Region
 a: Late Cretaceous, anomaly 32 (72 Ma) (After Kamp, 1986)
 b: Late Oligocene, anomaly 7 (26Ma) (Adapted from Kamp, 1986)
 c: Present (After AAPG, 1981).

(Fig. 13a). The coal measures are considered potential source facies (Nathan et al., 1986; Cook, 1988).

Regional thermal subsidence following the onset of spreading resulted in a marine transgression such that marginal to open marine conditions prevailed during the Late Late Cretaceous. In excess of 1000 m of sediment accumulated in

the Manganui Graben (Fig. 13b) during this period of postrift overprint on a synrift basin.

Paleocene Rifting in the Southern Ocean continued in the Paleocene. In the Manganui Graben extension was oblique to the pre-existing structural grain implying the possibility of strike-slip movement on the graben faults. The graben has a distinct asymmetric, half-graben profile north of the Rua Fault (Line 1, Fig. 4). The Rua Fault has the appearance of a transfer fault in the Bally (1981) model of crustal extension, with extension occurring in a direction parallel to the fault (Line 2, Fig. 5). The driving mechanism of this phase of synrift basin development may have been the Southeast Indian Rift extension into the Emerald Basin (Kamp, 1986).

Over 1000 m of sediment accumulated in the Manganui Graben during the Paleocene (Fig. 13c). A succession of stacked fluvial depositional sequences were deposited in a graben setting under the influence of eustatic sea level changes. The southward thinning is attributed to onlap of the basin margin and to regional peneplanation in the early Eocene.

This interval constitutes the reservoirs of the Kupe South Field. The associated coal measures have good source potential (Cook, 1988), although they are above the generative window in the Kupe South area.

Eocene This was a period of transition from synrift to postrift basin development. Uplift at the end of the Paleocene to earliest Eocene immediately preceded seafloor spreading in the Emerald and South Fiji Basins (Fig. 12c). The exposed Paleocene sequence was peneplaned whilst deposition continued in the more basinward areas. The unconformity marks the onset of postrift basin development and a marine transgression that culminated in the Early Miocene. In the Kapuni area, an hiatus in the Late Eocene may be due to local uplift on the Manaia Trend. This would be the earliest evidence of compression (Robinson, 1988) on the

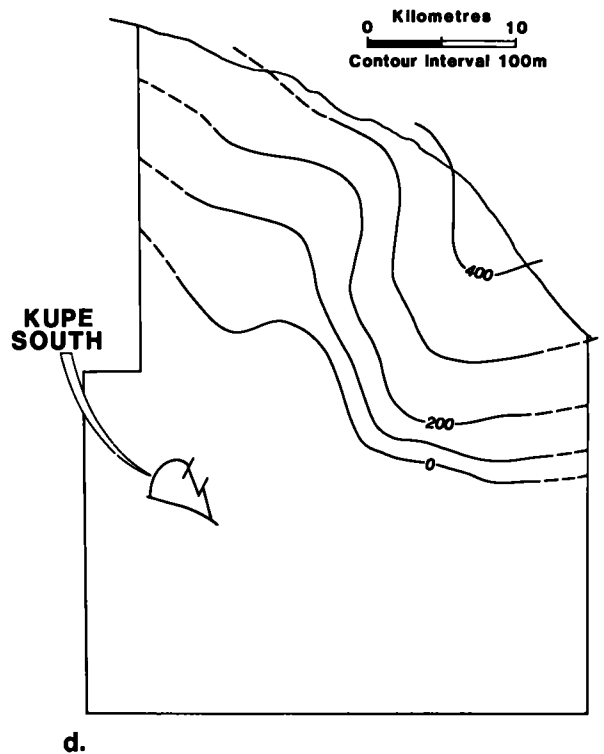
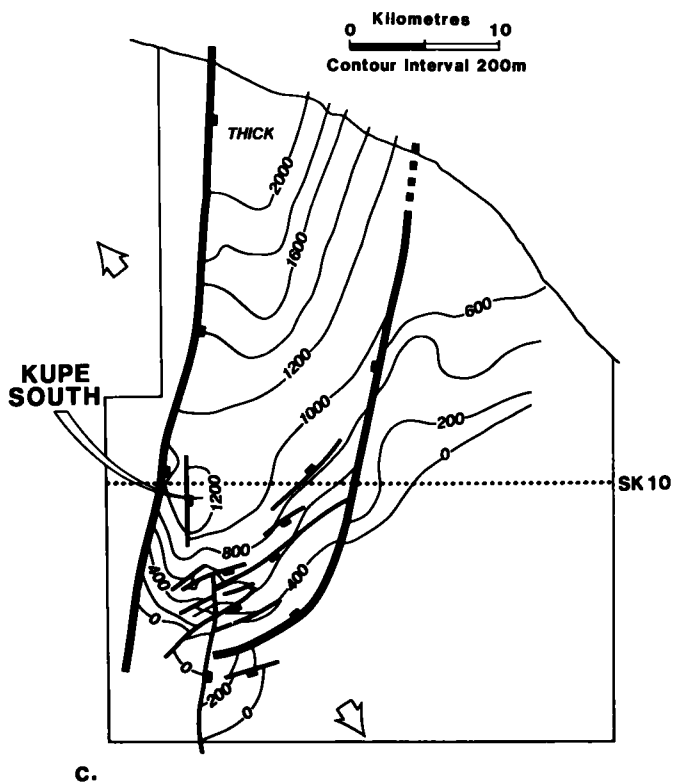
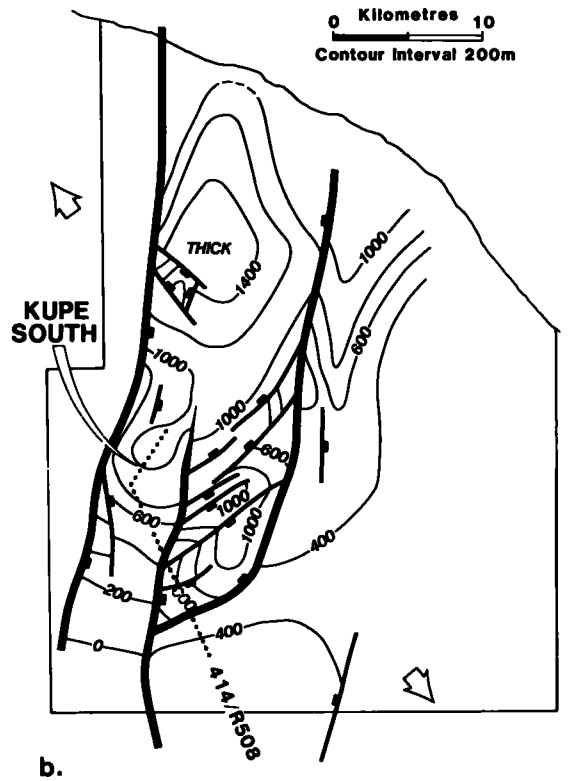
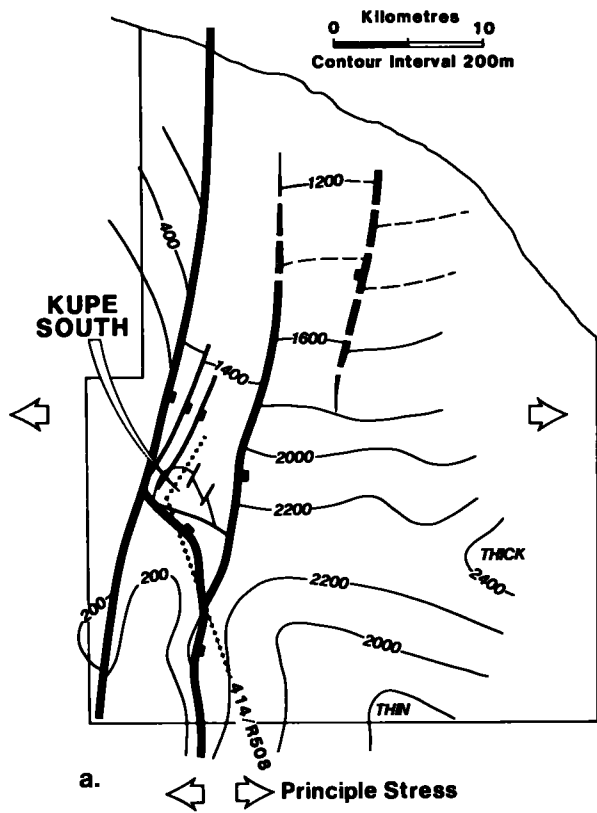


Fig. 13: Isopach maps of the Manganui Graben. a: Early Late Cretaceous b: Late Late Cretaceous c: Paleocene d: Eocene

Manaia Fault.

Eocene sediments in the Manganui Graben are confined to the onshore portion and adjacent offshore portion of the graben. Kapuni Deep-1 intersected about 1000 m of Eocene braided stream to lower coastal plain coal measures (Fig. 13d).

The Kupe South area remained emergent on a peneplaned surface during the Eocene. Sedimentation resumed in the Mid Oligocene under widespread marine conditions. This surface represents the top of the reservoir section and produces a strong seismic reflection. Down-dip, the Eocene coal measures are locally important as potential source rocks although they are probably immature in this part of the graben.

Oligocene Oblique convergence on the Hikurangi Margin produced compression and rapid basin subsidence as a result of crustal thickening and plate loading in the area referred to by Stern (1988) and Hobson (1989) as the foreland basin. This style of basin development was superimposed on the passive margin postrift phase. The variety of tectonic styles typical of a foreland basin setting have dominated the structural evolution of the graben since the Late Oligocene.

The rapid basin subsidence resulted in the deposition of outer shelf to upper bathyal marine shales. These shales form an effective regional seal for the Kupe South Field, and many other hydrocarbon occurrences in the basin.

The Oligocene section onlaps the regional unconformity progressively from north to south. The earliest deposition at Kupe South was in the Mid Oligocene. A pattern of offlap (basinward thinning) is evident to the northwest in the isopach map of this interval (Fig. 14a) and on Line 4 (Fig. 8). Thickening into the Taranaki Fault is also apparent.

The depositional environments for the Mid to Late Oligocene (Fig. 15) show an embayment parallel to the Taranaki Fault, with a thin zone of continental deposits occurring adjacent to the fault.

These factors, in conjunction with the latest Eocene hiatus along the Manaia Trend, suggest a latest Eocene to Early Oligocene age for the onset of compression and inversion of the Manganui Graben. This is between the times suggested by Kamp (1986) and Walcott (1987) for the inception of the Australia-Pacific plate boundary.

