POLYPHASE EVOLUTION OF THE TARANAKI BASIN, NEW ZEALAND: CHANGES IN SEDIMENTARY AND STRUCTURAL STYLE

P R King
New Zealand Geological Survey

The Taranaki Basin has undergone a complex evolution since the mid to late Cretaceous. Tectonic regimes recognised include rift transform, passive margin, wrench transform, back-arc foreland basin, and peripheral (outer) convergent margin. The last includes components of basin eversion, back-arc rifting and back-arc compressional flexure. In its history, the basin has been a part of, or been influenced by, the Australian-Pacific plate boundary during at least two different periods.

Late Cretaceous syn-rift sediments were deposited within a transform system associated with the New Caledonia Basin failed rift. Following rifting, the basin evolved through the Paleocene and Eocene into a passive margin, characterised by exponentially declining thermal subsidence rates and decreasing tectonism, peneplanation of the adjacent hinterland, and steady marine transgression.

In the late Early Oligocene very rapid subsidence commenced, particularly in the east. Structural and stratigraphic evidence suggests that this was caused by oblique compression, occurring initially as a local manifestation of a transform system that propagated through western New Zealand in response to active spreading in the Emerald and South Fiji Basins. Thereafter, orthogonal compression became increasingly dominant in the Taranaki region, and a foreland basin developed.

In the Early Miocene, major low angle westward overthrusting occurred along the Taranaki Fault Zone. This event coincided with an acceleration in the rate of convergence along the modern Indo-Australian and Pacific plate boundary through New Zealand. Since that time the sedimentary and structural development of the Taranaki Basin has been influenced by the evolution of this convergent margin. An increase in sediment supply caused a change from carbonate to terrigenous sedimentation, in a regression which is still continuing. Neogene structural elements in the eastern part of the basin reflect deformation on the periphery of the plate boundary zone, and specifically the encroachment and superposition of convergent tectonics related to distant subduction. The Western Platform has remained unaffected by convergence.

Hydrocarbon source rocks were deposited in the early rift phase. The most prolific reservoirs discovered to date were deposited in the passive margin and foredeep phases, whilst known successful structural traps all formed in the Miocene convergent phase. Maturation and migration occurred mostly in the Plio-Pleistocene.

INTRODUCTION

The Taranaki Basin is located mostly offshore along the central western flank of New Zealand's North Island (Fig. 1). It loosely defines an area made up of many sub-basins and depocentres which range in age from mid-Cretaceous to Recent. The modern basin lies at shelf depths and, so far, petroleum exploration wells have only been drilled inshore of the present-day continental shelf edge (200 m isobath). To the north and northwest, the basin deepens into the New Caledonia Basin, whereas to the south it shallows into the northern South Island. Sub-basins between this latter area and Taranaki are continuous, and any southern limit to the Taranaki Basin can only be vaguely or arbitrarily defined. The Taranaki Fault, defined geophysically and by wells, and the subsurface Patea-Tongaporutu basement high, are commonly regarded as the eastern limit of the basin. However, late Miocene and Pliocene sediments in the Taranaki Basin are contiguous with those in the neighbouring North Wanganui Basin to the east.

This study is based on well data (King, 1988a,b) and seismic mapping (Thrasher and Cahill, 1989). Outcropping rocks that continue into the subsurface Taranaki Basin are found in only two areas; a thin coastal strip immediately north of the Taranaki Peninsula, and in northwest Nelson, South Island.

Structurally, the Taranaki Basin includes four main tectonic provinces (Knox, 1982; Fig. 1), and the various sub-basins which underlie the Taranaki area collectively contain a nearly continuous sedimentary record from the Late Cretaceous. Taranaki Basin stratigraphy and sedimentary history are summarised in Fig. 2. The overall sedimentary record can be broadly subdivided into a mid to late Cret-

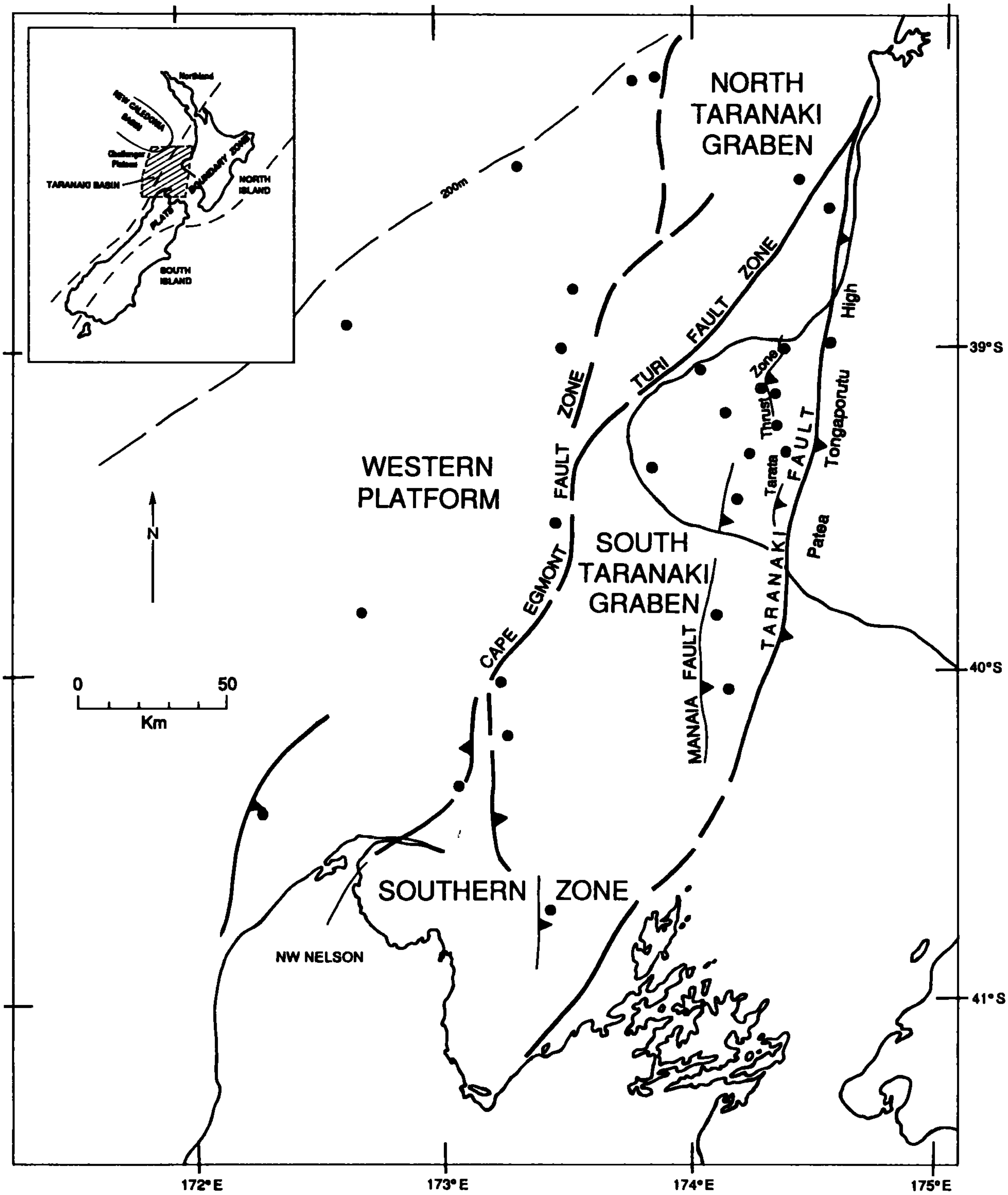


Fig. 1: Location map and main structural elements of the Taranaki Basin. Dots mark location of key wells used in study.

aceous terrestrial rift phase, followed by one long transgressive-regressive super-cycle lasting to the present.

Several phases in the evolution of the Taranaki Basin are recognised, and a broadly similar geological history to much of the rest of the New Zealand continent is evident. As in Canterbury, and in southern and western South Island especially, early syn-rift, drift, and post-drift passive margin phases are identified. The products of these phases have been disrupted and overprinted by Neogene tectonism caused by the propagation of the modern plate boundary through the New Zealand continental platform. Convergent tectonism has encroached upon the eastern and southeastern sides of the Taranaki Basin (Fig. 3). Although this was much less pronounced than other areas in New Zealand more proximal to the plate boundary, the associated compressive structures in the Taranaki Basin are nevertheless significant, and are proven hydrocarbon traps.