Miocene Subduction was initiated on the Hikurangi Margin during the Early Miocene. Pettinga (1989) noted that Miocene to Holocene accretionary prism sediments with slope affinities crop out in the East Coast Basin and are evidence of continued subduction. The compressional component increased markedly in the Late Miocene (10 Ma).

In the Manganui Graben structural inversion occurred primarily in the Late Miocene. The northwest trending faults across the Kupe South Field were active in the Early Miocene (Line 3, Fig. 7). These faults link with a deeper basement fault that was reactivated possibly with some strike-slip to accommodate differential reverse displacement on the Manaia and Rua Faults.

The strike-slip movement could in part explain the irregular thicknesses of the Paleocene section across the faults (Figs. 7 and 10b). By the end of the Miocene a closed structure had

formed in the Kupe South area (Fig. 9), and Early Late Cretaceous source rocks were buried to a depth in excess of 5000 m beneath the thrust Taranaki Fault zone. This depth approximates that necessary for the expulsion of hydrocarbons from coal rich source rocks (Cook, 1988).

Upper bathyal conditions prevailed throughout the Miocene and over 1000 m of marine shales were deposited in the Kupe South area (Fig. 14b). The marine transgression culminated in the Early Miocene.

Pliocene Backarc spreading in the Havre Trough and extension in the Wanganui Basin produced rapid subsidence in the neighbouring Manganui Graben. In excess of 1500 m of shelfal sands and muds accumulated in 3 Ma (Fig. 14c). Little fault activity accompanied the subsidence because the Manganui Graben was marginal to the main depocentres in the adjoining North Taranaki Graben and the Wanganui Basin.

The additional sedimentary cover greatly increased the volume of source rocks within the generative window, thus the Late Pliocene was a period of hydrocarbon generation and migration.

Pleistocene Dextral strike-slip faulting in the forearc region of the Hikurangi Margin has involved Quaternary sediments and produced regional uplift and tilting (Pettinga, 1989). Hobson (1989) referred to this area as a strike-slip duplex. Related strike-slip motion in the Manganui Graben has reactivated major basement faults, such as the Manaia, Rua and Taranaki Faults, in a dextral strike-slip mode. This movement has ruptured the brittle section above each fault where an en echelon fault pattern traces the basement fault. (Figs. 14d and 13a).

The thickness of Pleistocene deposits in the Kupe South area is unknown. The isopach map (Fig. 14d) indicates a maximum possible thickness of about 250 m. Nevertheless, the isopach map and Line 1 (Fig. 4) demonstrate the youthfulness of tilting and associated faulting over the Kupe South structure.

The tilting modified the paleoclosure on the Kupe South structure. As a result, Kupe-1 is no longer within closure, and hydrocarbons may have migrated up-dip. There is no structural closure mapped to the south over the Rua trend and a stratigraphic seal is consequently invoked to trap the Kupe South accumulation.

SUMMARY

The structural evolution of the Kupe South Field is summarised in Fig. 3.

The Late Cretaceous was a period of rifting and subsidence associated with spreading on the Tasman Ridge. Synrift basin development resulted in the deposition of more than 3000 m of terrestrial to marginal marine sediment in a graben setting. This is considered an important source rock interval in the Kupe South area.

Rifting, oblique to the earlier extension, continued into the Paleocene. The resultant pattern of extension is similar to that of the Latest Cretaceous and is considered to be associated with the Southeast Indian Rift. Continued activity on the graben boundary faults and eustatic sea level changes impinging on the basin margin were important controls on

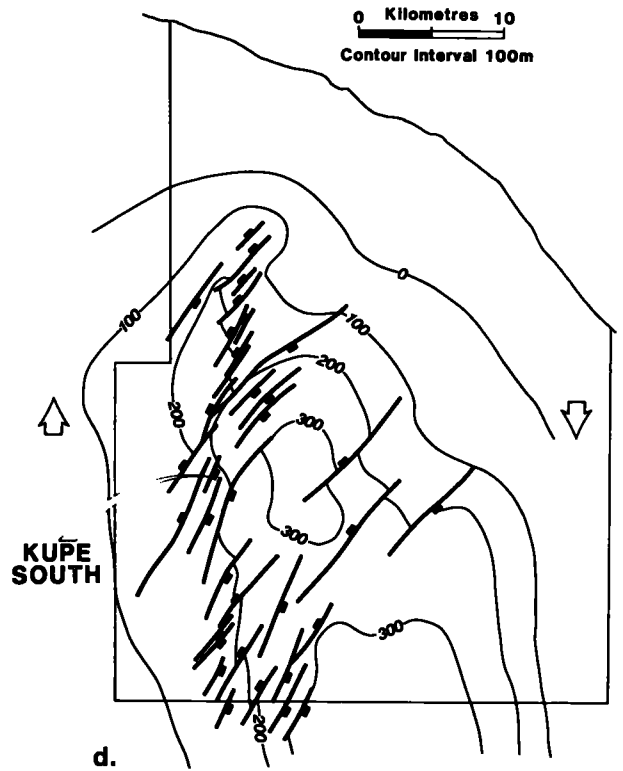
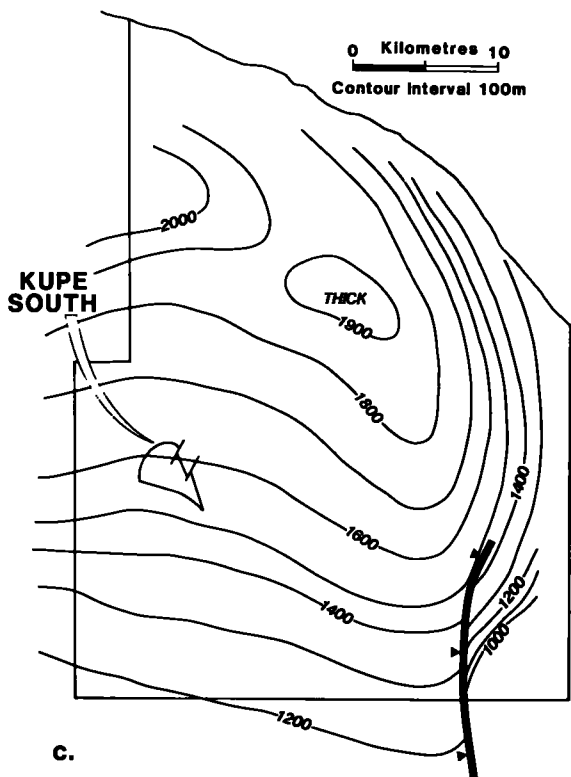
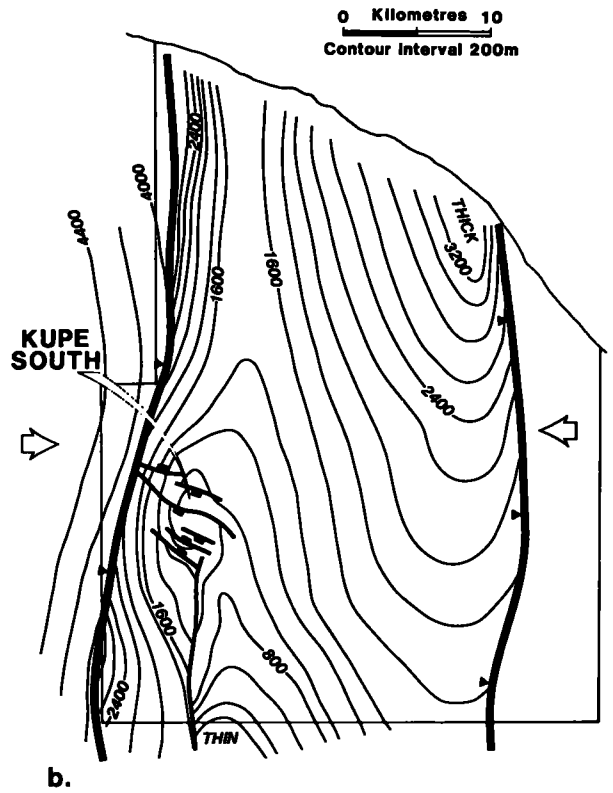
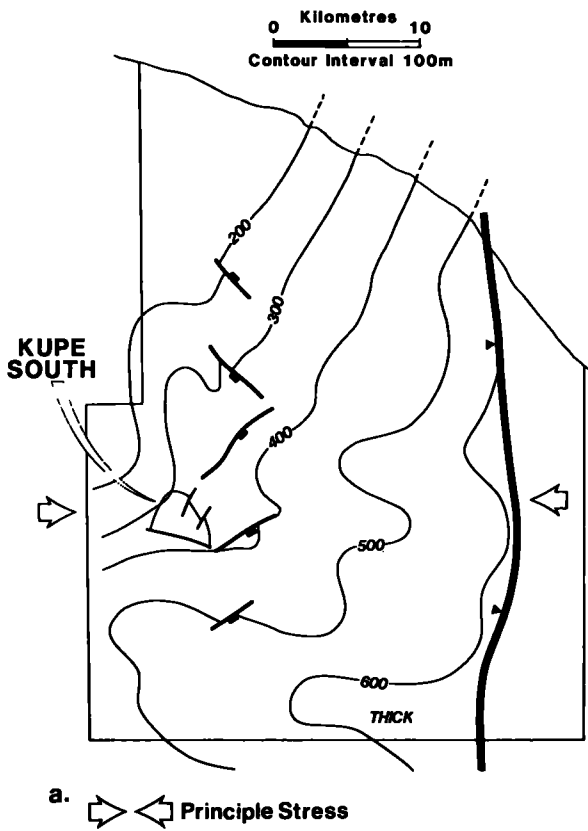


Fig. 14: Isopach maps of the Manganui Graben a: Oligocene b: Miocene c: Pliocene d: Pleistocene.

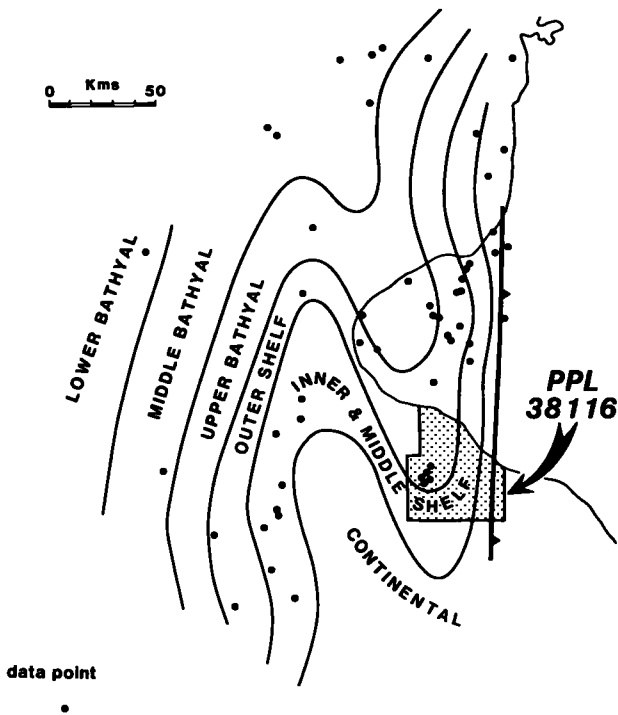


Fig. 15: Mid to Late Oligocene depositional environments.

the distribution of reservoir facies in the Kupe South Field.