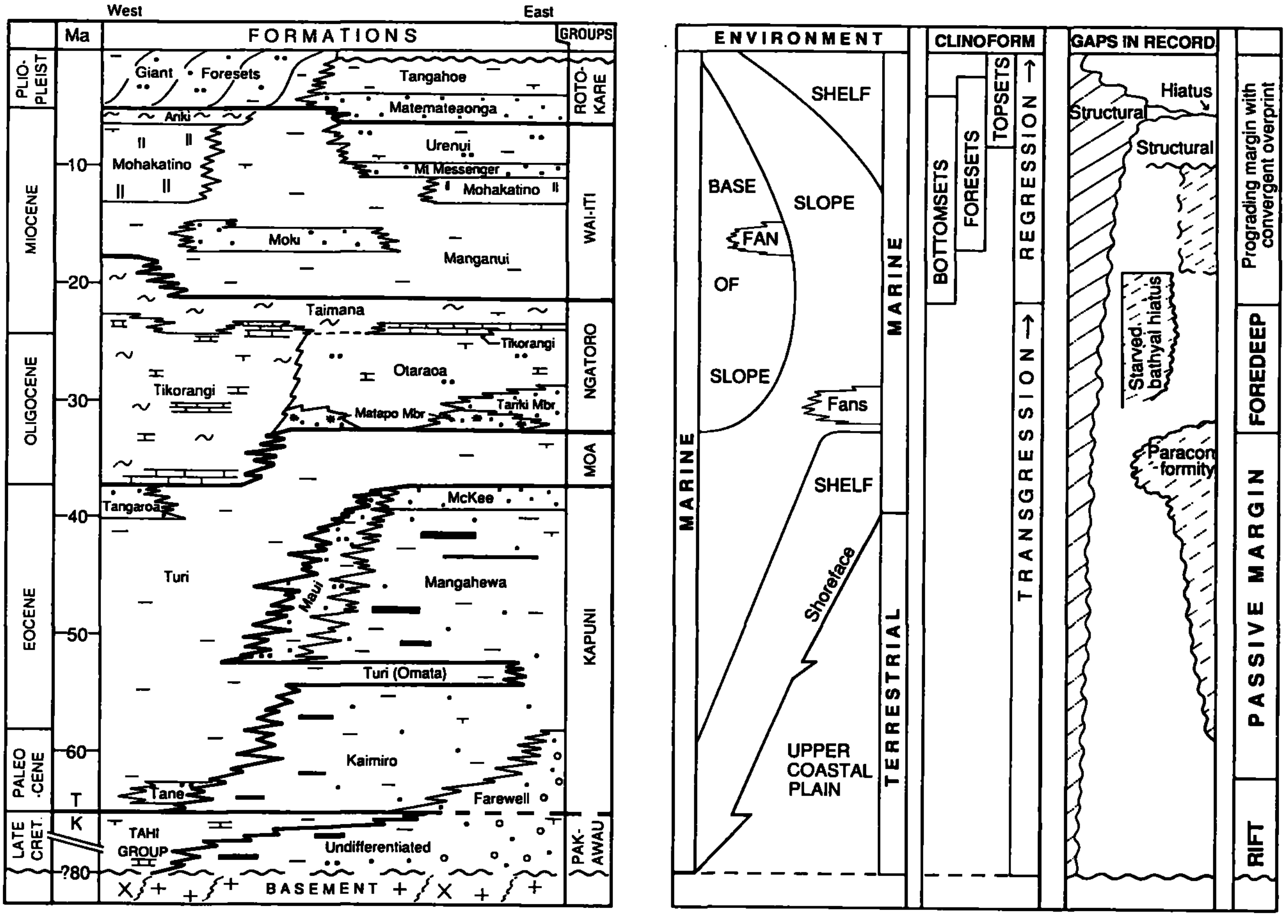
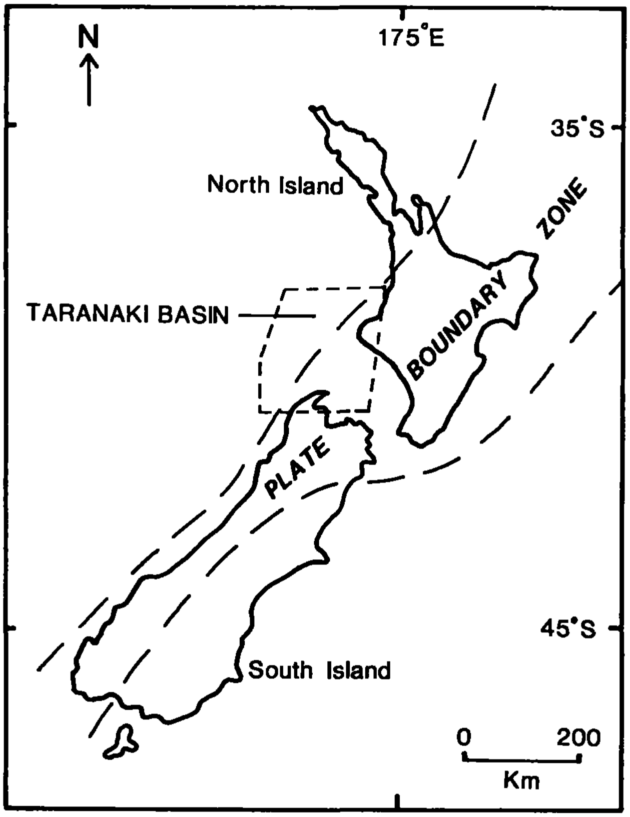


Fig. 2: Schematic litho-, chrono- and sequence stratigraphic framework for the Taranaki Basin. Groups are distinguished by bold lines. Pre-mid Oligocene sediments are grouped according to their marine (Tahi and Moa Groups) or terrestrial (Pakawau and Kapuni Groups) affinities. With one exception, all sediments younger than mid Oligocene are marine. These are grouped according to their terrigenous content, general sedimentation style and seismic character. Lithologic symbols from Shell Standard Legend (1976).



Essentially stable tectonics prevailed on the western side of the Taranaki Basin for most of the Cenozoic. Throughout this time the entire basin continued to develop as a continental margin, open to the New Caledonia Basin to the northwest, and with a hinterland of varying extent in the south and/or east.

The Taranaki Basin is to date New Zealand's only hydrocarbon producing province. Two large gas-condensate fields, two oil fields and a number of smaller fields attained a combined production in 1986 of around 29 000 BOPD and 160 BCF gas/year (Ministry of Energy, 1988). As a result of some successful new play concepts, and three recent oil discoveries (currently being appraised), the Taranaki Basin continues to be the focus of considerable exploration activity.

The intention of this paper is to document the main structural and sedimentary phases in the evolution of the Taranaki Basin. Some attempt is made to put these into a broader plate tectonic perspective. The significance of these episodes to the occurrence of hydrocarbons in Taranaki is also mentioned briefly.

Fig. 3: Location of the Taranaki Basin with respect to the modern Pacific and Indo-Australian plate boundary zone through New Zealand.

EARLY BASIN HISTORY: DEVELOPMENT AS A CONTINENTAL MARGIN

Syn-rift/drift phase

A quick resume of this basin phase is given here. For more detail, refer to Thrasher (this volume).

The oldest sediments in Taranaki Basin wells are mid Cretaceous, with wells penetrating sections as old as Raukumara and/or Clarence Series (Thrasher, 1989). Little is known of the nature and distribution of these older sequences. Generally, the oldest sediments encountered in Taranaki Basin wells are late Cretaceous (Haumurian) in age. They are predominantly terrestrial (Pakawau Group), and represent a range of fluviatile and fluvio-deltaic lithofacies that reflect distance from syn-sedimentary faulting and uplifted source areas (King and Robinson, 1988). Paleogeographic reconstructions indicate that drainage systems flowed northwards off a southern hinterland. Proximal conglomerates are most common in the south, where tectonic activity was greater. These (and lower coastal plain coal measures) occur in some southern wells and also outcrop in northwest Nelson, the type area (Suggate, 1956). They can also be distinguished on seismic reflection profiles (G.P. Thrasher, unpublished data). Braid plain and coastal plain interbedded coals, sandstones, siltstones and mudstones are common elsewhere in the basin. Latest Cretaceous marine sandstones and mudstones (Tahi Group) overlie and interfinger with the terrestrial sediments. These are best developed in the north, the presumed direction from which the sea transgressed and probed southwards into former fault-controlled valleys (King and Robinson, 1988, their Fig. 4).

Late Cretaceous sediments were deposited in sub-basins and half-grabens controlled primarily by NNE-SSW trending normal faults. These basins are considered by Thrasher (1989), to be part of an obliquely extensional transform system connected to active rifting in the New Caledonia Basin. The temporal and causal relationships between Gondwana breakup events and early sedimentation in the Taranaki Basin are still uncertain. It is also possible, for example, that the New Caledonia Basin is an older rift which failed once Tasman Sea spreading began around or prior to 80 Ma. In either event, the Taranaki transform was probably also linked to contemporaneous active spreading in the Tasman Sea. A connection to the southern end of the Tasman Sea spreading axis is most likely, via a continuation of the transform through the west coast, South Island (Fig. 4). This late Cretaceous extensional province was named the 'West Coast Rift' by Laird (1980). Although there are some problems reconciling its geometry (Fig. 4), the transform presumably developed to accommodate differential seafloor spreading rates (cf. Kamp, 1986a) as the New Zealand continent drifted away from Australia and Antarctica. This notwithstanding, there is considerable uncertainty in the plate tectonic literature concerning the need for and nature of a plate boundary through New Zealand in the late Cretaceous-Paleocene (cf. Molnar and others, 1975; Weissel and others, 1977; Stock and Molnar, 1982 and 1987; Kamp, 1986a). The Taranaki transform may help to resolve this, although its obliquely extensional nature conflicts with the convergence predicted in some relative plate motion reconstructions (e.g. Weissel and others, 1977; Stock and Molnar, 1982).

Post-rift/drift passive margin phase

The Tasman Sea stopped spreading around 55-60 Ma B.P. (Weissel and Hayes, 1977). Roughly coinciding with this event, extensional tectonism in the Taranaki Basin ceased in the latest Cretaceous and Paleocene. As fault activity and rapid differential subsidence of individual basins waned, the

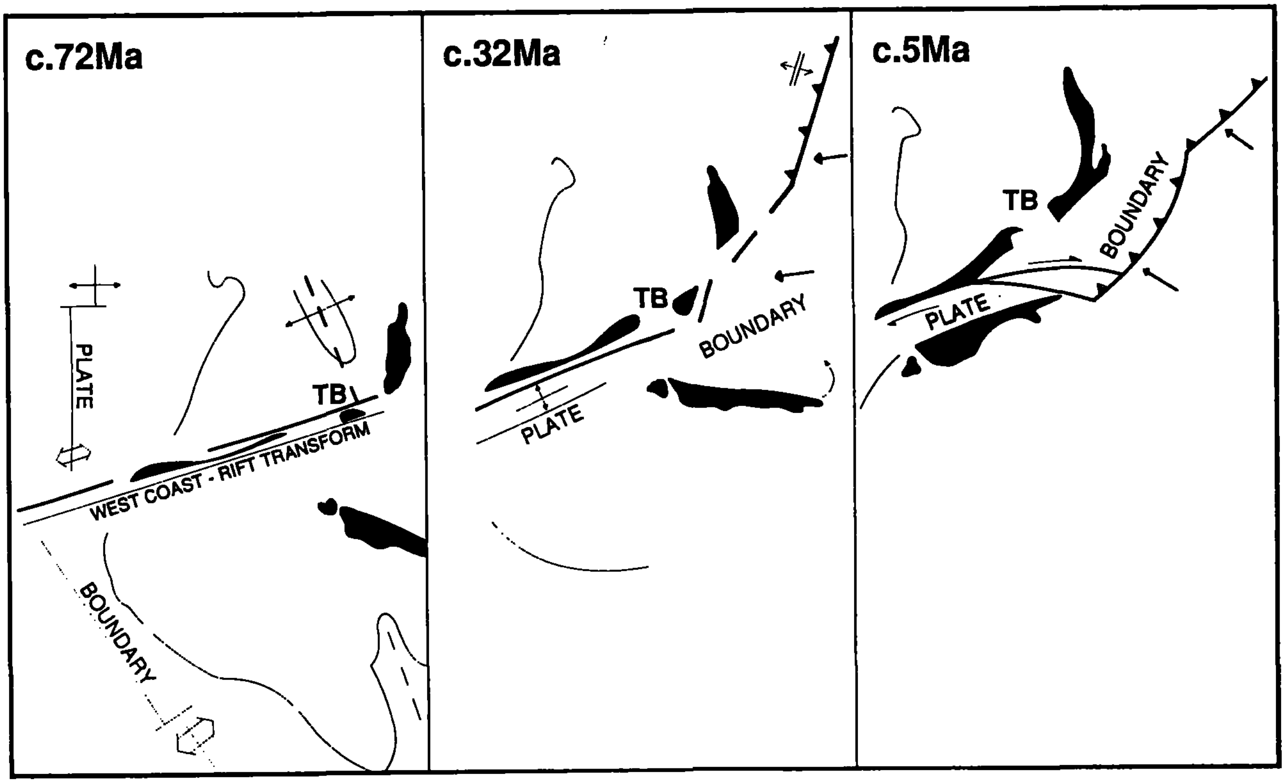


Fig. 4: Different generations and changing style of the Australia/Pacific plate boundary through New Zealand.

basin began to subside as a whole. For the period up to the mid Oligocene, subsidence curves show exponential decline in rate with time (Hayward and Wood, 1989; Fig. 5), closely following the pattern predicted by models of post-rift crustal cooling and thermal subsidence of continental margins (as summarised by Watts, 1981; 1982). This gradual attainment of thermal equilibrium conditions and increased crustal strength led to tectonic quiescence in the Taranaki Basin. In fact, the entire New Zealand continental block became stable, essentially remaining free of any plate boundary influences until latest Eocene or Oligocene times.