The Eocene was a period of transition from synrift to postrift basin development, during which the Kupe South area was emergent on a peneplain.

The inception of the Australia-Pacific Plate boundary in the Early Oligocene marked the onset of a foredeep setting in Taranaki Basin. Plate-loading on an already subsiding passive margin resulted in rapid subsidence. Outer shelf to upper bathyal conditions prevailed with the consequent deposition of a thick marine shale that forms an excellent regional seal.

Oblique convergence on the Australia-Pacific plate boundary continued into the Miocene during which subduction of the Pacific plate became fully established. Structural inversion of the Manaia Fault due to compression resulted in a closed structure forming in the Kupe South area by the end of the Miocene. Further burial under the overthrust Taranaki Fault Zone may have resulted in the early maturation and expulsion of hydrocarbons.

Backarc spreading in the Havre Trough occurred in the Pliocene as the subduction complex matured. This was accompanied by extension and subsidence further south, in the Wanganui Basin and adjacent Manganui Graben, which resulted in the burial of Late Cretaceous source rocks to the hydrocarbon generative window.

Subsidence and burial continued in the Pleistocene with further likely maturation and migration of hydrocarbons into the Kupe South structure. Later uplift tilted the structure so that hydrocarbons may have migrated southwards up-dip of Kupe-1, and into the Rua area. The Kupe South Field is not structurally closed in its present-day configuration and the accumulation may be stratigraphically sealed to the south.

PART II: THE DEPOSITIONAL MODEL

INTRODUCTION

This section presents an interpretation of the sedimentary setting for the Farewell Formation in the vicinity of the Kupe South Field. These interpretations are extended by correlation to include similar sequences in Kapuni Deep-1 and Tah-1.

Kupe South-1 and -2, which were cored through the reservoir section of the Farewell Formation, provide the basis for much of the sedimentological control and interpretation. Kupe-1 and Kupe South-3, with over 150 sidewall cores (SWC) from the Farewell Formation, also provide lithological control, particularly in the northern and eastern portions of the Kupe South Field (see Fig. 6).

THE FAREWELL FORMATION

In the type area of northwest Nelson, the Farewell Formation is predominantly coarse sandstone to granule and cobble conglomerate, interbedded with minor fine sandstone and siltstone (Titheridge, 1977). There is no recognisable marine influence, and the formation is interpreted to be a Late Cretaceous to Paleocene (Haumurian to Teurian) alluvial plain sedimentary sequence.

In the vicinity of the Kupe South Field, the Farewell Formation is up to 1200 m thick comprising dominantly coarse to medium grained sandstone with mudstone interbeds. The sands are immature, predominantly lithic arkoses, with a considerable igneous rock fragment component (Martin, 1988b). The mapped Farewell Formation sequence thins to the south by erosion and depositional onlap beneath an Early Oligocene unconformity. Kupe South-1 entered the Farewell Formation through a fault plane (Kupe South Fault) some 180 m below the top of the formation, and has penetrated to at least the middle of the formation. The four wells have therefore encountered only the upper Farewell Formation, while the lower 600 m is presently defined only by seismic character. One objective of the recently drilled Kupe South-4 well was to penetrate the lower Farewell Formation in order to evaluate the reservoir quality of the sequence and to determine the reservoir potential on the southern flank of the field. The results of Kupe South-4 are confidential and are not available for this study.

The Farewell Formation consists of a series of high-amplitude seismic events that represent cycles of interbedded sandstone and mudstone. The sandstones usually predominate in the lower part of a cycle, and the mudstones in the upper part. The top of a cycle is characterised by mudstone beds up to 25 m thick, which are in erosional contact with the overlying basal sandstone of the next cycle. This contact typically generates a high-amplitude reflection event (Figs. 10 and 11) on the seismic section.

The cycles are interpreted as *seismic* or *stratigraphic sequences* that reflect major sedimentary episodes, from basal, high-energy sand deposition to relatively quiescent mud-dominated deposition in the upper section. The Farewell Formation is composed of a series of these *cycles* or *sequences*. The upper 4 cycles ('A' to 'D' Sands, in descending order) have been penetrated by the Kupe South wells (Fig. 16).

'C' and older sands

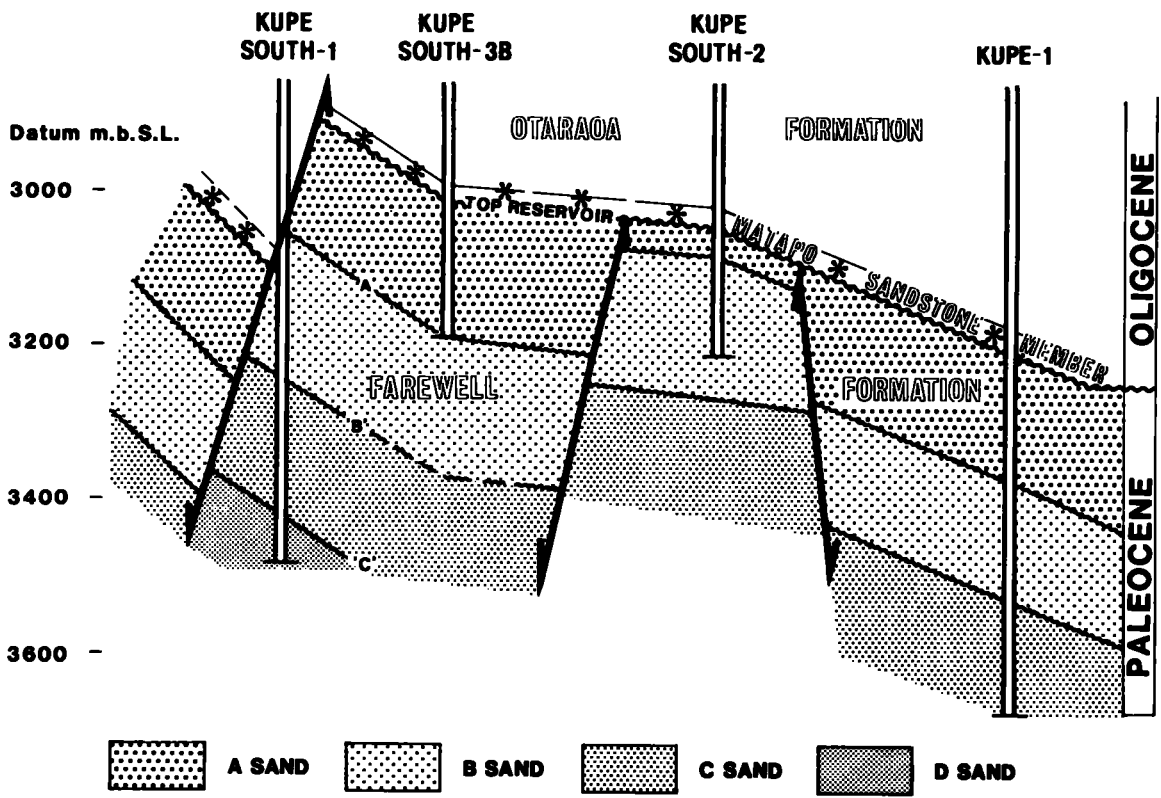


Fig. 16: Structural cross-section of the Kupe South Field, depicting correlations of the 'A', 'B', 'C' and 'D' Sands from Kupe-1 to Kupe South-1.

Little data exist on the lithological character of the 'C' and older sands within the Kupe South Field. In Kupe South-1, the 'C' Sand interval (Fig. 17) comprises 70% net sand, which is interbedded with mudstone beds, 0.20 to 8 m thick. The top of the interval is capped by a 25 m thick, laminated carbonaceous mudstone. Lower interbeds of mudstone within the 'C' interval are lithologically similar to the upper carbonaceous mudstone and generally occur as tops to the upward fining sand beds. The sandstones are medium to fine grained, with a muddy matrix. Bed thickness varies from about 0.20 m to stacked bedded sands in excess of 15 m. Upward fining within the sand beds is common, with only occasional coarsening upward trends. Discrete carbonate bands and nodules, up to 2 m thick, occur irregularly through the unit; more commonly associated with the sand beds below the oil-water contact.

In Kupe-1, the 'C' Sand interval comprises only 27% net sand, which is a substantial reduction compared to Kupe South-1. However, Kupe-1 penetrated only the upper 'C' Sand section which, like other sand cycles, tends to be fine grained and muddy towards the top of the sequence. In Kupe South-1, for instance, the net sand in the upper 'C' Sand is 64% compared to 79% for the lower section.

The 'C' Sand in Kupe South-1 is interpreted as a sequence of alluvial plain stacked channel sands with in-channel bar development and occasionally topped by vertical accretion or channel abandonment carbonaceous muds. The predominance of coarse to medium sand units with little mud development and no coals, suggests a relatively high-energy sedimentary setting such as that expected during braided

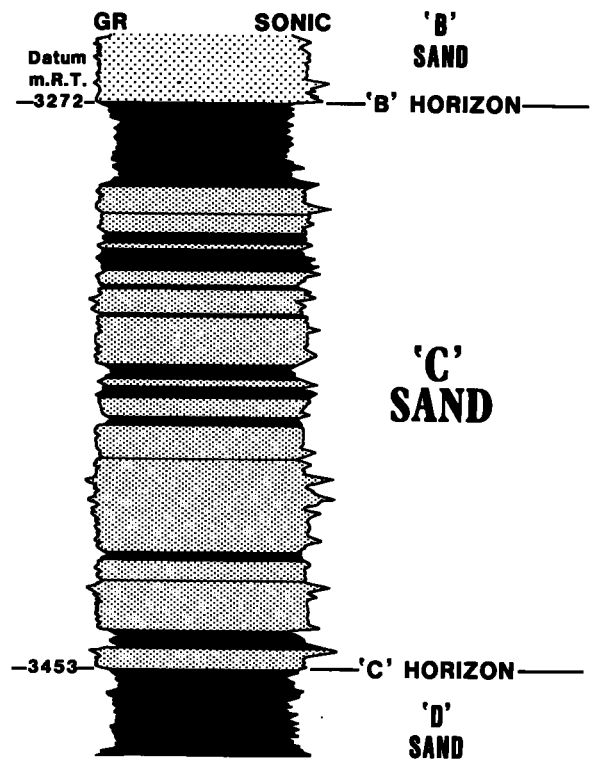


Fig. 17: 'C' Sand gamma ray and sonic log character from Kupe South-1.

river sedimentation. The finer-grained upper section of the 'C' Sand possibly indicates a waning in fluvial activity, such as expected in a lower coastal plain (meander belt) setting. Towards the centre of the basin, these mudstones are likely to be marine inundations, but in the vicinity of the Kupe South Field palynological analysis of the mudstones indicates a terrestrial environment with only occasional marginal marine influence, possibly estuarine.

The sparse well control for the 'C' and 'D' Sands limits our knowledge on the distribution and sedimentary trends of these sands. The rather tenuous dip data indicate a southerly paleocurrent direction. Sand: mud ratios indicate decreasing sand content and presumably decreasing fluvial activity to the north, suggesting a northerly paleocurrent direction. Because of possible spurious dip data, the latter criterion, combined with regional paleogeographic interpretation, is favoured. Thus a dominantly northward paleocurrent and paleoslope direction is inferred.

'B' Sands

'B' Sands were encountered in Kupe South-1, Kupe South-2 and Kupe-1 with 80, 50 and 45% net sand respectively. Detailed core logging was undertaken for the upper 'B' Sands of Kupe South-1 and -2 (Robinson, 1988). A similar lithological sequence to that encountered in the deeper sand units is evident. Sandstone interbeds predominate in the lower section, with increasing mudstone beds up-sequence. In Kupe South-1 multiple sandstone beds are stacked to form units 30 m thick, with little or no mudstone (Fig. 18). Similar stacked sand units are present in Kupe South-2 and Kupe-1, although they are usually 5-15 m thick in the former, and more commonly greater than 10 m thick in the latter. These multiple bedded units are usually separated by mudstone beds, 0.5 to 3 m thick. However, in the upper section of Kupe-1 one mudstone bed is 27 m thick (3411-3438 m).

The 'B' sandstones comprise moderately well sorted, coarse to medium, quartzofeldspathic sands (Fig. 19a). These sands are well stratified, with normal graded bedding. The sharp lower contact (often scoured) is occasionally overlain by conglomeratic coarse sands (Fig. 19b), that are trough and planar cross-bedded and grade upwards to planar and ripple-bedded, medium sands. Thin-bedded and laminated sandy muds form fine-grained tops to many of these graded units.

Other sedimentary features include contorted (slumped) bedding, convolute bedding, wavy and irregular bedding, bioturbation structures and numerous intraformational mudstone clasts (*rip-ups*). The ripple-bedding is predominantly asymmetric (current-derived), although possible wave-derived (symmetrical) ripples were identified. These sediments are only sparsely fossiliferous, with leaf impressions, carbonaceous (woody) fragments, spores, pollens and minor dinoflagellates.

Sand grain mineralogy is dominated by quartz and feldspar (plagioclase and K-feldspar) in almost equal proportions, with lesser, but nevertheless significant, amounts of lithic fragments and mica. The matrix is composed of detrital and authigenic clays (averaging about 16%). The carbonate content, which is widely variable (0-62%), occurs as discrete calcite nodules, bands and veins; only minimal carbonate occurs as disseminated siderite and ankerite.

In Kupe South-1 the entire cored section is within the 'B'

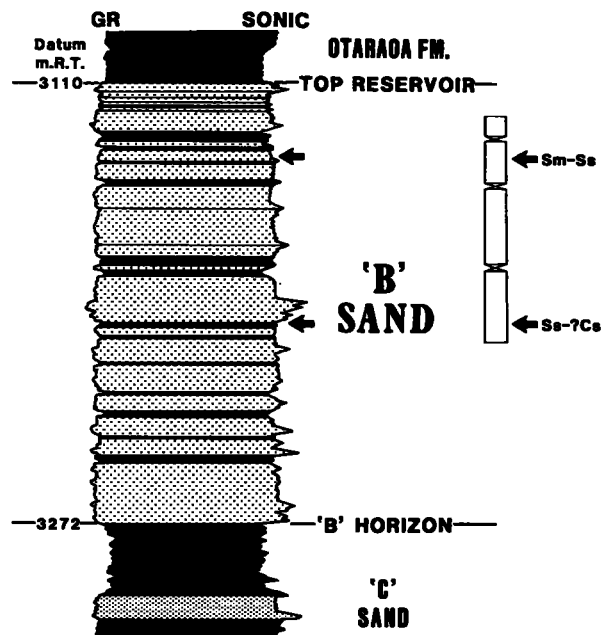


Fig. 18: 'B' Sand gamma ray and sonic log character from Kupe South-1. Sm-5m denotes the location of the massive to stratified sandstone illustrated in Fig. 19a. Ss-?Cs denotes the location of the stratified sandstone to conglomeratic in Fig. 19b.

Sand and comprises at least eight cycles of channel development in a dominantly meandering river setting. The high sand content, normally associated with braided river settings, is ascribed to the axial position of Kupe South-1 on the paleo-floodplain. Kupe South-1 reflects stacked channel sands where channel bar development predominated over vertical accretion and overbank sedimentation. Most of the sedimentary features within the Kupe South-1 cored section are assigned to a moderately low-energy braided river setting; possibly a transition between braided and meandering river conditions. The assignment of these sediments to a meandering river environment is, in part, a function of the nature of laterally equivalent sediments in Kupe South-2.

In Kupe South-2, the cored 'B' Sands comprise almost equal proportions of sand and mud. Sand beds fine-upwards, and are part of a generally upward-fining 'B' Sand interval. The beds contain basal pebble lags with dispersed mudstone rip-up clasts and carbonaceous fragments, and grade upwards through medium to fine sands that are often ripple-laminated towards the top. The beds are interpreted as stacked channel bars in a meandering river system. The mudstone units also exhibit an upward-fining character, usually with a sharp, often scoured upper contact. The muds are strongly bioturbated with bedding best developed where thin sand partings appear to have been rapidly deposited. These mud beds are variously interpreted as channel abandonment and overbank deposits or shallow subaqueous (lacustrine or inter-distributary) deposits. Kupe South-2 therefore reflects a sedimentary setting dominated by low-energy (suspension) deposition, which was periodically swept by a migrating river channel either on a low alluvial plain or a delta plain.

The 'B' Sands in Kupe South-2 are probably more distal and marginal in comparison to those of Kupe South-1.

The entire 'B' Sand interval was penetrated by Kupe-1 (Fig.

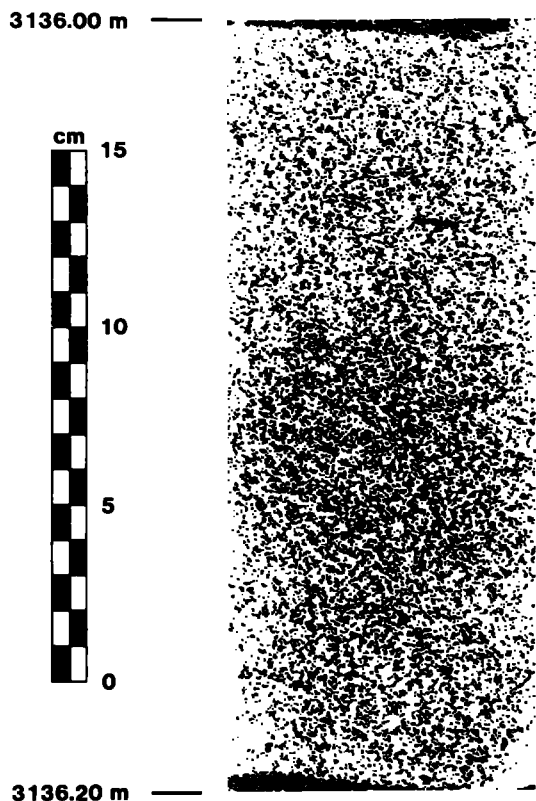


Fig. 19a: Core piece (3136.00-3136.20 m) of moderately well sorted, coarse to medium quartz-feldspathic 'B' Sand from Kupe South-1.

10). However, no cores were cut and the interpretation is based on down-hole logs and sidewall cores. The sequence in Kupe-1 is similar to that encountered in Kupe South-2, with over 50% mudstone, and is interpreted as a distal (down-slope) equivalent of the meandering river setting inferred for Kupe South-1 and -2. The south to north, proximal to distal relationship is reflected in the paleocurrent (dipmeter) data. A northerly component predominates, although widely divergent sedimentary dips are measured for the 'B' Sands in Kupe South-1 and -2. The divergence in current dip and channel axis orientation is characteristic of meandering river settings.

'A' Sands

The uppermost sandstone interval of the Farewell Formation is correlated across the entire Kupe South Field. To the north, the 'A' Sands are up to 200 m thick (Kupe-1) and continue at a similar thickness southward to approximately 200 m in Kupe South-3. Although not present in Kupe South-1, seismic mapping indicates the presence of at least 180 m of 'A' Sands on the northern upthrown side of the Kupe South Fault (see Fig. 10). Mapping south of the Kupe South Fault extends the 'A' Sands about 2.6 km to the south where they are interpreted to thin to a zero edge. The nature of this thinning, either by depositional onlap or top truncation, is equivocal.

In Kupe South-2, the entire 'A' Sand of 35 m was cored (Fig. 20). These sands are not considered representative of the 'A' Sands of the Kupe South Field. Seismic evidence indicates a dramatic thinning across a fault between Kupe South-3 and Kupe South-2 (Fig. 11). This NE-SW trending, down to the

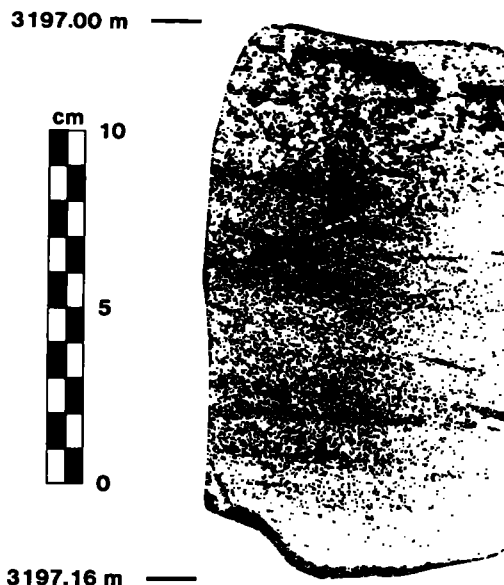


Fig. 19b: Core piece (3197.00-3197.16 m) of basal conglomeratic coarse sandstone in erosional contact with an underlying sand bed 'B' Sand, Kupe South-1.