Structural, sedimentological and paleogeographic evidence shows that the Taranaki Basin evolved as a passive continental margin through much of the Paleogene (Fig. 2). As the former rift landscape became inundated, the region appeared as a large northwest-facing embayment, open to the sea in the New Caledonia Basin, an (?oceanic) marginal basin that penetrated into the emergent New Zealand/Challenger continental block. Thus, Taranaki passive margin development was unusual, in that it took place within a virtual intra-cratonic setting. In fact, if there is no oceanic crust in the New Caledonia Basin, then the Taranaki region at that time might be better categorised as an intracontinental basin, rather than continental margin. Local subsidence patterns were controlled more by New Caledonia Basin post-rift evolution than the former Taranaki rift-transform configuration.

Facies distributions illustrate both the gradual inundation of the Challenger Plateau, and the establishment of a persistent NE-SW trending southern shoreline to the Taranaki embayment throughout the Paleogene. As in the Cretaceous sequence, sediments are categorised according to their marine (Moa Group) or non-marine (Kapuni Group) affinities (King, 1988a,b). In general, upper flood plain sandstones grade laterally (northward) and vertically (upward) into lower floodplain coal measures and marginal marine interbedded sandstones and mudstones. In the north, dark mudstones and siltstones were deposited over a broad shelf within the embayment. These sediments gradually transgressed southward as the continental margin gently subsided through the Eocene.

A cursory look at well and seismic stratigraphy (Pocknall and Beggs, this volume) suggests that fluctuations in shoreline position were superimposed upon the overall transgression. These might indicate eustatic variations in sea level. However, for the longer-term transgression, any eustatic influence must be subordinate to thermally controlled tectonic subsidence, especially considering that the global eustatic curve (Haq and others, 1987) shows a net sea level fall through this time.

During the Eocene, Taranaki Basin's southern and southeastern hinterland generally subsided very little, and erosion reduced it to a virtual peneplain (Robinson and King, 1988). This peneplanation produced major gaps in the sedimentary record across much of the southern basin (e,g, Kupe-1 and Fresne-1, refer to King, 1988b), where Oligocene sediments frequently overlie Paleocene-aged sediments, albeit with apparent conformity.

Eventually, the Taranaki Basin region became completely inundated in the earliest Oligocene. Calcareous mudstones and siltstones were deposited on the shelf in the southeast and south, whilst carbonate oozes were deposited in bathyal depths in the north and west. Where present, Early Oligocene sediments are very thin (generally less than 30 m) and represent extremely low sedimentation rates. A paucity of terrigenous sediment supply produced hiatuses in many parts of the basin. This starved basin setting marked the culmination of the first, or passive margin, phase of transgression in Taranaki.

MIDDLE BASIN HISTORY: TRANSITION TO CONVERGENT TECTONICS

The post-Eocene history of the Taranaki Basin is distinguished by several changes in tectonic style, which variously affected different parts of the basin, and which masked previous more extensive structural patterns. This tectonism was caused by the propagation of the Pacific-Australian plate boundary zone through the New Zealand continental platform. Neogene deformation in the Taranaki Basin reflects the progressive impingement of convergent tectonics as the plate boundary evolved. An initial phase of rapid subsidence in Taranaki may be related to a proto-plate boundary through western New Zealand.

Post-Eocene sedimentation patterns were strongly influenced by the interplay between intra- and extra-basinal tectonics. The initial rapid subsidence phase is mostly characterised by submergence with a paucity of sediment. Thereafter, extra-basinal sediment supply exceeded intrabasinal subsidence and accommodation, and a regressive phase developed (Fig. 2).

The remainder of this paper documents the complex evolution of the Taranaki Basin since the Eocene. The main tectonic and sedimentary phases are described, and related to changing plate boundary style and orientation. Particular emphasis is given to the transitional phase from quiescent and/or extensional tectonics to convergent tectonics.

Rapid subsidence phase (distal foreland basin)

Nature of subsidence Geohistory curves for many Taranaki wells (Hayward, 1987; Hayward and Wood, 1989) reveal an episode of rapid subsidence beginning in the late Oligocene (Fig. 5). This subsidence ended the relatively mature passive margin phase described above. Little significance has hitherto been placed on this event, but it is now apparent that it marked the onset of a new tectonic regime within the Taranaki Basin. Indeed, the subsidence represents the first manifestation in Taranaki, of a relatively new stress regime through the greater New Zealand continental crustal area.

Subsidence occurred across the basin but was particularly pronounced in the east (Fig. 6). Accordingly regional subsidence patterns display a marked east-west asymmetry. The subsidence developed relatively quickly, becoming well established in each location within the space of only about 3 - 4 Ma. In the northwest, the shelf had already foundered to bathyal depths during the previous passive margin phase. The late Oligocene subsidence accelerated this process and plunged eastern parts of the basin into bathyal depths also. Southern areas were submerged to shelf depths.

The amount of subsidence ranges from about 500 m to 2000+ m. Presumably, some of this was caused by water loading, once tectonism had initiated the subsidence. Sediment loading may have contributed along the basin's eastern margin.

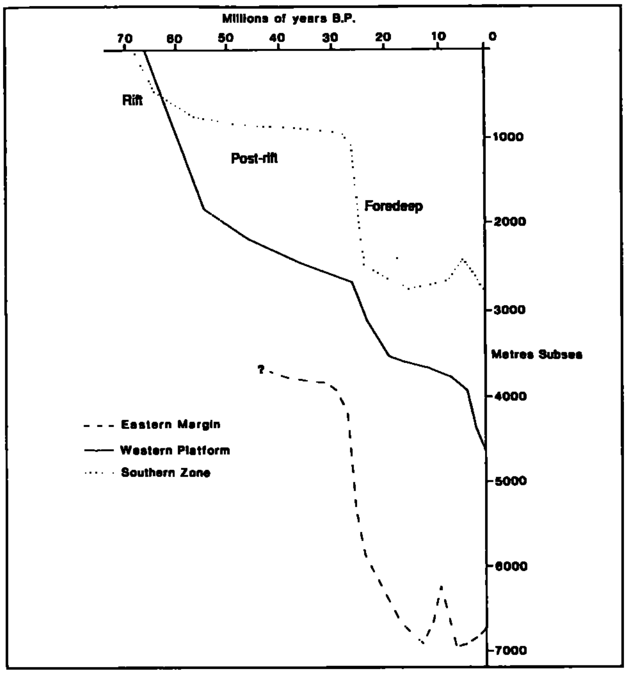


Fig. 5: Subsidence curves for three representative wells of major structural regions within the Taranaki Basin. The curves depict the burial depth of basement through time at the site of each well. They are constructed by cumulating sediment thicknesses (corrected for compaction) to paleobathymetric depths for a series of incremental time slices. Reproduced from King and Robinson, (1988); after Hayward, (1987).

The net effect of subsidence was rejuvenation of the previously slowed marine transgression and renewal of sediment accumulation. Turbidites were the first sediments deposited in the rapidly deepening eastern area. Elsewhere terrigenous sediments continued to be in scarce supply. By earliest Miocene times a carbonate platform had developed across most of the southern shelf area and a carbonate foredeep was present in the east. Very slow deposition of carbonate oozes continued in the west. These predominantly calcareous sediments are all assigned to the Ngatoro Group (Fig. 2).

Origin of subsidence The origin of the rapid subsidence is enigmatic. The pattern of both total subsidence and derived tectonic subsidence (Fig. 6), conforms roughly to the shape of the shelf around the southeast end of the New Caledonia Basin at the end of the Eocene (King and Robinson, 1988). Progressive southeastwards foundering of the shelf in response to tectonic influences is the likely subsidence mechanism. The nature of these tectonic influences is a little more uncertain.

Kamp (1986b) suggested that a continental rift extended along the western margin of New Zealand at this time. However, there is no direct evidence for a rift, in the strict sense, through Taranaki Basin. No obvious late Oligocene extensional faulting or graben formation is seen on seismic reflection profiles across the basin (G.P. Thrasher, pers. comm.). Conversely, there may have been some reverse faulting (e.g. the Manaia Fault). The North Taranaki Graben began forming much later in the basin's history (see below). Furthermore, with the possible exception of the clastic sediments in the east, Oligocene lithofacies with rift affinities have not been encountered. Similarly, there is no evidence of rift volcanics.

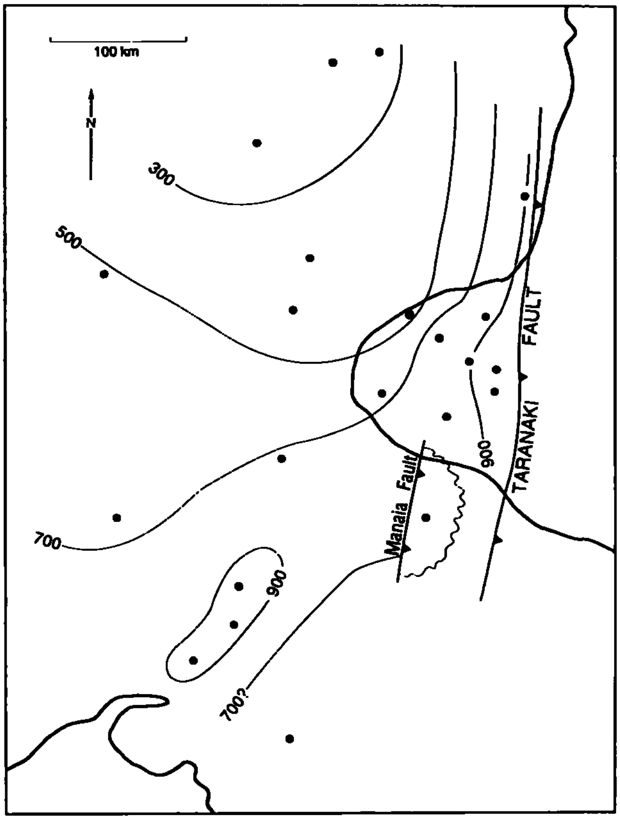


Fig. 6: Total tectonic subsidence in Late Oligocene-Early Miocene (32-22Ma) in the Taranaki Basin. Compiled from the geohistory curves of 23 wells calculated by Hayward and Wood (1989), in which the effects of sediment and water loading were calculated and removed from total; subsidence curves (derived from sediment thicknesses and paleobathymetry, with corrections for compaction and eustatic sea level). Contour interval in metres. Anomalously low subsidence, due to uplift along the Manaia Fault, is schematically depicted by the wavy line.