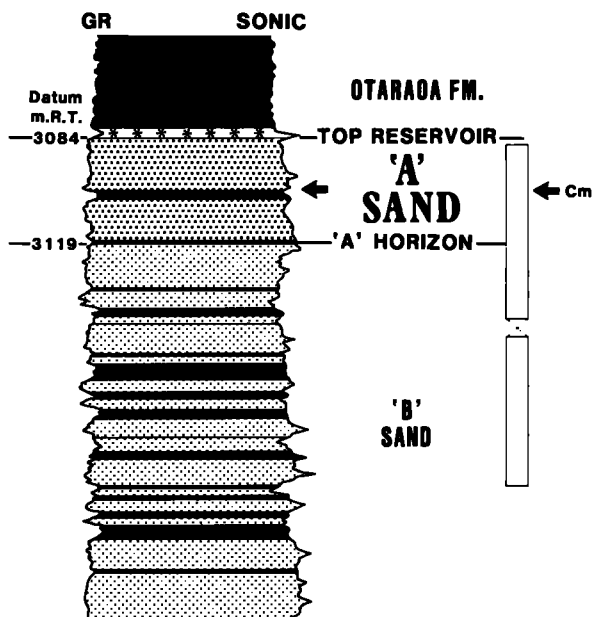


Fig. 20: 'A' Sand gamma ray and sonic log character from Kupe South-2. Cm denotes the location of the pebble conglomerate illustrated in Fig. 22.

east, normal fault is located 100-200 m east of Kupe South-2, and appears not to offset the top of the Farewell Formation. The fault is believed to have been active during 'A' Sand deposition and therefore the thin 'A' Sand section in Kupe South-2 is attributed to either uplift and erosion off the top of the 'A' Sand section, or late phase sediment onlap to an existing high, prior to marine inundation and the deposition of the overlying Otaraoa Formation. Field-wide models have been generated depicting these two alternatives (Figs. 21a and b). It is not possible to ascertain from seismic which

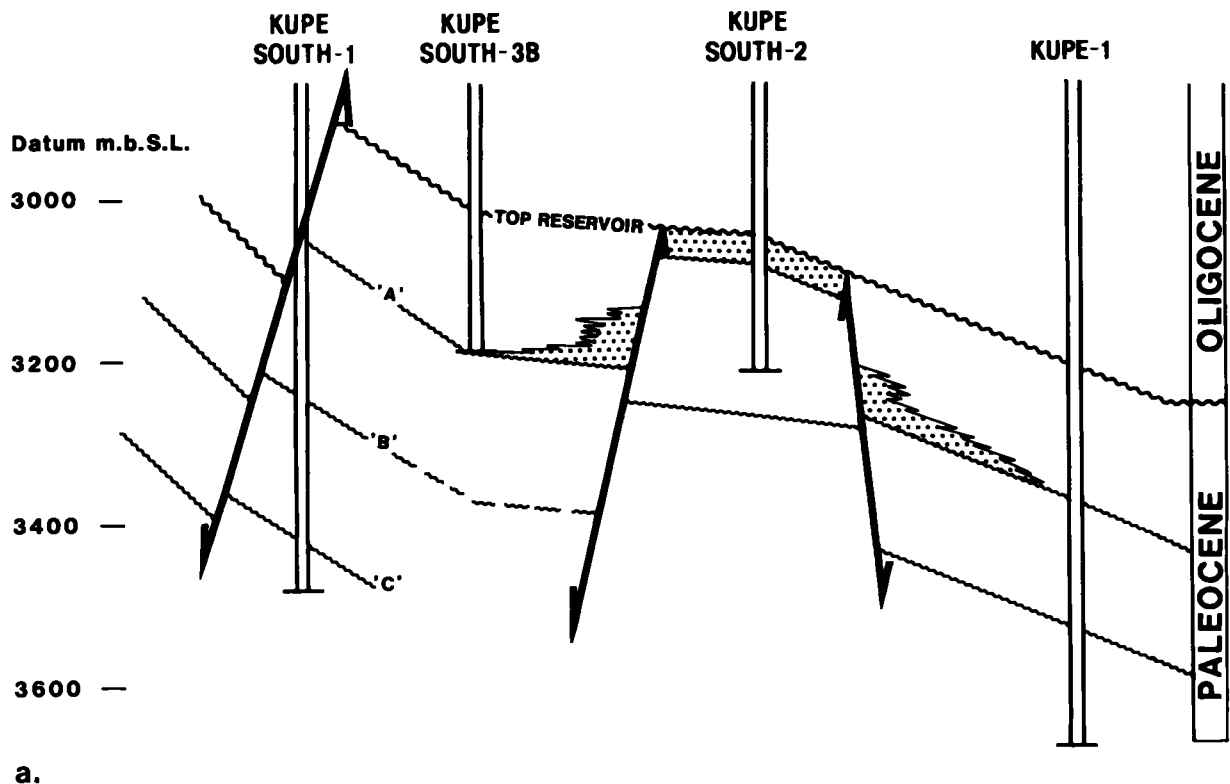


Fig. 21a: Structural cross-section of the Kupe South Field depicting early alluvial fan sand deposition at Kupe South-2.

model is the more appropriate, however, sedimentological and petrological evidence (reviewed later) favour faulting and erosion immediately prior to marine inundation (Fig. 21b).

The cored sequence in Kupe South-2, although not lithologically representative of much of the 'A' Sand interval, does provide information on the variability in lithology and sedimentary character within the 'A' Sands. Dominated by coarse to very coarse-grained sandstones, the 'A' Sand in Kupe South-2 is markedly different from the underlying 'B' Sand.

Individual sand beds commonly have thick (0.3 to 1.3 m) basal pebbly conglomerates (Fig. 22) with sharp, scoured lower contacts. These conglomerates, composed of igneous, volcanic, lithic and mudstone pebble (up to 50 mm) clasts, grade upwards to pebbly coarse sandstones that contain trough and planar cross-bedding, abundant carbonaceous fragments and mudstone (*rip-up*) clasts, and are usually only moderately well sorted. These sand beds are variously 0.5 to 2.5 m thick and exhibit a marked fining upward trend, such that 10 to 12 m of the stacked beds are topped by 1 to 3 m of ripple, cross-bedded, medium to fine sands and carbonaceous muds.

The abundance of pebbly, coarse sandstones and the virtual absence of mudstone interbeds reflect a high-energy sedimentary setting. Based on sedimentological features and facies analysis, the 35 m 'A' Sand interval in Kupe South-2 is interpreted as a lower alluvial fan to alluvial plain (braided river) channel setting. The sands depict multiple channel lag and bar development. The proximity of these sands to the then active Manaia Fault, suggests a westerly source for these sediments, which could have been shed as fans off a

developing fault scarp.

The 'A' Sands encountered in Kupe South-3 and Kupe-1 are lithologically and texturally different from Kupe South-2. In Kupe South-3 and Kupe-1 the sands are clean, generally medium- to coarse-grained, and exhibit both fining and coarsening upwards trends, although sharp upper and lower contacts are common. The net sand percentages are 73 % and 60% for Kupe South-3 and Kupe-1 respectively, whereas Kupe South-2 has 80% net 'A' Sand.

The 'A' Sands are lithic arkoses with a textural and compositional maturity compared to older sands. Paleocurrent and channel orientations determined from sedimentary dip analyses for the 'A' Sand indicate a strong northerly component, in contrast to the 'B' and older sands. These features suggest that the 'A' Sands, as seismically mapped and correlated, have sedimentological, lithological and petrological affinities that differ from the older sands. Such features are commonly associated with high-energy, fluvial activity such as encountered in braided river settings. On this basis, such a sedimentary environment is postulated for the 'A' Sand interval of the Kupe South Field.

Otaraoa Formation and Matapo Sandstone Member

The Otaraoa Formation is a regionally extensive Oligocene marine mudstone. The formation is generally calcareous and intensely bioturbated. It is, in part, the southern time equivalent of the Tikorangi Formation and provides a regional seal to the Kapuni Group reservoir sandstones. In the vicinity of the Kupe South Field, the basal Otaraoa Formation comprises a thin (1 to 2 m) poorly sorted, very fine to coarse, glauconitic sandstone (Matapo Sandstone Member). These sediments are recognised regionally and are interpreted as

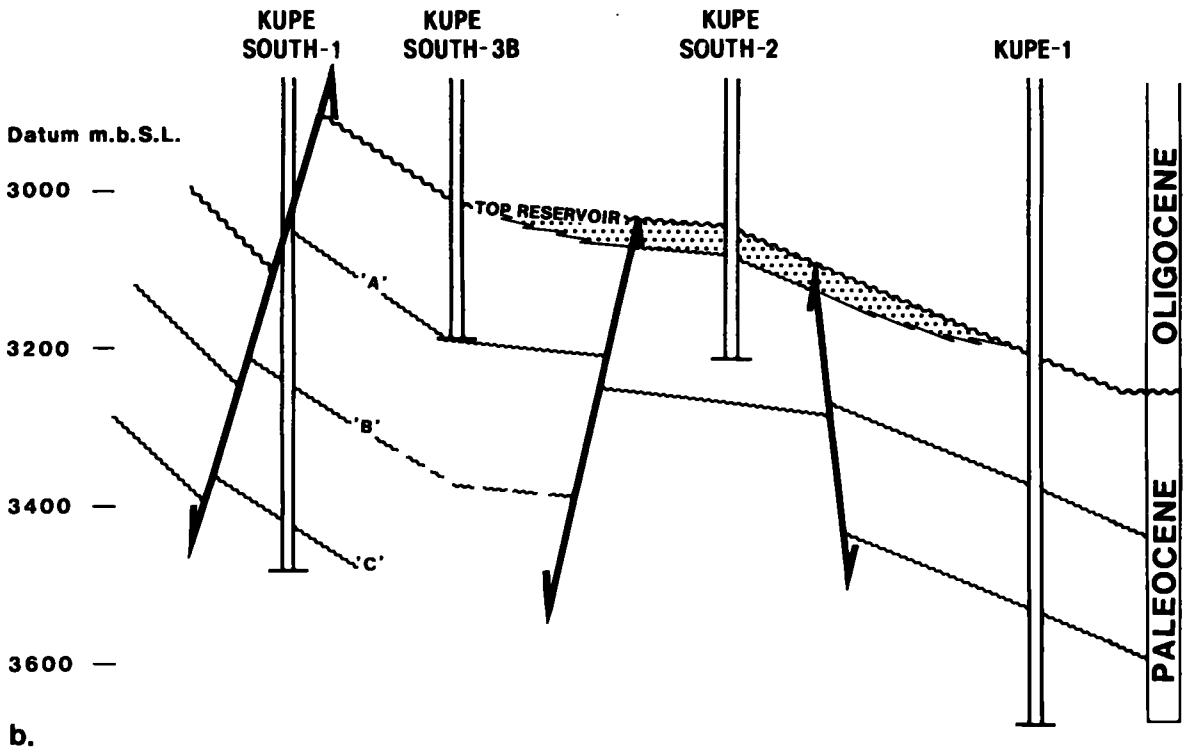


Fig. 21b: Structural cross-section of the Kupe South Field depicting late alluvial fan sand deposition at Kupe South-2.