Alternatively, compressive tectonics may have driven the mid Oligocene subsidence in Taranaki Basin. Stern and Davey (1989) have shown that crustal thickening has occurred under eastern Taranaki Basin. They concluded that this was caused by shortening under compression, and that the Taranaki Basin effectively represents a foreland basin (refer also to Stern, this volume). Whilst the foreland basin morphology is clear on their deep seismic profile, the timing of this development is not. East to west-directed basement overthrusting definitely took place along Taranaki Basin's eastern margin in earliest Miocene times (see below). However, the sedimentary evidence for a mid Oligocene age for inception of compression, and attendant pervasive subsidence in the central western North Island region, is mostly equivocal (see below). Nevertheless, from mid Oligocene times, the Taranaki Basin does display attributes in common with foreland basins. Characteristic features are the lack of fault movement (other than the loading thrust fault), and large width of the asymmetric basin. The overall shapes of the subsidence curve profiles for the interval of rapid subsidence are very similar in form to those exhibited by Rocky Mountain foreland basins (Cross, 1986).

The foreland basin model is the conceptual antithesis of the rift model, in that it invokes basin subsidence by flexural downwarping, under the compressional load of adjacent overthrusted blocks (Beaumont, 1981). Although this explanation for the Taranaki Basin has many merits, the amount, nature and timing of the initial loading is uncertain. Requisite uplift in the immediate hinterland was presumably not great, as emergent land areas were few in the Oligocene, judging by the relatively low input of terrigenous detritus into the developing foredeep (an exception being the fan sandstones of the Tariki Member, Fig. 2), and by general paleogeographic reconstructions (King and Robinson, 1988). Moreover, the neighbouring North Wanganui Basin also began to subside in the Oligocene (Nelson and Hume, 1977; McQuillan, 1977). Thus the main problem with invoking Oligocene compression and loading due to uplift is the apparent subsidence of parts of the hinterland and the eventual deposition of carbonates in eastern Taranaki Basin and the North Wanganui Basin by the end of this period.

Nevertheless, reasonable explanations can be found for the apparent paradox. If the Taranaki Basin and regions to the east were under compression as early as the mid Oligocene, then this compression may have been expressed as a broad zone of crustal downflexure over the entire area. Such broad downwarping might have been produced by incipient subduction processes. If subduction was already well advanced, other causes might be overthrusting and loading east of the North Wanganui Basin or back-arc flexure analogous to, and perhaps a precursor of, that in the South Wanganui Basin today (see Stern and Davey, 1989). Finally, basement overthrusting to the east of Taranaki could have taken place beneath the sea (Stern, this volume). However, prior to the onset of mid Oligocene subsidence, this area was most likely to have been low-lying land (McQuillan, 1977; King and Robinson, 1988).

Plate tectonic model From the preceding discussion it is clear that a profound change in the tectonic style of the Taranaki Basin occurred in Oligocene times. Based on geophysical observations, this has been explained as a manifestation of purely convergent tectonics (Stern, this volume). Intuitively, it also seems possible that the new tectonic regime evolved gradually from obliquely compressional wrenching to more orthogonal compression (Fig. 7). As will be seen shortly, an initial phase of oblique extension can not be ruled out entirely either. Due to the absence of active faulting within the Taranaki Basin during this period, any wrenching must have been related to progressive structural development along the basin's eastern margin, or still further east in the North Wanganui Basin. With this rationale in mind an attempt has been made to fit the observed subsidence in the Taranaki and North Wanganui basins into a plate tectonic model (Fig. 8), which has been adapted, in part, from Walcott's (1987) reconstructions of New Zealand through the Cenozoic.

Plate tectonic events dominating the greater New Zealand region during the Oligocene were active sea-floor spreading in the South Fiji Basin to the north of New Zealand (Malahoff and others, 1982) and in the Emerald Basin to the south (Weissel and others, 1977; Kamp, 1986a). It is reasonable to expect that this sea-floor spreading induced strain through the intervening New Zealand continent. Indeed, in spite of the earlier discounting of Kamp's (1986b) hypothesis of a rift through Taranaki Basin, there is ample evidence of Oligocene-aged basin formation in many parts of western New Zealand (e.g. McQuillan, 1977; Carter and Norris, 1978; Kamp, 1986b). Subsidence in the Taranaki Basin was roughly contemporaneous with pervasive subsidence in southern and western South Island, NW Nelson, North Wanganui Basin and Northland. It can therefore be presumed that a major tectonic lineament did propagate through the New Zealand continental block, in response to active spreading in the south from late Eocene times, and spreading and subduction in the north from early Oligocene times. This was a new transform boundary, essentially the precursor to the modern plate boundary (Figs. 4, 8a). Its deformation effects were first felt in the Taranaki region in the mid Oligocene.

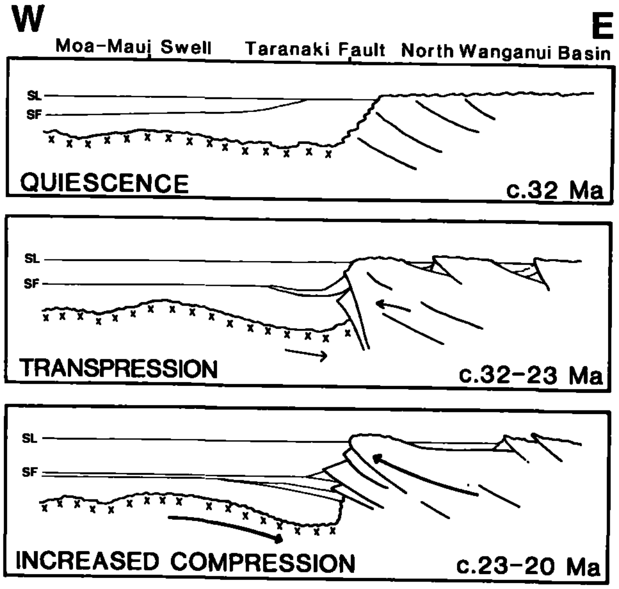


Fig. 7: Model to account for Late Oligocene and Early Miocene subsidence in the Taranaki Basin. A transition from oblique compression to orthogonal compression and foreland basin loading is depicted. Initial crustal flexure and downwarping may have been controlled by pre-existing basement morphology and lithology as wrench faults developed along the basin's oversteepened eastern margin and/or further east. During the early transform phase (see also Fig. 8), Taranaki's eastern hinterland may have also been subsiding as a result of incipient subduction processes still further east.

The main tectonic stresses and structural deformation style probably varied along the length of the transform. In the far south, basins formed within an extensional or transtensional regime driven by spreading in the Emerald Basin (Carter and Norris, 1978). The northern end of the transform was more likely to have involved strike-slip motion. The exact nature of this motion, and the location of the transform through the proto-North Island are debatable. These partly depend on the age of first subduction to the north of New Zealand, and on the configuration and orientation of this subduction. Of particular importance (see below) is the age, and southernmost extent through time, of the dogleg bend (Hikurangi Trough) at the southern end of the subduction zone (see Walcott, 1984, 1987). I have introduced the Hikurangi limb at the start of the Miocene (Fig. 8c), closely following the end of South Fiji Basin spreading (Malahoff and others, 1982), and coincident with both Alpine Fault inception

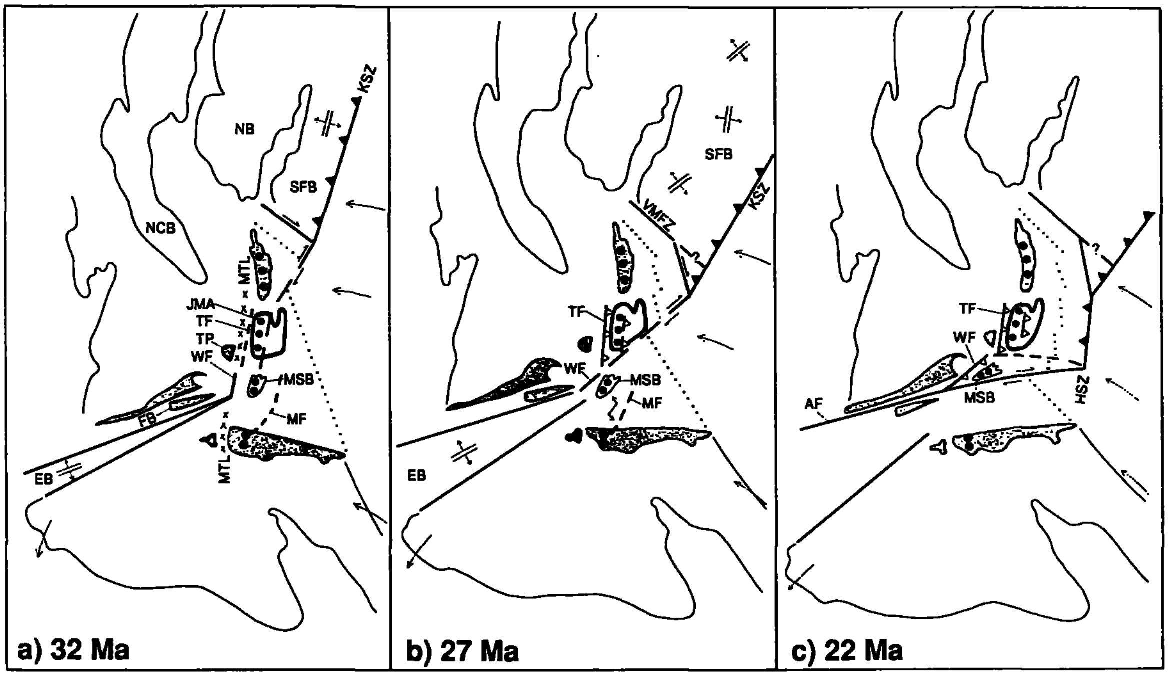


Fig. 8: Schematic reconstruction of plate boundary zone through New Zealand in 5 Ma increments through the late Oligocene. As the Kermadec subduction zone (KSZ) migrated and propagated southwards, the associated transform (linking through the North Island to seafloor spreading in the Emerald Basin; EB) stepped southwards and rotated clockwise. Main effects were: increasing convergence in the central proto-North Island region (large unshaded area); evolution of the Taranaki Fault (TF) from being a possible part of the transform (32 Ma) to an increasingly convergent transform splay (27Ma), to a back-arc overthrust (22 Ma); increasing parallelism between transform alignment and Pacific plate convergence vectors (large solid arrows; after Walcott, 1987); successive capture of parts of the Pacific plate (e.g. Marlborough Sounds Block; MSB) by the Australian plate, and vice versa (e.g. Fiordland (Paleozoic) Block; FB); bending of the Junction Magnetic Anomaly (JMA; large dots). Note also, that as the North Island initially lay within a transitional tectonic area, a north to south gradation from oblique extension to oblique convergence along the transform is possible (especially 32 Ma). Small dots (at approximately the continental shelf break) illustrate relative lateral deformation across the migrating transform. Plate configurations have been adapted from Walcott (1987), apart from a later Hikurangi subduction zone (HSZ) inception postulated here. Spreading in the South Fiji Basin (SFB) is stylised after Kamp (1986a, his figure 8). Solid sawtooth pattern = subduction, open = reverse thrust fault; NB = Norfolk Basin; NCB = New Caledonia Basin; TP = Taranaki Peninsula; AF = Alpine Fault, WF = Waimea Fault; MF = Moonlight Fault; VMFZ = Vening Meinesz Fracture Zone; MTL = Median Tectonic Line. Present-day 2000 m isobath defines New Zealand continental outline.