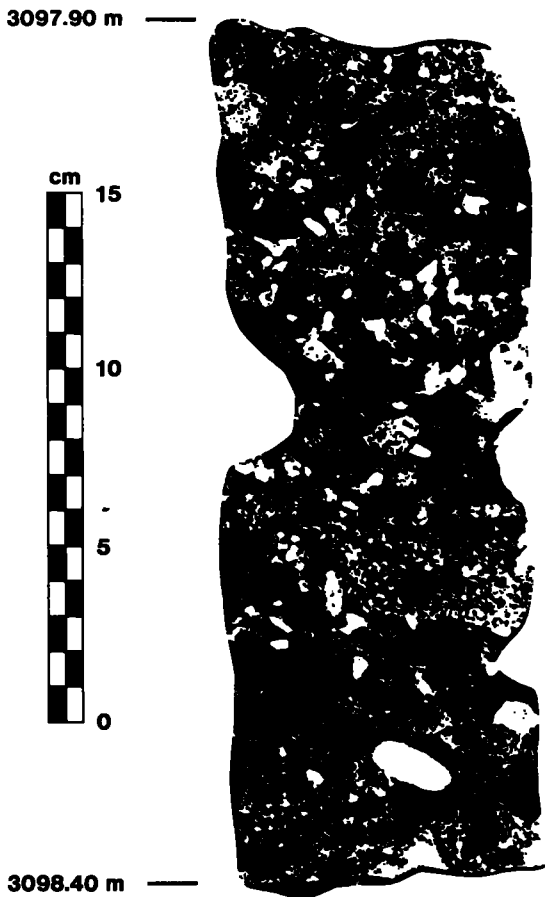


Fig. 22: Corepiece (3097.90-3098.14 m) of pebble conglomerate within the 'A' Sand, Kupe South-2.

indicating the onset of rapid subsidence and major marine transgression in the Oligocene. The glauconitic sandstone probably represents a period of low sedimentation and marine re-working of the top of the Farewell Formation during transgression. The calcareous muds of the Otaraoa Formation represent deepening marine conditions where carbonate precipitation and detrital deposition were occurring simultaneously.

In the vicinity of the Kupe South Field an hiatus between the Matapo Sandstone and the underlying Farewell Formation represents some 15 million years (Late Paleocene-Early Oligocene). This discordance is most likely a function of penneplanation, represented by depositional thinning to the south with some late phase, possibly latest Eocene to earliest Oligocene erosion. Further south, in the vicinity of the Rua Structure, the unconformity is more obviously a function of erosion of the underlying Farewell Formation.

Sequence summary

The variation in the sedimentary setting of the drilled sequence can be determined utilising associations of lithofacies, their diagnostic sedimentary features and comparing them with facies models. The principal facies for alluvial and deltaic environments are illustrated in Fig. 23. These facies trends provide analogues for the sediments encountered within one sequence of the Kupe South Field, and indicate a transgressive sequence from a possible lower alluvial fan, through braided river to delta plain setting. The 'B' Sands illustrate this transition from braided river to meandering river setting, and possibly a period of delta plain deposition. Similar sedimentary cycles are inferred for the 'C' and 'D' Sands. The sediments are cross-bedded, medium to coarse sandstones that grade upwards to muddy sandstone

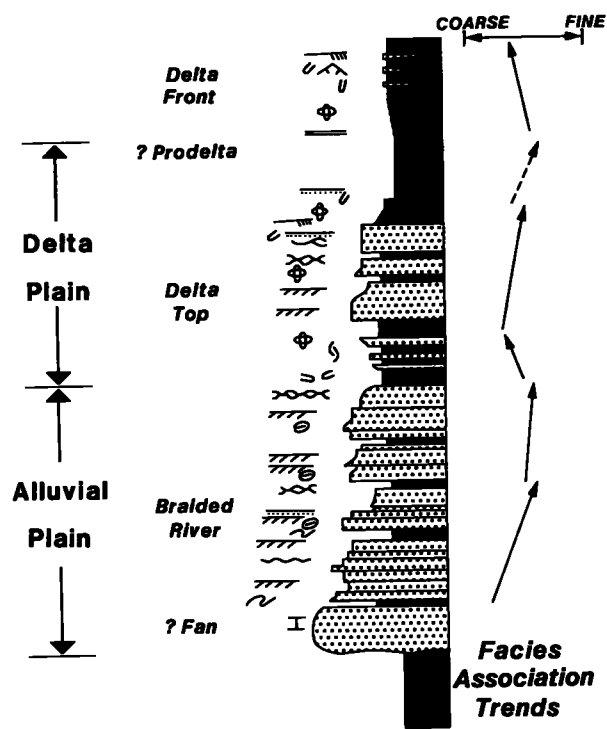


Fig. 23: An idealised sedimentary sequence for one sand cycle within the Farewell Formation, Kupe South Field, and bioturbated mudstones.

These finer sediments are interpreted as overbank deposits, perhaps becoming interdistributary or lacustrine in setting as the transgressive cycles proceeded. A progressive decrease in sediment grain-size and improved sorting, combined with a transition from large to small-scale cross-stratification within these sands, indicates a decrease in fluvial activity. Presumably this is the result of increasing distance from source, reduction in paleoslope and a possible onset of marine conditions. This evidence suggests that the uppermost sections of the 'B', 'C' and 'D' Sands represent a virtual cessation of sand influx at maximum transgression.

The 'A' Sands in the Kupe South Field are locally deposited on an eroded 'B' interval, as evidenced by truncation of seismic reflectors along the eastern edge of the field (Fig. 11). Elsewhere a more conformable relationship is apparent. Alluvial fan to alluvial plain deposits, comprising pebbly conglomerates and coarse sandstone, appear restricted to the western margin of the field. Elsewhere, 'A' Sands include upward fining, and upward thinning, pebbly sandstones with occasional, very thin intervals of ripple-bedded, fine sandstone and mudstone. These sediments represent channel bar development with bar top accretion and channel abandonment.

A pronounced decrease in fluvial activity in the upper 'A' Sand is not apparent. The finer sediments marking the top of the 'A' cycle were probably removed by later erosion during the doming along the Manaia Trend, as inferred in the *Early Sand Model* (Fig. 21b).

In the vicinity of the Kupe South Field each sequence represents a cycle of transgression, however the overall trend of the Farewell Formation appears to be progradational.

LITHOLOGICAL CORRELATION

Figs. 21a and 21b are structural cross-sections indicating the seismically determined correlation of the 'A', 'B' and 'C' Horizons and the two preferred models for the sequence history of the 'A' Sand. Seismic correlations between the wells were refined having regard for similarities in log character and core lithologies. Petrological analyses were of considerable assistance in correlation, particularly where sand and clay mineralogical parameters are different for the 'A' and pre-'A' ('B' and older) sands (Martin, 1988 a and b).

PALEOGEOGRAPHY SKETCHES

Introduction

Palynological and foraminiferal age dating of the Farewell and basal Otaraoa Formations in the Kupe South wells indicate a Early Paleocene (Early to Mid Teurian) age for the former and Early Oligocene (Late Whaingaroan) age for the latter. A more refined age dating within the Farewell Formation is not possible, thus preventing the development of a detailed chronostratigraphy and consequent paleogeographic maps. However, five approximate time-horizons were selected to depict various sedimentary settings through the upper Farewell Formation.

Paleogeographic sketches (Figs. 24a to e) were developed through the late 'B' Sands, early, mid and late 'A' Sands and prior to full marine transgression. Paleocurrent and paleochannel data were obtained from stratigraphic dipmeter plots. The combination of sedimentary features, net to gross sand distributions and seismic mapping enabled a paleoslope to be determined for each time horizon. Each sketch is only a representation of sand development at one instant in geologic time and, therefore, not a reflection of the total sand distribution of a particular time interval.

Paleogeographic reconstructions

Late 'B' Sand deposition (Early Paleocene) The Kupe South Field was dominated by low-energy fluvial activity associated with lower coastal plain (meandering river) setting (Fig. 24a) towards the end of 'B' Sand deposition. Kupe South-1 appears to have been in an axial position with stacked channel sand development for much of the 'B' Sand deposition. Kupe South-2 in a lower energy setting to Kupe South-1, and is inferred to be in a marginal and slightly more distal position.

Kupe-1 is dominated by fine-grained sediments in the upper 'B' Sand and again a marginal and more distal relationship to Kupe South-1 is inferred. Sedimentary dip data indicate a north to northeasterly paleo-drainage direction and this is reflected in the net : gross sand trends, where sand content decreases to the north.

A wide, relatively flat alluvial plain dominated by fine sediment deposition in overbank, lacustrine and abandoned channel settings is postulated for the late 'B' Sand depositional phase (Fig. 24a). River channels were present but their discharge, competence and frequency of migration were reduced compared to the early 'B' and the overlying 'A' sands settings. The late 'B' Sand setting may represent an interval of *depositional near-starvation*, when rising sea-level moved sediment depocentres towards the hinterland in front of a flooding event. The onset of 'A' Sand deposition is depicted by the basinward migration of these depocentres and the

downcutting into the 'B' interval. The resulting unconformity represents the sequence boundary correlated as the 'A' horizon.

Early, mid and late 'A' Sand deposition (Mid Paleocene)
A change in the base-level occurred at the onset of 'A' Sand deposition. This effect was probably due to both eustatic sea level change and subsidence of the Manganui Graben along the eastern side of the Manaia Fault. This configuration during early 'A' Sand deposition is depicted in Figure 24b.

The Manaia Fault was probably active as a scarp, where 'B' and older units as well as basement rocks were being stripped from the western or upthrown side of the fault. Also, sediment was likely being contributed from the east, and from the uplifted Rua area to the south.