(Kamp, 1986b) and major compression along the Taranaki Basin's eastern margin. These interrelated events are presumed to result from the changing and/or accelerated migration of the Australia/Pacific finite rotation pole since 20 Ma B.P., documented by Stock and Molnar (1982) and Walcott (1984).

Also critical to early subduction position is whether Norfolk Basin spreading was contemporaneous with South Fiji Basin spreading, or had already been completed. In the former case, the northern subduction zone and transform system through the North Island would have to be shifted north and westwards, to allow for subsequent east-west spreading in the Norfolk Basin. However, in this model (Fig. 8a), I have assumed that the Norfolk Basin was already open when South Fiji Basin spreading began.

Having concluded that a transform probably existed through central New Zealand in the Oligocene, a number of intriguing questions remain, concerning its effect on the tectonics and sedimentation within Taranaki Basin and neighbouring areas. The first problem is, where did the transform that was linked to the southern end of the trench off eastern Northland (Fig. 8a), lie with respect to the Taranaki and North Wanganui Basins? It is tempting to invoke the Taranaki Fault as the transform. The present-day Taranaki Fault loses its identity at about the latitude of Manukau Harbour (Thrasher and Cahill, 1989), and it may veer eastward at this location. The superficial appearance of this constriction (Manukau Harbour) in the present-day coastline is circumstantial evidence that it may be a relict zone of tectonic detachment. The transform boundary may have passed through this area, then offshore to the northeast.

A problem with this theory is the apparent continuity, albeit with bending, of the Permian-aged Junction Magnetic Anomaly (Wellman, 1973) to the north and south of Manakau Harbour. This has long been regarded as a major correlation marker within New Zealand's basement rocks. However, it is worth noting that the magnetic anomaly has much fainter expression over a distance of some 50 km north and south of Manakau Harbour (Davey and Robinson, 1978). If, as suspected, the Taranaki Fault zone has involved several tens of kilometres of shortening, particularly in the early Neogene, then its main Oligocene expression could have been just to the east of the Manakau Harbour, thus obviating the need for any dislocation of the magnetic anomaly. Compression in the Neogene could then have produced the bending seen in the magnetic anomaly trend (Fig. 8). In the North Island, the likely early parallelism of the Oligocene transform with basement trends means that only a little offset of the anomalies may have occurred. This would also follow from the expected rapid west to east sidestepping of the roughly N-S trending major faults as the entire plate boundary system evolved. Similarly, at any given time, the transform may have comprised a number of side-stepping en echelon faults (e.g. Fig. 8a: Waimea Fault, Taranaki Fault, and postulated fault northeast of North Island), which could have accommodated strain along former lines of weakness with minimal E-W offset. Interestingly, there is another significant break in the Junction Magnetic Anomaly just north of the onshore Marlborough Sounds (Davey and Robinson, 1978). This corresponds to a sidestep from the northern Waimea Fault to the southern Taranaki Fault (see Thrasher and Cahill, 1989).

Alternatively, the Taranaki Fault may have been only one of several faults forming a zone of distributed shear. There are several major N-S trending basement faults and lineaments to the east of the Junction Magnetic Anomaly in the central North Island which could have been part of an early transform system (e.g., Waipa Fault). Initial fault-controlled sedimentation in the Waikato Basin could well have occurred within a transform setting. McQuillan (1977) concluded that similar basin development in the North Wanganui Basin was controlled by oblique transform tectonics. With progressive migration of the subduction zone southwards, one would intuitively expect that a concomitant southerly shift and clockwise rotation in the transform position would have occurred (Fig. 8). Further investigation is required to identify any such former transform zones.

Other questions concerning the direct influence of the Oligocene transform on Taranaki Basin evolution have yet to be resolved. These relate to the nature of the transform through the proto North Island and, in particular, how much strike-slip motion was involved, and to the timing and location of compressive and/or extensional components. Early in this tectonic evolutionary phase, the Taranaki Basin lay between an area of extension in southern New Zealand, and an area to the north of the transform, in which compression associated with subduction might be expected. Thus, as stated above, the timing, location and orientation of this subduction is critical in determining whether the phase of rapid subsidence in Taranaki was initially caused by compression or extension. The further south subduction had extended, the more likely it is that Taranaki Basin subsidence occurred within a compressional regime (Fig. 8b). Equally, there is more likelihood that the transform was located to the east of the North Wanganui Basin, which would then also have been under compression. If the roughly N-S oriented Hikurangi limb of the subduction zone was already well established, as inferred by Walcott (1987), then Oligocene compression in the greater Taranaki region can be even more readily demonstrated. Conversely, it is conceivable that this part of the central North Island was first influenced by rifting further south (Fig. 8a), in which case obliquely extensional sub-basins would have formed in the North Wanganui Basin. Crustal dislocation along the transform system, and regional crustal thinning, could have contributed to the initial rapid subsidence of the Taranaki continental shelf. If so, an obliquely compressive regime must have evolved shortly thereafter (Fig. 8b), and with it, foreland subsidence. There is little indication of this transition on Taranaki Basin subsidence curves (Fig. 5). There is apparently no easy way of resolving Oligocene tectonic style and subsidence mechanisms in the plate boundary transition zone in central proto-North Island. Unless such features as, for example, mid-Oligocene reverse faulting are recognised (in outcrop or on seismic reflection profiles), the geologic evidence will remain equivocal. To this end, a re-appraisal of North Wanganui Basin Oligocene paleogeography and structure, from a convergent tectonic perspective, is recommended.

It is unlikely that pure strike-slip faulting caused Taranaki Basin subsidence. Nevertheless the evolutionary continuum depicted in Fig. 8 does imply some relative lateral movement across the plate boundary, either as oblique or pure strike-slip motion, depending on location. Stock (1989) stated that 200 - 350 km (±100 km, depending on the amount of coeval extension in the Transantarctic Rift) of relative motion occurred between the Pacific and Australian plates in the interval 36-20 Ma. Although there has hitherto been little evidence for this in the New Zealand geologic record, in light of the previous discussion a closer search is warranted. Of particular use would be a re-examination of basement terrane juxtaposition and relationships with mid-Cenozoic rocks, in central and central-western North Island.

LATE BASIN HISTORY: BEHIND-ARC INFLUENCES

Miocene convergent phase

Proximal foreland basin/fold-thrust belt (Eastern margin): Structure

Convergent tectonism definitely impinged upon Taranaki Basin in earliest Miocene times (around 23-20 Ma B.P.), when basement was overthrust westwards into the basin along the generally low-angle east-dipping Taranaki Fault (King and Thrasher, in press). Other parallel faults within basement were probably also involved. The timing of this thrusting is inferred from several seismic profiles. These invariably show the leading edge of the thrust truncating a reflector corresponding to a limestone dated at 24-23 Ma in several wells. Further corroboration is provided by the timing of an influx of terrigenous sediment into the adjacent foredeep to the west (King, 1988a) and by the timing of differential uplift of outcropping sediments overlying basement to the east (Nelson and Hume, 1977). The late Early Miocene age of sediments onlapping basement in wells drilled into the overthrust also constrains the timing of thrust emplacement. Compression caused thin-skinned *sled-runner* type overthrusts in the sedimentary sequence ahead (west) of the Taranaki Fault (King and Thrasher, in press). Sediment thicknesses and general sedimentation patterns suggest that episodic movement and growth occurred on these structures (Tarata Thrust Zone) and along the Taranaki Fault until around 10 Ma B.P. (see also Hayward and Wood, 1989).

Emplacement of the Taranaki Fault coincided with the onset of increased convergence along the Pacific-Australia plate boundary. This event (around 23Ma B.P.) is regarded by Kamp (1986b) as marking the inception of the Alpine Fault as the main plate boundary through New Zealand. An increase in the rate of rotation between the two plates since 20 Ma B.P. (Walcott, 1984), due to an accelerated southeastward drift of the finite rotation pole (Stock and Molnar, 1982), presumably caused the increased convergence. This began shortly after the cessation of spreading in the South

Fiji and Emerald Basins. Stock (1989) asserts that there was a lessening in strike-slip motion between the Pacific and Australian plates in the interval 20-10 Ma.

By this time, the subduction zone to the east of the North Island had extended sufficiently far south that its associated transform had *jumped* somewhere to the southeast of the Taranaki and North Wanganui Basins. These regions now lay within a zone of active compression influenced by subduction (Fig. 8c). Effectively, the Taranaki Fault (and Tarata Thrust Zone) represented the outer (western) mobile flank of a large area of back-arc contraction. It is presumed that the Taranaki Fault still existed as a splay, or en echelon splay, off the (Alpine Fault) transform (Fig. 8c).

Regressive sedimentary phase (I)

As a result of the thrusting along the eastern margin, and of convergent uplift in the southeastern hinterland, a change from carbonate- to terrigenous-dominated sedimentation took place within the Taranaki Basin in the earliest Miocene. In the east, this event is well marked by a baseline shift in gamma-ray well logs (King, 1988a). In the south, siltstone deposition superceded carbonate deposition. Although pronounced foreland subsidence continued, particularly adjacent to the Taranaki Fault, this influx of terrigenous sediment marked the onset of a major regressive sedimentary phase in the basin, which has continued to the present day. The regression began in earnest in the late Early Miocene, when sand-mud turbidites were deposited beyond the shelf edge in the south of the basin. Thereafter, continuing excess sediment supply resulted in further fan-lobe deposition and the eventual up- and out-building of the shelf sedimentary wedge in a northwesterly direction. Throughout most of the Miocene, sedimentation in the Taranaki Basin was mud-dominated. Submarine fan sandstones are the main exception. The fine-grained lithologies partly reflect depositional paleobathymetries. They may also reflect reworking of older sediments from the hinterland.