The 'A' Sand in Kupe South-2 is inferred as basal in the 'A' interval (see Fig. 21a) representing lower alluvial fan sediments shed from the Manaia Fault scarp. Later uplift removed the upper 'A' Sands. Elsewhere, in the vicinity of Kupe South-3, Kupe-1 and possibly Kupe South-1, braided river channel sedimentation predominated, with paleo-drainage to the north. A similar sedimentation pattern could have been developed in the eastern Manganui Graben along the Taranaki Boundary Fault.

Sedimentation continued through the mid Paleocene (mid and late 'A' Sand deposition; see Figs. 24c and 24d). The energy of the fluvial system declined as relief to the west, south and east was reduced by erosion, and the Manganui Graben was infilled. Alluvial fan deposition was probably restricted to the westernmost margin of the graben (Fig. 24c) with braided rivers sweeping across the Kupe South area and encroaching the ridge east of the Kupe South Field. During late 'A' Sand deposition (Fig. 24d), this ridge and the Manaia Fault scarp were buried and the Manganui Graben developed as a large alluvial plain. Braided river systems were probably still active in the vicinity of the Kupe South Field, with meandering rivers developing to the north. Low-energy, lower coastal plain sedimentation may have suc-

ceeded the braided river setting, but any resulting deposits were subsequently removed by erosion.

Seismic mapping and regional sedimentation patterns indicate an hiatus through the Late Paleocene and Eocene in the southern portion of PPL 38116. During this time the Kupe South area was probably peneplaned with lower coastal plain and shoreface sedimentation further to the north, around the Toru and Kapuni Structures (see Fig. 25).

Marine transgression (Early Oligocene) A flooding event or transgression associated with regional subsidence occurred during the Early Oligocene (Late Whaingaroan)(Fig. 24e). Prior to this marine inundation, arching may have occurred along the eastern side of the Manaia Fault, with consequent minor erosion from the Rua, Kupe, Toru and Kapuni structures just prior to the onset of full marine conditions.

In the vicinity of Kupe South Field, the nature of the structuring is uncertain. Arching along the Manaia Trend may have been caused by wrenching, or by compression to the east. However, it appears likely that minor extensional faulting along the Manaia Fault Zone continued into the Late Eocene-Early Oligocene. The effects of this faulting may have extended across the Kupe South Field as a series of small, down to the east, normal faults with progressively increasing fault-throws to the west. The subsequent reversal on the Manaia Fault continued from the Late Oligocene through the Miocene.

SUMMARY

A *depositional model* for the Kupe South Field has been developed from detailed sedimentological studies. This model has been placed within a regional structural and sedimentary history (Fig. 25) and is thus useful in predicting likely reservoir trends within and beyond the present limits of the Kupe South Field.

The Early-Mid Paleocene Farewell Formation, in the vicin-

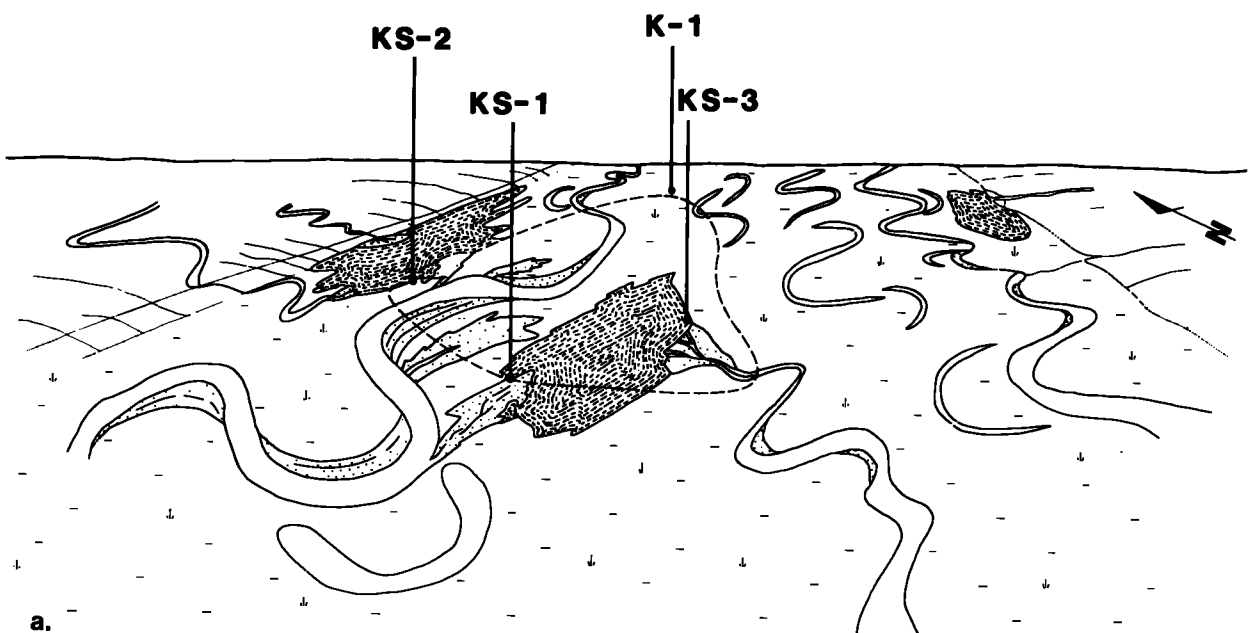
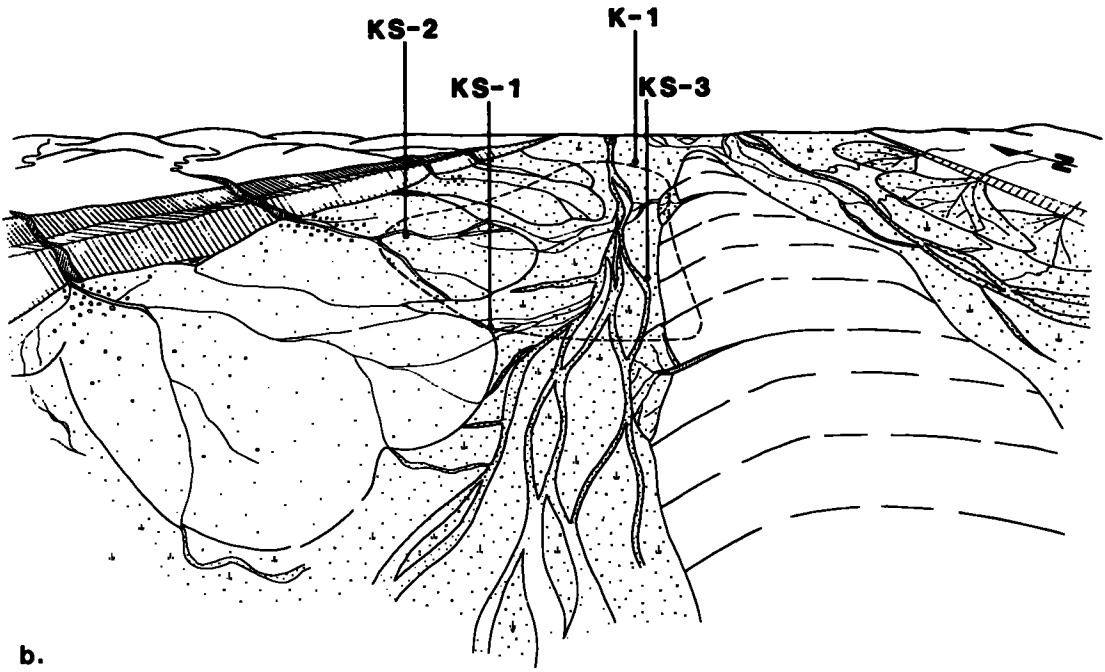
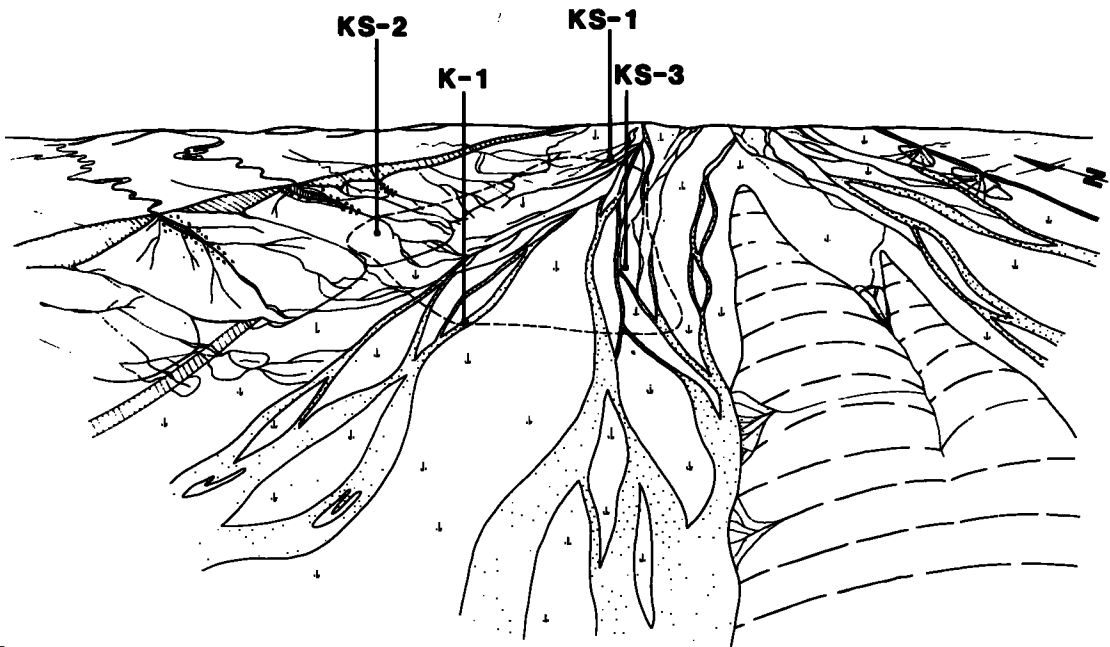


Fig. 24a: Early Paleocene paleogeographic sketch depicting deposition of the late 'B' Sand in the Manganui Graben.

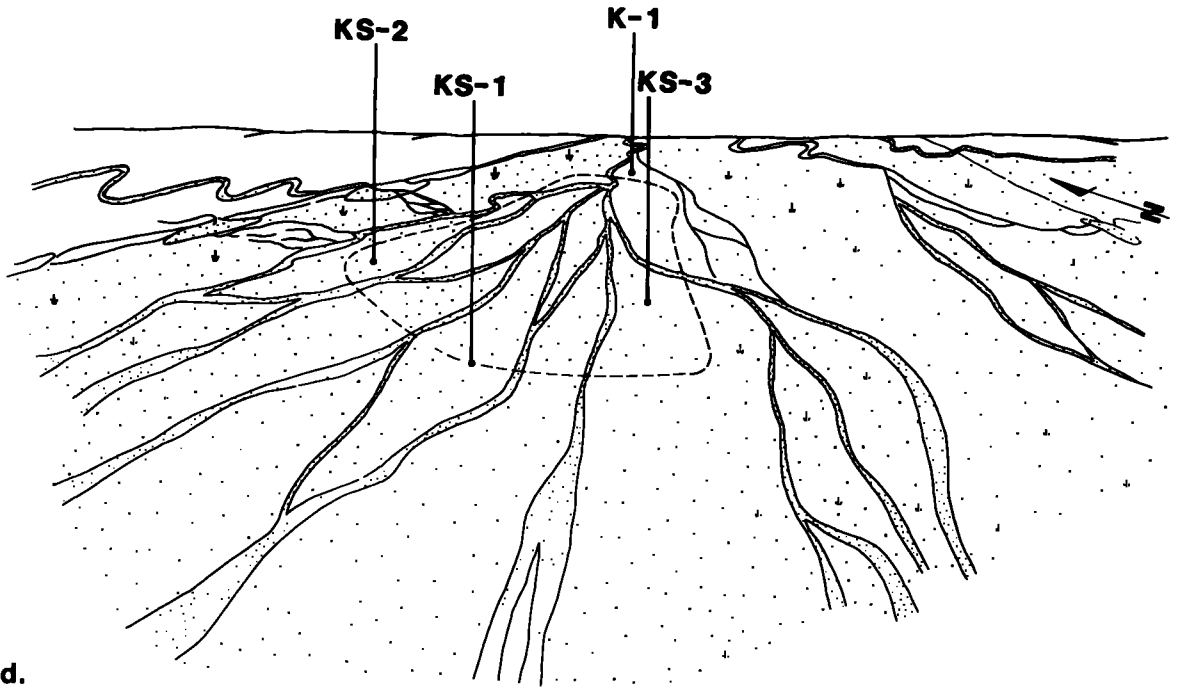


b.

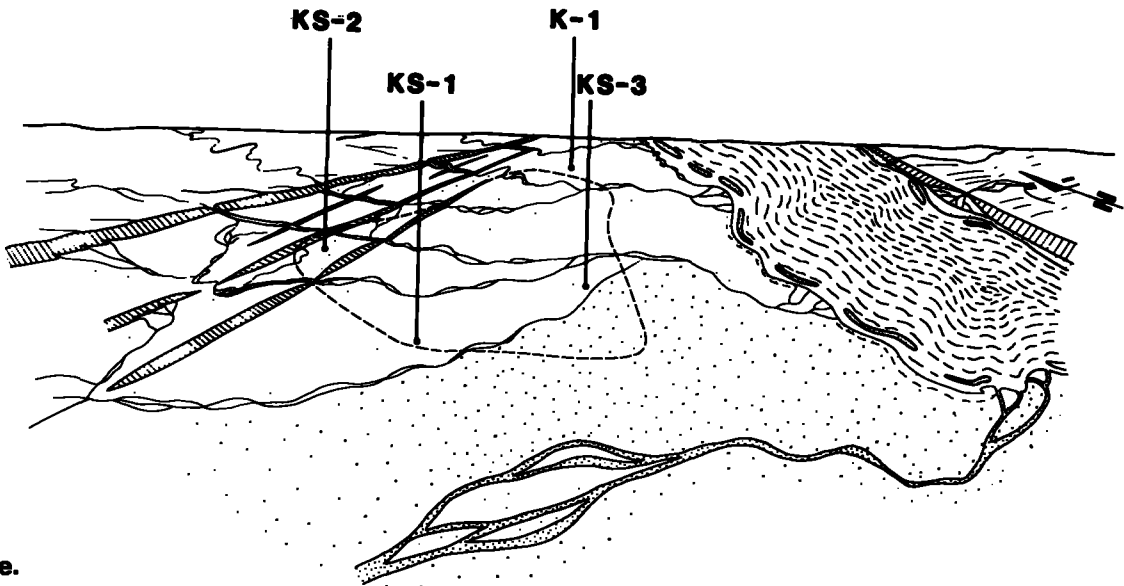


c.

Figs. 24b, c and d: Early Paleocene paleogeographic sketches of deposition of the *early, mid and late* 'A' Sand in the Manganui Graben.



d.



e.

Fig. 24e: Early Oligocene paleogeographic sketch of the onset of marine conditions in the Manganui Graben.

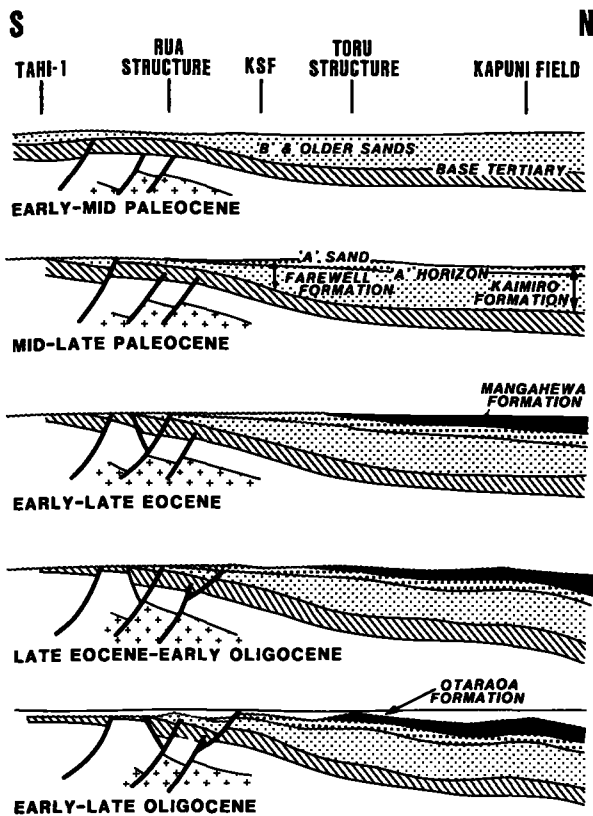


Fig. 25: Paleogene structural and sedimentary history along the Manaia Trend, South Taranaki Graben.

ity of the Kupe South Field, represents a series of transgressive terrestrial cycles ('A', 'B', 'C' and 'D' Sands) in a dominantly regressive sequence. Channel sand sedimentation marked the onset of each cycle, where erosion and sediment infilling of paleotopography led to a subdued relief and consequent reduction in traction current activity, changing alluvial plain and braided river conditions to a meandering river setting. Each progressive sand cycle appears to have been slightly higher energy, indicating a northward migration of terrestrial depocentres through time (Fig. 26), such that the uppermost cycle ('A' Sands) was a high-energy, lower alluvial fan to upper alluvial plain settings.

Various sand distribution patterns developed as a result of these sedimentary cycles. The braided river settings of the 'A' Sands and basal parts of older sands, provide laterally and vertically interconnected channel and bar sands. The meander belt to delta plain setting (much of the 'B', 'C' and 'D' Sands) has more restricted channelised sand patterns. In this setting, vertical accretion and minimal channel migration has resulted in substantial mud deposition, with consequent poor interconnection of the channel sands.

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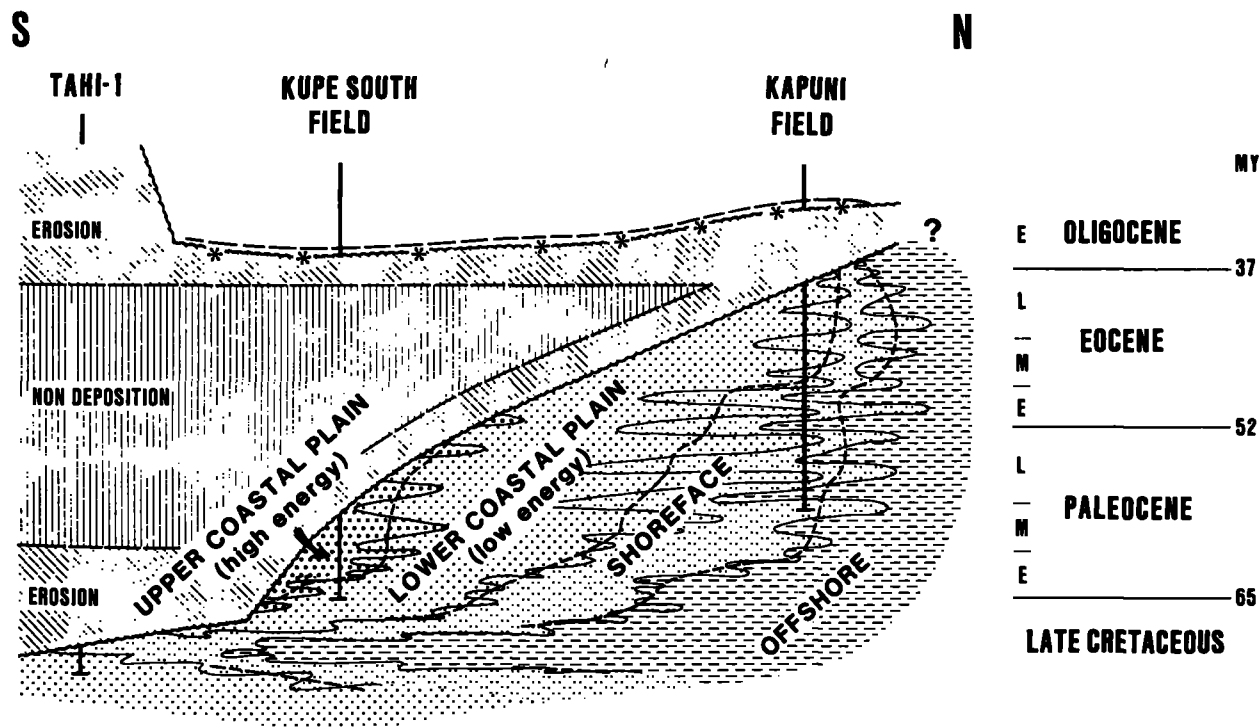


Fig. 26: Chronostratigraphic cross-section along the Manaia Trend, South Taranaki Graben. Cut offs of 10% porosity and 40% shale for the logged intervals have been applied to all net sand figures.

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