A shift in compressive locus

About 10 Ma ago the compression affecting the North Wanganui Basin and Taranaki Basin's eastern flank ceased. Detailed well (King, 1988a), seismic (Thrasher and Cahill, 1989), and geohistory (Hayward and Wood, 1989) data in the eastern peninsula region reveal that episodic growth on the Tarata overthrust structures continued until about this time. In the north Taranaki coastal section, Mohakatino Formation rocks (dated 12-10 Ma) exhibit considerable syn-sedimentary slumping due to movement on the nearby Patea-Tongaporutu High. Overlying sediments of the Mount Messenger Formation (approx. 10-9.5 Ma) show relatively little deformation. Subsidence ensued over the entire eastern side of the study area and sedimentation became more *layer-cake* and regional. Gradual inundation and burial of the Patea-Tongaporutu High from the north also began.

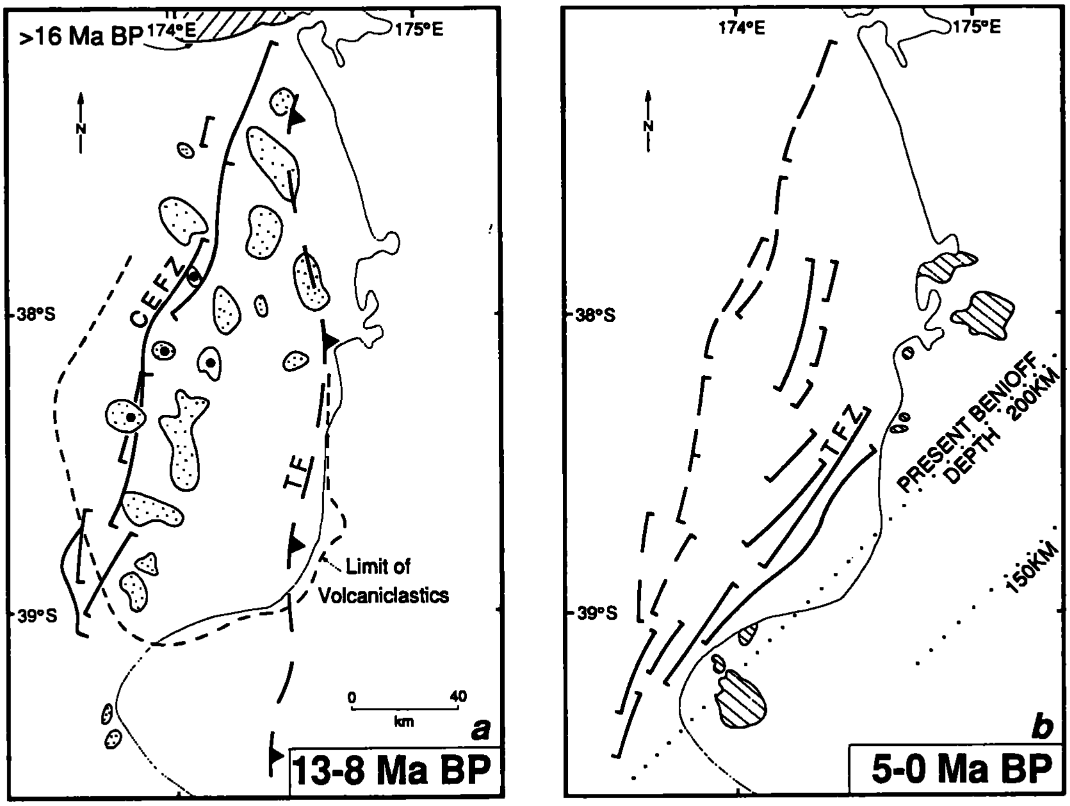


Fig. 9: Distribution and age of andesitic volcanoes. All the mid Late Miocene edifices lie within the North Taranaki Graben (between the Cape Egmont and Turi Fault Zones). Older volcanics occur to the north. The distribution limit of associated volcaniclastic sediments is derived from (other) well data, plus onshore outcrop. Four wells have drilled the volcanics; each encountered high-potash andesites. If the NNE trend of the mid-late Miocene volcanics defines the coeval subduction strike, then a clockwise rotation in subduction orientation (now defined by the Benioff trend), of approximately 30°, has occurred over the last 13-8 Ma. Offshore mapping after Thrasher and Cahill (1989). Onshore after Kear (1960) and Hay (1967). Depth of present Benioff Zone after Adams and Ware (1977). TF=Taranaki Fault; CEFZ=Cape Egmont Fault Zone; TFZ=Turi Fault Zone.

The termination of thrusting in northeastern Taranaki Basin is attributed to a major change in the convergence vector between the Pacific and Australian plates. This occurred around 10 Ma (Walcott, 1987). Ongoing southwards propagation and clockwise rotation of the Hikurangi subduction zone (Walcott, 1987) caused the main locus of compression associated with this development to shift southwards. In the Taranaki Basin, this resulted in cessation of movement on the Taranaki Fault, particularly in the north, and onset of compression in the south and southeast (Fig. 10).

Volcanism (northeast)

During late-middle to Late Miocene times, a considerable volume of andesitic rocks were extruded over a large area offshore and immediately north of the Taranaki peninsula (Fig. 9a). These and older buried volcanic edifices to the north of Taranaki Basin were originally inferred from large magnetic and gravity anomalies along the entire western offshore region of the northern North Island (Hatherton et.al., 1979). Their distribution in the Taranaki Basin has been further refined by seismic mapping (Knox, 1982; Thrasher and Cahill, 1989). Four offshore exploration (and several appraisal) wells in Taranaki have penetrated the volcanics, which are all high-potash calc-alkaline andesites. Volcaniclastic sediments derived from these volcanoes are found in several other north Taranaki wells (e.g. King, 1988b); they also outcrop along the North Taranaki coastline (Fig. 9a) as the Mohakatino Formation (Hay, 1967).

Some sediments intruded by and overlying the volcanics, plus other associated volcaniclastic sediments, have been micropaleontologically dated by the New Zealand Geological Survey and referred to the international time scale using the correlation of Edwards and others (1988). An age of 13 to 8 Ma B.P. is inferred for the main period of volcanism. The highly volcaniclastic sediments of the Mohakatino Formation exposed onshore north Taranaki have been similarly dated at about 12-10 Ma B.P. (G.H.Scott, pers. comm.). A tuffaceous component is also present in the overlying Mount Messenger and Urenui Formations, though this is masked by terrigenous detritus. There is, however, some uncertainty regarding both the lower and upper age limits of volcanism (B.W. Hayward, pers. comm.). Some earlier volcanism may have occurred, with very limited distribution of volcaniclastic sediments. Episodic volcanism may have continued locally as late as 4 Ma B.P. (Hayward, 1985).

Some Plio-Pleistocene andesite volcanoes are found in onshore Taranaki (Fig. 9b). These were regarded by Hatherton (1969) as having been sourced at depth from a westward-dipping subducting plate. As they are geochemically broadly similar to the offshore Miocene volcanics (G.A. Challis, pers. comm.), a subduction origin for the older volcanics also seems reasonable.

A line of early Miocene andesite volcanoes is well known to the north of Taranaki Basin, offshore western Northland. Although there is some debate in the literature (summarised by Kamp, 1986c), concerning the origin of these volcanics, which are larger than those in the Taranaki Basin (Hatherton and others, 1979), a subduction derivation is accepted here.

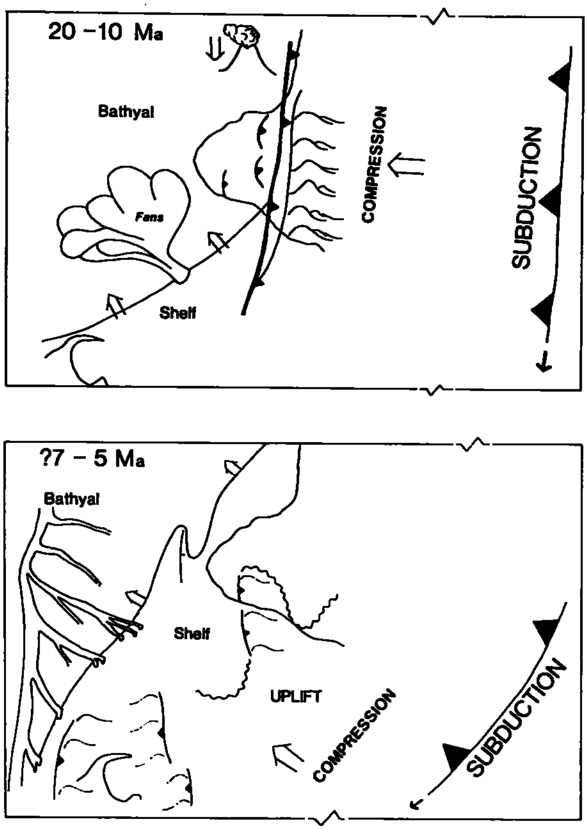


Fig. 10: Main Miocene structural and sedimentary events in the Taranaki Basin, and their relationship to the orientation and rotation of the Hikurangi subduction zone. Shelf-edge distributary channel pattern after Thrasher and Cahill (1989). Not to scale.

Some inferences concerning subduction orientation can be made from age and spatial relationships of the volcanics both within Taranaki, and between Taranaki and western Northland. The Taranaki Miocene volcanics appear to represent a continuation and southwards propagation of the more northerly volcanics. This may relate to the southwards migration of the subduction zone off to the east of the northern North Island. The Pliocene volcanics then represent a slight eastwards shift in the eruptive locus within the Taranaki region. It is presumed that the almost N-S oriented late Miocene volcanics in the Taranaki Basin roughly parallel the trend of the subduction zone at that time. This is only an approximation, as older fault trends may also have influenced the volcanic alignment. The delineation of a younger volcanic line, trending north-northeastwards from Pliocene andesitic volcanism in the northern peninsula (Fig. 9b), is more tenuous. Nevertheless, we do know the strike of the presently subducting plate beneath this area (Adams and Ware, 1977, Fig. 9b). Extrapolating forward from the late Miocene, a clockwise rotation (of about 30 °) in subduction strike appears to have occurred in about the last 10 Ma. The overall picture of andesite migration described above supports the hypothesis that there has been a southeastwards shift throughout the Neogene in the loci of andesitic volcanism in the North Island (Kear, 1959; Challis, 1978). It also tends to support the concept (Hatherton, 1969; Cole, 1986) that this has also involved a clockwise rotation in orientation of the subducting margin.

This rotation of the plate boundary in the last 10 Ma has been inferred from a variety of evidence. In the Taranaki Basin, the evidence includes the timing and nature of compression around the basin's eastern and southern periphery. However, it is not clear whether there was any relationship, other than a presumed mutual origin behind a convergent margin, between the volcanics and the compressive episodes in eastern Taranaki. Latest compression along the Taranaki Fault roughly coincided with the onset of volcanism. This was also synchronous with major reactivation of the Cape Egmont Fault Zone (G.P. Thrasher, pers. comm.) which, together with the distribution of the volcanics, suggests that the andesite magma migrated to the surface along faults associated with and/or parallel to the Cape Egmont Fault Zone.

Eversion (Southern Zone)

The Southern Zone (Fig. 1) defines a broad area of late Miocene compression and uplift in southern Taranaki Basin, extending from immediately offshore northwest Nelson, across to, and possibly including, the South Wanganui Basin. It extends southward into onshore regions of the South Island, and northward to encompass the Maui and Kapuni Fields. The onset of uplift in the south is difficult to establish from well data, owing to the variable absence of Late Miocene and Pliocene sediments on structures drilled. The amount of time missing increases in a southerly direction. The smallest time gap (in Maui-4), is used to constrain the timing and minimum duration of uplift. This indicates that the main uplift occurred in the latest Miocene (around 6-5 Ma B.P.). Uplift and erosion were greatest toward the south, and structures remained elevated for longer in this direction. Some continuation of uplift into the Pliocene is possible. So too is a degree of earlier progressive uplift and non-deposition in the mid Miocene, especially in the east of the basin.

The Southern Zone in the Taranaki Basin constitutes the distal edge of a broad compressive front associated with movement on the plate boundary. This compression impinged on Taranaki as a band of deformation aligned roughly NE-SW. Progressively later onset of compression in a southwestwards direction is likely (Fig. 10). Uplift took the form of major structural eversion of former large half-grabens of late Cretaceous and earliest Paleocene age (Knox, 1982). Reversal was controlled by individual steeply-dipping faults which involved basement at depth. The faults trend roughly N-S to NNE-SSW. This structural style is considered by Harding (1985) to be a result of direct compression. There is no obvious seismic evidence for wrenching in the Taranaki Basin at this time (G.P. Thrasher, pers. comm.). Nevertheless, the primary convergence vector was probably oblique to the observed structural trends. Furthermore, a component of strike-slip induced by plate boundary relative motion might be expected. Apparently, interference between various convergence directions produced roughly E-W compression overall, or the compressive component of strain was accommodated along lines of least resistance, namely the dip planes of older fault traces.

The significant change, over the last 10 Ma, in convergence rate and direction of relative motion between the Pacific and Australian plates, plus clockwise rotation of the Hikurangi margin (Walcott, 1984,1987; figure 10), presumably caused the southwards relocation of compression within the Taranaki Basin. At the end of the Miocene this influence abruptly waned, as the plate boundary compressive focus migrated further southward, resulting in pronounced uplift of the Southern Alps over the last 5 Ma (see Adams, 1979). Simultaneous development of the North Island transcurrent fault and distributed shear zone (Walcott, 1987), may have also contributed to ending compressive uplift in the southern Taranaki Basin.

Plio-Pleistocene phase

Throughout the Plio-Pleistocene the effects of the plate boundary zone of deformation continued to impinge upon the eastern Taranaki Basin. The frequent implication in the literature that eastern Taranaki comprises one large graben, and the inherent connotation that this graben has a singular origin, is fallacious. Although this region may have had a common early development, its present-day expression as two structural entities, the North and South Taranaki Grabens (Fig. 11), is predominantly due to Plio-Pleistocene tectonism. This is expressed as back-arc extension and compressional downflexure respectively.

The Plio-Pleistocene period is also characterised by very high sediment input to the basin. Sediments overfilled the tectonically controlled depocentres forming in the east, and an accelerated northwestward progradation of the shelf sedimentary wedge ensued. For details concerning the nature of this progradation refer to Beggs (this volume). Apart from eversion possibly continuing into the Early Pliocene in the south, and late-stage regional southward tilting in the east (see below), the Plio-Pleistocene was devoid of significant intra-basinal uplift. The Western Platform continued to be stable throughout this time.

North Taranaki Graben

The North Taranaki Graben began forming in the Late Miocene. Several kilometres of sediments accumulated in the graben in the Plio-Pleistocene (Thrasher and Cahill, 1989). The graben has a wedge shape, open to the north and closed to the south (Fig. 11). It is bounded on both sides by linear zones of closely spaced, down-stepping normal faults. The N-S striking Cape Egmont Fault Zone in the west became active in the latest Miocene. The graben's eastern limit is marked by a NE-SW striking swath of normal faults (Turi Fault Zone), some of which continue into the onshore North Island. First activity along this zone postdates that on the Cape Egmont Fault Zone (G.P. Thrasher, pers. comm.).

The North Taranaki Graben appears to have formed as a southward propagating rift related to back-arc extension. An analogy is drawn with the modern Central Volcanic Region located some distance to the east and at a similar latitude (Fig. 11). This back-arc rift has been actively forming through the same period by clockwise opening in a south-easterly direction (Stern and Davey, 1989). Clockwise fan-like opening of the North Taranaki Graben is also possible, especially considering the relative ages of the bounding fault zones (see comment above). This apparent rotation direction mirrors that of the evolving subduction zone. Thus the North Taranaki Graben may be a less mature, secondary manifestation of the same processes (namely back-arc extension associated with the southeastward retreat and clockwise rotation of the northern end of the Hikurangi Trench), which are controlling development of the Central Volcanic Region. Residual high heat flows from the period of Miocene andesitic volcanism may be a contributing factor.

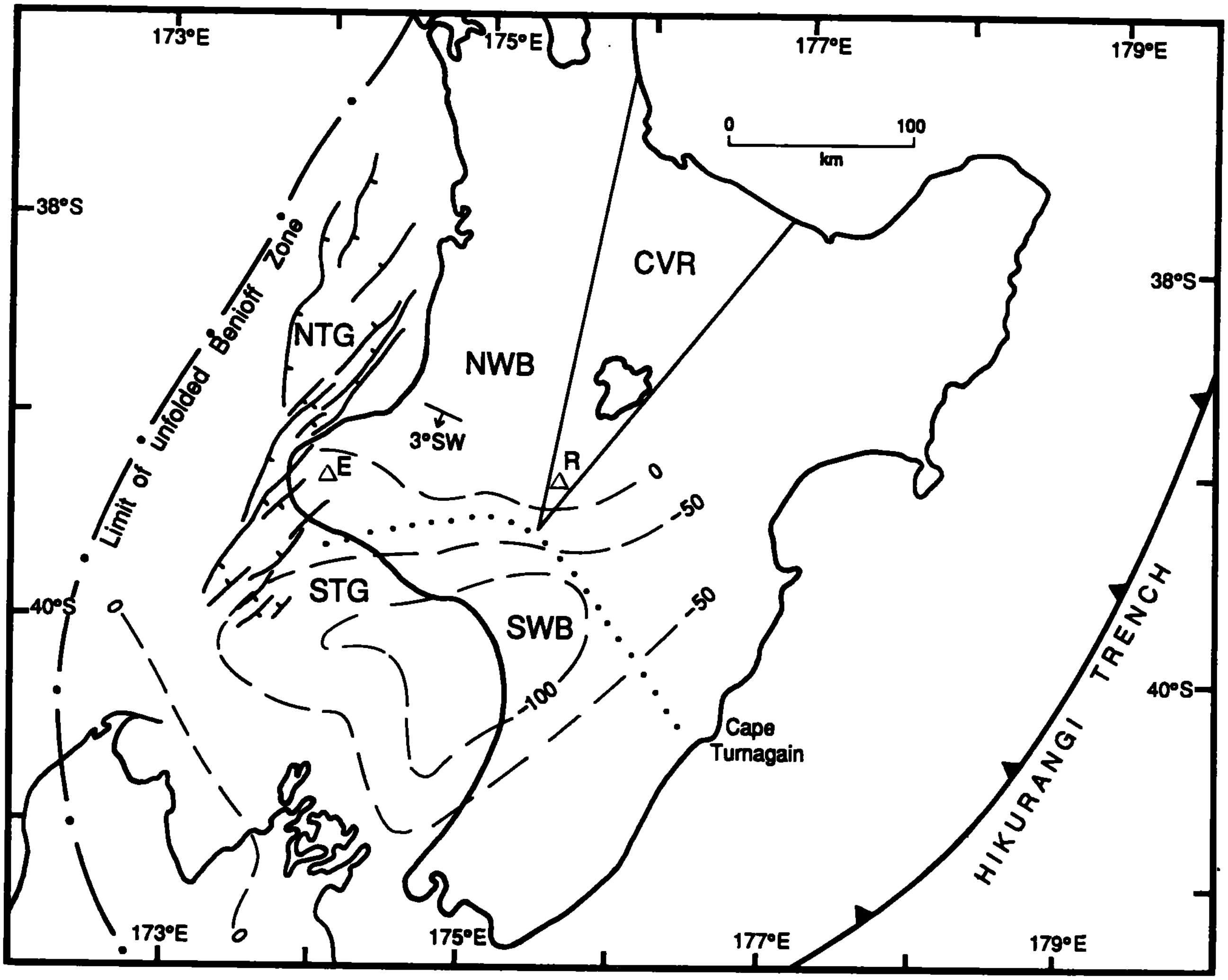


Fig. 11: Map of central New Zealand, showing Pliocene back-arc basins. Note the physiographic and geographic relationship between the North and South Taranaki Grabens (NTG, STG) and the Central Volcanic Region (CVR) and South Wanganui Basin (SWB) respectively. STG lies east of the depicted normal faults. Note also the regional (2-3 ° SW) tilt (measured dips of Mio-Pliocene sediments) into the South Wanganui Basin area, of the older (Miocene) fold-thrust back-arc basin, the North Wanganui Basin (NWB). The dotted line approximately separates areas within the central North Island of back-arc extension (north of line) and compression (south of line); developed after Walcott (1987). The long-dashed lines are gravity anomaly contours in mgal (after Reilly, 1965). Stylised shape of Central Volcanic Region after Stern and Davey (1989). Limit of unfolded Benioff Zone after Ansell and Adams (1986). E=Mount Egmont; R= Mount Ruapehu. Drawn on Lambert conformal conic projection with standard parallels at -37 and -45 ° south.

The present trend of the Turi Fault Zone parallels that of the subducting plate (Adams and Ware, 1977; Knox, 1982). Only minor strike-slip (few kilometres) occurs along this zone, which is the most distal (to the plate boundary) lineament accommodating transcurrent movement through the central North Island.

South Taranaki Graben

The so-called South Taranaki Graben has a composite origin which, for the most part, belies the rift genesis implied by its name. Extension only occurred in the early phases (Late Cretaceous to early Paleogene) of basin history, when a graben formed between the Taranaki and Manaia Faults. From Late Oligocene to mid Late Miocene times this region developed as a foreland basin to the west of the compressive Taranaki Fault. As compression ceased, extension along the Cape Egmont Fault Zone to the west became pronounced. There may have been some time overlap between these events. A deep Plio-Pleistocene depocentre immediately adjacent to the latter fault zone is the southernmost extent of the North Taranaki Graben (Fig. 11).

The remaining area south of the Taranaki peninsula is also one of considerable Plio-Pleistocene subsidence, being part of a broad depocentre in which infilling sediments continue across the dormant Taranaki Fault into the South Wanganui Basin (Anderton, 1981).. The shape and location of these overlapping Plio-Pleistocene basins is mirrored by a large negative gravity anomaly (Reilly, 1965; figure 11), much of which Stern and Davey (1989) attributed to crustal downwarping, caused ultimately by back-arc flexure induced by excess mass of the subjacent subducted Pacific plate. In this way, subsidence in the extreme southeastern part of the Taranaki Basin is directly linked to the evolution of the South Wanganui Basin.

Extra- and intra-basinal uplift, tilting and stable areas

Regressive sedimentary phase (II)

A significant feature of Taranaki's Plio-Pleistocene history is the influx of a very large volume of sediment into the basin. This sediment was mostly derived from the Southern Alps, which underwent considerable uplift in the last 5 Ma (Adams, 1979). It was transported into the Taranaki region by longshore drift (Beggs, this volume). Some sediment may have been initially derived from erosion of eversion structures in the south of the basin. Intra-basinal sedimentation rates increased dramatically in the Pliocene and even more dramatically in the Pleistocene (King and Thrasher, in press). A distributary network of large channels concomitantly developed along the shelf edge (Thrasher and Cahill, 1989; Fig. 10). These funnelled sediment into the New Caledonia Basin.

Most of the Taranaki Basin (and North Wanganui Basin) was stable throughout the Plio-Pleistocene, with the exception of the tectonic events referred to in previous sections. Even then, such was the supply of sediment into the region, that the evolving structural depocentres in the east were repeatedly infilled as they subsided, and eventually overtopped. A broad shelf then developed as the sedimentary wedge rapidly prograded to the northwest. Thus the sediment influx caused an overall acceleration of the regression initiated in the Miocene.

Superficially, from a sedimentation point of view, the entire region behaved as a regressive passive margin. From a structural perspective, the Western Platform had continued to develop as a passive margin through most of its post-Cretaceous history. In the Neogene, and particularly the Plio-Pleistocene, this evolution was characterised by load-induced subsidence and regression. This contrasts with its earlier passive margin phase which was distinguished by thermal subsidence and transgression, with waning sediment supply.

Since the Late Pleistocene, the area east of the Turi Fault Zone has been tilted a few degrees to the southwest. Much of this tilting was probably caused by downwarping in the South Wanganui Basin (Fig. 11) and, together with subsequent uplift onshore, has resulted in the erosion and northwards exposure of progressively older sediments within the South and North Wanganui Basins.

In the Taranaki region, another recent manifestation of subduction at the Hikurangi margin, is the volcano of Mount Egmont (and adjacent eruptive centres).

BASIN EVOLUTION AND ORIGIN OF HYDROCARBON ACCUMULATIONS

This section discusses the role of the main basin evolutionary phases in forming the more important hydrocarbon accumulations discovered to date in the Taranaki Basin. For hydrocarbons to have accumulated, several geologic conditions must have been met. Consideration will be given here to the following: source, reservoir, seal, trap, maturity and migration. Each of the major tectonic and sedimentary episodes has variously contributed one or more of the known parameters. There remains considerable potential for other successful play combinations.

Within the last few years a number of new hydrocarbon discoveries have been made in the Taranaki Basin. These each differ considerably in play type. They also differ from the traditional play concept established with the earliest successes in the basin. Nevertheless, they all have several features in common, and a number of general patterns are evident with respect to their exploration parameters.

A very stylised sequential reconstruction of a cross-section of the Taranaki Basin is depicted in Fig. 12. The main structural and sedimentary phases are shown. Listed opposite each are the main successful exploration parameters attributed to that phase. These parameters are collectively summarised (for all accumulations) at the right of the diagram, to show the relative periods in the basin's history responsible for their development. As would be expected, a sequential pattern is evident.

Taranaki hydrocarbons are generally considered to have a terrestrial organic (probably coal) source (Cook, 1987). Coals (within the Pakawau Group) deposited during the late Cretaceous rift phase are the predominant source, as suggested by recent geochemical studies (see Lipke, 1989; Johnston, 1989). Coals (within the Kaimiro and Mangahewa Fms) deposited on flood plains of the younger passive margin may have also sourced some Taranaki hydrocarbons.

The passive margin and foredeep (rapid subsidence) phases produced several different reservoirs. These include floodplain and shallow marine sandstones (Kapuni Group), and both distal fan (Tangaroa Member) and proximal foredeep turbidite sandstones (Tariki Member). Some of these sandstones lapped onto, or were deposited as drape over, the older rift topography. Marine mudstones (Turi Formation) are the ubiquitous seal. Foredeep limestones (Tikorangi Formation) constitute another important reservoir. It is interesting to note that reservoirs formed during these basin phases are the most prolific found thus far.

Several domed and overthrust structures, which formed along the leading edge of the mobile fold/thrust belt, have proved to be very significant hydrocarbon traps. The same compressive phase initiated a sedimentary regression. Miocene turbidite fans (Moki Formation) deposited ahead of the advancing shelf are proven reservoirs. Surrounding deep-water mudstones (Manganui Formation) form the seal.

Hydrocarbons have been found on the flanks of mid-late Miocene volcanic structures. The southern compression and eversion, also of mid-late Miocene age, produced several very important structural traps.

The most important Pliocene event to contribute to hydrocarbon accumulation was the deposition of a very thick sedimentary pile. In this accelerated margin offlap phase, marked by a large sediment supply, several kilometres of sediment accumulated in eastern structurally controlled depocentres. Our current understanding is that Taranaki Basin source rocks require at least five kilometres of burial before hydrocarbon generation occurs (Johnston, 1989). The Pliocene burial would have played a significant, and perhaps critical, role in this generation. The load induced by Neogene sediments is also vital in another way. This applies to a play type which is difficult to categorise in the terms

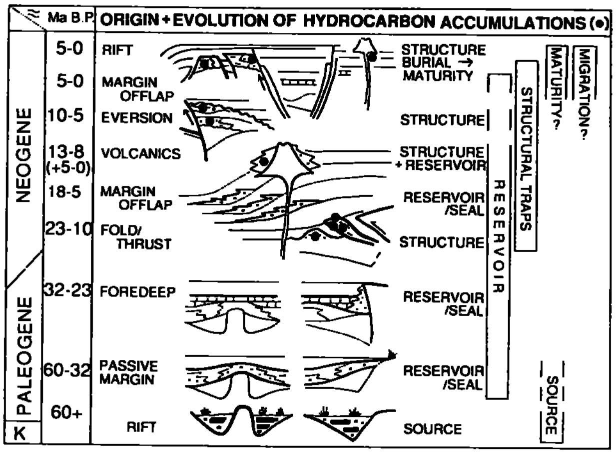


Fig. 12: Evolution of main hydrocarbon accumulations in the Taranaki Basin, depicted in terms of successful exploration parameters, and their origin with respect to major tectonic and sedimentary phases. Syn-rift terrestrial sediments are the main source rocks. Prolific reservoirs were commonly deposited in the passive margin and foredeep phases. Most accumulations occur in structural traps formed in the Neogene. Maturity and migration occurred relatively late in the basin's history.

outlined above and which, for example, may include the largest field in the basin, the Maui Field. These plays involve the deposition of reservoir and seal (Maui and Turi Formations) across former basement highs, then the formation of a structure by (Neogene) differential compaction and drape about this high. Pliocene sediments (Matemateaonga Formation) also have reservoir potential; a minor reservoir has been encountered in aggraded shelf sediments in the present onshore Taranaki region (Moturoa Field).

Successful Taranaki Basin plays have sometimes included a component of stratigraphic trapping, although so far this has not been the main closing mechanism. Nevertheless considerable potential exists in the Taranaki Basin for discovering stratigraphically trapped hydrocarbons.

SUMMARY

Predominantly subsurface data from the Taranaki Basin makes an important contribution to the New Zealand post-mid Cretaceous geologic record. The basin's sedimentary history largely corroborates that deduced from outcrop over much of onshore New Zealand. Nevertheless the near continuous stratigraphic record and well-defined structural development together provide added insight to, and place some constraints upon, plate tectonic syntheses involving the New Zealand continental platform.

The Taranaki Basin is a composite basin. Several phases in its structural evolution are evident. Most of these are the direct or indirect result of movements between the Pacific and Australian plates. Two different generations of this plate boundary have influenced Taranaki Basin tectonics. These were separated by a quiescent period in the Paleogene. The first phase was manifest as a late Cretaceous rift transform. Structural style is characterised by normal faulting and localised basin development across most of the Taranaki region. The second active tectonic regime was initiated and controlled by the propagation of the modern plate boundary through New Zealand. A two-fold evolution of this boundary is documented in the greater Taranaki area. An early transform phase in the late Oligocene is identified largely by the incidence of rapid subsidence. This was a precursor to foreland basin development in Taranaki, itself an expression of greater convergence along the plate boundary. Compression along the Taranaki Basin's eastern margin had definitely begun by the earliest Miocene. Thereafter, structural events within the Taranaki Basin reflect the evolution of the plate boundary. Some insight to the migration and rotation of the Hikurangi subduction zone is possible. Plate boundary deformation only impinged upon the eastern side of the Taranaki Basin. The Western Platform remained essentially stable throughout, apart from a period of accelerated subsidence in the Late Oligocene. This event separated phases of transgressive and regressive passive margin development in the west.

Sedimentation within the Taranaki Basin can be divided into three main phases. Initially, late Cretaceous sedimentation was largely confined to fault-controlled depocentres. Thereafter, once this early rift phase had ceased, regional sedimentation patterns prevailed. A net transgression continued until the end of the Oligocene. This culminated in marine inundation of virtually the entire basin. Carbonate deposition predominated at this time. Finally, with increasing compression in the east from early Miocene times, a greater supply of terrigenous sediment entered the basin. This marked the beginning of a long-lived regressive phase which is still continuing. Increasing sediment supply throughout the Neogene, and in particular the Plio-Pleistocene, indicates increasing uplift in the hinterland. In turn, this reflects increasing convergence across the Pacific and Australian plates.

The evolution of hydrocarbon accumulations in the Taranaki Basin follows a natural progression. Various essential exploration parameters can be linked to distinct phases of basin development. Source rocks were deposited in the early rift phase. Reservoir (and seal) rocks have been deposited throughout, but the most prolific were laid down in the passive margin and foredeep phases. Most of the accumulations occur in structural traps. These all formed during the Neogene, and relate to the impingement of plate boundary deformation. Migration pathways would have existed from the time of emplacement of individual structures. However, threshold source rock maturity and subsequent hydrocarbon expulsion was probably only achieved in the Pliocene. Migration was therefore also restricted to this period.

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